TEMPLECITY INSTITUTE OF TECHNOLGY AND ENGINEERING (TITE)
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LECTURES NOTES

ON

Renewable Power Generating System

Notes-1

DEPARTMENT OF ELECTRICAL ENGINEERING

Subject Name- **Renewable Power Generating System**

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Branch- EE

Semester- 5^{th} Semester

Mod - 1 OMM

Renewable Energy System / Source

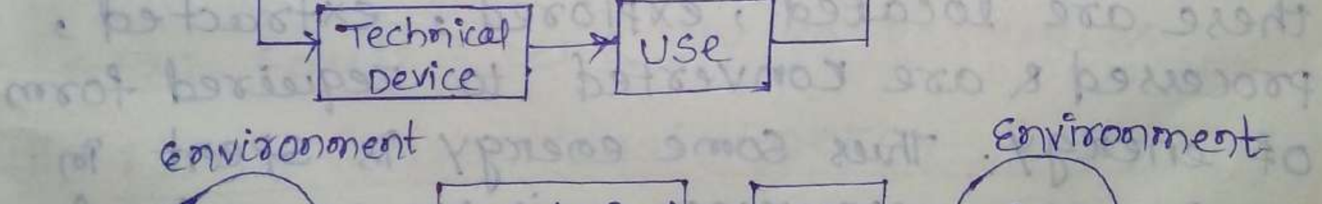
Introduction :

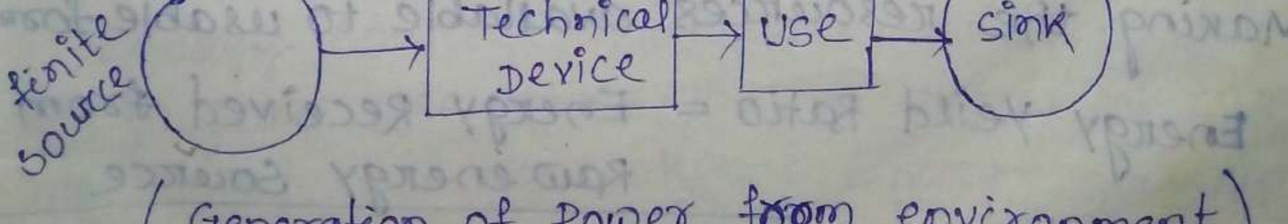
The origin of fire, heat & light is energy. The term energy can be described as capacity to do work.

Electric Energy From Conversional Sources ⇒

Thermal plants (coal, oil, gas, neuclear) & hydro power stations are the major conversional method of generating electrical energy.

Rise in the cost of fossil fuel has created an urgency to conserve them. So the renewable energy system came. The Renewable source of energy are solar, wind, Biomass & hydrogen. These are also called infinite source of energy. The conversional source of energy are also called finite sources of energy.





(Generation of power from environment)
Source of Energy

Classification of Energy Resources →

It is classified as :

a) Based on usability of energy.
b) Based on Traditional use.
c) Based on long-term availability.
d) Based on commercial Application.

a) Based on usability of Energy :

(i) Primary Resources.
(ii) Intermediate Resources.
(iii) Secondary Resources.

Primary Resources.

These are the resources available in nature prior to undergoing any human made conversion.

Ex: coal, crude oil, sun light, wind, running River, uranium etc.

- These resources are generally available in raw forms & therefore known as Raw energy Resources.
- This form of energy can't be used as such, these are located, explored, extracted, processed & are converted to required form of energy. Thus some energy is spent in making the resources available to usable forms.

$$\text{Energy Yeild Ratio} = \frac{\text{Energy Received from Raw energy Source}}{\text{Energy spent to obtain Raw energy Source}}$$

Greater the energy yeild ratio, the energy source is highly considered for the exploration.

Secondary Resources.

The form of energy which is finally supplied to a consumer for utilisation is known as secondary or usable energy.

Ex: Electrical Energy, Thermal energy (steam, Hot water), chemical energy (In the form of Hydrogen or fossil fuels)

Intermediate Resources.

These are obtained from Primary energy by one or more steps of Transformation.

Ex: Electricity & Hydrogen.

b) Based on Traditional Use.

(i) conventional Energy Resources.

(ii) Non-conventional Energy Resources.

(i) Conventional Energy Resources.

Conventional Energy Resources are those resources which are being traditionally used for many decades.

Ex: Fossil fuel & Hydro Resources.

(ii) Non-Conventional Energy Resources.

Energy sources which are considered for large scale use after the oil prices of 1973 are called non-conventional energy sources.

Ex: Solar, wind, Biomass.

c) Based on Long - term Availability.

(i) Non Renewable Energy Sources.

(ii) Renewable Energy Sources.

(i) Non - Renewable Energy Sources.

which are finite & don't get renewed after their consumption.

Ex: Fossil fuel, Uranium.

(ii) Renewable Energy Sources.

which are renewed by nature again & again & their supply is not affected by the rate of their consumption.

Ex: Solar, wind, Biomass, osian, Geothermal, Hydro.

d) Commercial Application.

(i) Commercial Energy source.

(ii) Non-commercial Energy source.

(i) Commercial Energy Source.

The secondary usable energy forms such as electricity, petrole, Dissel, Gas are essential for commercial activities. And are catagorised as commercial energy sources.

(ii) Non-Commercial Energy Source.

The energy derived from nature & used directly without passing through a commercial outlet is called non commercial Resources.

Ex: wood, Animal Dung cake, croop Resedues.

Fossil Fuel Based Systems :-

Fossil fuels are obtained from biologically degradable materials such as plant & animals only after undergoing million of years of heat, pressure, chemical & Biological reaction. Thus formation of these fuels takes very long time.

After the industrial revolution Energy demand has increased tremondanously, which results in the consumption of fossil fuel at a much faster rate than their formation. As a result the fossil fuel reserves of the world have become items of limited qty. while the demand of the resources are unlimited. This Imbalance indicates that our activity on the earth can't be sustain for ever. At the most it can last only a century with ever increasing consumption of fossil fuel.

Types of fossil fuels :

(i) Solid Fuels (coal)
(ii) Liquid fuels (crude oil)
(iii) Gasseous Fuels (Natural Gas)

Solid Fuels :

The main constituent of coal are carbon, Hydrogen, oxygen, Nitrogen, Moisture & ash. The coal is formed by natural decomposes of organic Matter.

Different types of coals are:
Peat, Anthracite, Lignits, Bituminous.

Liquid:

It is the Mixture of Hydrocarbon & some amount of Inorganic elements like oxygen. crude oil can be refined to gets various products like petrole, dissel & also some solid materials like plastic.

Gasseous

It is the Mixture of Methane, Ethene, Propane etc.

Reserves:

Solid → 16500×10^6 tons.
Liquid → 1200×10^9 barrels.
Gasseous → 180×10^9 m^3

Impact of fossil fuel Based System:

- The Technical def^n of fossil fuel is material that can be burn or otherwise consume to produce heat.
- In our moredanised weston world fossil fuels provides laxurious Importance. we retrive these fossil fuels ~~from~~ under the ground & under the sea & have them converted into electricity.
- Approximately 90% of the world's electricity demand is generated from the use of fossil fuel.
- Combustion of these fossil fuel is considered to be largest contributing factor to the release of green house gasses into the atmosphere.
- There are many types of harmful outcomes which result from the process of converting fossil fuel to energy. Some of these include Green house effect, air polut^n, water polut^n, human illness etc.

Green house Effect:

→ A Green house is an encloser having transparent Glass Sheets. It Behaves differently for incoming visible radiat^n & outgoing Infrared radiations.

→ It maintains a controlled warmer environment inside for growth of Plants in the places where the climate is very cold.

→ The CO_2 envelope present arround the globe in the atmosphere behave similar to a glass sheet & forms a big global green house. This tends to prevent the escape of heat from the earth which leads to Global warming. This Phenomenon is known as Green house effect.

Loss of Aquatic Life:

→ CO_2 is considered is the most ~~do~~ dominet contributer to the global warming issue. The impact of the global warming on the enviroment is extensive & affects many areas. In the antarctica warmer temp. may result in more rapid ice melting with increases the sea level & compromises the composition of surrounding waters. so it may hamper the Aquatic life.

Air Pollution :

→ Excessive use of fossil fuels can result in format" of smoke. other than causing human illness, smoke can also affect the sustainability of crops.

→ Smoke seeps through the protective layer on the leafs & destroyes essential cell membranes.

→ when coal is burn it releases nitrous oxide this is kept in the atmosphere for very long time. The harmful Impact of this chemical would take off a couple of hundred years to make itself known.

→ converting fossil fuels may also result in the accumulation of solid based. This solid wastes required adiquate land space for treatment. This type of waste also increases the risk of toxic Run off. which can poission the surface & ground water sources.

→ This also endangerous surrounding vegiterial wild life & Marine life.

→ Delivery of the fossil fuels can result in oil spills. & seepages from foundation like that of pipe lines can also results in similar destroction for habitate & wild life.

Non-Conventional Energy Sources

Features / Importance :

- The demand of energy is increasing due to rapid industrialisation & population growth & hence the conventional source of energy will not be sufficient to meet the growing demand.
- conventional energy sources (except Hydro) & are non-renewable & will be finished one day.
- conventional sources (fossil fuels) Nuclear also cause polution. There by they are use degrades the environment.
- Large hydro resources affect wild life & cause deforestation.

Merits :

- Non-conventional sources are available in nature free of cost.
- They produce very little pollution. Thus they are environment friendly.
- It is unlimited.
- They have a low time interval for the development

Demerits :

- The energy is available in dilute form from this sources.
- Though it is available in nature, the cost of Extracting energy from the sources is high.
- Availability is uncertain. The energy flow depends on various natural phenomena.
- Difficulty in transporting such forms of energy.

Availability :

→ Solar Energy :

Solar energy can be a measure source of power & can be utilised by using thermal & photovoltaic conversion system. Solar radiatⁿ receive on the surface of earth on a bright sunny day at noon time is approximately 1 kw/m^2. The earth continuously intersects solar power of 178 billion mw which is about 10,000 times the world's demand. But so far it couldn't be developed on a large scale. If all buildings of the world are covered with solar photovoltaic pannels it can fulfill electrical power requirements of the world. Solar PV power is considered an expensive source of power at present the capital cost of a solar PV system is Rs. 200 per watt i.e. 200 crore per mw. Against Rs. 4 crore per mw for coal fired thermal plant.

In India the solar plant is there in Banglore & Mumbai.

Wind Energy :

The power available in the winds flowing over the earth surface is 1.6×10^7 mw. The highly successful wind power programme is initiated in India in the year 1983-84. The current installed capacity for wind power is 8696 mw. And is mostly located in Tamilnadu, Gujurat, Maharastra & Rajasthan.

Biomass Energy :

A large qty of Biomass energy is available in our country in the form of dry waste like fuel wood, twigs etc & wet wastes like cattle dung, sugar cane bagasse, banana stems etc. For dry waste power generation is 16,881 mw. wet waste is 5000 mw.

Small Hydro Resources :

Hydro Resources of capacity less than 25 mw are called small, If less than 1 mw are called mini, & less than 100 kw are called micro Hydro Resources. The total potential is 15000 mw out of which 2015 mw has been realised by 211 plants.

Geothermal Energy :

The total potential in the country is 10,000 mw. Most of them are low temp hot water resources & can be utilised for direct thermal appliⁿ & only some of them can be considered

Suitable for electrical power generation. Geothermal reservers have been located in Tatapani → Chhatisgarh dist.

Puge vally → Laddk, Jammu & Kashmir. Hot water resources are located in Badrinath, Kedarnath & a few other locatn in the Himalayan ranges.

Oceian Tidal Energy :

There is no functional tidal plant are present. The total potential is estimated as 9000 mw. 3 sides have been identified for development of a Tidal energy.

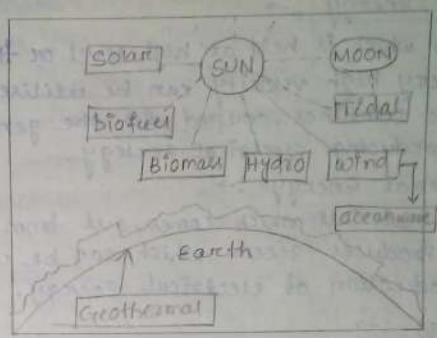
* Gulf of Kutch
  Potential → 900 mw.
* Gulf of Cambay
  Potential → 7000 mw.
* Sundarban, Potential - 1000 mw

Ocean wave & OTEC Resources :

OTEC - Ocean thermal Energy Conversion.
The avg. potential in India is 0.2 mw/meter of wave front. A 150 KW plant has been instaled at Vizhingum harbour of Thiruvananthgpuram of Kerala.

Renewable Energy Sources & features.

Renewable Energy Sources available in nature which are regenerative. Those are Solar energy, wind energy, hydro power,



Geothermal, Biomass, tidal, wave energy. Renewable energy source contribute to about 5% of the total power generation capacity in India.

Solar energy :→

- The energy radiated by the sun is in the form of electro magnetic waves which includes heat, light & a lot of ultraviolet radiatn. This radiated heat energy can be utilised for producing steem by focusing the heat over a boiler by the use of some deflectors.
- Solar energy can also produce electrical energy by photo voltaic radiations.

Wind energy :→

- The wind which is produced has sufficient energy which can be utilised to drive small generators whose o/p will be used for charging batteries for continuous use.

Hydro Energy :→

Water which is held at high level or flowing with very high velocity can be utilised to run the turbines, coupled with the generator for producing electrical energy.

Geothermal Energy :→

The materials which comes out from the earth produces steem which can be utilised for production of electrical energy.

Biomass :→

The energy sources which are available from animals & plants are called Biomass energy. Ex: trees, cultivated plants grown for energy etc.

- These biomass materials may be transformed by chemical or biological process to produce intermediate biofuels such as biogass (Mithene), Ethanol & charcoal.

Tidal Energy :→

It is the form of hydro power that converts energy of ocean tides into electricity or other useful forms of power.

Wave Energy :→

Energy in the waves can be harnessed in the form of mech. energy using wave energy converters so known as wave machines or wave devices & the flactuating mech. energy obtained is used to drive the generator for producing elect energy.

A wave device is placed in ocean in various possible locations.

Hybrid Energy systems :→

Renewable energy sources such as wind or solar energy can be utilised as independent sources of electrical power in the areas where the demand of power is low. But the nature of these sources in very different for conventional ones. The supply of these sources depend on the weather cond^n & is fluctuating. So it mayn't be possible to provide a contineuous supply over long period of time using these sources.

Desel driven alternators provide a relable contineuous source of elect. energy but there are certain disadvantages.

(i) High Running cost.
(ii) Poor fuel efficiency.
(iii) High transportation cost.
(iv) Relatively high cost of maintaince & operation in the remote areas.

So some efficient systems can be developed by integrating renewable energy systems (wind or solar) and battery inverter subsystems into desel generator sets. This is known as hybrid energy systems. The advantage of these system is that under favourable wind conditions wind turbines can partially releaf the desel sets of its load, there by saving some fuel. If sufficient wind power is available the desel set can be shut down & power demands will be made by the wind generator so the running cost is reduced.

Distributed Energy System :->

It is otherwise called decentralised energy systems. It covers a local energy source to generate electric power for distribution to consumers in a particular area. It may be a mini / micro hydroplants or wind turbine units of capacity 3KW to 10,000 KW.

Dispersed Energy Systems :->

It refers to use of generating units less than 25 KW O/P to serve individual houses, business & defence instalation in remote areas.

Ex: Desel generators, solar PV instalation, fuel cells, small wind generators.

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Solar Photovoltaic Systems

Solar PV cell :

- Solar PV system convert solar energy into electrical energy. The conversion device is used is known as solar cell / solar PV cell.
- Solar cells were first produced in 1954 & were rapidly developed to provide power for space sattelite & based on SC electronic technology.
- A solar cell is the most expensive component in a solar PV system. i.e. 60% of the total.
- Commercial solar cells may have efficiency in the range of 10 to 20% & can produce elect. energy of 1-2 KW hour per sq. meter per day.
- Tipically it produces potential difference of 0.5 V & a current density of about 200 Amp / sq. meter of solar cell area.
- It has life span of about 20 years. It has no moving parts. So it gives almost maintaince free service for long period of time.

Uses :

(1) Space sattelites.
(2) Remote Radio communicatn stations.
(3) Marine warning lights.
(4) Water Pumping.
(5) Solar power vehicles.
(6) Battery charging etc.

Advantages :

- It converts solar energy directly into elect. energy without going through thermal mechanical link. It has no moving parts.
- It is reliable, durable & maintaince free.
- It is compactable with almost all environments & respond instantaneously to solar radiat^n. It has life span of 20 years or more.
- As it is universally available, solar PV system can be located at the place of use & hence min. distribution n/w is required.

Disadvantages :

1. Cost of solar cells are high.
2. Low efficiency. (10-20%)
3. As the elect. energy storage is required it makes the whole system more expensive.

Semi-conductor :

- The S.C are substances whose resistivity lies bet^n a conductor & a insulator.
  Ex: Silicon, Ge.
- There are 2 types of S.C.
  a) Intrinsic b) Extrinsic.

a) Intrinsic S.C :

- These are pure S.C which has little current carrying capacity or negligible conductivity at room temp.
- A 'Si' crystal is intrinsic if every atom in the crystal is 'Si' atom. There are equal no. of free $\bar{e}$ & holes in an Intrinsic S.C.

b) Extrinsic S.C :

- Extrinsic S.C are those which has increased conductivity by adding impurity atoms to Intrinsic S.C.
- Depending upon the type of impurity added the Extrinsic S.C is classified as n-type & p-type.

n-type →

- When a small amount of pentavalent impurity is added to a pure S.C or Intrinsic S.C then n-type extrinsic S.C is formed.
- Addition of pentavalent impurity provides a large no. of free e° in the S.C crystal & such impurities are called as donor impurities / n-type impurities.
  Ex: P, Arsenic, Antymony

p-type :→

- When a small amt. of trivalent impurity is added to an Intrinsic S.C then a p-type Extrinsic S.C is obtained.
- The addition of trivalent impurity provides a large no. of holes in the S.C crystal & such impurities are called Acceptor Impurities / P-type Impurities.
  Ex: B, Al, Ga.

Doping :→

The process of addition of an impurity in an intrinsic s.c material in order to alter it's elect. c/s is known as dopping.

Fermi level (E_F) :→

→ E_F or c/s energy (in ev) for a crystal represents the energy state with a 50% probability of its being ~~fill~~ filled by charge carrier. i.e. $\bar{e}$ in n-type & holes in p-type get excited to become charge carriers.

→ Fermi level of an n-type material is :

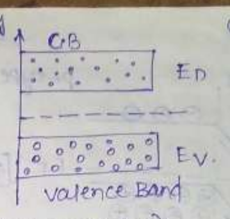
$$E_F = E_C - KT \ln\left(\frac{N_C}{N_d}\right)$$

Where:
E_C = Conduction Band energy.
N_C = Effective density in C.B.
N_D = Donor concentration / Density.
K = Boltzmann's const in ev / degree kel.
T = Absolute temp in degree Kelvin.

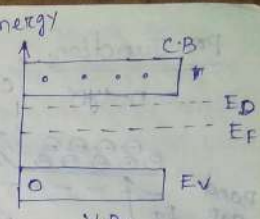
→ Fermi level of an p-type material is :

$$E_F = E_V - KT \ln\left(\frac{N_V}{N_a}\right)$$

Where:
E_V = Valence Band energy
N_V = Effective density in V.B.
N_a = Acceptor density / concentrat^n.



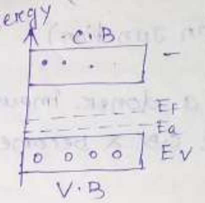
(Intrinsic s.c)



(n-type)

E_D = Energy levels of donor ions.

E_A = energy levels of Acceptor ions.



(P-type)

(Position of fermi levels)

Problem :

Q. A p-type 'si' has effective density of states in the V.B as 1×10^{22} per cm^3. An impurity from the 3^{rd} group with concen. of 1×10^{19} per cm^3 is added. If the band gap for 'si' is 1.1 ev. find the closeness of the fermi level with V.B at the temp. of 27 K.

A. $N_V = 1\times10^{22}$
$N_a = 1\times10^{19}$
$T = 27\ K = 27 + 273 = 300°C$

$$E_F - E_V = KT \ln\left(\frac{N_V}{N_a}\right)$$

$$= 8.62\times10^{-5} \ln\left(\frac{1\times10^{22}}{1\times10^{19}}\right) \times 300$$

$$= 1.3$$

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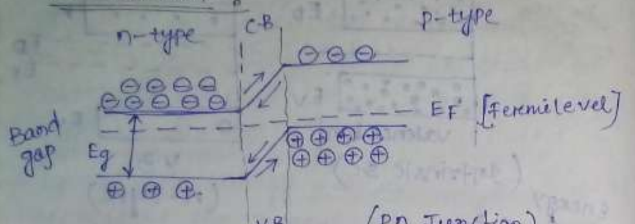
pn Junction :



(pn Junction)

→ A S.C when dopped by a doner impurity increases the e^- in the C.B & become n-type material.

→ when a S.C is dopped by an acceptor material it becomes p-type material with excess holes. When those n-type & p-type material are joined then a junction is formed which is known as pn junction.

→ The no. of e^- in n-type matrial is large. So when an n-type material is brought into contact with p-type material, e^-s on the n-side flow into holes of the p-type material. Thus in the vicicity of the junct^n n-materials becomes +vely charged & p-materials becomes -vely charged. The process of diffusion of carriers contineues till the junct^n potential reaches an equilibrium value. In this cond^n 'v' is the contact potential developed bet^n the pn junction. Now if an external voltage V_f is applied across the pn junct in such a way that magnitude of the potential difference across the pn junction is reduced ~~to~~ from V to $(V - V_f)$. The junct^n is said to be in the forward biased mode. F.B increases the flow of e^-s in the p material & flow of holes in the n-material across the junct^n. Thus the current flow across the pn junction increases sharply.

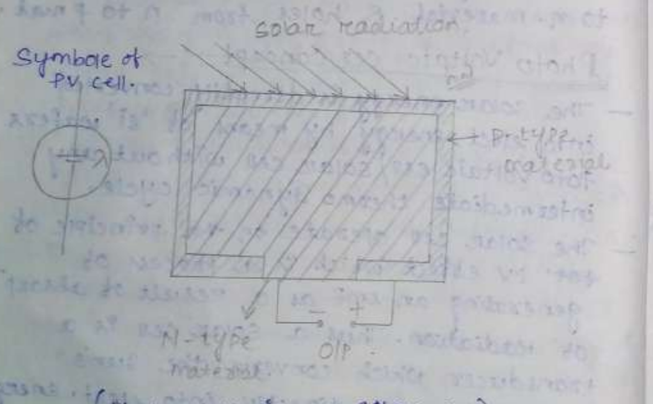
When a large R.B voltage V_b is applied across the junction, then the potential difference across the junct^n increases from V to $V + V_b$. Now the current flow is only due to the e^- from p material to n-material & holes from n to p mat.

Photo Voltaic cell concept :→

- The solar energy is directly converted into elect energy by means of 'Si' wafers poto voltaic cell / solar cell without any intermediate thermo dynamic cycle.
- The solar cell operate on the principle of ~~pot~~ PV effect which is a process of generating an emf as a result of absorp^n of readiation. Thus a solar cell is a transducer which converts the sun's radient energy directly into elect. energy.
- The PV effect can be observed in a veraity of materials but the materials having the best performance in the sunlight are the S.C.

- Pure s.c like 'si' is having no free charge carriers at ordinary temp. But if this 'si' is dopped with pentavalent impurity then there will be an extra $\bar{e}$/atom of the impurity leading to n-type mat. Similarly, if 'si' is dopped with trivalent impurity then there will be defficiency of $\bar{e}$ leading to p-type s.c. If these 2 types i.e. n type & p type impurities are connected by some means, a potential energy gap 'Eg' is created at the junction.

Symbole of PV cell.

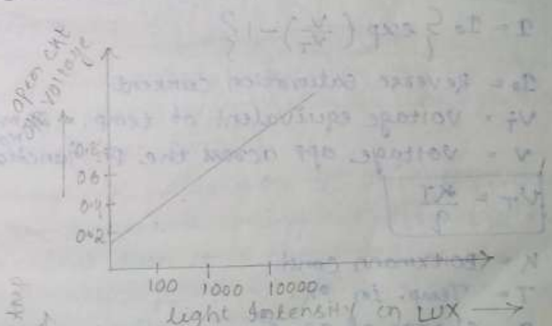


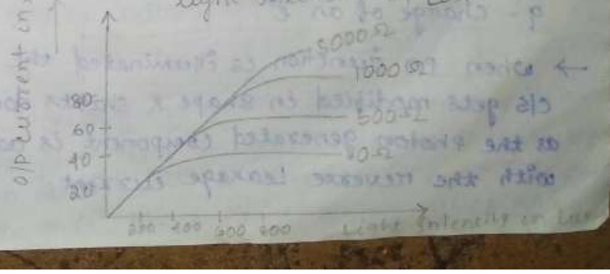
(Photo-voltaic or solar cell)

- When a photon of energy $h\nu$ is allowed to fall on the P region, it is absorved in the V.B. If this $h\nu$ exceeds the engy gap 'Eg', then the $\bar{e}$ will migrate to the n region. If $h\nu < Eg$ then the photon will be absorved by a hole which will migrate to p-region. This charge separ^n creates an electric field opposite to the electric field created by the diffusion of the free $\bar{e}$s of the n-region. Due to which PV cell generate a voltage w.r.t which is proportional to the electromagnetic radiation intensity.

→ Si solar cell consist of single crystal p-type si upto $2cm^2$ into which a very thin layer (0.5μ) of n-type material is diffused.

open ckt O/P voltage c/s of PV cell. :→





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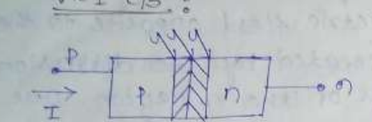
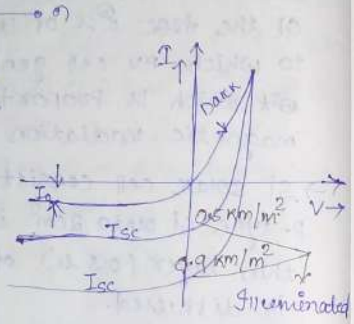
SOLAR CELL CHARECTERISTICS :→

V~I c/s :



Illuminated Junction.



(V-I c/s of dark & illuminated pn junction)

$$I = I_0 \left\{ \exp\left(\frac{V}{V_T}\right) - 1 \right\}$$

I_0 = Reverse saturation current.

V_T = Voltage equivalent of temp. = 26mV at room temp (20°C)

V = Voltage app across the pn junction

$$V_T = \frac{KT}{q}$$

K = Boltzmann Const.

T = Temp. in °K.

q - Charge of an e^-.

→ When pn junction is illuminated the c/s gets modified in shape & shifts downwards as the photon generated component is added with the reverse leakage current.

So,

$$I = -I_{sc} + I_0 \left\{ \exp\left(\frac{V}{V_T}\right) - 1 \right\}$$

→ When the junction is short cktd at it's terminal, then V = 0. And a finite current I = - Isc flows through the external path. where Isc is the sc current whose value depend on the magnitude of solar radiation.

→ If a voltage source is inserted in the external path with positive polarity on the p-side & is gradually increased from zero then the current starts decreasing. The value of the voltage at which the current becomes zero is known as open ckt voltage i.e. Voc.

$$V_{oc} = V_T \ln\left\{ \left(\frac{I_{sc}}{I_0}\right) + 1 \right\}$$

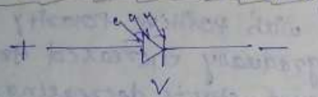
→ An illuminated pn junction can be considered as an energy source with oc voltage Voc & short ckt current Isc.

By sign convension for an energy source if the current is coming out from the +ve terminal then it is considered as +ve. So mathematically the VI c/s of a solar cell may be written as :

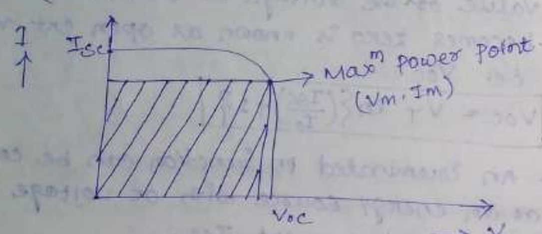
$$I = I_{sc} - I_0 \left\{ \exp\left(\frac{V}{V_T}\right) - 1 \right\}$$

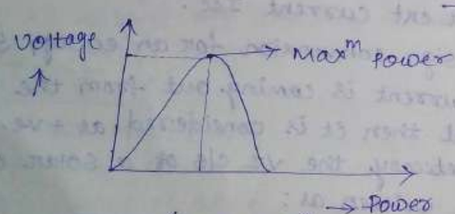
In order to obtain as much energy as possible from the solar cell it is desirable to operate the cell to produce max^m power. The max^m power point can be obtained by

Plotting the hyperbola defined by VI = Const. The voltage & current corresponding to this point are called peak point voltage (V_m) & peak point current (I_m). Operating the cell other than max^n power point will produce a lesser elect. energy & more thermal energy. The max^n power point can also be found out by simply plotting the cell power Vs cell voltage.



(Symbol of PV cell)





(P~V c/s)

→ If a rectangle of max^m possible area is drawn inside the V~I c/s, then it meets the c/s at peak point. Closeness of the c/s to the rectangular shape is a measure of quality of the cell. An ideal cell would have a perfect rectangular c/s.

Fill Factor :

It indicate the quality of the cell, which is defined as the ratio of peak power to the product of open ckt voltage & S.C current.

$$FF = \frac{V_m I_m}{V_{oc} I_{sc}}$$

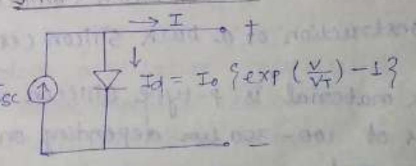
→ For an ideal cell, the ff value is one/unity. The conversion efficiency of a solar cell is given by :

$$\eta = \frac{V_m I_m}{\text{Solar power}}$$

$$\eta = \frac{FF \times V_{oc} I_{sc}}{\text{Solar power}}$$

Equivalent ckt of a Solar cell :→

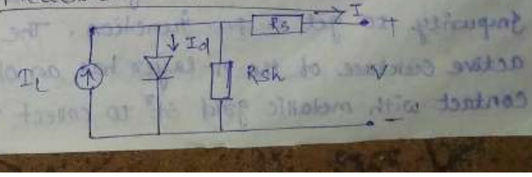
(i) Ideal solar cell :



Series resistance = 0

Parallel resistance = ∞

(ii) Practical solar cell :→



→ Here, I_{sc} is not equal to the light generated current I_L but it is less than that becoz a current is flowing through shunt resistance R_{sh}.

Also an internal voltage drop of $I*R_s$ is also included in the terminal voltage.

$$I = I_L - I_0\left\{\exp\left(\frac{V+IR_s}{V_T}\right)-1\right\} - \left(\frac{V+IR_s}{R_{sh}}\right)$$

→ for high quality 'Si' cell, on 1^2 inch series resistance R_s = 0.05 to 0.1 Ω & R_{sh} is 200 to 300 Ω.

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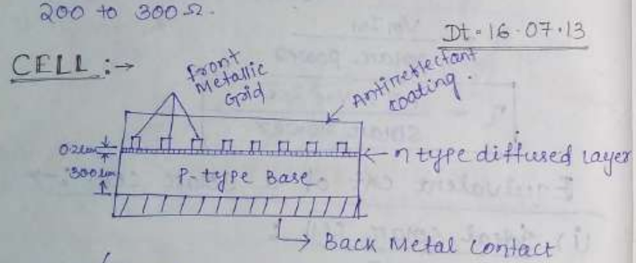
CELL :→



(Construction of a bulk silicon cell)

→ The bulk material is P-type silicon with a thickness of 100 - 350 μm depending on the technology used.

→ A thin layer of n-type silicon is formed at the top surface by diffusing a pentavalent impurity to get a pn-junction. The top active surface of the n-layer has an ohmic contact with metallic grid str to collect the current produced by the photon.

→ The metallic grid covers min possible top surface area to leave enough uncovered surface area for incoming photons. Similarly the bottom surface has metallic contact over the entire area.

→ These two metallic contacts on P & n layer respectively formed the +ve & -ve terminals of the solar cell. Antireflective coating is provided to capture min. photon & direct them towards the junction.

Solar PV Module :→

A single cell can't be used for outdoor energy generation by itself. It is becoz :

(i) The o/p of a single cell is very small.

(ii) It requires protection against dust, moisture, mechanical shock etc.

Workable voltage & reasonable power is obtained by interconnecting appropriate no. of cells. The unit is fixed on a durable back cover of several sq. feet with a transparent cover on the top to make it suitable for outdoor application. This assembly is known as solar module. 32 or 36 Si cells are connected in series to make it capable to charge a 12 V storage battery.

2/ Cell Mismatching in a Module :→

In a module, a no. of cells are interconnected & it is very important that these cells should match as closely as possible. i.e. V_{oc}, I_{sc}, I_m, V_m or the fill factor for all the cells must be exactly same. Any mismatch of these cells leads to mismatch losses so the peak power of the combination is always less than the sum of individual peak power of the cell. Under ideal case the resultant peak power will be equal to the sum of individual cell power. When 2 cells with mismatched c/s are connected in series & a load is applied then both the cells are bound to carry the same current. The composite c/s of the combinⁿ can be obtained by adding individual o/p voltage of the cell. At a particular operating point while one cell may be operating at peak power, the other cell mayn't be operating at this point. Thus the peak power of the combinⁿ is less than the sum of individual peak power of each cell. If such a combinⁿ is short circuited, equal & opposite voltages V_1' & V_2' are produced by individual cells & therefore one cell will be generating power & other cell will dissipate it.

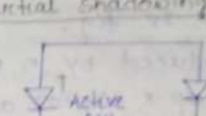
→ In a parallel combⁿ of 2 mismatched cells the voltages of the cells are bound to be equal but the currents will be different so the maxᵐ power point will be different.

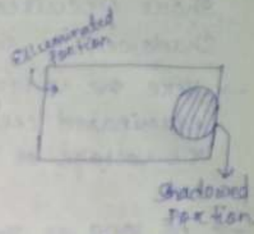
→ To reduce the mismatch losses, the modules are fabricated from the cells belonging to the same batch / same V-I c/s.

18-07-2013

Effect of Shadowing :

1) Partial shadowing →



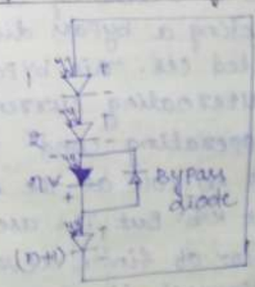


→ When a cell is partially shadowed, the shadowed portion will not produce any power but the unshadowed or illuminated portion will remain active & produce power.

→ The vol. which is generated by illuminated portion will f.b the parallel rectifier corresponding to the shadowed portion.

→ If the shadowed area is relatively small a large circulating current will flow through it, which results in excessive heating of the shadowed portion. This phenomena is known as hot spot effect & it may completely damage the module.

(ii) Complete shadowing :-



(Shadowed cell & bypass diodes connection)

→ A series string of (n+1) cells which are short circuited with one cell completely shadowed is shown in the fig.

→ Here the voltages produced by 'n' no. of elluminated cells add up & appear as r.b voltage of 'nV' volts accross the shadowed cell.

→ As long as the peak inverse voltage (PIV) of shadowed cell is more than the r.b voltage 'nV', current will not flow.

→ If PIV is less than reverse bias voltg nV, current will flow through the string discipating large power in the shadowed cell which leads to damaging of the module.

→ With increase of the no. of cells the chances of damage to the shadowed cell due to excessive heating increases.

→ By connecting a load to the series string of cell, the chances of damage comes to lesser extenet.

→ The damage due to shadowing can be avoided by connecting a bypass diode across the affected cell. This bypass diode would allow an alternating current path.

→ During normal operating condⁿ the bypass diode has no role as the cell voltage to keep it r.b. But its use result in some losses becoz of finite reverse leakage current through it.

Solar Photovoltaic Pannel (Series & Parallel connection)

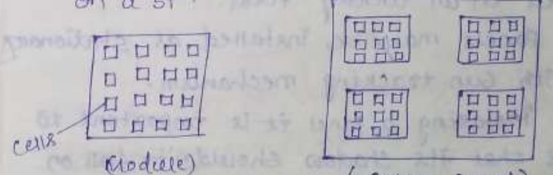
— Several solar modules are connected in series parallel combinⁿ to increase the voltage & current ratings.

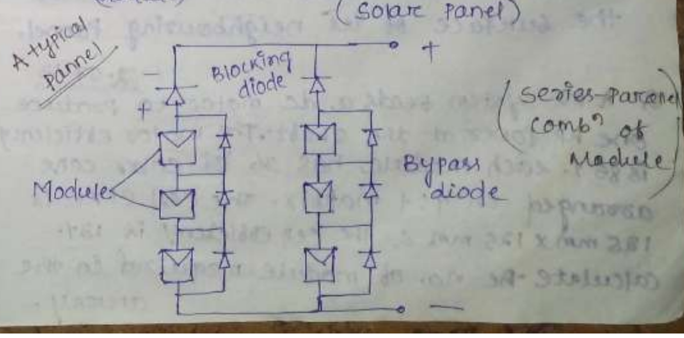
— When the modules are connected in series, it is desirable to have maxᵐ power prodⁿ of such module occur at the same current.

— When the modules are connected in parallel it is desirable to have each module maxᵐ power prodⁿ occur at the same voltage.

— While interconnecting the modules this informⁿ should be available for each module.

— Solar panel is the group of several modules connected in a series parallel combⁿ in a frame that can be mounted on a stⁿ.





- The above fig. shows a series - parallel comb^n of modules in a panel.
- In a parallel connection blocking diodes are connected in series with each series string of modules so that if any string would fail, the power o/p of the remaining strings will not be absorved by the fault module.
- The bypass diodes are installed across each module so that if one module would fail then the o/p of the remaining modules in a string will bypass the fault module.

Solar PV Array :

- A large no. of interconnected solar panels are known as solar PV array are installed in an array field.
- These panels may be installed as stationary or with sun tracking mechanism.
- While installing a panel it is important to ensure that its shadow shouldn't fall on the surface of its neighbouring pannel.

22.07.13

Q. A PV system feeds a dc motor to produce one hp power at the shaft. The motor efficiency is 85%. each module has 36 'Si' solar cells arranged in 9:4 matrix. The cell size is 125 mm x 125 mm & the cell efficiency is 12%. calculate the no. of module required in the array. Assume solar radiation incident normally to the pannel on 1 KW/m².

Ans: Motor o/p = 1 HP. = 746 watt

i/p to the dc motor = $\frac{o/p}{efficiency}$

$= \frac{1 \text{ HP}}{0.85} = 877.64$

The cell area in 1 module

$= 9 \times 4 \times 125 \times 125 \times 10^{-6}$.

$= 0.562 \text{ m}^2$.

Let's consider 'n' no. of modules are required.

Solar radiation incident on pannel

$= 1 \text{KW/m}^2$

$= 1000 \text{ watt/m}^2$.

Solar efficiency $= 12\% = 0.12$.

o/p of solar cell $= 1000 \times 0.562 \times 0.12 \times n$

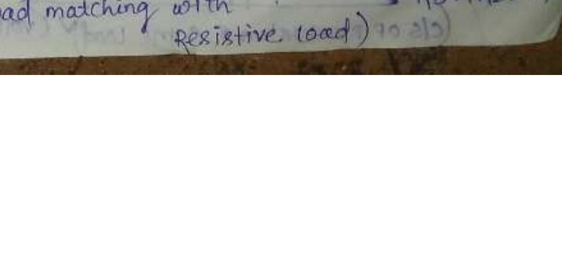
$= 67.44 n$

$67.5 \times n = 877.64$

$\Rightarrow \boxed{n = 13.}$ Ans

∴ 13 no. of modules are required.

Maximizing the solar PV o/p & load Matching :→



(load matching with Resistive load)

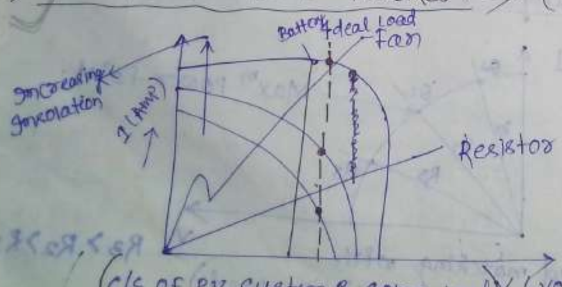
→ In a solar PV system, the o/p is maximised in 2 ways.

(i) By mechanically tracking the sun & always orienting the pannel in such a direction as to receive max^m solar radiatⁿ under changing posⁿ of the sun.

(ii) By electrically tracking the operating point by manipulating the load to maximize the power o/p under changing condition of insolation (solar radiation) & temp.

→ The operating pt. of an electrical system is determined by the intersection of source c/s & load c/s. If a resistive load is connected to a solar PV system then for a lower value of resistor R₁ the system operates at Q1 for R₂ the max^m power pt. moves to Q2 & for R3 (higher value) the max^m power point moves to Q3. So the max^m power point is available for the resistor R2. Thus such load matching is required for extracting max^m power from a PV system.

Max^m Power Point Tracker. → (MPPT)



(C/S of PV system & some load)

(MPPT → DC to DC voltage Regulator)

— When a solar PV pannel is used for pract. applⁿ, the VI c/s of it changes with insolation & temp.

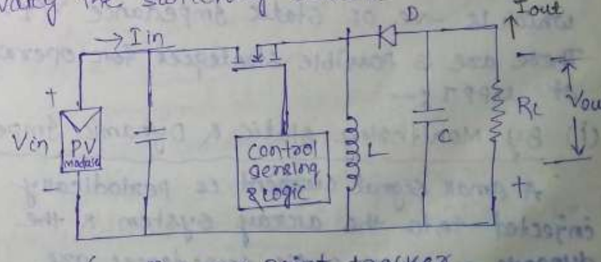
— To receive max^m power, the load must adjust itself to track the max^m power point.

— An ideal load is one that tracks the max^m power point.

— If the operating point departs significantly from the max^m power point then, an electronic max^m power pt. tracker (MPPT) is placed betⁿ solar PV system & load.

— MPPT is a type of dc to dc voltage regulator. When it is coupled to the load it can provide a higher voltage at low current or low voltage at high current.

— A buck-boost scheme is commly used with voltage & current sensors tied into a feedback loop using a controller to vary the switching scheme.



(Max^m power point tracker using buck-boost converter)

$$\text{Duty cycle} = \frac{T_{on}}{T_{on} + T_{off}} = \frac{T_{on}}{\text{Total Time}}$$

23.07.13

(Duty cycle > 0.5 → Boost
Duty cycle < 0.5 → buck)

$$V_{out} = \frac{D}{1-D} \times V_{in}$$ D = Duty cycle. $0 < D < 1$.

→ The power o/p of a PV system is given by $P = VI$ with incremental change in voltage & current, the modified power is given by $P + \Delta P = (V+\Delta V)(I + \Delta I)$

$= VI + V\Delta I + \Delta V I + \Delta V \Delta I$

Neglecting the smaller terms,

$\Rightarrow \Delta P = V\Delta I + I\Delta V$

At peak point $\Delta P = 0$.

So, $\frac{\Delta V}{\Delta I} = -\frac{V}{I}$

which is the dynamic impedance of the source which is -ve of static impedance V/I.

There are 3 possible strategies for operation of MPPT :-

(i) By Monitoring Static & Dynamic Impedances

A small signal current is periodically injected into the array system & the dynamic as well as static impedances are measured i.e. Z_d & Z_s. The operating voltage is then adjusted until the cond^n $(Z_d = -Z_s)$ is achieved.

(ii) By Monitoring the Power O/P :-

From the shape of PV c/s, $\frac{dP}{dV}$ is zero at max^m power point. This property is utilised to track the max^m power point. Voltage is adjusted & power o/p is sensed. (The operating voltage is increased as long as $\frac{dP}{dV}$ is +ve. If $\frac{dP}{dV}$ is sensed -ve then the operating voltage is decreased. The voltage is unaltered if $\frac{dP}{dV}$ is near zero.)

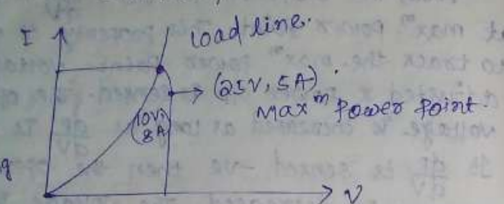
(iii) By fixing the O/P voltage as a fraction of Voc :-

For most PV cells, the ratio of the voltage at max^m power point to the open ckt voltage is approximately a constant K. for High crystalise 'Si' cell, $K = 0.72$. An additional identical unloaded cell is installed on the array to face same environment as the module in use & its open ckt voltage is contineuously measured so the operating voltage of the array is set at $(K \cdot V_{oc}) = V_m$.

The implement of this scheme is simplest among all the available scheme.

Q. A PV source is supplying power to a load whose load line intersects the c/s at 10V, 5Amp. Determine the additional power gain if an MPPT is interposed bet^n the source & the load. If the cost of MPPT is ₹5.4000 for how long does the system need to operate in order to recover the cost of MPPT. The cost of electricity may be assumed as Rs. 3 per KW hr. Efficiency is 95%.

Ans



without using MPPT Power produced = 8 × 10 = 80 watt

Max^m power prod^n capability of the PV module

= 25 × 5 = 125 watt

Actual power produced in MPPT with a efficiency of 95% = 95% × 125

= 118.75 W.

Surplus power produced by use of MPPT is 118.75 − 80 = 38.75 W

Surplus energy produced in 't' hrs =

(Power × time) Kwh

$= 38.75 \times t = \left(\frac{38.75}{1000} t\right)$ Kwhr.

$= 0.03875\, t$

Cost of surplus energy = 3 × 0.03875 t

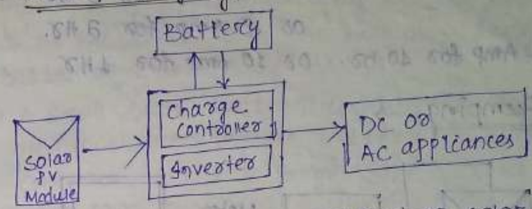
= 0.11625.

Time required to recover the cost of MPPT

is $= \frac{4000}{0.11625} = 34408.6$ hrs.

Application of Solar Cell :

1. Battery charging :-



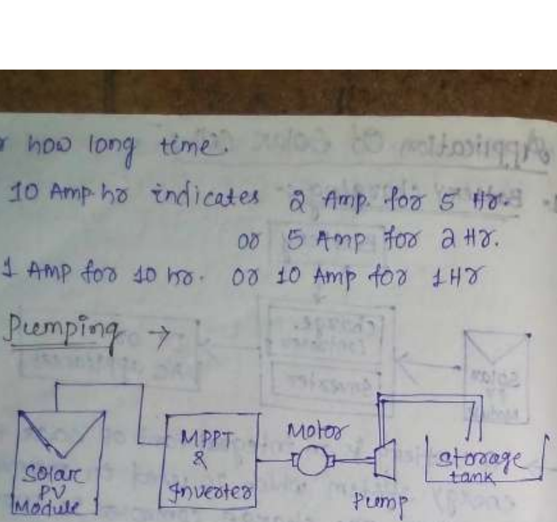
→ A battery is an integral part of solar PV energy system which is used in inverter or UPS. One charge controller is provided along with the inverter for protecting the battery from over charging or complete discharging. Beyond the limit because in both the cases battery life decreases.

→ Inverter converts DC to AC. So it is used in houses and in other industrial appliances where AC power is used for operat^n. The o/p of a battery is DC. So by using a inverter DC will be converted to AC which is fed to the AC appliances.

→ A battery converts chemical energy which is stored inside it into elect. energy. A battery is rated for its o/p voltage & current capacity which is determined by the amt. of energy which can be stored inside the battery. The current capacity of a battery is given in terms of Amp hr. which indicate that how much current can be extracted from a fully charged battery for how long time.

Ex: 10 Amp-hr indicates 2 Amp for 5 Hr.
or 5 Amp for 2 Hr.
1 Amp for 10 hr. or 10 Amp for 1 Hr

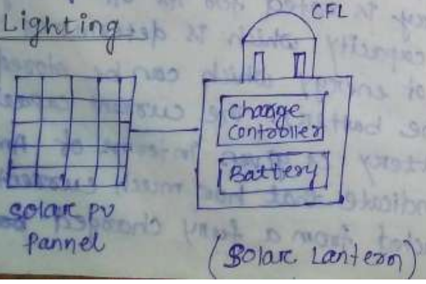
2. Pumping →



→ A solar PV system can be used for water pumping purpose which consists of PV modules, MPPT, motor & storage tank, Pump. This system may involve DC or AC motor. An MPPT can also be used with the system to match the O/P impedance of the PV module with that of motor to extract max^{m} power through out the day.

→ A PV system can be designed for a very small water pumping requirement for drinking water & large volume of water requirement for irregation purpose.

3. Lighting



(Solar Lantern)

→ A solar PV system can be designed to supply power for lighting application of a household. The lighting application may be the glowing of all the lights with the help of a large size batter or a small solar lantern.

→ A small solar lantern consist of a solar PV pannel, rechargeble battery, charge controller, CFL & a large size batter consist of the solar PV module, inverter & a charge controller.

29.07.13

4. Peltier cooling :—

Peltier cooling uses the peltier cooler to create temp. difference bet^{n} the junction of 2 different types of material. A Peltier cooler is a solid state active heat pump which transfers heat from one side of the device to other side against temp. gradient i.e. from cold junction to hot junction with consumption of electrical energy. The peltier device can be used for heating or cooling. i.e. as a temp. controler. But the main applicat^{n} is cooling. The peltier cooler works on the principle of peltier effect which states that "there is presence of heat at an electrical junction of 2 different metals i.e. when current flows through a junct^{n} made up of 2 different materials then the heat is generated at the junct^{n} which raising the temp. of the junct^{n}

& which is absorved by another junction there by decreasing the temp. of the junctⁿ. The peltier heat absorved by one junctⁿ per unit time is given by:

$$Q = \eta_{AB} I$$

$$= (\eta_B - \eta_A) I$$

Where: η_A & η_B = Peltier coefficient of the junction A & B.

The peltier coefficient gives the indicatⁿ of continuity of charge carrier across a junctⁿ. i.e. if the 2 materials are same then there is no heat flow. But if the 2 materials are different then there is heat flow.

Advantages.

1. Lack of moving parts.
2. Small size.

Disadvantages

1. The main disadvantage of the cooler is that the cooler is having high cost with high power efficiency.

Solar Radiation :—

Solar radiation is the energy radiated by the sun.

- The radiated energy received on earth surface is called solar irradiation.
- Solar radiation received on a flat horizontal surface on earth is called solar insolation.
- The solar radiatⁿ is of 2 types.
  a. Extra terrestrial solar Radiation
  b. Terrestrial solar radiation.

1. Extra terrestrial solar Radiation :—

- The solar radiatⁿ incident on the outer atmosphere of the earth is known as extra terrestrial radiatⁿ.
- The extra terrestrial solar radiatⁿ received on the surface of earth is essentially const. through out the yr. becoz the medium betⁿ earth & sun doesn't change with time & the distance betⁿ the 2 remains nearly const.
- The extra terrestrial solar radiatⁿ is given in terms of solar constant. Solar const. is defined as the energy received from the sun per unit time on a unit area surface which is ⊥ʳ to the directⁿ of propagⁿ of the radiatⁿ at the top of the atmosphere. The value of the solar const remains const. through out the year however this values changes with locatⁿ becoz the earth sun distance changes seasonally with time.
- The extra terrestrial radiatⁿ observe on different days is known as apparent extra terrestrial solar irradiance &

can be calculated on any of the years using the following relation.

$$I_0 = I_{sc}\left[1 + 0.033\cos\left(\frac{360(n-2)}{365}\right)\right]$$

$$\simeq I_{sc}\left[1 + 0.033\cos\frac{360}{365}n\right]$$

I_0 = Apparent extra terrestrial solar irradians in watt/m^2.

n = No. of days of the year counting January 1st as the 1st day of the year.

I_{sc} = Solar constant. = 1353 watt/m^2.

I_{sc} can also be measured from experimetal measurement.

- The apparent solar E radiants will be max^n during december last or 1st week of Jan as the earth centre is nearest to the sun during these days

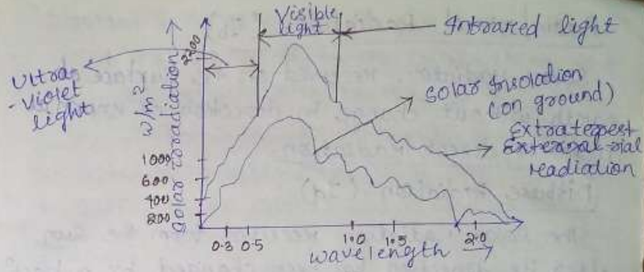
2. Terrestrial Solar Radiation.

The solar radiat^n that reaches on the surface of the earth is called terrestrial solar radiation.

[Dt. 5.08.13]

Spectral Distribution of Solar Radiation.

- Light rays radiated from the sun are in the form of electromagnetic waves in infrared visible & ultraviolet freq. bands. The freq. spectrum of solar light is a graph of wavelen



(Solar Spectrum)

& solar irradiation. The solar spectrum has the following 3 basic levels.

1. Infrared Band.
2. Visible Band.
3. Ultraviolet Band.

→ Infrared band wavelength lies bet^n 0.75 & to 1.95 microns & the freq. range is 4×10^{14} Hz to 7.5×10^{10} Hz.

→ Visible band wavelength lies bet^n 0.39 micron to 0.75 micron. & the freq. range is 6×10^{16} Hz to 7.69×10^{14} Hz.

→ Ultraviolet Band wavelength lies bet^n 0.005 micron to 0.39 micron. & the freq. range is 6×10^{16} Hz to 7.5×10^{10} Hz.

Terms Used in Solar Radiation.

Beam/Direct Radiation. (I_b)

Solar radiation received on the surface of earth without change in direction is known as beam or direct radiation.

Diffuse Radiation (I_d)

The solar radiation received from the sun after its direction has been changed by reflectⁿ & scattering by atmosphere is known as diffuse radiatⁿ.

Total Radiation (I_t)

The sum of beam & diffused radiations intercepted at the surface of earth per unit area of location is known as total radiation. It is also known as Insolation. Mathematically

$$I_t = I_d + I_b$$

Air Mass. (M_a)

It is the path length of the radiation through the atmosphere considering the vertical path as unity.

- $M_a = 1$ when sun is at zenith.
- $M_a = 2$ when zenith angle $\theta_z = 60^\circ$.
- $M_a = \sec\theta_z$ when $M_a > 3$.
- $M_a = 0$. Just above the earth atmosphere

$$\text{Air Mass} = \frac{\text{Path length of beam Radiation}}{\text{vertical path length of atmosphere}} \text{ i.e. } \sec\theta_z.$$

Reasons for variation in solar Radiation reaching the earth than Received on the outside of the atmosphere :-

As the solar radiations pass through the earth's atmosphere, the ultraviolet rays are absorbed by ozone in the atmosphere & the infrared rays are absorbed by CO_2 & moisture in the atmosphere. A portion of radiatⁿ is scattered by the components of atmosphere such as water vapour & Dust. A portion of this scattered radiation always reaches the earth surface as Diffused radiation.

These radiations finally received at the earth surface consist partly of beam radiatⁿ & partly of diffused radiations.

Solar Energy Reaching Earth Surface at Different position of Sun :-

Air Mass	Solar radiation flux reaching earth's surface in watt/m²
Extraterrestrial	1367
Overhead Position	1105
Terrestrial Region	894.

6.08.13

SOLAR COLLECTORS.

The solar energy is captured naturally by different surfaces to produce thermal effect or to produce electricity by means of PV cell. Solar energy can be converted to thermal energy by using solar collectors. This thermal energy can be converted to elect.

energy by using PV. cell: The surface of the solar collector is designed for high absorption & low emission. The solar energy conversion can be achieved by following 2 completely different Rules.

(i) Solar thermodynamic

(ii) Solar PV.

Solar collectors in various Ranges & application :—

① Low Temperature

$t = 100°c$

a) water heating
b) Drying
} Flat Plate collectors.

② Medium Temperature

$t = 100°c$ to $200°c$

i) various vapour engines & turbines
ii) Refrigeration
iii) cooking
} focussing collector with cylindrical parabola reflectors.

③ High temperature.

$t > 200°c$

i) steam engines & turbines
ii) Thermo electric generators
} Paraboloid mirror arrays

→ The foccousing type collector give high temp than flat plate collectors. But they have the following limitations:

1. Non-availability & high cost of materials are required.
2. Foccousing type collectors require direct sunlight & are not operative when the sun is even partly covered with clouds.
3. They need tracking system & the reflecting surfaces undergo deterioration with the passage of time.

Principle of conversion of solar energy into heat :—

When solar radiatⁿ from the sun in the form of light reaches earth, visible sunlight is absorved in the gnd & converted into heat energy. But non-visible light is reradiated by the earth & the carbondioxide in the atmosphere absorves this light & radiates back a part of it to the earth. which results in the increase in temp. This whole process is known as greenhouse effect.

Collection systems :—

1. Solar thermal collection system :—

A solar thermal collection system works in the following manner.

1. It gathers the heat from the solar radiatⁿ & gives it to the heat transport fluid (Also called primary coolant).
2. The fluid delivers the heat to the thermal storage tank (Boiler steam generator / heat exchanger).

3. The storage system stores heat for a few hrs. & then the heat is released during cloudy hours and at night.

2. Thermal electric conversion system.

This system receives thermal energy & drives steam turbine generator or gas turbine generator. The electrical energy is supplied to the electrical load or to the grid.

3. Cogeneration plants.

In co-generat^n plants, heat in the form of hot water may be supplied to the consumer in addition to the electrical energy. In this case hot water from the reservoir may be pumped through outlet pipe to the load side. 8/8/13.

Factors affecting collector systems efficiency.

(i) shadow factor

(ii) cosine loss

(iii) Dust

1. Shadow factor :-

- when the angle of elevation of sun is less than 15° i.e. sun rise & sun set, the shadow of neighbouring collector panels falls on the collector surface.

- The shadow effect is reduced with the increase of sun elevation angle.

$$\text{Shadow factor} = \frac{\text{solar collectors surface receiving light}}{\text{Total collector surface}}$$

Shadow factor is less than 0.1 when the elevation angle is less than 15° & then equal to one during noon time when the angle of elevation is nearly equal to 90°.

Cosine loss factor :-

when the collector surface receives the sun rays perpendicularly, Max^m power collection is realised. if the angle bet^n the plane $\perp^r$ to collector surface & the direction of sun ray is θ then the area of sun beam intercepted by the collector surface, is proportional to cos θ. In case fixed type collector panels are their, cosine loss varies due to the daily variat^n & seasional variation of the direct^n of sun rays.

3. Dust factor / Reflective loss factor →

To the glass surface of the collector & the surface of the reflector collects dust, dirt & moisture. As a result the reflector surface gets rusted deform & looses the shine. Hence with the passage of time, the collectors efficiency is reduced significantly. Thus to prevent the loss daily maintaince & seasional maintaince should be done.

Types of solar

Classification of Solar collector :-

- Solar collector
  - Non concentrating type (Flat Plate collector)
    - i) Liquid Flat plate collector
    - ii) Flat Plate air heating collector
  - Concentrating type
    - Focus type
      - Line focus (one axis tracking)
        - i) cylindrical Parabolic concentrator
        - ii) Fixed mirror solar concentrator
        - iii) Linear fresnel lens "
      - Point focus (2 axis)
        - i) Paraboloidal dish collector
        - ii) Hemispherical bowl mirror concentrator.
        - iii) Circular fresnel lens concentrator
        - iv) central tower receiver
    - Non focus type
      - i) Modified flat Plate collector
      - ii) compound parabolic concentrating type (CPC)

Comparison betn Concentrating & Nonconcentrating (Flat plate type) solar collector

Concentrated type ->

- In this type of solar collector solar radiation is convers from large area into a smaller area using optical means.
- Beam radiation which has a unique directn & travels in a straight line, can be conversed by reflection or refraction techniques.
- Diffused radiation has no unique direction & so doesn't obey optical principle. Therefore diffused component can't be concentrated.
- Thus concentrating type solar collectors mainly make use of the beam radiation components + very little diffused components.
- The main advantage of concentrating type collector is that high temp. can be obtained due to concentn of radn. This also give high temp. thermal energy.

Nonconcentrating type. ->

- This type of collectors absorves both beam as well as diffused radiation.
- A flat plate collector doesn't require sun tracking & is simple in concentration.
- As the collector is installed outdoors & exposed to atmospheric disturbances, the Flat Plate type is more likely to withstand outdoor condn.
- Becoz of its simple stationary design it requires little maintaince.
- The disadvantage of a flat plat collector is that becoz of the absence of optical concentn the area from which heat is lost is large due to which high temp can't be attempt.

Performance Indices of solar collector.

i) collector efficiency.
ii) Concentration Ratio.
iii) Temp. range.

1. Collector efficiency.

- It is defined as the ratio of the energy actually absorve & transport to the heat trasport fluid by the collector to the energy incident on the collector.

2. Concentration Ratio (CR)

It is defined as the ratio of area of ~~apparature~~ aperture of the system to the area of receiver. The aperture of the system is the projected area of the collector facing the beam.

3. Temp. Range

It is the range of temp. to which the heat transport fluid is heated up by the collector.

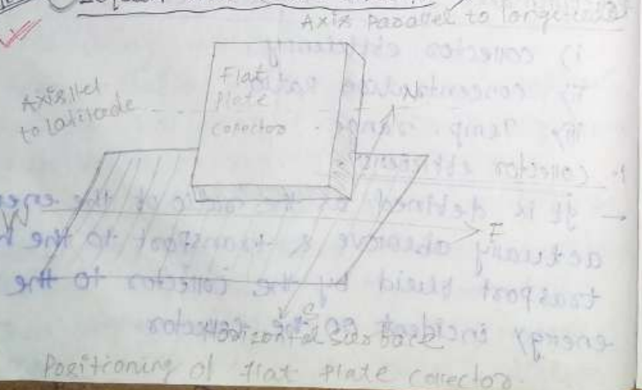
— For flat plate collector CR = 1 as no optical system is used to concentrate the solar radiation. & the temp. range is < 100°C.

Line focus collectors

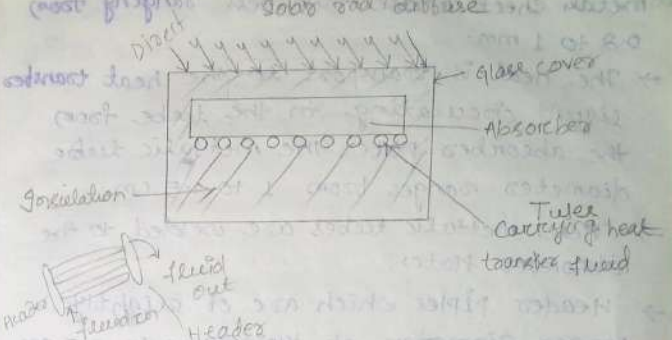
— concent^n ratio upto 100 & temp. range is 150° — 300°C.

- Point focus collector → concent^n ratio upto 1000 & temp range 500°C — 1000°C.

12/8/13 Liquid flat plate collector →



Positioning of flat plate collector



→ The basic elements of a liquid flat plate collector are transparent cover of glass or plastic, blackent absorber plate usually of Cu, Al, or steel, Tubes channels or passages in thermal contact with the absorber plate, weather tight; insulated container to enclose the above components.

Description.

→ A liq. (Generally water) is used as heat transport medium from the collector to the next stage of the system.

→ Sometimes during night when the temp is likely to fall, a mixture of water & etheline glycol (Anti freeze mixture) is also used.

→ As the solar radiat^n strikes on the mettalic absorver plate, it is absorved & raises the temp of the plate. The absorber plate is usually made from a metal sheet whose thickness ranging from 0.2 to 1 mm.

→ The heat is transport to the heat transfer liquid circulating in the tube from the absorber plate. The mettalic tube diameter ranges from 1 to 1.5 cm.

→ These mettalic tubes are welded to the absorver plate.

→ Header piples which are of slightly larger diameter of typically 2 to 2.5 cm lead the water in & out of the collector & distribute to the tubes. The metal i.e. most commonly used for the absorber plate, tube, header piples is copper.

→ In the bottom & along the side walls, thermal insulat^n is provided by a 2.5 – 8 cm thick layer of glass which prevents heat loss from the rear surface & side of the collectors.

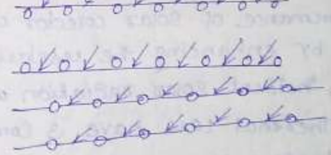
→ The glass cover permits the entry of solar radiation as it is transparent. It allows the incoming short wave length but is largely opaque to the longer infrared rad^n reflected from the absorber. As a result the heat is remain trap in the air space bet^n the absorver plate & glass cover.

→ The glass cover may reflect 15% of incoming solar radiation which can be reduced by applying antireflective coating on the outer surface of the glass. Transparent plastics may also be used in place of glass but they offer inferior performance as compaired to glass.

→ The absorbor plat can broadly divided into 3 types.

i) Pipe & Fin type.
ii) Rectangular or cylindrical full sandwich pipe.
iii) Roll bond or semi sandwich pipe.

i) Pipe & Fin type :–



→ The liquid flows only in the pipe & hence they have low wetted area & liq. capacity.

ii) Rectangular or cylindrical full sandwich pipe :–

→ In this both the wetted area & water capacity are high.

iii) Roll band & Semisandwich types :-

→ It is an intermediate betⁿ the above 2 types.

Application

→ For low temp requirement like warming of swimming pool full water sandwich type is used.

→ For high temp. applicatⁿ i.e. for industrial application pipe & fin type plate is more suitable.

Imp.

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Performance Analysis of a Liquid flat-Plate collector :-

- The performance of solar collector can be improved by enhancing the useful energy gain from incident solar radiation with minⁿ loss. Thermal loss have 3 components.
  (i) conductive loss
  (ii) convective loss.
  (iii) Radiative loss.

→ Conductive loss is reduced by providing insulation on the bottom & sides of the absorber plate.

→ convective loss can be minimized by keeping the air gap of about 2cm betⁿ the glass cover & the plate (absorber).

→ Radiative losses from the absorber plate are lower by applying a spectrally selective absorber coating.

→ During normal steady state operation useful heat delivered by solar collector is equal to the liquid flowing through the tube minus the losses.

→ The energy balance of the absorber can be represented by ;

$$Q_u = A_p S - Q_L \qquad (1)$$

Q_u = useful heat delivered by the collector (w)
A_p = Area of the absorber plate (m^2)
S = solar heat energy absorbed by the absorber plate (w/m^2)
Q_L = rate of heat loss by convection & radiatⁿ from the top, by conduction & radiation from the bottom & sides (watt).

→ The solar flux falling on an inclined surface is express by

$$I_T = I_b R_b + I_d R_d + (I_b + I_d) R_r \qquad (2)$$

Where:
$I_b R_b$ = Beam radiation.
$I_d R_d$ = Diffused radiation.
$(I_b + I_d) R_r$ = Re-radiation or reflected radiation.

→ The flux absorbed is obtained is obtained if the eqⁿ (2) is multiplied by transmission transmissivity - absorbtivity product ($\tau\alpha$).
Therefore

$S = I_b R_b (\tau\alpha)_b + [I_d R_d + (I_b I_d) R_r] (\tau\alpha)_d$

where:

τ = Absorptivity of absorber plates.

α = transmissivity of glass cover which is defined as the ratio of solar radiation coming through after reflection at the glass-air interfaces & the absorption in the glass to the radiatn incident to the glass cover system.

$(\tau\alpha)_b$ = Transmissivity, Absorptivity product for the beam radiation falling on the collector.

$(\tau\alpha)_d$ = Transmissivity, Absorptivity product for the diffused radiation falling on the collector.

→ The instantaneous collector efficiency is defined as the ration of useful heat gain to the radiation falling on the collector instantaneous efficiency (η):

$$\eta = \frac{Q_u}{A_p I_T}$$

Q_u = useful energy delivered by the collector.

→ In case the flow of liquid through the collector is stop, the useful heat gain & the collectors efficiency becomes zero. At this stage the absorber plate attains a temp. so that $Q_L = A_p S$.

→ It is the max^m temp. that the absorber plate can attain. which is called stagnation temp. This data helps in selecting an appropriate material for manufacturing of collector. Q_u is the useful heat gain in 1hr which is expressed in KJ/hr. I_T = Energy falling on the collector surface in 1 hr. (KJ/m^2·hr)

→ The heat lost from the collector in terms of overall loss coefficient eq is given by:

$$q_L = U_L A_p (T_{pm} - T_a)$$

where: U_L = Overall loss coefficient.

A_p = Area of absorber plate.

T_{pm} = Mean or avg. temp of the absorber plate.

T_a → Temp. of surrounding air.

→ The heat lost from the collector is the sum of heat loss from the top, the bottom & the sides. Therefore the total heat loss of the collector is given by:

$$q_L = q_t + q_b + q_s$$

q_t = The rate at which the heat is lost from the top.

q_b = The rate at which the heat is lost from the bottom.

q_s = heat is lost from the sides.

→ Each of this loss components may also be expressed in terms of individual loss coefficient i.e.

$$q_t = U_t A_p (T_{pm} - T_a)$$
$$q_b = U_b A_p (T_{pm} - T_a)$$
$$q_s = U_s A_p (T_{pm} - T_a)$$

we know, $U_L = U_t + U_b + U_s$

eq^n ① can be written as;

$$q_u = A_p S - q_L$$
$$q_u = A_p S - U_L A_p (T_{pm} - T_a)$$

→ A modified eq^n in which the absorber plate temp T_{pm} is replaced by the local fluid temp t_f (temp. of fluid flowing in tubes) can be obtained as:

$$q_u = F' [A_p S - U_L A_p (T_f - T_a)] \quad — ④$$

F' = collector efficiency factor which is defined as the ratio of the actual useful heat collection rate to the useful heat " " " which would occur if the collector absorber plate was at temp t_f. The range of F' varies from 0.90 to 0.95. By considering the heat removal process due to fluid flow becoz this temp dates can't be obtained. so a modified expression can be obtained in terms of the inlet fluid temp t_{fi} which is usually a known qty. so eq^n ④ becomes:

$$q_u = F_R A_p [S - U_L (T_{fi} - T_a)]$$

where: $F_R = \frac{mC_p}{U_L A_p} \left[1 - \exp\left(\frac{-F' U_L A_p}{mC_p}\right)\right] \quad — ⑤$

Where: F_R = collector heat removal factor. It represents the ratio of the actual heat collect^n rate to the useful heat collect^n rate which would occur if the collector absorber plate is at temp t_{fi} every where. This eq^n ⑤ is referred as Hottel-Whillier Bliss eq^n. For a properly designed flat-plate collector an instantaneous efficiency of the order of (50-60)% may be achieved.

Dt. 14.08.13

Effect of various Parameters on Performance

1) Selective Surface →

Absorber plate surfaces which exibits c/s of a high value of absorptivity for incoming solar radiation & low value of emissivity for outgoing re-radiation are called selective surfaces. Such surfaces maximises the net energy collection.

Ex: Cu oxide, Nickel black & black chrome.

2) No. of covers (Glass covers) →

With the increase of no. of covers the value of $(\tau\alpha)_b$ & $(\tau\alpha)_d$ decreases & thus the nett flux absorved by the absorver plate decreases so the value of heat loss from the absorber plate decreases. However the amount of decrease is not same in both cases. The max^n efficiency is obtained with one or 2 glass cover.

3) Spacing →

Heat loss varies with the spacing between 2 glass covers & also the spacing bet^n 1st glass cover & the absorber. The spacing at which min. loss occurs varies with temp & also with tilt. Since collectors are designed to operate at different locations with varing tilts, an optimum value of spacing is difficult to specify. Spacing in the range of 4 to 8 cm is normally suggested.

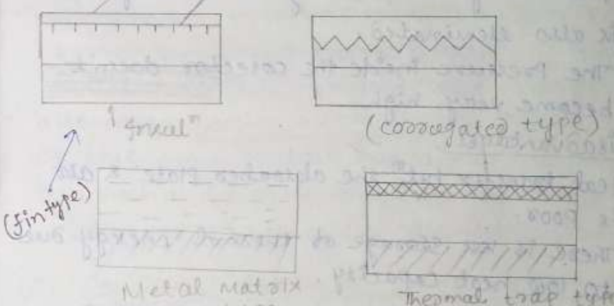
4) Collector tilt →

Flat plate collectors are normally used in a fixed pos^n & don't track the sun. Therefore the tilt angle at which they are fixed is very important. Optimum tilt depends on the nature of application. The usual practice is to recomend a value of $(\phi+10°)$ to $(\phi+15°)$ for winter appl^n (water heating, space heating) & $(\phi-10°)$ to $(\phi-15°)$ for summer application like refrigeration plant.

5) Dust on the top of the cover →

When the collector is placed for practical system dust gets accumulated over it. Reducing the transmitted flux through the cover. This requires continuous cleaning of the cover, which is not possible in a practical system. For this reason a incident flux is multiplyed by a correct^n factor. In general the correct^n factor is from 0.92 to 0.99 is taken.

Flat Plate air heating collector :—



(Various type of flat plate air-heating collector)

→ A solar air heating collector is similar to liquid flat plate collector with a change in the configurat^n of absorber & tube. The value of heat transfer coefficient bet^n the absorber plate & the air is low. For this reason the surfaces are sometimes rubbend or longitudinal fins are provided in the air flow passage.

Applications :-
- Drying for agricultural & Industrial process
- Space heating.

Advantage over Liquid flat plate collector:
- It is compact, simple in const^n & requires less maintaince.
- The need to transfer energy from the working fluid to another fluid is eleminated as air is used directly as the working fluid.
- Corrosion is completely eleminated.
- Leakage of air from the duct is less serious.
- Possibility of freezing of working fluid is also eleminated.
- The pressure inside the collector doesn't become very high.

Disadvantages
- Heat transfer bet^n the absorber plate & air is poor.
- There is less storage of thermal energy due to low heat capacity.
- A large amt of fluid is to be handled due to low density. As a result the elect. Power required to blow the air through the system can be significant if the press. drop is not kept within the prescribed limit.

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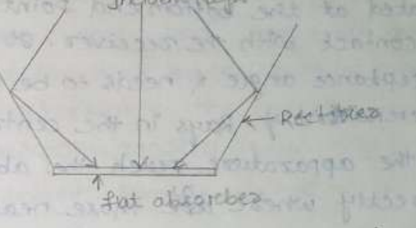
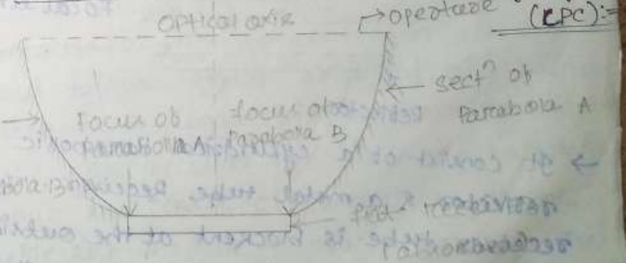
Concentrating type solar collector :-

(1) Modified flat plate collector → (flat plate collector with booster mirror)



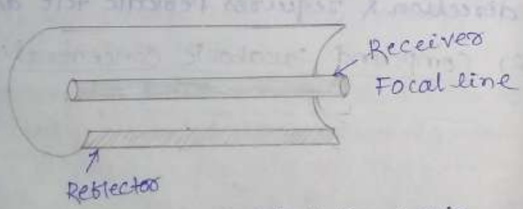
By providing plane reflectors at the edges of a flat plate collector to reflect additional radiation into the receiver, the concentration of solar radiation can be increased. The mirrors are also called Booster mirrors. The concent^n ratio of this concentrators has a max^n value of '4'. Such a design is allign in the east, west direction & requires periodic tilt adjustment.

(2) Compound parabollic concentrating type (CPC):-



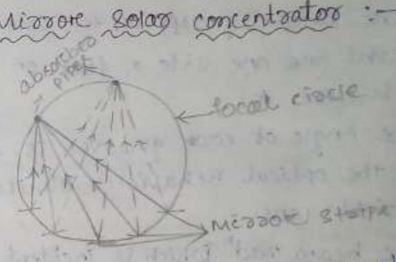
A compound Parabolic concentrator consist of 2 Parabolic mirror segments attached to a flat receiver. The segments are oriented such that the focus of one is located at the bottom end point of the other in contact with the receiver. It has a large acceptance angle & needs to be adjusted intermittently. Rays in the central region of the apparatus reach the absorber directly whereas those near the edges undergo one or more reflect before reaching the absorber. The concentration ratio achieved from this collector is in the range of 3 to 7.

③ Cylindrical parabolic concentrator :-



→ It consist of a cylindrical Paraboilic reflector & a metal tube Receiver. The receiver tube is blackent at the outside surface to increase the absorption. It is rotated about one axis to track the sun. The heat transfer fluid flows through the receiver tube carry the thermal energy & transfer to the next stage of the system. This type of collector may be oriented in any one of the 3 directⁿ that are East-west, N-S or Polar directⁿ. The Polar configuration intersects more solar radⁿ per unit area as compaired to other modes & thus gives the best performance. The concentⁿ ratio of these collectors ranging from 5 to 30.

④ Fixed Mirror Solar concentrator :-



Due to practical difficulty in manufacturing a large mirror in a single piece in a cylindrical Parabolic shape long narrow mirror strips are used in this type of concentrator. The concentrator consists of fixed mirror strips arranged on a circular reference cylinder with a tracking receiver tube. The receiver tube is made to rotate about the centre of curvature of the reflector module to track the sun. The concentratⁿ ratio is approximately the same as the no. of mirror strips.

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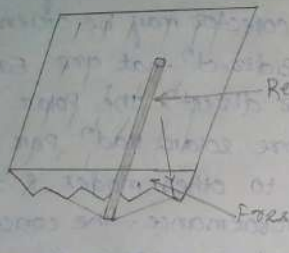
⑤ Linear Fresnel Lens collector.



→ In this collector a fresnel lens which consists of fine linear groups on the surface of the material on one side & flat on the other side is used.

→ The angle of each grooves is designed to make the optical behaviour similar to a spherical lens.

→ The beam radⁿ which is incident normally converges on the focal line where receiver tube is provided to absorve the radiation.

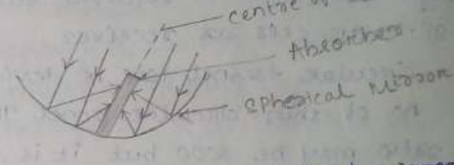
→ A concentration ratio of 10-30 may be realised which gives the temp betⁿ 150°C - 300°C

⑥ Paraboloidal Dish collector (Scheffler solar concentration)

→ When a parabola is rotated about its optical axis, a paraboloidal shape is produced.

→ Beam radⁿ is focused at a point in the paraboloid. This requires 2 axis tracking. It can have a concentⁿ ratio ranging from 10 - few thousands. It can yeild a temp of 3000°C. Paraboloidal disk collectors of 6-7 m in diameter are commonly used.

⑦ Hemispherical Bowl mirror concentrator.

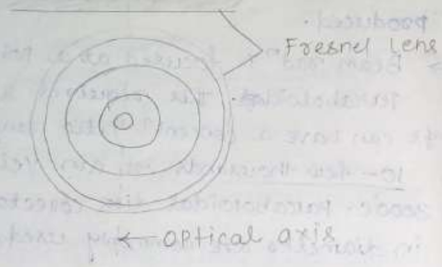


→ It consist of a hemispherical fixed mirror, a tracking absorber & a supporting stʳ.

→ The absorber is to be moved so that its axis is alway aligned with the solar rays passing through the centre of the sphere.

→ The absorber is adjusted periodically during the day. This type of concentrator gives lesser concentration as compaired to paraboloidal concentrator.

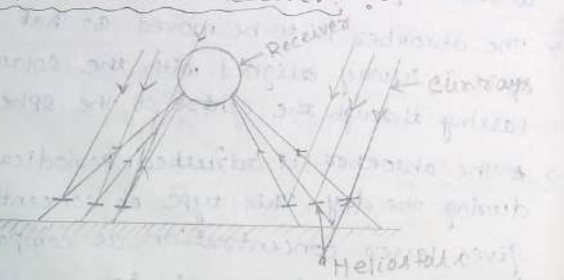
⑧ Circular Fresnel Lens collector



→ This type of lens is generally used where high solar flux is required such as with 'Si' solar cells as receiver.

→ Circular fresnel lens is devided into a no. of thin circular zones. The concentⁿ ratio may be 2000 but it is less than that of Paraboloidal reflectors.

⑨ Central tower Receiver :-



→ In this type of collector the receiver is located at the top of the tower. The beam radⁿ is reflected on it from a large no. of flat mirrors known as Heliostates spread over a large area on the ground surrounding the tower. Thousands of such heliostates track the sun to direct the beam radⁿ on the receiver from all sides.

→ concentⁿ ratio of appox. 3000 can be obtained. The absorved energy can be extracted from the receiver & delivered at a temp & press. suitable for driving the turbines for power generation.

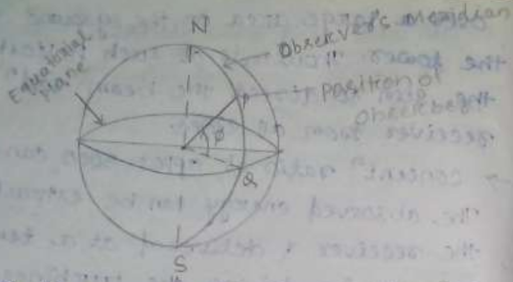
Application of solar collectors.

(i) Solar water heater.
(ii) Space heating & cooling system.
(iii) Solar Industrial heating system.
(iv) Solar Refrigeratⁿ & air conditioning system.
(v) Solar cookers.
(vi) Solar furnaces.
(vii) Solar dryer
(viii) Solar Green house
(ix) Solar distillation.
(x) Solar Thermo mechanical system.

27.08.13

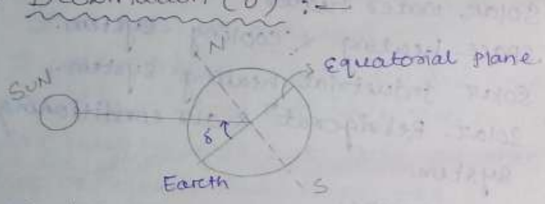
Solar Radiation Geometry.

(1) Latitude (Angle of latitude) (ϕ) →
The latitude of a locatⁿ on the earth surface is the angle made by a radial line joining the given locatⁿ to the centre of the earth with its projectⁿ on the



Equator plane. The latitude is +ve for the northen hemisphere & -ve for southern hemisphere.

2. Declination (δ) :-



It is defined as the angular displacement of the sun from the plane of earth equator. It is +ve when measured above the equatorial plane in the Northern Hemisphere.

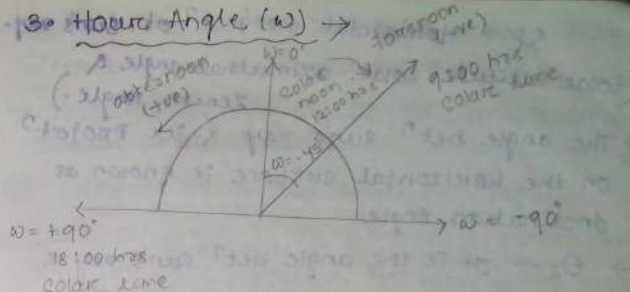
Declination angle (δ) =

$$23.45 \times \sin\left[\frac{360}{365}(284+n)\right] \text{ degree}$$

Where:

n = Day of the year counted from 1st Jan

3. Hour Angle (ω) →



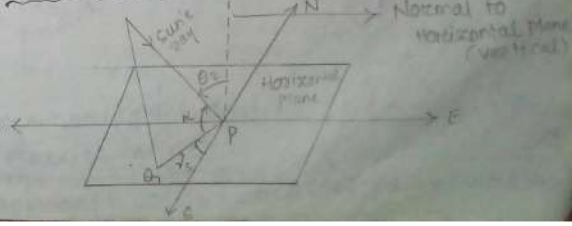
The hr angle at any moment is the angle through which the earth must turn to bring the meridian of the observer directly in line with the sun's ray.

(OR) At any moment it is the angular displacement of the sun towards east or west of local meridian (Due to rotation of earth on its axis).

→ One hour corresponds to 15° of rotation. At solar noon as the sun's ray is in line with the local meridian, the hour angle (ω) = 0.

$$\omega = [\text{Solar time} - 12 \text{ hrs}] \text{ in hrs} \times 15^\circ$$

4. Inclination Angle (Altitude) (α) →



QP → Horizontal project^n of sun's ray.

(Solar altitude, solar azimuthal angle & zenith angle.)

→ The angle bet^n sun's ray & its project^n on the horizontal surface is known as Inclination Angle.

→ θ_z → It is the angle bet^n sun's ray & $\perp^r$ or normal to the horizontal plane.

→ γ_s → It is the angle on a horizonal plane bet^n the line due South & the project^n of the sun's ray on the horizontal plane. It is taken as +ve when measured from South towards west.

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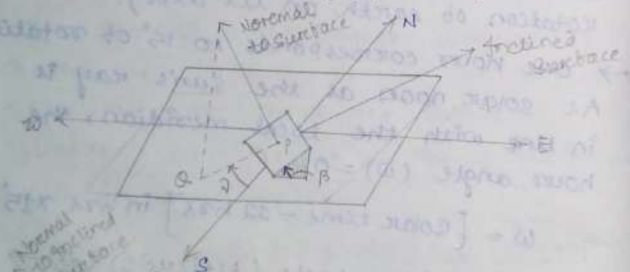
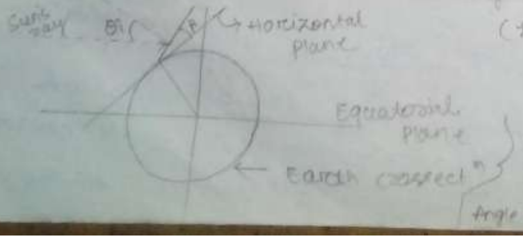
(5) SlOPE → (Tilt Angle) (β) →



{Surface Azimuthal Angle & Slope (tilt Angle)}



Angle of Latitude, tilt Angle & Angle of Incidence

→ It is the angle bet^n the inclined plane surface (collector) and the horizontal surface.

→ It is taken to be +ve for the surface sloping towards south.

⑥ Surface azimuthal Angle (γ) →

→ It is the angle in the horizontal plane bet^n the line due south & the horizontal proj^n of the normal to the inclined plane surface (collector). It is taken as +ve when measured on South towards west.

⑦ Angle of Incidence (θ_i) →

→ It is the angle between the sun's ray incident on the inclined plane surface (collector) & the normal to that surface.

→ In general the angle of incidence can be expressed as: ~~$\cos\theta_i = (\cos\phi\cos\beta + \sin\phi \sin\beta$~~

$$\cos\theta_i = (\cos\phi\cos\beta + \sin\phi\sin\beta\cos\gamma)\cos\delta\cos\omega + \cos\delta\sin\omega\sin\beta\sin\gamma + \sin\delta\,(\sin\phi\cos\beta - \cos\phi\sin\beta\cos\gamma) \quad —— ①$$

Special cases

(1) For a surface facing south, $\gamma = 0$.

So, $$\boxed{\cos\theta_i = \cos(\phi-\beta)\cos\delta\cos\omega + \sin\delta\sin(\phi-\beta)} \quad ②$$

② For a horizontal surface, $\beta = 0$ & $\theta_i = \theta_z$ (zenith Angle).

So, $$\boxed{\cos\theta_i = \cos\theta_z = \cos\phi\cos\delta\cos\omega + \sin\delta\sin\phi} \quad ③$$

(3) For a vertical surface facing south
$\gamma = 0$; $\beta = 90°$.

So, $\boxed{\cos\theta_i = -\sin\delta\cos\phi + \cos\delta\cos\omega\sin\phi}$ — (1)

Solar Time (Local Apparent Time)

→ A solar time is measured with reference to solar noon, which is the time when the sun is crossing the observer's meridian.

$$\boxed{\text{Solar time} = \text{standard time} \pm 4(L_{st} - L_{loc}) + E}$$

Where: L_{st} & L_{loc} → standard longitude used for measuring standard time of the country & the longitude of observer's location.

(+)ve sign → If the standard meridian of the country lies in the western hemisphere.

(-ve) sign → If it lies in eastern hemisphere.

E → correction due to the variation in the length of solar day.

$= (9.87\sin 2B - 7.53\cos B - 1.5\sin B)$ min

$$\boxed{B = \frac{360}{364}(n-81)}$$

n → no. of day of the year starting from 1st Jan.

Solar Day Length →

→ During sun rise the sun's ray are parallel to the horizontal surface. Hence the angle of incidence $\theta_i = \theta_z = 90°$. The corresponding power angle $\omega_s = \cos^{-1}(-\tan\phi\tan\delta)$

And, $\cos\theta_i = 0 = \cos\phi\cos\delta\cos\omega_s + \sin\delta\sin\phi$)

The angle betⁿ sun rise & sun set is:

$$2\omega_s = 2\cos^{-1}(-\tan\phi\tan\delta)$$

Since, 15° of hour angle is equivalent to 1 hour duration, the duration of sun shine hours, t_d or day light hour is given by:

$$\boxed{t_d = \frac{2}{15}\cos^{-1}(-\tan\phi\tan\delta)}$$

Q) Calculate the angle of incidence of beam radiation on a plane surface, tilted by 45° from the horizontal plane & pointing 30° west of south located at Mumbai at 1:30 pm on 15th November. The longitude & latitude of Mumbai are 72° 15' east & 18° 54' North respectively. The standard longitude is 81° 54' east.

Ans: from eqⁿ (1);

$\cos\theta_i = (\cos\phi\cos\beta + \sin\phi\sin\beta\cos\gamma)\cos\delta\cos\omega + \cos\delta\sin\omega\sin\beta\sin\gamma + \sin\delta(\sin\phi\cos\beta - \cos\phi\sin\beta\cos\gamma)$

so, $\theta_i = \cos^{-1}(\ \ \ \ \ \ )$

$n = 319$

$\delta = 23.45 \times \sin\left(\frac{360}{365}(284+n)\right)$

Dt. 2.09.13

WIND ENERGY

Introduction →

→ wind energy is one of the most available & Exploitable forms of renewable energy.

→ wind flow from a region of higher atmospheric press to that of lower atmospheric press. The difference in the press. is caused due to the fact that:

(i) The earth surface is not uniformly heated by the sun.

(ii) Due to the earth's rotation.

→ wind energy is the biproduct of Solar energy available in form of kinetic energy of air. It is a natural source of mechanical power.

Power contained in wind →

The power contained in wind is given by the kinetic energy of the flowing air mass per unit time.

$P_0 = \frac{1}{2}$(air mass per unit time)(wind velocity)^2

$= \frac{1}{2}(\rho A V_\infty)(V_\infty)^2$

$$P_0 = \frac{1}{2}\rho A V_\infty^3$$

P_0 = Power contained in wind in watts.

ρ = Air density $\simeq 1.225\ kg/m^3$ at $15°C$ and normal press.

A = Rotor area in m^2

V_∞ = wind velocity without rotor interferance i.e. at ∞ distance from the rotor in m/sec.

Wind Energy Conversion →

→ wind turbine converts energy of wind into elect. energy with the help of a generator. A wind turbine is very similar to that of a fan but it works in reverse principle. i.e. a wind turbine converts air flow into mechanical energy which gives elect. power.

→ wind is the low quality energy it is basically a relatively unidirectional motion of air molecules, but not all the molecules move in same direction. There is random motion of these molecules in all direction. The algebric summation yeilds resultant in one direct^n. So the order of this form of energy is low in compairsion ~~of~~ with motion of the shaft where all the molecules share a common motion.

→ In wind energy conversion, the wind energy is transform into the rotation of a shaft or the flow of electrones.

→ 2nd law of thermodynamics states that whenever there is a transformat^n from low quality to high quality energy, it is impossible to get 100%. efficiency. There is always a theoritical max^m limit on the efficiency. In case of conversion of wind energy into mech. energy of a rotating shaft, there must be some theoritical upper limit on the efficiency of conversion.

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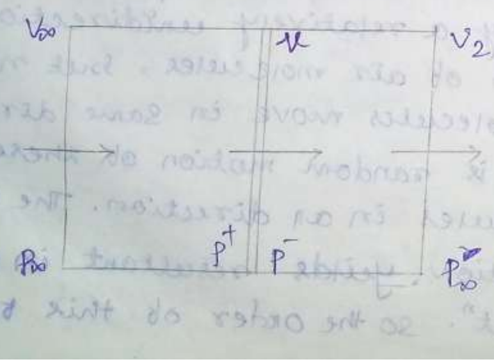
Efficiency limit for wind energy conversion :— (Betz limit)



Let us consider an ideal converter in the form of a disk of area 'A' which extracts a fract^n of the power contained in the wind flowing through it.

Let the velocity of the incoming air unaffected by rotor interferance is V_∞. The velocity of air passing through the disk is 'v'. velocity of air ~~are~~ at infinite distance from the disk is 'V_2'. The pressure of the incoming & outgoing air at '∞' distance from the disk are same i.e. P_∞. But there is a press. difference $(p^+ - p^-)$ bet^n the 2 sides of the disk. It is assume that the air flow is axial & no rotational energy is applied to the air stream.

Applying Bernoulli's theorem for the air streams on the 2 sides of the disc, we get,

$$\frac{1}{2}\rho V_\infty^2 + P_\infty = \frac{1}{2}\rho v^2 + p^+ \quad \text{——} (1)$$

$$\frac{1}{2}\rho V_2^2 + P_\infty = \frac{1}{2}\rho v^2 + p^- \quad \text{——} (2)$$

Subtracting eq^n (1) & (2) we get,

$$p^+ - p^- = \frac{1}{2}\rho(V_\infty^2 - V_2^2) \quad \text{——} (3)$$

The thrust on the disc is given by the area multiplied by the press. difference i.e

$T = A(p^+ - p^-)$

$= \frac{1}{2}\rho A(V_\infty^2 - V_2^2)$ — ④

The thrust is also given by;

$T = \dot{m}(V_\infty - V_2) = \rho A V(V_\infty - V_2)$ — ⑤

Equating eqⁿ ④ & ⑤ ;

$\frac{1}{2}\rho A(V_\infty^2 - V_2^2) = \rho A V(V_\infty - V_2)$

or, $V = \frac{1}{2}(V_\infty + V_2)$ — ⑥

It is conventional to work out the axial interferance factor 'a' in terms of $V = V_\infty(1-a)$.

For, a = 0 → There is no interference so $V = V_\infty$.

at a = 1, There is complete blockage of flow of wind. so $V = 0$.

For a normal wind turbine, 'a' value lies betⁿ 0 to 1. Substituting the value of 'V' in eqⁿ ⑥ we get the expression of V_2 in terms of 'a'. i.e.

$V_\infty(1-a) = \frac{1}{2}(V_\infty + V_2)$

$\Rightarrow V_2 = V_\infty(1-2a)$ — ⑦

Power extraction is given by the drop in the KE of a air stream per unit time

$P_1 = \frac{1}{2}\rho A V(V_\infty^2 - V_2^2)$ — ⑧

Substituting for V & V_2,

$P_1 = 2\rho A V_\infty^3 a(1-a)^2$ — ⑨

Thus the Power O/P is a nonlinear function of 'a'. At a = 0 & a = 1, O/P Power = 0.

Therefore the O/P power should reach a maxᵐ for some value of 'a' betⁿ 0 & 1. To find this value of 'a' we differentiate P_1 w.r.t 'a' & equate it to zero. so,

$\frac{dP_1}{da} = 2\rho A V_\infty^3(1 - 4a + 3a^2) = 0$ — ⑩

This quadratic eqⁿ has 2 sol's. at a = 1 & 1/3

If a = 1, then V = 0 which is impossible.

so at a = 1/3, it gives the maxᵐ extractable power. So,

$P_{max} = \frac{8}{27}\rho A V_\infty^3$ $\quad \left\{ P_0 = \frac{1}{2}\rho A V_\infty^3 \Rightarrow \rho A V_\infty^3 = 2P_0 \right\}$

$P_{max} = \frac{16}{27} P_0$ — ⑪

This maxᵐ value will be reached when $V = \frac{2}{3}V_\infty$.

The theoritical maxᵐ Power extractable from wind is 16/27 times the Power contained in the wind. This limit is called **Betz limit**.

8/9/13

Types of wind Energy conversion Device.

(i) HAWT (Horizontal axis wind turbines)

→ Dutch type/grain grinding wind mills.

→ Multiblade water ~~Energy~~ Pumping.

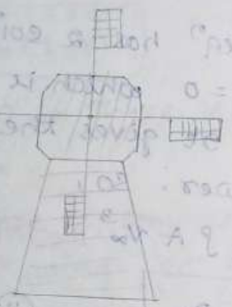
→ High speed propeller type wind mills.

(ii) VAWT (vertical axis wind turbines)

→ The savonius rotor.

→ the darrieus rotor.

a. Dutch type wind Mills. →



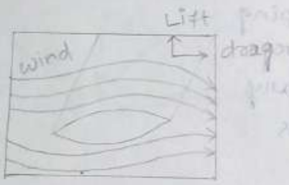
- These wind mills operates on the thrust exerted by wind.
- The four blades are inclined at an angle to the ~~Plane~~ plane of rotatⁿ.
- The wind being deflected by the blades exert a force in the directⁿ of rotatⁿ. The blades are made up of wooden slats (narrow strip of woods)
- In the early stages of development of wind mills, Orienting the blades in the directⁿ of wind was accomplished manually. Later the 'fan-tail' system was introduced in which there was a small wind mill behind at right angles to the main one, directly driving the orientation system.
- when the main wind mill face the wind, the 'fan-tail' didn't. when the wind directⁿ changes, the 'fan-tail' is rotated & ~~to~~ turned the main wind mill back to the wind.

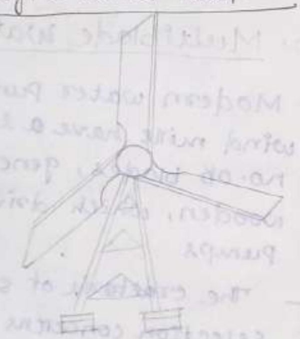
b. Multiblade water Pumping wind Mills.

- Modern water pumping wind mills have a large no. of blades, generally wooden, which drives pumps.
- The craiteria of sight selection concerns water availability & not windyness. Therefore the m/c must be able to operate at slow wind.
- The large no. of blades give a high torque which is required for driving a centrifugal Pump even at slow wind. Hence sometimes these are called Fan mills.
- The blades are made up of flat, steel Plates working on the thrust of the wind. These are attached to a metal ring to ensure ~~stru~~ structural strength.

- There m/c should have an inbuild protect" against high winds & storms. This may be achieved by mounting the tail-vane slightly off the axis off the main rotor.
- The wind mill orientation depends on the combination of the thrust of the wind on the rotor & the thrust on the tail-vane.
- During high wind flow it makes the rotor face away from the wind.

c. High speed propeller type wind mill.





flow of wind over an aerofoil blade

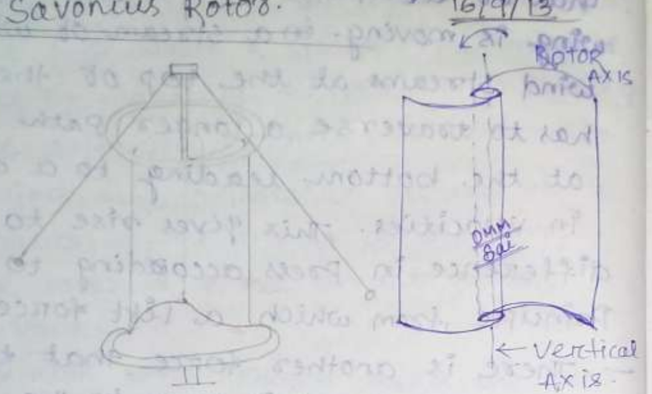
→ The Horizontal axis wind turbines that are used for elect. power generation don't operate on thrust force. They depend mainly on the aerodynamic forces that develop when wind flows arround a blade of aerofoil design.

→ wind mills working on the thrust force are inherently less efficient.

→ The principle of operation is same as that of aeroplane wing. When the aeroplane wing is moving in a stream of wind, the wind streams at the top of the aerofoil has to traverse a longer path than that at the bottom. leading to a difference in velocities. This gives rise to a difference in press according to Bournoulli Principle, from which a lift force results.

- There is another force that tries to push the aerofoil back in the direct" of wind. This is called the drag force.
- The aggrigate force on the aerofoil is then determine by the resultant of these 2 forces. If the lift force dominents the drag force, there will be a resultant force along the direct" of motion giving a +ve push to it. This is the force that creats the torque in a wind turbine.
- The blades of the wind mill are so alligned that the drag force is minimized & the lift force is maximized which gives the blades a net +ve torque.
- This type of turbines are useful for electrical power generat".

d. The Savonius Rotor. 16/9/13



→ It consists of 2 identical hollow semi cylinder fixed to a vertical axis.

→ The inner side of the 2 half cylinders face each other. As the wind flowing into the st^r meet with 2 dissimilar surfaces i.e. one convex & other concave, the forces exerted on the 2 surfaces are different which gives a rotor torque. By providing a certain amount of overlap bet^n the 2 semicylinders, the torque can be increased. This is because the wind flowing into the concave surface turns around & give a push to the inner surface of the other semi cylinder, partly cancelling the wind thrust on the convex side. It has been found that an overlap of about 1/3 red of the 2 cylinder diameter gives the optimum result.

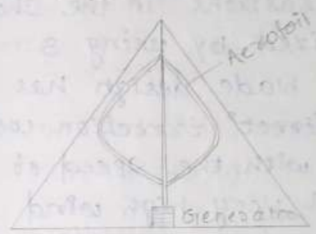
Advantages :-

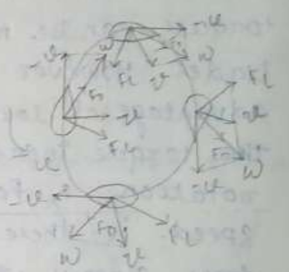
- It is inexpensive & simple.
- The material used is available in rural areas

Disadvantages

The utility is limited to pumping water becoz of its low efficiency.

e. The Darrieus Rotor. :-



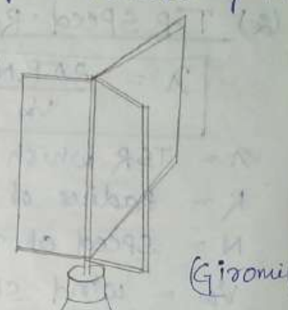


u → Blade velocity
v → wind velocity
w → Relative wind
F_L → Lift force
F_D → Drag force.

— Two or more flexible Blades are attached to a vertical shaft, the blades are taking the shape of a parabolla. The forces on the blades at the 2 sides of the shaft are same, producing no torque. It developes a +ve torque only when it is rotating. Hence such a rotor has no starting torque & has to be started using some external means. The principle of operat^n is shown in the fig.

One blade of the rotor is shown in 4 successive posⁿ along the path of rotatⁿ. At each posⁿ the lift force has a +ve component along the directⁿ of rotatⁿ giving rise to net +ve torque. These torque is not same in all posⁿ, It varies from zero when the blade is moving directly in the directⁿ of wind to a maxⁿ about 1/4 of the revolution. The pulsastions in the shaft torques can be minimized by using 3 blades. However two blade design has advantage of lower ~~direct~~ errection cost the torque increases with the speed of rotation. & falls at very high wind speed. i.e. these design has an inbuild protⁿ from stromy wheather. i.e. the rotor tends to stall at high winds. This type of rotor operates on lift force. So the efficiency is same as that of propeler type wind mills. The theoritical limit of power extractⁿ is 0.554 times the power contained in wind. As it has high efficiency & high speed it is used for electrical power generatⁿ.

→ The main disadvantage is that it is unable to operate at high wind speeds available at higher alt ultitude. The starting torque is generally provided by an electrical m/c which initially run as a m/r but latter changes to the generator mode as the rotor starts generating power. A varrient of this m/c using the same concept is the Giromill. In which the blades are straight resulting in simple construction.


(Giromill)

→ In this case the centribugal force developed in the bade will produce stress, trying to bend it

→ The balades have to be strong enough to withstand these stress

Important Defⁿ.

(1) Solidity.

→ The solidity of a wind rotor is the ratio of the projected blade area to the area of the wind intersepted.

→ The solidity of a S rotor is unity as the wind has no free passage through it.

→ For a multiblade water pumping wind mill it is arround 0.7. For high speed horizontal axis m/c it lies betⁿ 0.01 to 0.1. For adarrious rotor it is of the same order as that of high speed horizontal axis m/c.

→ High solidity rotors have high torque & low speed & are suitable for pumping water.

- Low solidity rotor have low torque & high speed & are suitable for electrical power generatⁿ.

(2) Tip Speed Ratio. (TSR)

$$\lambda = \frac{2\pi R N}{V_\infty}$$

λ = TSR which is non dimensional.
R = Radius of the swept area in meter.
N = Speed of rotation in r.p.s.
V_∞ = wind speed without rotor interption in rps.

→ TSR of a savanious rotor & multiblade water pumping windmills are generally low. For high speed horizontal axis rotors & darrious rotors the TSR is 9.

→ High solidity rotors have low TSR & vice versa.

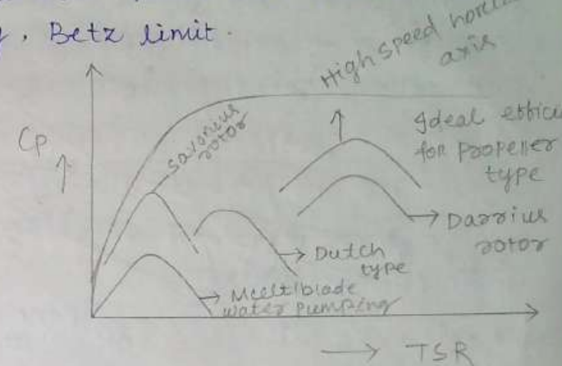
(3) Power coefficients. (C_p) 17/9/13

Power coefficient of a wind energy converter

$$C_p = \frac{\text{Power o/p from wind m/c}}{\text{Power contained in wind.}}$$

The difference betⁿ the power coeffient & efficiency is that, efficiency includes losses where as cp is just the efficiencyⁿ of conversion of wind energy into mechanical energy of shaft.

- In high speed horizontal axis m/c, the theoritical maxᵐ power coefficient is given by, Betz limit.



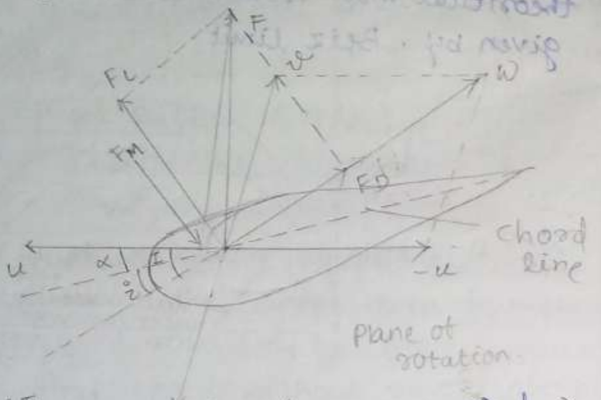
(4) Wind Turbine Ratings & specifⁿ:

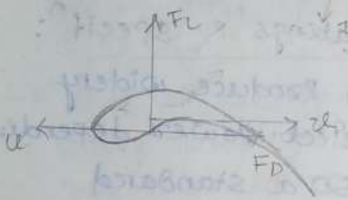
A wind turbine can produce widely varying amount of elect. power depending on the wind speed. So a standard procedure must be evolved to specify the rating of the m/c with the combⁿ of rotor diameter & peak power rating of generator. ~~one~~ work ~~one~~ index is used to compaire various wind turbine design is the specific rated capacity (~~SCR~~) (SRC)

→ $SRC = \frac{\text{Power rating of the generator.}}{\text{Rotor swept area.}}$

→ SRC varies betⁿ 0.2 for small rotors to 0.6 for large one.

Aerodynamics of Wind Rotors





(Relative wind direct^n & aerodynamic forces.)

Where : FL → Lift force
FD → Drag force
FM = Moment force
ϑ = wind velocity
u = aerofoil velocity
I = Inclinat^n angle.
i = incidence angle
α = pitch angle
w = Relative wind direct^n.

Axial speed of wind →
speed of wind through the rotor in m/sec denoted by $\vec{\vartheta}$.

Speed of Blade element →
The speed of a blade element at a dist.

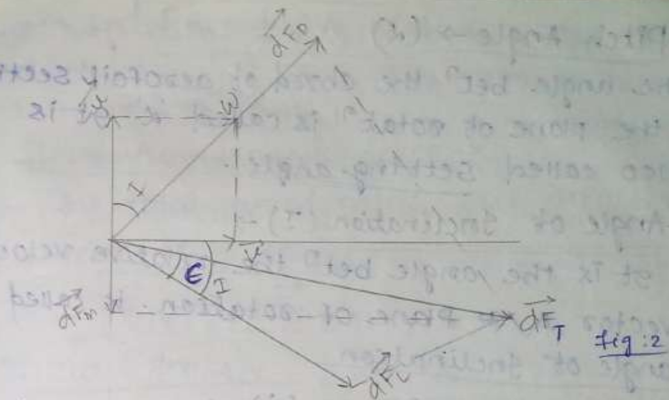


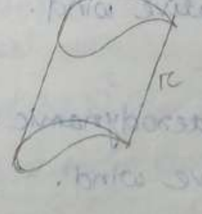
fig : 2

'r' from the rotor axis is 2πrN in m/sec. denoted by $\vec{u}$.

Relative velocity →
The velocity of air flow relative to the blade. $\vec{w} = \vec{\vartheta} - \vec{u}$.

Blade Axis →
The longitudinal axis through the blade. It is possible to vary the inclination of the blade relative to the plane of rotat^n around this axis.

Blade section at r →
The intersection of the blade with a cylinder of radius 'r' whose axis is the rotor axis, the section is aerofoil shape.



Pitch Angle → (α)

The angle betn the chord of aerofoil section & the plane of rotatn is called 'α'. It is also called setting angle.

Angle of Inclination (I) →

It is the angle betn the relative velocity vector & a plane of rotation. is called angle of inclination.

Angle of Incidence (i) →

The angle of incidence is the angle betn relative velocity vector & the chord line of the aerofoil denoted by i.

$$i = I - \alpha$$ It is also called the angle of attack.

Lift force →

The Lift force is the component of aerodynamic force in the directn ⊥r to the relative wind.

$$F_L = \frac{1}{2} \rho A_b \omega^2 C_L \text{ Newton.}$$

Where: A_b = Blade area in m^2

C_L = Dimension less lift coefficient.

ω = Relative wind.

Drag Force :-

The component of aerodynamic force in the directn of relative wind.

$$F_D = \frac{1}{2} \rho A_b \omega^2 C_D$$

C_D = Drag coefficient.

Total Aerodynamic force →

The total aerodynamic force on a blade element is given by,

$$\vec{F} = \vec{F_L} + \vec{F_D}$$

Thrust force →

The component of $\vec{F}$ along the direction of wind denoted by $\vec{F_T}$.

Torque force →

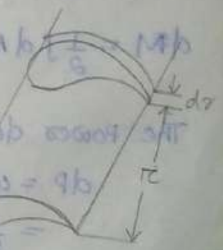
The component of $\vec{F}$ along $\vec{r}$ denoted by $\vec{F_M}$.

Aerodynamic Movement →

The movement of $\vec{F}$ about the axis in Nm denoted by 'M'.

18/9/13 Axis Using blade Element Theory :-

Consider a blade element of length 'dr' at a distance 'r' from the rotor axis. The magnitude of lift & drag forces developed in this blade element are :



$$dF_L = \frac{1}{2} \rho A_b \omega^2 C_L \quad \text{——} (1)$$

$$dF_D = \frac{1}{2} \rho A_b \omega^2 C_D \quad \text{——} (2)$$

The resultant of these 2 forces give the total aerodynamic force 'dF' which can be resolved into axial thrust dF_T & Movement producing flux dF_M. The aerodynamic movement given by 'r' multiplied by dF_M.
From fig-2 we see that;

$$dF_T = dF_L \cos I + dF_D \sin I \quad \text{--- (3)}$$

$$dF_M = dF_L \sin I - dF_D \cos I \quad \text{--- (4)}$$

$$dM = r(dF_L \sin I - dF_D \cos I) \quad \text{--- (5)}$$

If the angular velocity is 'ω' then we can write $w^2 = u^2 + v^2$

$$= r^2\omega^2 + v^2 \quad \text{--- (6)}$$

where: $u = r\omega = v \cot I$ — (7)

Substituting all values in eq^n (3) & (5) we get;

$$dF_T = \frac{1}{2}\rho dA_b v^2 (1+\cot^2 I)(C_L \cos I + C_D \sin I) \quad \text{--- (8)}$$

$$dM = \frac{1}{2}\rho dA_b v^2 r(1+\cot^2 I)(C_L \sin I - C_D \cos I) \quad \text{--- (9)}$$

The power developed in watts is given by;

$$dP = \omega dM$$

$$= \frac{1}{2}\rho dA_b v^3 \cot I \operatorname{cosec}^2 I (C_L \sin I - C_D \cos I) \quad \text{--- (10)}$$

The torque & the aerodynamic power depends on I. which in term depends on the wind speed & rotational speed.

The lift & drag coefficient depend on the angle of attack i which is $i = I - \alpha$.

This coefficient can be varied by varying the pitch angle α. Thus based on this eq^n a max^m amount of power can be produced at any wind speed by suitably varying the pitch angle α.

Aerodynamic efficiency :—

The aerodynamic efficiency of a blade element is given by:

$$\eta_a = \frac{\text{useful power extracted from the wind}}{\text{Power supplied by the wind.}}$$

$$= \frac{\vec{u}\cdot d\vec{F}}{\vec{v}\cdot d\vec{F}}$$

$$= \frac{u\,dF_M}{v\,dF_T} = \frac{u(dF_L \sin I - dF_D \cos I)}{v(dF_L \cos I + dF_D \sin I)} \quad \text{--- (1)}$$

Diving N^r & D^r by $dF_L \sin I$, we get;

$$\eta_a = \frac{u}{v}\,\frac{(1-(dF_D/dF_L)\cot I)}{(\cot I + dF_D/dF_L)} \quad \text{--- (2)}$$

From the fig-2 let ϵ be the angle bet^n $\vec{dF_L}$ & $\vec{dF}$.

$$\tan\epsilon = \frac{dF_D}{dF_L} = \frac{C_D}{C_L} \quad \text{--- (3).}$$

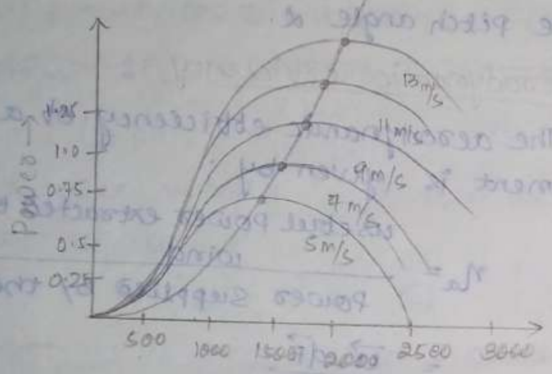
Putting $u = \omega r = v \cot I$ & eq^n (3) in eq^n (2) we get,

$$\eta_a = \cot I\left[\frac{1-\tan\epsilon \cot I}{\cot I + \tan\epsilon}\right]$$

$$\eta_a = \frac{1 - \tan\epsilon \cot I}{1 + \tan\epsilon \tan I}$$

* When $\tan\epsilon$ is less we get high η.
Dt/19/09/13 i.e. $\tan\epsilon$ <<< high η_a.

Power ~ Speed c/s



(A typical power ~ speed c/s of wind turbine)

→ The fig. shows that the mechanical power that can be extracted from the wind depends on the rotor speed.

→ For a given turbine C_p depends not only on the TSR but also on the blade pitch angle.

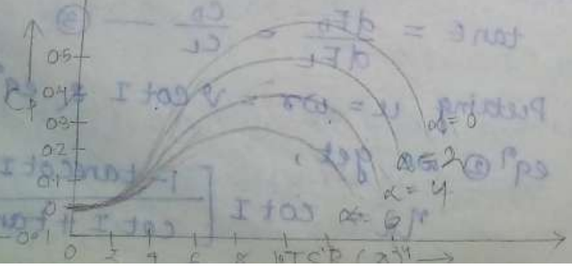


fig: (Variation of power coefficient w.r.t TSR(λ) with blade pitch control)

→ Power contained in wind = $\frac{1}{2} \rho A V_\infty^3$

$$C_p = \frac{\text{O/P from wind m/c}}{\text{Power contained in wind}}$$

⇒ Mechanical power = C_p × Power contained in wind

$$= C_p \times \frac{1}{2} \rho A V_\infty^3$$

$$P_m = \frac{1}{2} C_p \rho A V_\infty^3$$

P_m → Mechanical power transmitted to the shaft

→ C_p is a function of λ & α. For a wind turbine with radius R, the above eq^n can be written as,

$$P_m = \frac{1}{2} \rho C_p \pi R^2 V_\infty^3$$

→ For a given wind speed, the power extracted from the wind is maximized if C_p is maximized.

→ The optimum value of C_p i.e. $C_{p,opt}$ always occurs at a definite value of λ i.e. λ_{opt}. For max^m power o/p from the wind turbine at different wind speed, the rotor speed should be adjusted acc. to the value of λ_{opt}.

$$\lambda = \frac{2\pi RN}{V_\infty}$$

$$\lambda = \frac{\omega R}{V_\infty} \Rightarrow V_\infty = \frac{\omega R}{\lambda}$$

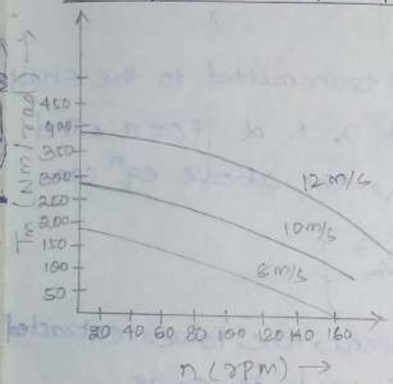
The max^{m} value of shaft mechanical Power for any wind speed can be expressed as;

$$P_{max} = \frac{1}{2} C_{p,opt} \pi \rho R^2 \left(\frac{\omega R}{\lambda_{opt}}\right)^3$$

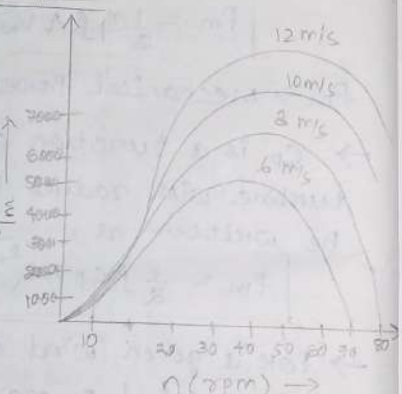
$$\boxed{P_{max} = \frac{1}{2} C_{p,opt} \pi \rho \frac{\omega^3 R^5}{\lambda^3_{opt}}}$$

$$\boxed{P_{max} \propto \omega^3}$$

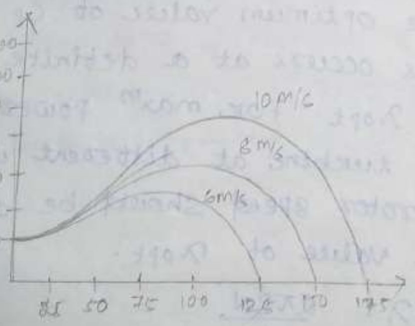
Torque ~ Speed c/s



(T~n c/s of savonius Rotor)



(For Darries Rotor)



(High speed Propeller Type Rotor)

→ Torque ~ speed c/s of any prime mover (wind Turbine) is very important for properly matching the load & ensuring stable operat^n of elect. generator. The torque Vs speed curves follow from the power curves since torque & power are related as:

$$T_m = \frac{P_m}{\omega}$$

$$= \frac{1}{2} \rho C_{p,opt} \pi \frac{R^5}{\lambda^3_{opt}} \omega^2$$

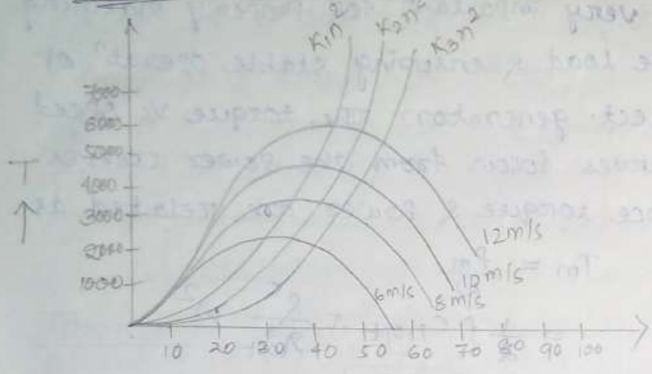
$$\Rightarrow \boxed{T_m \propto \omega^2}$$

$$\Rightarrow \boxed{T_m = K\omega^2}$$

K = constant of propertanility.

→ The max^{m} shaft torque varies with the sqr. of rotational speed. The choice of const. of propertanility is very imp. At the optimal value the load curve follow the Max^{m} shaft power. But at higher value the load torque may exceed the turbine torque for most speeds consiquently the m/c would fell to speed up above the rated value. If the constant K is lower than the optimum value, the m/c may overspeed at rated wind speed, activating the speed limiting mechanism. Thus the proportionality const of the load needs to be selected which is about 10-20% of the optimum Power value.

Torque ~ Speed c/s.



(T~n c/s of wind turbine at different value of K)

25/9/13

Wind Turbine Control system.

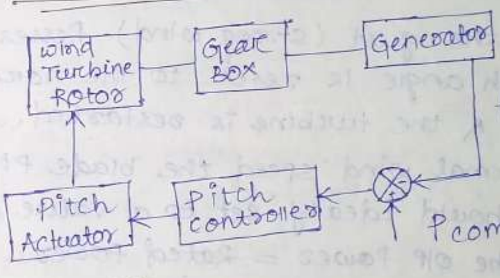
1. Pitch angle control.
2. Stall control.
3. Power electronic control.
4. Yaw control.

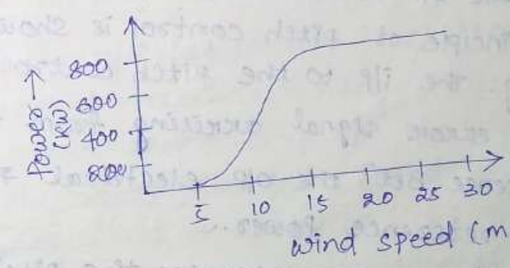
→ Wind turbine require certain control system. In high winds it is desirable to reduce the load & protect the gen. & power electronic equipment from overloading. This can be done by limiting the turbine power to the rated value upto the furling speed.

→ At high wind speed the m/c has to be stalled. At low & moderate wind speed the power must be extracted as efficiently as possible. The rated wind speed is the min. wind speed at which the wind turbine produces its designated o/p power. For most turbines this speed is normally 9 betⁿ 9 m/s to 16 m/s. The generator rating is chosen so as to best utilise the mechanical o/p of the turbine at rated wind speed.

→ Wind turbine can have 4 different type control mechanism.

① Pitch Angle control.





→ This system changes the pitch angle of the rotor blade according to the variation of wind speed. With this control it is possible to achieve a high efficiency by continuously aligning the blade :

the direction of relative wind. As the wind speed exceeds its rated speed the blades are gradually turned about its longitudinal axis & o/p out of the wind to increase the pitch angle. This reduces the aerodynamic efficiency of the rotor & also the rotor o/p reduces.

→ When the wind speed exceed its safe limit, the pitch angle is so changed that the power o/p reduces to zero & the m/c shifts to stall mode.

→ After the gust (strong wind) passes, the pitch angle is reset to the normal position & the turbine is restarted.

→ At normal wind speed the blade pitch angle should ideally set to a value at which the o/p power = Rated power.

→ The principle of pitch control is shown in the fig. The i/p to the pitch controller is the error signal arrising from the difference betⁿ the o/p electrical power & the reference power.

→ This pitch controller operates the pitch ~~actural~~ actuator to alter the pitch angle.

→ During the operⁿ bet below rated speed the c.s tries to set the blade at an pitch angle that maximizes the rotor efficiency. The generator must be able to absorve the mechanical power o/p & deliver it to the load & hence the generator o/p power needs to be adjusted simultaneous.

→ This control mechanism is relatively expensive however the stalling mechanism must be incorporated to prevent damage to the turbine during high wind speed.

(2) Stall control :—

It is of 2 types.

① Passive stall control.

② Active stall control.

Gene → Stall C.S

Passive stall control.

— Generally stall control is applied to const pitch of turbine driving induction gen. to limit the power o/p at high winds.

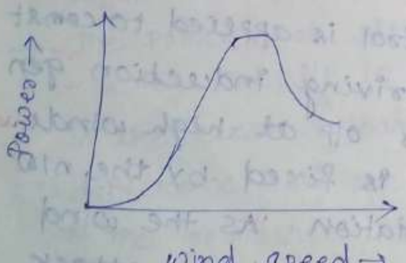
— The rotor speed is fixed by the n/w with 1-2 % variation. As the wind speed increases, the angle of attack of the blade which is running at a const speed also increases.

— Beyond a perticular angle of attack the lift force decreases causing the rotor efficiency to drop. The lift force can be further reduced to restrict the power o/p at high wind.

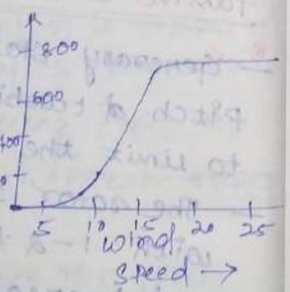
— A passive control m/c shows a drop in power at high wind.

Active stall control.

In this method of control, at high wind speeds the blade is rotated by a few degrees in the direction opposite to that in a pitch controlled m/c. This increases the angle of attack which can be controlled to keep the o/p power at its rated value at high wind speed. The action of active stall control is sometimes called 'deep stall'. This control scheme is generally used with high capacity m/c.



(Passive control)



(Active control)

(3) Power Electronic Control.

By using a power electronic interface betn the generator & load, the electrical power delivered by the generator to the load can be dynamically controlled.

→ The instantaneous difference betn the mechanical & electrical power changes the rotor speed according to the following eqn :

$$J \frac{d\omega}{dt} = \frac{P_m - P_e}{\omega} \quad \text{—— (1)}$$

where: J = Moment of inertia of rotor

ω = Angular speed of rotor

P_m = Mechanical power produced by the turbine.

P_e = elect. power delivered to the load.

Integrating eqn (1) we get ;

$$\int_{\omega_1}^{\omega_2} J \frac{d\omega}{dt} = \int_{t_1}^{t_2} (P_m - P_e)\, dt$$

$$\Rightarrow \frac{1}{2} J(\omega_2^2 - \omega_1^2) = \int_{t_1}^{t_2} (P_m - P_e)\, dt \quad \text{—— (2)}$$

→ The advantage of this control is that it is smooth in operatn.

→ Disadvantage is that fast variation of speed requires a large difference betn the i/p & o/p power which results in a large torque & hence the stress on the blades increases.

→ Contineuous control of the rotor speed by this method implies contineuous fluctuation of the power O/P to the grid which is undesirable to the power system.

④ Yaw Control :-

→ This control orients the turbine contineuously along the directⁿ of wind flow. In small turbines this is achieved with a tail ven.

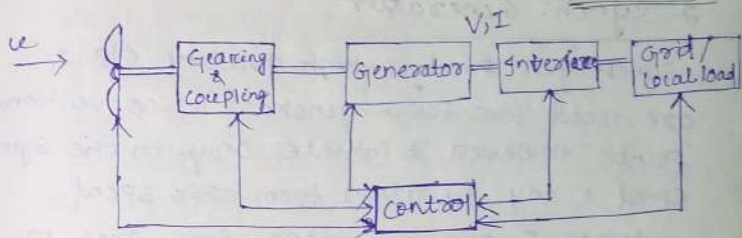
→ In the large m/c this can be achieved by using motorised control systems activated either by fan-tail or in case of a wind farm, by a centralised instrument for the detection of wind direction.

→ It is also posible to achieve yaw control by simply mounteng the turbine down wind so that the thrust force auto--metically pushes the turbine in the directⁿ of wind.

→ This control mechaniem can also be used for speed control. The rotor is made to face away from the wind directⁿ at high wind speeds thereby reducing the mechanical power. If pitch control is used then yaw control is sheldom used becoz it produces stress on the rotor blade. It also produces loud noise.

Dt. 24.9.13

WIND ENERGY CONVERSION SYSTEM. (WECS) :-



(BLOCK Diagram of WECS)

→ WECS convertes wind energy into elect. energy. If WECS is connected in ||el with a local AC grid then this is known as grid connected system.

→ A small system isolated from the grid feeding only to a local load is known as Autonomous/ Decentralised system.

→ The control unit moniters & controls interaction among various blocks.

→ It derives the ref. voltage & freq. signal from the grid & receives wind speed wind directⁿ & process them & controles various blocks for optimal energy balance.

1. DC generator

Conventional DC generators are not favored due to their high cost, weight & maintance problem of the commutator.

DC m/c are used with permanent magnet which are considered in small rating systems.

2. Synch. Generator.

Synch gen. produce high quality o/p & are used for power generat^n in conventional plants. However it rotates only in the synch speed & any deviation from this speed reflects in the generator freq. Due to this region a synch m/c is not used for wind power gener^n. Requirement of dc current to excite the rotor speed which needs carbon brushes on slip rings also causes limit^n in its use. The need of dc field current & brushes can be eliminated by using reluctance motor. The m/c rating is limited to some tense of kW. (10-99)

The advantage is that it generates both active as well as reactive power.

3. Induction Generator

The 1° advantage of an Ind^n m/c are

1. Brushless const^n.

2. No need of separate dc power.

3. Tolerance of sligh variation of shaft speed i.e. ±10% as these variations are absorved in the slip. As compaired to DC & synch. m/c induction generator have low maintance & better transient performance for these reason Ind^n gen. are extensively used in wind power plant.

→ The Ind^n m/c requires AC excitation current which is mainly reactive. In case of a grid connected system, the excitat^n current is drawn from the grid & therefore the n/w must be capable of supplying this reactive power.

→ In a stand alone/decentralised system the Ind^n gen. is self excited by shunt capacitor.

→ Based on the gen drive 2 schemes have been developed for the operat^n of WECS.

① fixed speed drive scheme

② variable speed drive scheme.

Fixed speed drive scheme.

1. One fixed speed.

The shaft speed is fixed for the whole range of wind speed. The major disadv. of this drive is that it never captures the wind energy at the peak value of power coefficient (Cp). Wind energy is wasted when wind speed is higher or lower than optimal value. The use of this drive is limited to small m/c.

2. Two fixed speed.

The indn gen. is designed to operate at 2 speeds. This is achieved either having 2 stator wndgs with different no. of poles or using single wndg. with pole changing arrangement.

In separate wdg m/c matching with system requirement is easy & change of speed setting is made without losing the control of the m/c. However separate windgs are difficult to accomodate.

In the pole changing method the poles are either P or 2P. The only possible speed ratio is 2 : 1. Also a dead time is to be allowed for the coil reconnectn during every speed transition.

Variable speed drive →

In this scheme rotor speed is allowed to vary optimally with the wind speed to capture max^m power. As a result it can capture about 1/3rd more power as compaired to fixed speed drive system. It is of 3 types.

① Variable speed drive using power electronics.

The variable voltage & variable freq. o/p available from a synchronous / Induction generator is first rectified to dc & then converted to fixed freq. & voltage AC using an inverter. The harmonics are filtered o/p to get better quality o/p before connecting to the grid. This has 2 measured benifits.

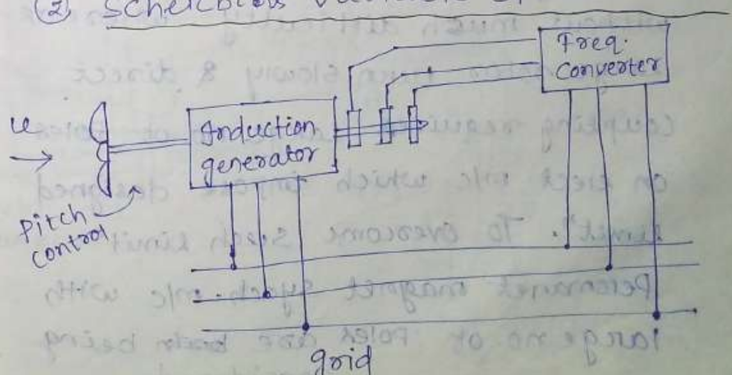
(i) Opertunity for remote control which makes its suitable for ~~offshope~~ offshore application.

(ii) Fine tuning for superior grid connn to make it better suitable for meeting the demand of the grid.

Dis:

① used of PE ckt adds to the cost, elect. noise & losses to the system.

② Scherbius variable speed drive.



It make use of wound rotor / slip ring rotor indn m/c. The stator is connected to the grid & the rotor is connected to variable freq. source or freq. convertor via 3 slip rings. The speed is controlled by controlling the freq. of the external voltage injected into the rotor. It offers lower cost & improves the power quality. However the use of slip rings leads to increased maintance.

③ Variable speed Direct Drive

The generator is directly coupled to the turbine shaft without gear & operate at turbine speed. It doesn't make use of PE. The main benifits are reduced noise, vibration & lower power loss. For small sized turbine where the rotor speed is high, direct coupling to the generator is possible without much difficulty. whereas large rotor turn slowly & direct coupling required large no. of poles on elect. m/c which impose designed limitn. To overcome such limitn Permanent magnet synch. m/c with large no. of poles are ~~bein~~ being considered.

25/9/13

Grid connected & Self excited Induction Generator Operation

There are 2 types of excitation.

① Line excitation. (used in slip ring rotor)

② Self excitation. (used in Squirrel cage rotor)

Constant voltage, constant freq. operatn.

→ single o/p system.

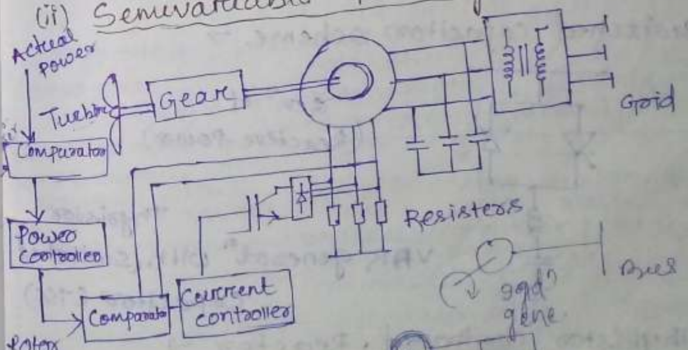
→ Double o/p system

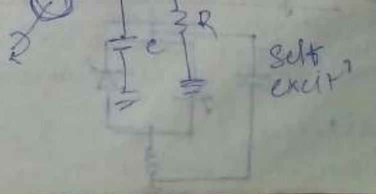
(i) fixed speed system

(ii) Semivariable speed system.

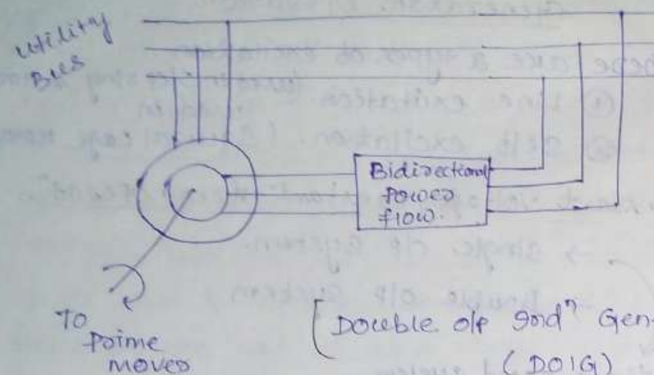
(i) Fixed speed System →

(ii) Semivariable speed system →

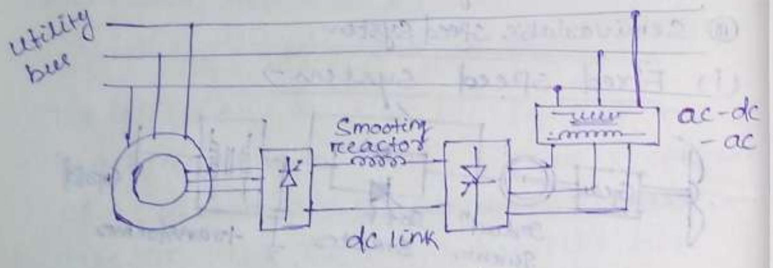




Double Excited System :

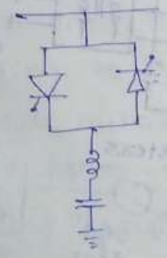


[Double o/p ind^n Generator (DOIG)]



Reactive Power Compensation.

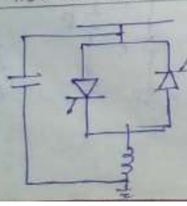
① Switched Capacitor scheme →



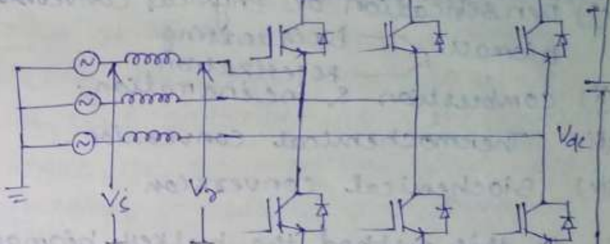
Gen^n of (Reactive power)

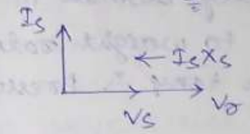
Thyristor VAR generat^n with switched Capacitor (TSC)

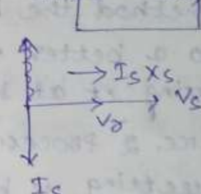
② Thyristor controlled Reactor →



③ Static VAR compensator.







Mod - 3

BIOMASS ENERGY

Biomass Resources

Biomass

- Energy crops (arid area plantation) (Cultiv^n of plants which supply fuel wood)
- Natural vegetable growth (oil can be extracted Sunflower, coconut, gnd nut etc)
- Organic wastes & residues
  - Forest residue (timber, fuel wood)
  - Agricultural crop residue (rice husk, corn cobs etc)
  - Animal waste (combustible) (Rice dung cake)
  - Urban waste
    - Municipal solid waste (house hold garbage, commercial waste)
    - Sewage liquid waste (domestic sewage & from institutional activities)
  - Industrial waste (paper industry waste)

Biomass Conversion Technology.

(i) Densification or physical conversion of biomass.
- Breiquetting
- pelletization.

(ii) combustion & incineration.
(iii) Thermochemical conversion.
(iv) Biochemical conversion.

(i) In this method the bulkey biomass is reduced to a better vol. to weight ratio by compressing it at high temp & pressure.
There are 2 process.

(i) **Breiquetting** is brought about by compression & squeezing out moisture & breaking down the elasticity of wood. If elasticity is not sufficiently removed then the compressed wood will regain its precompression volume.

(ii) **Pelletization** is the process in which waste wood is pulverised, dried & forced under pressure through a device. The extracted mass is in the form of pellets (rod) facilitating its use in steel power plants. This process reduces moisture to about 7 to 10%.

(ii) Combustion → Direct combustion is the main process adopted for utilizing biomass energy. It is burn to produced heat utilized for cooking, space heating, industrial process & electricity generation.

This is very inefficient process due to this heat transfer loss which is about 30-90%.

Incinerⁿ → It is the process of burning completely the solid biomass to ashes by high temp oxidation. It is the special process where the dry municipal solid waste is incinerated to reduced the volume of solid waste & to produce heat, steam, & electricity.

Waste incineratⁿ plants are installed in large cities to dispose of urban waste & generate energy.

(iii) Thermochemical conversion →
It is a process of decomposⁿ of biomass with various combination of temp & press.
It is of 2 ways.
(i) pyrolysis
(ii) Gasification.

(i) **Pyrolysis** :→
Biomass is heated in the absence of oxygen or with a limited oxygen supply to produce hydrocarbon, a mixture of gas (H_2, CO_2 & hydrocarbons) an oil like liquid & charcoal). This biooil produced can be transported easily & refined to give a product similar to refining crude oil. There is no waste product.

(iii) Gasification → It is the conversion of a solid biomass at a high temp with controlled air into a gaseous fuel. The o/p gas is known as producer gas which is a mixture of CH_4, N_2, CO_2 & carbonmonoxide, methane. It can be burn to produce heat & steam or it may be used in internal combustion engines or gas turbines to produce electricity.

(iv) Biochemical conversion →

(i) Anaerobic digestion.

(ii) Ethanol

(i) It is the process which converts the cattle dung & other organic waste with high moisture contained into biogass in the absence of air. This is otherwise known as anaerobic formentat^n.

(ii) Ethanol can be produced by the decompos^n of biomass containing sugar like sugar cane, beet, patato, graphe, corn etc into sugar molecules such as glucose & sucrose.

Betz limit

Albert Betz, a German physicist, calculated that no wind turbine could convert more than 59.3% of K.E of wind into mech. energy i.e turning a rotor. This is known as Betz limit & is the theoretical max. co-efficient of power for any W.T

Derivation of Betz limit:

The ratio of ~~~~ o/p power of turbine to the available power : Power co-efficient

$$C_P = \frac{P_{turbine}}{P_{wind}(K.E)} = \frac{P_{turbine}}{1/2 \rho A V^3}$$

* The power o/p of W.T / rotor, is governed by aerodynamic charc. of rotor & its no. of blades.

→ As air passes thru the rotor surface, the wind speed reduces, the amount is given by the factor "a" [axial interference factor].

$$a = \frac{V_{down}}{V_{up}}$$

(*) From a conservation of mass & momentum process, C_p can be equated to an equ.

$$C_p = \frac{1}{2}\left[1-a^2\right]\left[1+a\right] = \frac{1}{2}(1+a-a^2-a^3)$$

Diff:

$$\frac{dC_p}{da} = \frac{1}{2}\left[1-2a-3a^2\right]$$

$$= \frac{1}{2}\left[1-3a\right]\left[1+a\right]$$

From hit & trial method, exp. results have shown, that C_p is max at $a = 1/3$.

~~$\therefore C_p = \frac{1}{2}\left[1-3\frac{1}{3}\right]\left[1+\frac{1}{3}\right]$~~

$$C_p = \frac{1}{2}\left[1-\frac{1}{9}\right]\left[1+\frac{1}{3}\right]$$

$$= \frac{1}{2}\left[\frac{8}{9}\right]\left[\frac{4}{3}\right] = \frac{16}{27} = 0.5986$$

∴ This yields Betz criteria for max. power generation i.e 59.3% of wind power can be converted.

(*) Rotor blade materials:

→ Wood, wood epoxy, wood fiber epoxy.

→ Steel & Al. (small Turb)

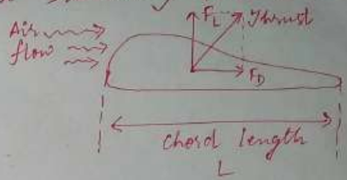
→ Carbon or aramid fibers such as Kevlar.

→ Glass fiber Reinforced Plastics (GRP) →

large W.T.

Aerodynamics of Rotor Blade

i) Forces on a stationary Rotor Blade.



WIND ELECTRICAL SYSTEM

6·9·10

Wind energy is one of the most available & exploitable forms of renewable energy. Wind blows from a region of higher atmospheric pressure to one of lower atmospheric pressure. This difference in pressure caused due to:

(i) The fact that the earth's surface is not uniformly heated by the sun

(ii) The earth's rotation

Power contained in wind:

The power contained in wind is given by the kinetic energy of the flowing air mass per unit time. It is denoted as P_0.

$$P_0 = \frac{1}{2} \times (\text{air mass / unit time}) \times (\text{wind velocity})^2$$

$$\Rightarrow P_0 = \frac{1}{2} \times (\rho A V_\infty) V_\infty^2$$

where P_0 - power contained in wind (in watts)

ρ - air density $\simeq 1.225\ Kg/m^3$

(At 15°c & normal pressure)

A - rotor area in m^2

V_∞ - wind velocity without rotor interference (i.e. ideally at infinite distance from rotor) in m/s

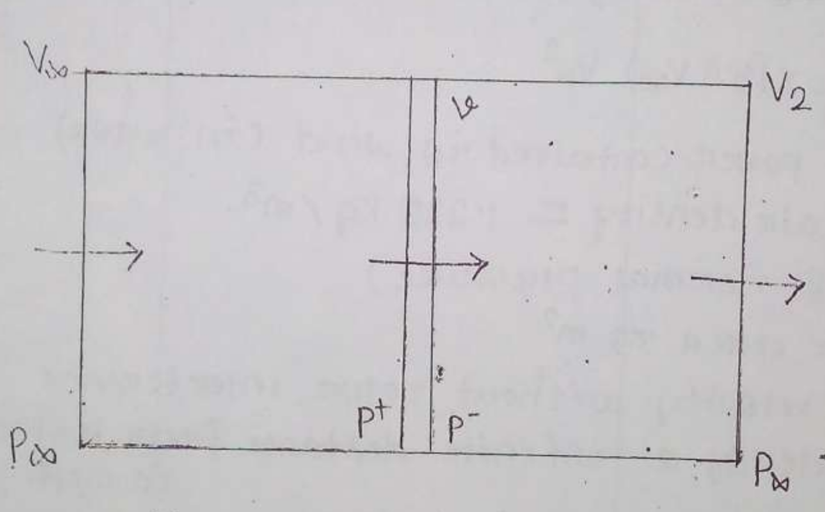
Wind energy conversion - Thermodynamics of wind energy:

Although wind is kinetic in nature, wind is low quality energy. It is basically a relatively uni-directional motion of air molecules, in that not all molecules move in the same direction. There is a random & disorderly thermal motion of the molecules in all direction. Only the algebraic summation yields a resultant value in one direction.

Naturally, the order & organisation of this form of energy is low in comparison with motion of a shaft where all molecules share a common motion. The objective in wind energy conversion is to transform this energy into rotation of a shaft or flow of electrons.

The 2nd law of thermodynamics states that, whenever there is a transformation from low quality energy to high quality energy, it is not possible to achieve 100% efficiency even in theory. There is always a theoritical maximum limit on the efficiency.

Efficiency limit for wind energy conversion :



Let us consider an ideal converter in the form a disc of area 'A' which extracts a fraction of power contained in the wind flowing through it. V_∞ = velocity of incoming air unaffected by rotor interference

v = air passing through the disc.

V_2 = Velocity of outgoing air at infinite distance from the disc.

P_∞ = pressure of incoming & outgoing air at infinite distance from the disc

$(p^+ - p^-)$ = Pressure difference between two sides of disc

Assumptions :

The flow is axial & no rotational kinetic energy is imparted to the air stream.

Applying Bernoulli's theorems on the two sides of a disc,

$$P_\infty + \frac{1}{2}\rho V_\infty^2 = P^+ + \frac{1}{2}\rho v^2 \quad \text{——— (1)}$$

$$P_\infty + \frac{1}{2}\rho V_2^2 = P^- + \frac{1}{2}\rho v^2 \quad \text{——— (2)}$$

Substracting eqn (1) & eqn (2), we get

$$P^+ - P^- = \frac{1}{2}\rho\left(V_\infty^2 - V_2^2\right)$$

The thrust on the disc is given by area multiplied with the pressure difference.

$$T = A(P^+ - P^-)$$

$$\Rightarrow T = \frac{1}{2}\rho A\left(V_\infty^2 - V_2^2\right) \quad \text{——— (3)}$$

The thrust is also given by,

$$T = m(V_\infty - V_2)$$

$$\Rightarrow T = \rho A v (V_\infty - V_2) \quad \text{——— (4)}$$

Now equating eqn (3) & eqn (4), we get

$$\frac{1}{2}\rho A\left(V_\infty^2 - V_2^2\right) = \rho A v (V_\infty - V_2)$$

$$\Rightarrow v = \frac{1}{2}(V_\infty + V_2) \quad \text{——— (5)}$$

Let 'a' be the axial interference factor. Air passing through the disc in terms of 'a' is given by,

$$v = V_\infty(1-a) \quad \text{——— (6)}$$

For $a=0$, there is no interference. So, $v = V_\infty$

For $a=1$, there is a complete blockade of flow of wind & $v=0$

So, for a normal wind turbine 'a' will take some value between 0 & 1.

Substituting value of v in eq^n (5), we get

$$V_\infty (1-a) = \frac{1}{2}(V_\infty + V_2)$$

$$\Rightarrow \boxed{V_2 = V_\infty (1-2a)} \qquad \text{——— (7)}$$

Power extraction is given by the drop in kinetic energy ~~per~~ of air stream per unit time is given by,

$$\boxed{P_1 = \frac{1}{2} \rho A v (V_\infty^2 - V_2^2)} \qquad \text{——— (8)}$$

Substituting the value of 'v' & 'V_2' we get,

$$\boxed{P_1 = 2 \rho A V_\infty^3 a (1-a)^2} \qquad \text{——— (9)}$$

So, the power output 'P_1' is a non-linear function of 'a'. At two extreme values $a=0$ & $a=1$, the power output is zero. So, the power output should reach a maximum for some value of 'a' between 0 & 1.

To find this value of 'a', we differentiate 'P_1' with respect to 'a' & equating to '0'.

$$\frac{d}{da}(P_1) = 0$$

$$\Rightarrow \frac{d}{da}\left[2 \rho A V_\infty^3 a (1-a)^2\right] = 0$$

$$\Rightarrow 2 \rho A V_\infty^3 (1 - 4a + 3a^2) = 0$$

This quadratic eq^n has two solutions, $a=1$ & $a = \frac{1}{3}$. $a=1$ would mean $v=0$ which is not possible.

So, $a = \frac{1}{3}$ is physically acceptable.

So, maximum extractable power P_{max} is given by,

$$\boxed{P_{max} = \frac{8}{27} \rho A V_\infty^3} \qquad \because v = V_\infty (1-a) \Rightarrow v = \frac{2V_\infty}{3}$$

$$\Rightarrow P_{max} = \frac{8}{27} \times 2 \times \frac{1}{2} \rho A V_0^3$$

$$\Rightarrow \boxed{P_{max} = \frac{16}{27} P_0} \quad \text{where } P_0 = \frac{1}{2} \rho A V_0^3.$$

This means the theoritical maximum power extractable from wind is $\frac{16}{27}$ times the powere contained in wind. This limit is called Betz limit.

7.09.10

Types of wind energy conversion devices:

Wind energy converesion devices can be broadly catagorised into two types accoreding to theire axis alignment.

(1) Horizontal axis wind turbines - which is furthere subdivided into 3 types.
- (i) Dutch type grain-grinding wind mills.
- (ii) Multiplate water pumping wind mills.
- (iii) High speed propeller type wind mills.

(2) vertical axis wind turbines - which is further subdivided into 2 types.
- (i) Savonius rotore
- (ii) The darrieus rotore

(1) (i) Dutch wind mills:

These wind mills were used during the middle ages by dutch people. It operates on the thrust exerted by the wind. There are 4 plates (made of wood, shails) which are inclined at an angle to the plane of rotation. Orientation of plate in the direction of wind was done manually and later with the "fan-tail" system, in which a small wind mill was installed behind and reight angle to the main, directly driving the orientain system.

(ii) Multiplate water pumping wind-mills:

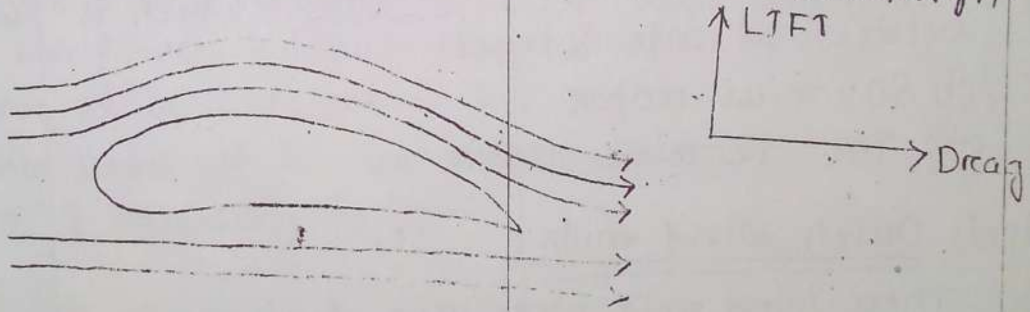
These mills have large no. of plates (wooden, metallic slats) driving a reciprocating pump. As the mill has to be installed directly over a well, the site selection depends upon water availibility. So, the mill has to operate in slow winds. Large no. of plates give high torque required by the motor even at low wind.

→ It is also called as fan-mills.

→ The blades are made up of flat steel plates working on the thrust of winds. These are hinged to a metal ring to ensure structural strength. The orientation of plate is achieved by tail-vane system.

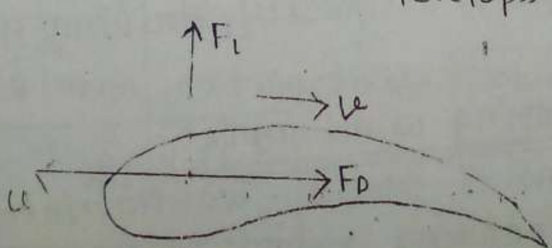
(iii) <u>High speed propeller type wind mills:</u>

The horizontal axis wind turbines that are used recently for electrical power generation don't operate on thrust force (as they have less efficiency). They depend mainly on aerodynamic forces that develop when wind flows around a plate of aerofoil design.



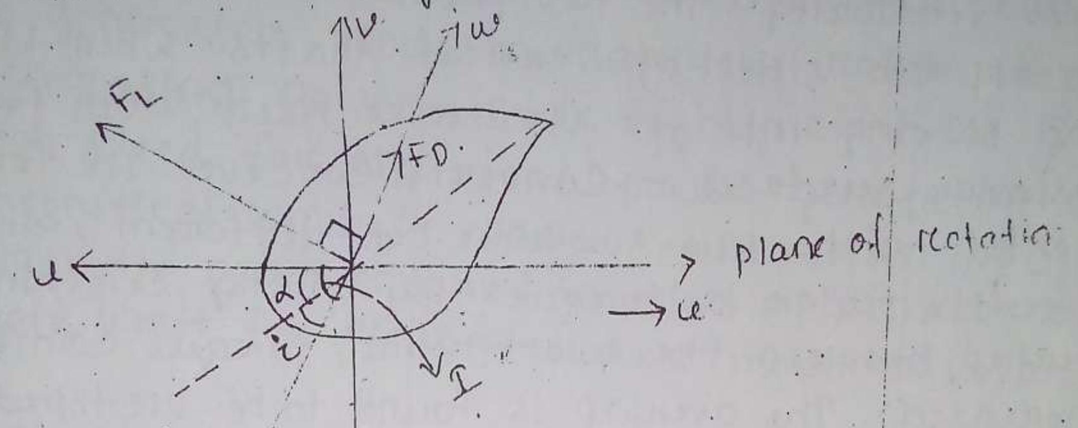
Q: How does an aerofoil works?

<u>Ans:</u> Let an aerofoil wind is moving in a stream of wind. The wind stream at the top of aerofoil has to traverse a longer path than that of the bottom, leading to difference in velocities. According to Bernoulli's principle, this gives rise to difference in pressure. From this a lift force develops.



→ There is also another force that tries to push the aerofoil back in the direction of wind. This is called drag force. (F_D).

→ The aggregate force on the aerofoil is determined by the resultant of F_L & F_D. If the aerofoil & wind don't move along the same line



→ These forces are determined as seen by aerofoil & called relative wind. It is given by vector summation of wind velocity & negative of aerofoil velocity.
F_L is perpendicular to relative wind (w).
F_D is parallel to 'w'. The magnitude of these forces will be proportional to that of relative wind.

→ The lift force & the drag force have opposing component along the direction of motion. If the lift force dominates the drag force, there will be a resultant force along the direction of motion, giving a +ve push to it.

In fact this is the force that creates the torque in a modern wind turbine. The plates are of aerofoil structure which move along the stream of wind. They are so aligned that the drag force is minimized & lift force is maximized & these gives the plate a net +ve torque. There will be another component of the two forces perpendicular to the direction of blade motion. This force is called thrust force. This force tries to topple the tower & is a problem at high wind speed.

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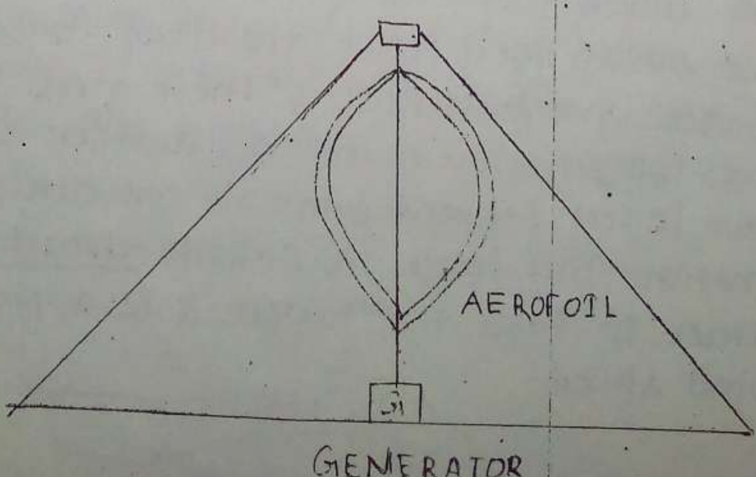
(i) Savonius rotor :

It is extremely simple vertical axis device that works entirely because of the thrust force of wind. The basic structure is a drum cut into two halves vertically. The two parts are attached to the two opposite sides of vertical shafts. When the wind blowing into the structure meets with two dissimilar surfaces – convex & concave. The force exerted on the two surfaces are different, which gives the rotor a torque. By giving certain overlap between the two drums, torque can be increased. The overlap is found to be one third of drum diameter to give maximum output. This wind mill has low efficiency & is utilised for pumping water.

ii) Darrieus rotor :

The pecularity of a darrieus rotor is that its working is different from its appearance. Two or more flexible blade are attached to a vertical shaft. The blades bow outward taking approx. the shape of a parabola & are of symmetrical aerofoil section. The force on the blades at the two sides of shaft is same; producing no torque,



when rotor is stationary. It produces a torque only when it is already rotating. This means the rotor has no starting torque & is started using some external means. The starting torque is generally provided by an electrical machine which initially runs as motor, but later changes to generator mode as darrieus rotor starts generating power. It is highly efficient & has high speed for electrical power generation. The theoretical limit of power extraction is 0.554 times the power contained in wind (P_0). The corresponding betz limit for horizontal axis machine is 0.593.

Solidity:

→ The solidity of a wind rotor is the ratio of the projected blade area to the area of wind intercepted (projected blade area - the blade area projected in the direction of wind).

→ The solidity has direct relation with torque & speed. High solidity rotor has high torque & low speed and suitable for pumping water.
Low solidity rotor have high speed & low torque & are suitable for electrical power generation.

Tip speed ratio (TSR)

The TSR of a wind turbine is defined as,

$$\lambda = \frac{2\pi RN}{V_\infty}$$

Where R - radius of swept area in m.
N - rotational speed in revolution per sec.
V_∞ - wind speed without rotor interruption in m/s.

> High solidity rotor have low TSR & vice-versa.
· TSR of savonius rotor & multiblade water pumping mills are low.
TSR of darrieus rotor & high speed horizontal axis rotor are high.

Power Co-efficient:

Power co-efficient of a wind energy converter is given by C_p.

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

Power co-efficient includes the losses in mechanical transmission, electrical generation etc. Whereas efficiency is calculated only on conversion of wind energy into mechanical energy at the shaft.

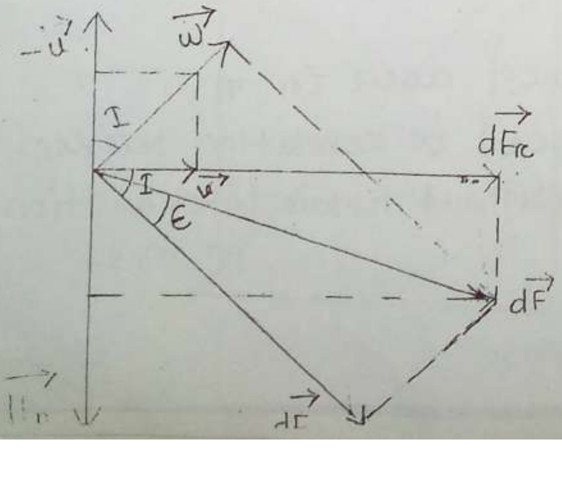
Wind turbine rating & specification:

A meaningful specification of a wind turbine is given by the combination of the rotor diameter & the peak power rating of the generator.
Specific rated capacity (SRC) is equal to power rating of the generator by rotor swept area.

$$SRC = \frac{\text{Power rating of generator}}{\text{Rotor swept area}}$$

Aerodynamics of wind rotor:

Vector diagram of velocities & forces



Blade Rotor $\vec{R}$ is Normal to the plane of diagram.

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→ **Axial speed of wind ($\vec{V}$):**

Speed of wind through the rotor in m/s.

→ **Speed of blade element: ($\vec{u}$)**

Speed of blade element at a distance 'r' from the rotor axis is $2\pi rN$ m/s. It is denoted as $\vec{u}$

→ **Relative velocity: ($\vec{w}$)**

The velocity of airflow relative to the blade. ($\vec{w}$)

$$\vec{w} = \vec{v} - \vec{u}$$

→ **Blade axis:**

The longitudinal axis going through the blade, it is possible to vary the inclination of the blade relative to the plane of rotation around this axis.

→ **Blade section at 'r':**

The intersection of the blade with the cylinder of radius 'r' whose axis is the rotor axis.

→ **Pitch angle (setting angle):**

The angle 'α' between the chord of the aerofoil section at 'r' & the plane of rotation.

→ **Angle of inclination (I):**

The angle between the relative velocity vector & plane of rotation.

→ **Angle of incidence (i) (Angle of attack):**

It is the angle between relative velocity vector & the chord line of aerofoil.

$$i = I - \alpha$$

→ **Lift force: (F_L)**

The lift force is the component of aerodynamic force in a direction perpendicular to the relative wind. It is given by,

$$\boxed{F_L = \frac{\gamma A_b w^2 C_L}{2}} \text{ N.}$$

C_L - Dimensionless lift co-efficient

A_b - Blade area in m^2

→ **Drag force: (F_D)**

Drag force is the component of aerodynamic force on the direction of relative wind.

$$F_D = \frac{\rho A_b \omega^2 C_D}{2}$$

C_D Drag co-efficient

→ **Total aerodynamic force:**

The total aerodynamic force on a blade element is given by,

$$\vec{F} = \vec{F_L} + \vec{F_D}$$

→ **Thrust force:**

The component of $\vec{F}$ along the direction of wind. It is denoted as $\vec{F_T}$

→ **Torque force:**

The component of $\vec{F}$ along $\vec{\omega}$. It is denoted as $\vec{F_m}$.

→ **Aerodynamic movement:**

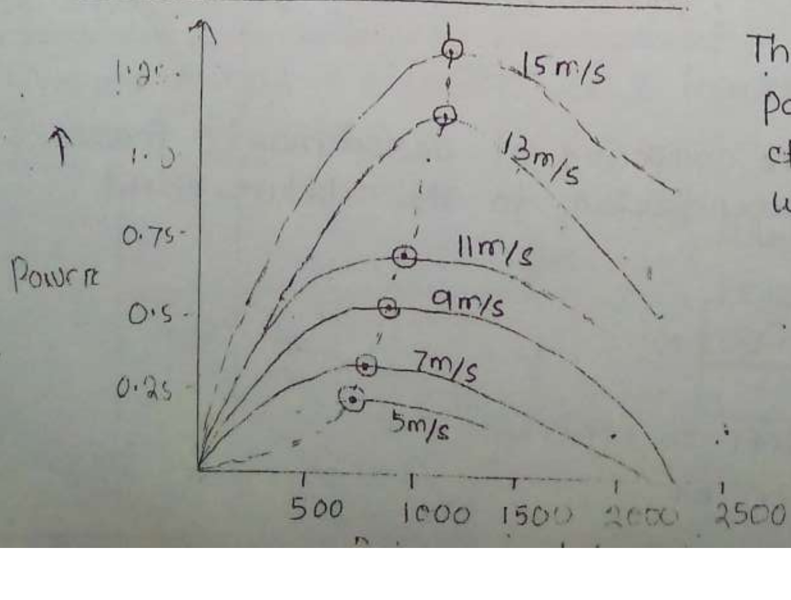
The movement of $\vec{F}$ about the axis in Nm. It is denoted as M.

→ **Aerodynamic efficiency: (η_a)**

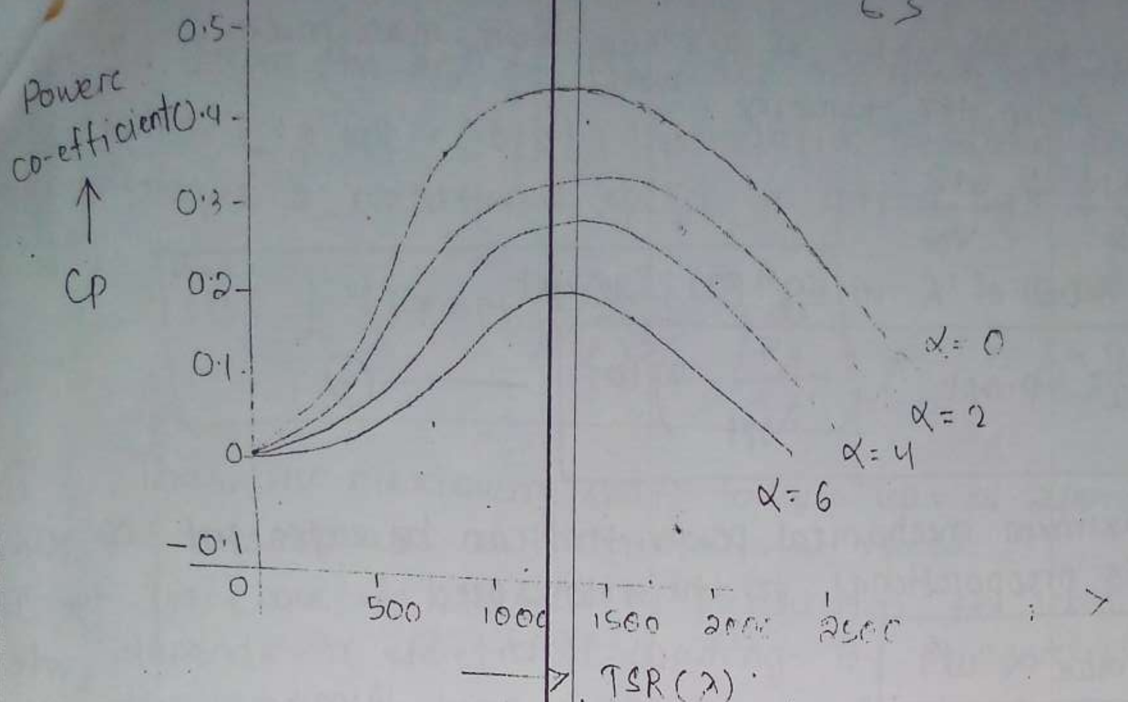
It is denoted as η_a.

$$\eta_a = \frac{\text{Useful power extracted from the wind}}{\text{Power supply by the wind}}$$

Power speed Characteristics:



The graph shows power ~ speed characteristics of a wind turbine.



Power co-efficient ~ TSR for various pitch angle (α).

∴ Per each wind speed, there is an optimum turbine speed at which the extracted wind power at the shaft reaches the maximum. For a given turbine, the power co-efficient not only depends on TSR but also on the blade pitch angle.

$$P_0 = \frac{1}{2} \rho A V_\infty^3$$ P_0 – Power contained in wind

$$C_p = \frac{P_m}{P_0}$$ P_m – power output of wind machine

$$\Rightarrow P_m = P_0 \times C_p$$

$$\Rightarrow \boxed{P_m = \frac{1}{2} \rho A C_p V_\infty^3} \quad \text{——— (1)}$$

Where C_p is a function of TSR (λ) & pitch angle (α).

For a wind turbine with radius 'R', eqn (1) can be written as,

$$\boxed{P_m = \frac{1}{2} \rho \pi R^2 C_p V_\infty^3} \quad \text{——— (2)}$$

For a given wind speed, the power extracted from the wind is maximized if C_p is maximized. The optimum value of $C_p \rightarrow C_{p.opt}$ always occurs at a definite value of $\lambda \rightarrow \lambda_{opt}$. This means for varying wind speed, the rotor speed should be adjusted proportionally to the value of $\lambda = \lambda_{opt}$ for maximum power output from the turbine.

$$\lambda = \frac{2\pi RN}{V_\infty} = \frac{\omega R}{V_\infty}$$

Putting the value of 'λ' in eqn (2), we get

$$P_{max} = \frac{1}{2} C_{p.opt}\, \pi \left(\frac{R^5}{\lambda_{opt}^3}\right) \omega^3 \quad \text{—— (3)}$$

Thus, the maximum mechanical power that can be extracted from wind is proportional to the rotor speed.

i.e. $P_{max} \propto \omega^3$

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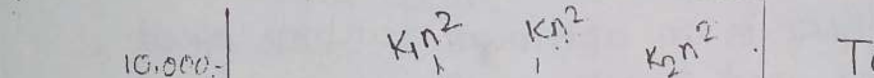
Torque-Speed Characteristics:



Torque-Speed characteristics of a wind turbine with $T \propto n^2$ (load for different values of proportionality constant K)

The torque ~ rotational speed characteristics of any primemover is very important for proper matching the load & ensuring proper stable operation of the electrical generator.

The torque & power relation is given by.

$$T_m = \frac{P_m}{\omega}$$

So, from the eqⁿ of P_{max} at optimum operating point ($C_{p.opt}$, λ_{opt}), the relation between aerodynamic torque & rotational speed is given by,

$$T_m = \frac{1}{2} \rho C_{p.opt} \pi \left(\frac{R^5}{\lambda^3_{opt}}\right) \omega^2$$

$T \propto \omega^2$
$\Rightarrow T \propto n^2$

Thus, the maximum shaft torque varies approximately as the square of the rotational speed.

→ In case of electricity production, the load torque depends on electrical loading. By properly choosing the load, the torque can be made to vary as the square of rotational speed.

→ The choice of constant of proportionality of the load is very important. At optimum value, the load torque follow the maximum shaft power, but at a higher value, the load torque may exceed the turbine torque for most speeds. But the machine would fail to speed up above a very low value.

→ If constant K is lower than the optimum value, the machine may over speed at a rated wind speed - activating speed limiting mechanism.

→ So, proportionality constant of load is selected to be around 10-20% of optimum power curve.

→ Point of maximum torque is not same as that of maximum power.

→ In terms of power co-efficient C_p, the aerodynamic torque becomes,

$$T_m = \frac{P_m}{\omega}$$

$$\Rightarrow T_m = \frac{P_m R}{V_\infty \lambda} \quad \left(\because \omega = \frac{V_\infty \lambda}{R}\right)$$

$$\Rightarrow T_m = \frac{1}{2} \rho \frac{C_p}{\lambda} \pi R^2 V_\infty^3 \times \frac{R}{V_\infty} \quad \left(\because C_T = \frac{C_p}{\lambda}\right)$$

C_T - Torque co-efficient

$$\Rightarrow \boxed{T_m = \frac{1}{2} \rho C_T \pi R^3 V_\infty^2}$$

Wind turbine Control System :

→ Wind turbine requires certain control system. Horizontal axis wind turbine have to be oriented to face the wind. In high winds, it is desirable to reduce the drivetrain loads & protect the generator & power electronics equipments from overloading.

→ At gust speed, the machine has to be stalled. At low & moderate wind speed, the power is captured as efficiently as possible.

The output of a turbine is always calculated at a particular wind speed - rated windspeed. This is the minimum wind speed at which the wind turbine produces its designated output power. It is normally between 9 & 16 m/s.

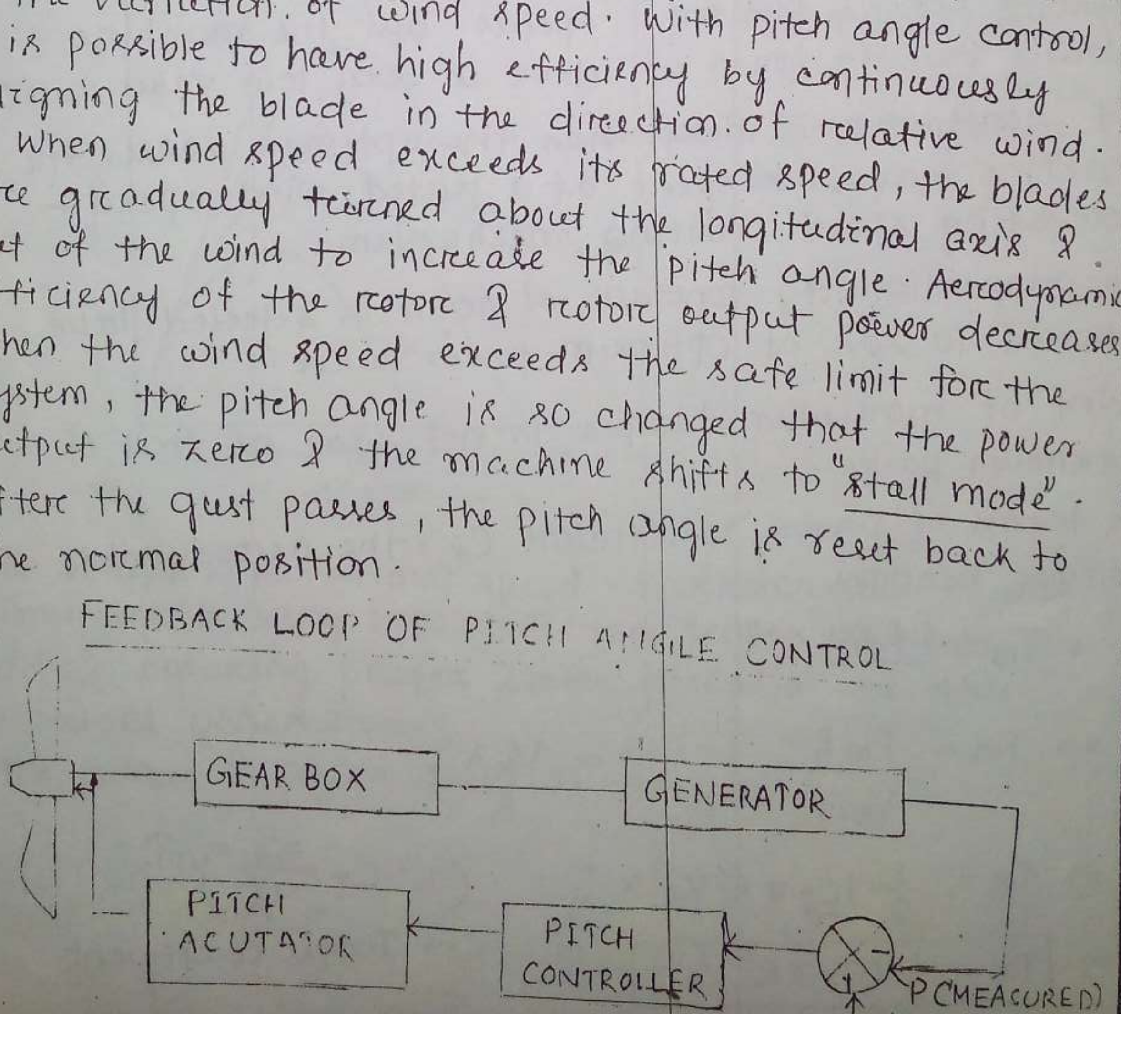
→ Wind turbines have 4 types of control mechanism.

(1) Pitch angle control :

This system changes the pitch angle of the blade according to the variation of wind speed. With pitch angle control, it is possible to have high efficiency by continuously alligning the blade in the direction of relative wind.

When wind speed exceeds its rated speed, the blades are gradually turned about the longitudinal axis & out of the wind to increase the pitch angle. Aerodynamic efficiency of the rotor & rotor output power decreases. When the wind speed exceeds the safe limit for the system, the pitch angle is so changed that the power output is zero & the machine shifts to "stall mode". After the gust passes, the pitch angle is reset back to the normal position.

FEEDBACK LOOP OF PITCH ANGLE CONTROL



Pitch angle control Principle:

→ The input variable to the pitch controller is the error signal arising from the difference between the output electrical power & the reference power.
→ The pitch controller operates the blade accuator to alter the blade angle.
→ During operation below rated speed, the control system tries to pitch the blade at an angle that maximizes the rotor efficiency. The generator must be able to absorb the mechanical power output & deliver to the load. So, generator output power needs to be adjusted simultaneously.

(2) Stall Control:

Passive stall control:

→ Stall control is used to limit the power output at high winds & is applied to constant pitch turbines driving induction generators. The rotor speed is fixed by the network allowing 1-4% variation. As wind speed increases, the angle of attack also increases for the blade running at a near constant speed.
→ Beyond a particular angle of attack, the lift force decreases causing rotor efficiency to drop.

Active stall control:

In this method, at high wind speeds, the blade is rotated by a few degree in direction opposite to that in a pitch controlled machine. This increases the angle of attack which can be controlled to keep the output power at its rated value. The passive control machine shows a drop in power at high winds. The action of active stall control sometimes called deep stall. Due to economic recession, active control is generally used only with high capacity machines.

3) Power electronics Control:

A system having power electronics interface between the generator & the load (grid), the electrical power delivered by the generator to the load can be dynamically controlled.

The instantaneous difference between mechanical power & electrical power changes the rotor speed, following the eqn,

$$J \cdot \frac{d\omega}{dt} = \frac{P_m - P_e}{\omega}$$

where J - polar moment of inertia of the rotor
ω - angular speed of the rotor
P_m - Mechanical power produced by turbine
P_e - Electrical power delivered to the load

Integrating this eqn, we get

$$\frac{1}{2} J (\omega_2^2 - \omega_1^2) = \int_{t_1}^{t_2} (P_m - P_e) \cdot dt$$

Advantages:

This method of speed control doesn't involve any mechanical action & is smooth in operation.

Disadvantages:

Fast variation of speed requires a large difference between the input power & output power, which scales the moment of inertia of the rotor. This results in large torque & hence increase stress on the blade. Continuous control of the rotor speed by this method means continuous fluctuation of power output to the grid, which is undesirable for power system

4) Yaw control:

This control orients the turbine continuously along the direction of wind flow. Yaw control is achieved -

(i) in small turbines - using a tail-vane system

(ii) in large turbines - using a fan-tail system

(iii) in wind firms - using a centralised instrument for the detection of wind direction.

It is also used in speed control. The rotor is made to face away from the wind direction at high wind speeds, thus reducing mechanical power. This method is used with pitch control method. Yawing often produces loud noise & the yawing rate is minimized to reduce the noise.

Ex: A H.A.W.T. is installed at a location having free wind velocity of 15 m/s. The 80m diameter rotor has 3 blades attached to the hub. Find the rotational speed of the turbine for optimal energy extraction.

Ans: T.S.R. at optimum output:

$$\lambda_{opt} = \frac{2\pi R}{n d}$$

Where R - radius of swept area
n - no. of blades
d - length of wind strongly pertubed by rotating blades

Assumption as per practical observation:

$$d \approx \frac{1}{2} R$$

$$\lambda_{opt} = \frac{2\pi}{n}\left(\frac{R}{d}\right) \Rightarrow \lambda_{opt} = \frac{4\pi}{n}$$

Given data:

Rotor diameter = 80m.
Rotor radius = 40m.
$V_\infty = 15 m/s$, $n = 3$

$$\lambda_{opt} = \frac{4\pi}{n} = \frac{4 \times 3.14}{3} = 4.188$$

$$\lambda = \frac{\omega R}{V_\infty} \Rightarrow \omega = \frac{\lambda V_\infty}{R} = \frac{4.188 \times 15}{40}$$

$$\Rightarrow \omega = 1.57$$

Let 'N' is the rotor speed in rpm.

$$\omega = \frac{2\pi N}{60} \Rightarrow N = \frac{60\omega}{2\pi} = \frac{60 \times 1.57}{2 \times 3.14} = 15 \text{ rpm}$$

$$\therefore N = 15 \text{ rpm}$$

Therefore for optimum energy extraction, the rotor speed should be maintained at 15 rpm.

Conversion of electrical power - Induction & Synchronous generator:

Analysis of certain electrical machine like induction generator & synchronous generator are required further application in conversion of wind energy to electricity. Earlier dc generators were used for low voltage & low capacity wind power systems charging storage batteries to operate light & small appliances. For large machines, dc machines have been faced out due to problems associated with commutator. AC generators like induction generator & synchronous generators are used for major wind turbines.

Induction generator:

Self-excited generators working in isolation with variable speed primemovers, such as wind turbines have poor voltage and frequency regulation. So, squirrel cage induction machines are choosen due to their ruggedness, low cost & low maintainance. The generated ac voltage may either be used directly or converted into dc voltage. DC power can be used directly in certain dc equipments such as battery charger or fed to ac mains, through an invertor.

Synchronous generator:

A synchronous generator can be used in a variable speed wind energy conversion scheme. In case of a synchronous generator, the generated voltage can be controlled more easily by using a voltage regulator in the field circuit. It requires no shunt ...

are controlled inductor to achieve voltage regulation.

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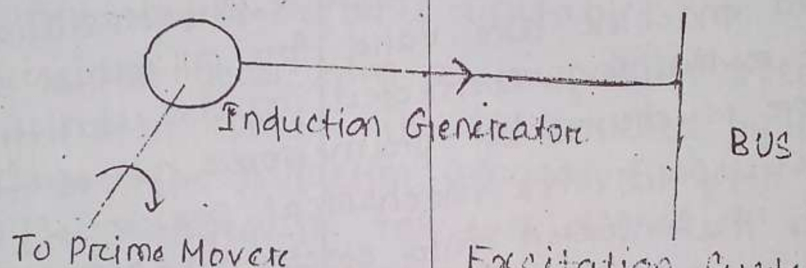
Grid connected & Self-excited Induction Generator Operation:

There are two ways of exciting an induction generator. Based on method of excitation, induction generators are classified into two basic catagories.

(1) Constant voltage & Constant frequency generator
(2) Variable voltage & variable frequency generator

(1) Constant voltage & constant frequency generator:

In the constant voltage & constant frequency category, the generator drives its excitation from the utility bus.



Excitation System - Line system

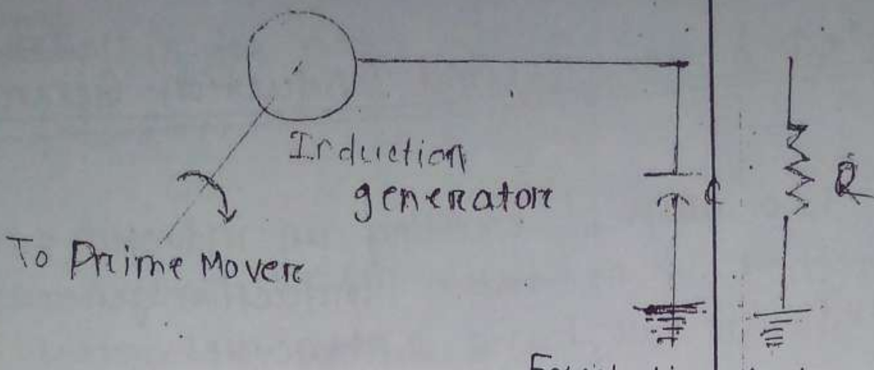
The generated power is fed to the supply system when the rotor is driven above synchronous speed.

In a cage type rotor, feeds only through the stator & generally operate at low negative speed.

In a wound type rotor, feeds power through the stator as well as the rotor to the bus over a wide speed range.

(2) Variable voltage & variable frequency generator:

This is analagous to a self-excited dc generator. A Capacitor when connected across the induction machine helps to built up the terminal voltage. Building of voltage also depends on factors such as speed, capacitor value and load. Squirrel cage machine is generally used as a self-excited induction generator.



Excitation System - Self excitation

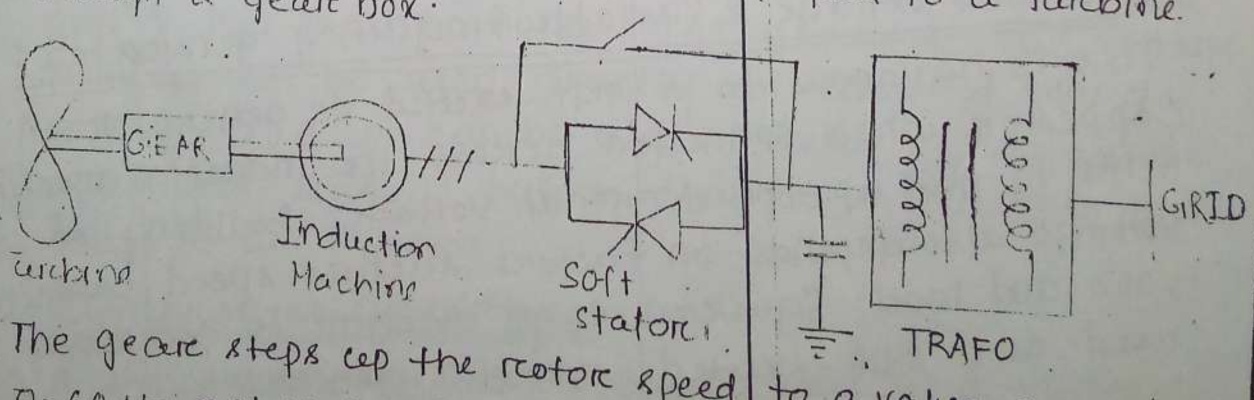
Constant voltage, constant frequency generation with power-electronics control:

An induction machine in the generating mode operates fundamentally in the same manner as in the motoring mode except for the reversal of power flow. So, the equivalent circuit, performance eqn., derivation in case of induction machine are valid for all values of slip. The stator remaining connected to the utility grid, if the rotor is driven by primemover above the synchronous speed, the mechanical power of the primemover is converted into electrical power.

Single output system:

Fixed speed system:

In this system, squirrel cage induction generators are used, which provides the power output only through the stator winding. The system contains a grid connected squirrel cage induction generator coupled to a turbine through a gear box.



The gear steps up the rotor speed to a value around 0-60 Hz network. The generator always draw reactive ower from the network. capacitors are used to ompensate the lagging power. The capacitors may ause the induction machine to self-excite over voltages at the time of disconnection of wind turbine from the electrical system. Because of its coupling to the grid, the speed varies over a very small range above the synchronous speed (usually around 1%). As the speed variation is small, the system is known as fixed speed system.

For such a system, the TSR, λ varies over a wide range & the rotor efficiency decreases for wind speeds other than rated wind speed. The gear box ratio selected for optimal Cp for the most frequent wind speed. Fixed speed wind turbine employ pitch & stall regulation to limit the power at high wind. This is required because if the input mechanical pow is more than the power corresponding to the pullout torque, the system becomes unstable.

Appreciable generation at low wind speed requires reduced rotor speed. This is achieved by using two speed cage type induction generator, with the stator winding arrangement for two different no. of holes. The large no. of holes is for low wind speed & small no. of holes for high wind speed. With the two speed system, the audible noise at lower wind speed is reduced. The turbine accelerates the induction machine to the synchronous speed using wind power, the machine is then connected to wind. The direct connection of an induction machine to the supply produces high in-rush current. Such connection can also cause the ~~rotor~~ torque pulsation leading to gear box damage. In order to reduce magnetisation current search - soft stators are used.

Soft stators are phase controlled anti-parallel thyristors (ac voltage controller) which controls the applied stator voltage, when the induction machine is connected to the network. After some seconds, when normal current is established, these stators are by-passed. Such ac voltage controller are used for connecting the machine to the grid during acceleration from zero speed to operating speed.

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Semivariable Speed Operation:

The advantages of a grid connected fixed speed squirrel cage generator are its lower capital cost, simple system configuration and robust mechanical design. As the rotor speed is nearly constant, fluctuation in wind speed result in torque which may lead to unwanted grid voltage fluctuation and strains on turbine component. High winds specially lead to large torque variation.

Semivariable speed operation in this single output system brings down the pulsation in grid power (voltage) & mechanical stress on the blades.

If the generator shaft input (i.e. turbine output) can be dissipated in the rotor, the grid input power (which is the power flow across the air gap) can be labelled under fluctuating wind speed regulation.

→ The electrical power consumed in the rotor circuit is given by.,

$$\boxed{P = S \times P_{in}}$$

Where P_{in} – Power transferred across the airgap i.e. power input to the rotor.

So, the rotor electrical power ∝ slip. By this, speed control can be done by controlling the energy dissipated in a rotor resistor.

Variation of rotor resistance is given as,

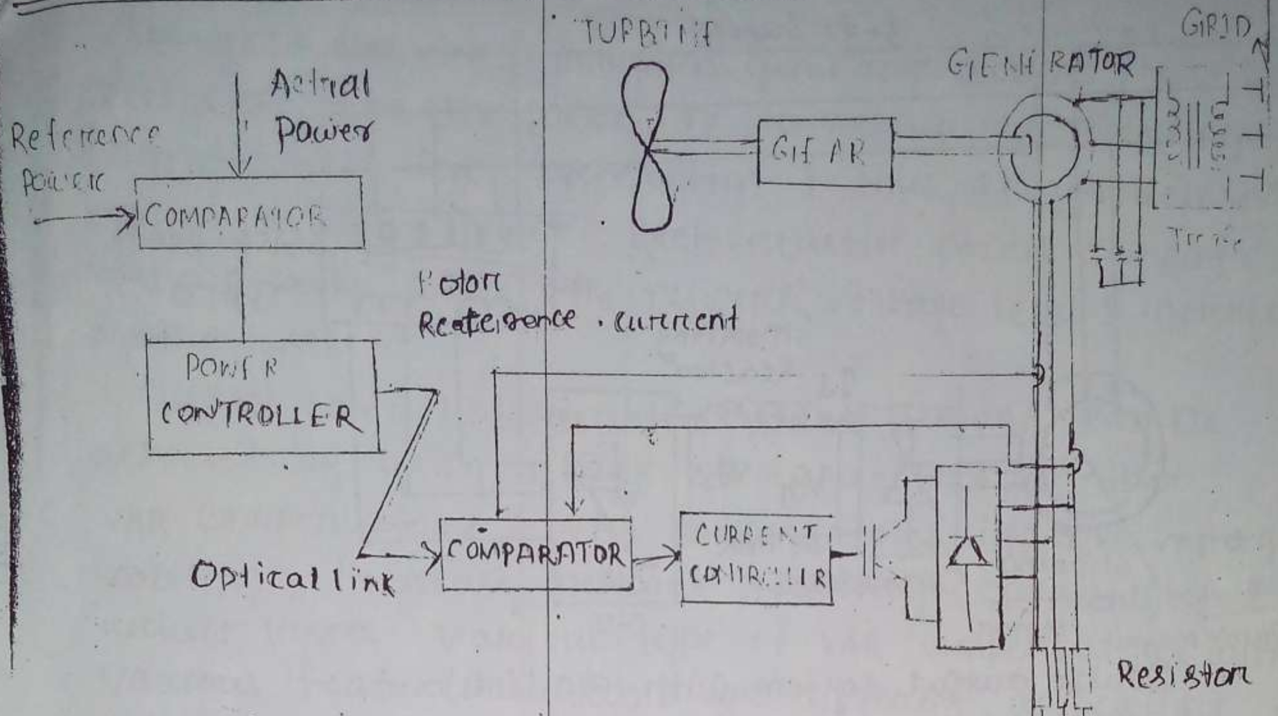
$$\boxed{\frac{R_r + R_x}{S} = \text{Constant}}$$

R_r – Rotor resistance

R_x – Rotor External resistance , S – Slip

So, the rotor current & air gap power (torque multiplied by synchronous speed) is constant. Thus, the main aim of the control strategy will be to keep the rotor current at a set value irrespective of speed variation within a range, for constant power output from the stator.

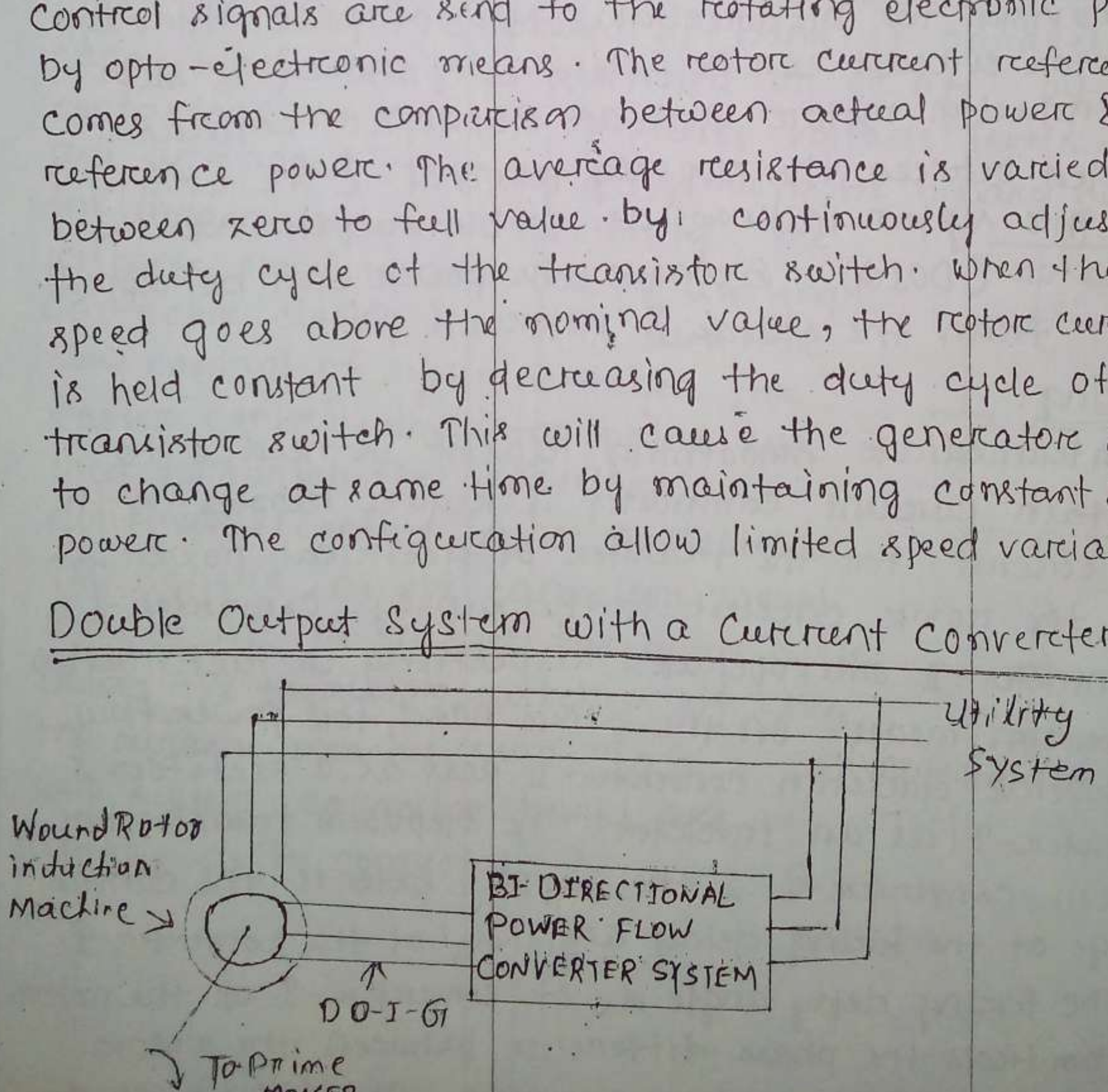
system with dissipated slip energy :



Working :

The converter & the resistance rotate in the rotor. Control signals are send to the rotating electronic parts by opto-electronic means. The rotor current reference comes from the comparison between actual power & reference power. The average resistance is varied between zero to full value by continuously adjusting the duty cycle of the transistor switch. When the wind speed goes above the nominal value, the rotor current is held constant by decreasing the duty cycle of the transistor switch. This will cause the generator speed to change at same time by maintaining constant stator power. The configuration allow limited speed variation.

Double Output System with a Current Converter :



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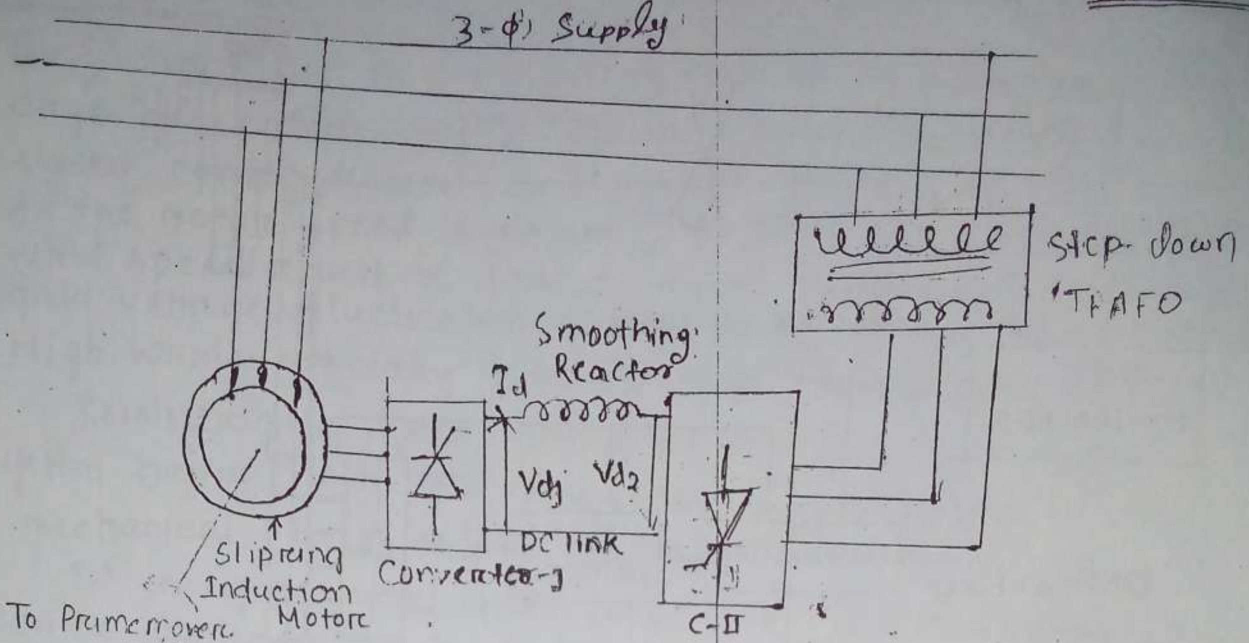


(Double output system with dc link)

Power is fed into the supply system over a wide speed range by controlling the rotor power from a variable frequency source in a slip ring induction machine. The provision for bi-directional flow of power through the rotor circuit can be achieved by use of a slip ring induction motor with an ac/dc/ac converter connected between the slip ring terminal & the utility grid. This system is known as double output induction generator (DOIG). Because the power can be tapped both from the stator & rotor.

Working:

The intermediate smoothing reactor is needed to maintain current continuity & reduce ripples in the link circuit. For the transfer of electrical power from the rotor circuit to the supply, converter-I & converter-II are operated respectively in rectification & inversion modes. On the other hand, for power flow in reverse direction converter-II acts as a rectifier & converter-I as an inverter. The step down transformer between converter-II & the supply extends the control range of the firing delay angle α_2 of the converter-II.

The firing delay angle α_1 of converter-I on the rotor side controls the phase difference between the rotor phase voltage & the rotor current. The delay angle α_2 of converter-II on the line side ...

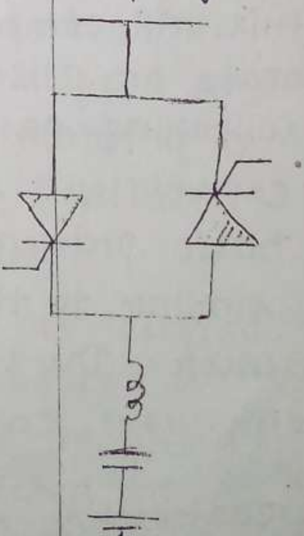
Reactive Power Compensation:

The grid connected induction generator draws its excitation from the power line to set-up its rotating magnetic field for regeneration & thus always demands lagging reactive power. Such reactive power demand may adversly affect the network voltage level & increase system losses.

Direct control of reactive power demand can be achieved by using a bank of capacitors or other VAR compensators. VAR compensators improve voltage stability, increase network ~~stability~~ capability & reduce losses. Various type of VAR compensators with various features suitable for different applications are in used.

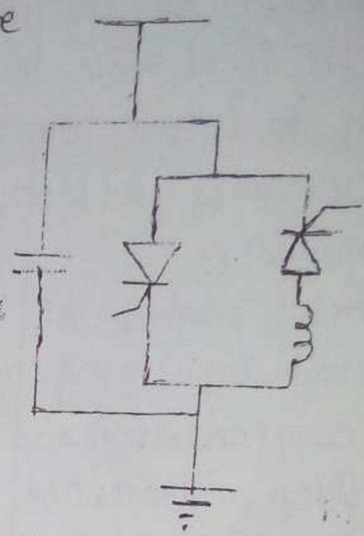
(1) The switched Capacitor Scheme (TSC Scheme):

The TSC scheme comprised of bank of parallel capacitors which are switched on or off by contactors in response to preset voltage levels. These are arranged stage by stage with the binary system for maximum control flexibility. The response speed is controlled by limiting contactor closing time & is used for slow control of system voltage. For faster control, thyristor pairs are used to switch the capacitors. Continuous control is not possible in TSC scheme, as the capacitor would remain in the circuit for a full cycle before the thyristor switches off when the current reaches zero. In a 3-ϕ system, capacitor banks are usually delta connected.



(VAR generation with TSC)

(2) Thyristor Controlled ~~Rectifier~~ Reactor (TCR) :



Continuous control of effective reactive power is possible using TCR reactors, are used parallel with fixed capacitor bank. Variable VAR is realised by varying firing angle between 90° & 180°. The excess of reactive power from the capacitor bank is absorbed by the reactor, when the delay angle approaches 90°. Due to its high cost, this can be used at large wind firms.

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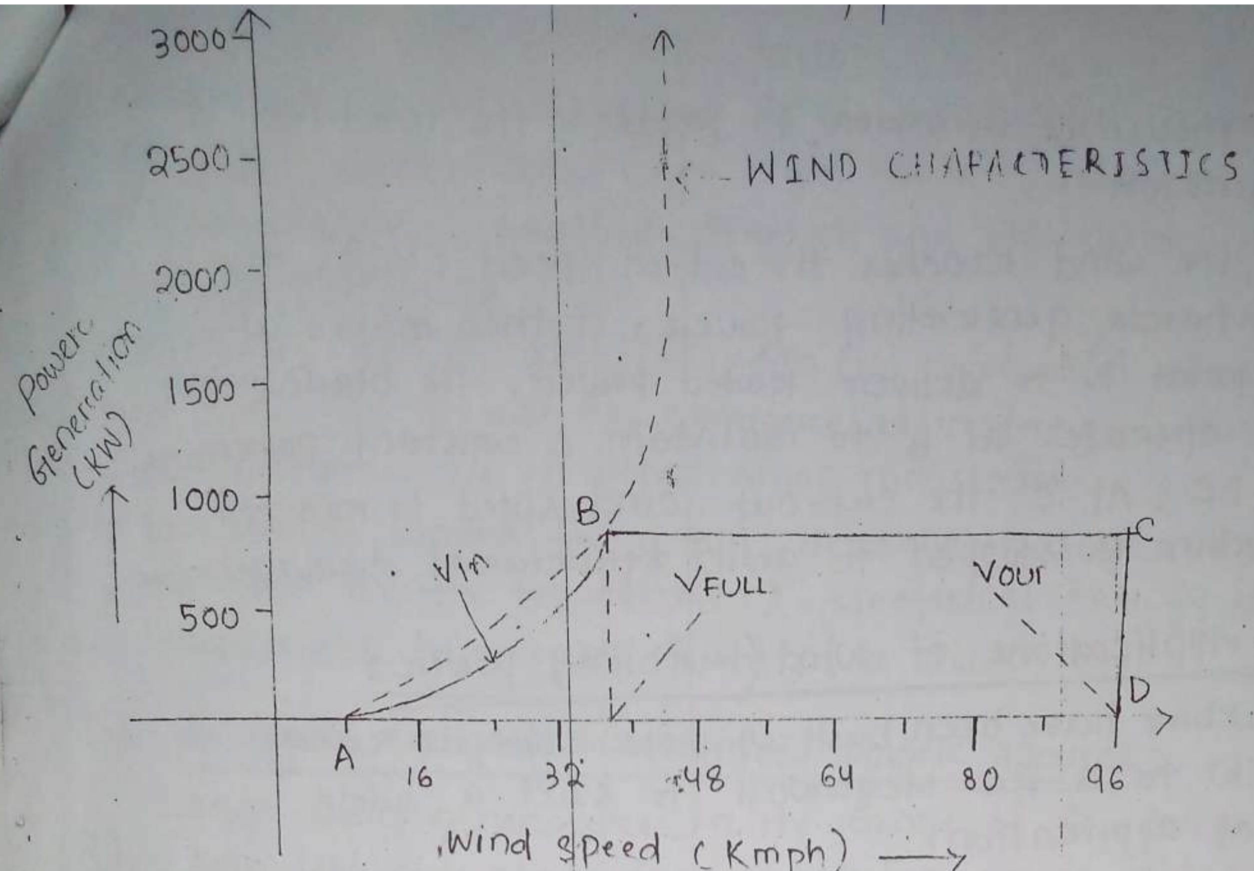
(3) Static VAR Compensator :

The recent trend in reactive power control is based on forced commutated voltage source PWM converter. It is a static realisation of synchronous condenser. Inductors are included in series with the ac supply and a capacitor on the dc side. The main features of this VAR compensator is that the converter can generate or absorb reactive power by controlling the switching pattern of the devices with gate turn off capability, such as GTO thyristor & IGBT. The basic principle of control of reactive power flow are similar to those of the rotating synchronous condenser. The static VAR generator can provide fast & continuous control of reactive power.

Characteristics of a Wind Power Plant :

The power curve of a wind turbine indicates power output as a function of wind velocity at hub height (hub implies blades are fixed to a hub which is central solid part of the turbine). The curve shows a steady idealised characteristics, but practically wind speed constantly varies.



→ A wind turbine develops less power than the wind stream power due to friction and spillage & the curve shows the following limiting speed.

→ There are

(i) <u>Cut-in speed (Vin) :</u>

- It is the wind speed (14 kmph or 4 m/s) at which the turbine output begin. It is higher than the speed at which the turbine starts rotating. Before starting to rotate, the turbine remains in the break position.

(ii) <u>Rated speed (VFULL) :</u>

It is the wind speed at which the turbine is designed to generate the rated power. When the wind speed is more than the cut-in speed but less than the rated speed, the pitch angles of blades are selected to deliver maximum power. Pitch angle is controlled to maintain constant rated power above the rated wind speed.

(iii) <u>Cut-out speed (Vout) :</u>

When the speed reaches the upper limit (90 kmph) or 20 m/s), the turbine stops to generate power as a safety measure in order to protect the turbine & the generator.

As the wind reaches the cut in speed (V_{in}), the W.T.G. starts generating power, it then moves up to the point 'B' to deliver rated power, The blade pitch control operates at 'B' to maintain a constant power output BC. At 'C', the cut-out wind speed is reached and turbine is stopped to avoid structural damage.

Major Applications of wind (turbine) power:

Wind turbine have been built-in power output range from KW to a few Megawatt to suit a wide range of application.

(1) Applications requiring mechanical Power:

(i) Wind Pumps:

Lower power turbines are used for producing mechanical power for pumping water in remote area. These are also known as wind pump. Reciprocating or centrifugal pumps are used to supply water to live stock, small scale irrigation, aquatic breeding & domestic water supply.

(ii) Heating:

Direct dissipation of mechanical power produces heat. Available hot water is used as such or employed for space heating.

(iii) Sea transport:

Wind turbines are installed on boated to power propellers in ferries operating on short routes.

(2) As off-grid electrical power:

→ Machines of lower power with a rotor diameter of about 3m & 40-1000 W rating can generate sufficient electrical energy for water heating, battery charging, space heating and for operating domestic ...

such as fan, light and small tools.

→ Wind turbines having about 50KW. production are used for navigation signal (ex- light house), remote communication, weather stations and off-shore oil drilling platforms.

→ Turbines having about 100-250 KW. production are used in farms co-operatives, commercial refregeration, de-sailination and in other small industries.

→ For lifting water to a hill; aero-generators are installed on the top of hill & electrical energy is transmitted to a pump fixed at a lower level.

(3) <u>As grid connected electrical power source:</u>

Large aero-generators in the range of few 100 KW. to few MW. are plant for suppeying power to utility grid. Large arrays of aero-generatore are known as wind farms are deployed in open planes or off-shore for this purpose.

Solar PHOTO VOLTAIC SYSTEM:

→ Photovoltaic power generation is a method of producing electricity by using solar shells. Solar PV system converts.

→ A solar cell is essentially a semiconductor device fabricated in a manner which generates a voltage when solar radiation falls on it. In S.C. atoms carry 4 e⁻ in their valence shells some of which can b dislodged to move freely in the material if external energy is supplied.

Thus the S.C attains the property 4 current conduction. This is the basic principle upon which the solar shell works & generates power.

→ A solar shell can also b called as a electrical current source driven by flux of radiation. e.g. we are using space satellite, remove radio communication, buster station, marine warning lights, lighting, water pumping, medical refrigeration in remote area

Solar shell fundamentals

Semiconductors: Certain substances like, Si, Ge, C are neither good conductors like Cu nor insulators like glass. So resistivity of these materials lies b/w C + I.

Imp. properties of S.C.:

- Resistivity of s.c. lies b/w I & C.
- Resistance of s.c. is inversely propor-tional to temperature, e.g. Ge is an insulator at low temp but becomes a good conductor at high temp.
- When suitable metallic impurity is added to a s.c. (As, Ga) their conductivity changes appreciably.

In Si & Ge the valence shell is having 4 e^-. So the form bond by sharing of e^- which is called as covalent bond. At absolute zero a s.c. is an insulator with no charge carrier. But when temp ↑ the vibration of e^- sometimes dislodges e^- from the valence shell which is called as free electron. And the vacancy thus created is known as a hole.

So with breaking of each covalent bond an e^--hole pair is produced.

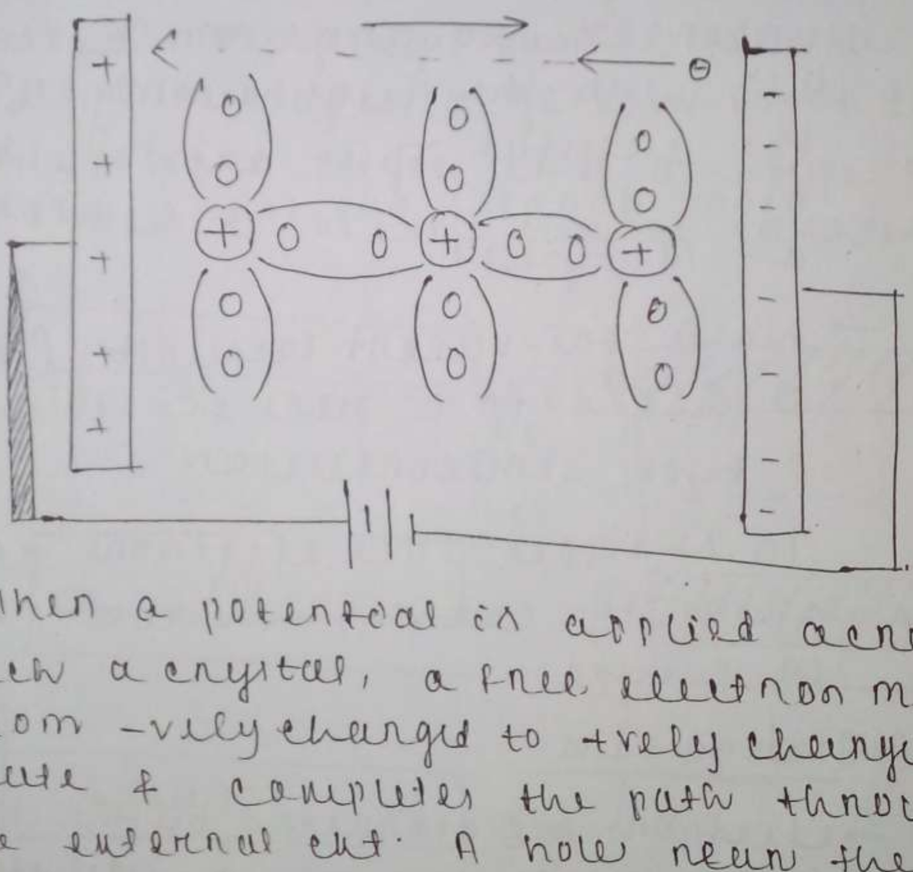
∴ Electron-hole pairs are produced at room-temp due to the effect of thermal energy. But this can also be produced by imparting energy by some other means like light

Sometimes free e^- move randomly throughout the crystal approach a hole feels its attraction & fall into it.

This merging of e^--hole is called <u>recombination</u>.

→ The amount of time b/w crea^n & disappearance (due 2 recombi^n) of an e^--hole pair is called a life-time.

→ A S.C in its <u>extremely</u> pure form is called as <u>intrinsic S.C</u>. There are equal no. of e^--hole pair in an intrinsic semiconductor.



→ When a potential is applied across such a crystal, a free electron moves from -vely charged to +vely charged plate & completes the path through the external ckt. A hole near the +vely charged plate e^- from other side. This causes the valence e^- to move into the hole creating a new hole in a new location. This effect is same as moving the original hole to right.

This process continues & valence e^- move across the crystal from -ve to +ve & holes from +ve to -ve. Thus e^- & hole move in opposite direc^n & constitute electric current.

→ One way to increase the conductivity is by adding impurity atom to s.c. (intrinsic type) which is known as doping.

The dopped s.c. is called extrinsic s.c.

→ When impurity is pentavalent such as As, Sb, one extra e^- will remain unbonded to any atom after sharing $4e^-$ with the neighbouring $4e^-$ in the crystal. Thus each pentavalent atom donates one free e^- & is known as N-type s.c.

→ When tri-valent impurity (Al, B, Ga) is added to a pure s.c. it is called P-type semiconductor.

In N-type free electrons are majority carries whereas holes are in P-type.

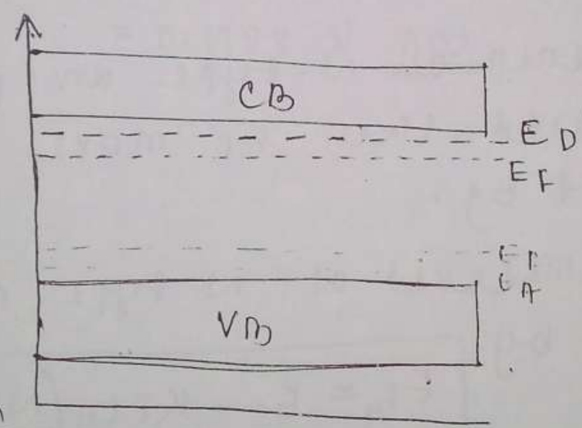
Energy band

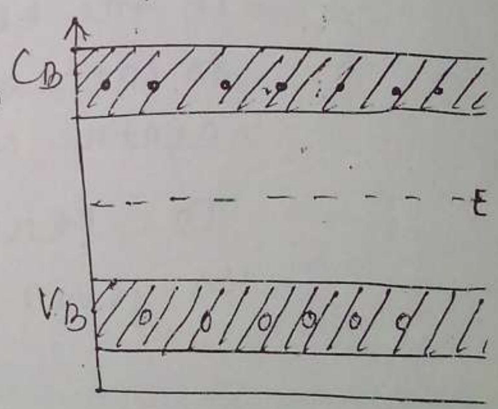
→ electrons are attracted by the nucleus. Extra energy is read to lift the e^-. Energy sources → heat, light.

→ Each orbit has its own band of energy. When an e^- in the VB receives sufficient energy to overcome the energy gap E_g, it jumps to the next higher level known as CB leaving behind the hole in VB.

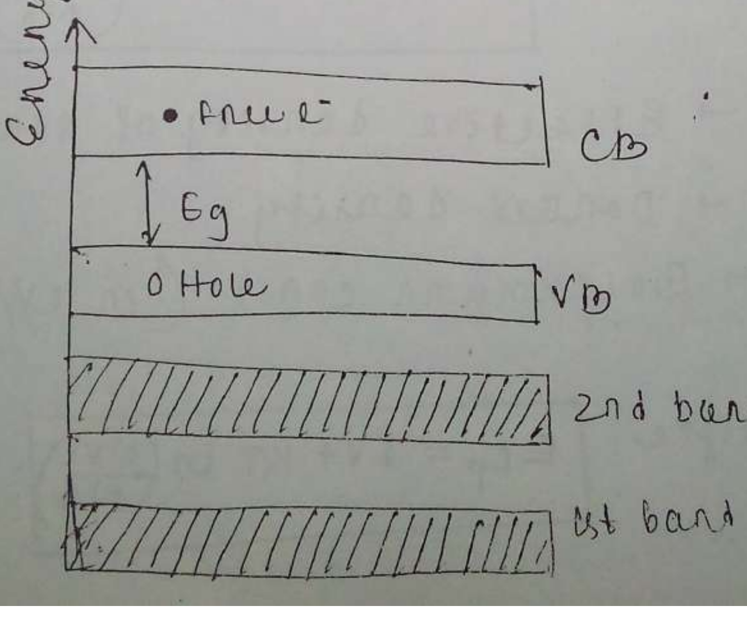
→ In an intrinsic s.c there are equal no. of free-electrons & holes. On application of voltage across such a s.c, the free e⁻ move in the CB while holes move in the VB. No conduction is possible if all the states with an energy band are occupied or when all are empty.

→ Fermi level or characteristic energy (in) for a crystal represents the energy state with a 50% probability of its being filled by a charge carrier. F.E level is an energy position within the band gap from where a greater no. of carrie i.e. holes in p-type or e⁻ in N-type get excited to become charge carriers.





Intrinsic



→ In an intrinsic S.C. Fermilevel lies at the centre of forbidden energy gap, indicating equal conc. of free electron & holes. If a donor type impurity is added, assuming all donor atoms are ionised the E_F becomes closer to the CB which indicates many of the energy states in CB are filled by donor electrons and fewer holes exist in VB.

Similarly E_F must move from the centre of forbidden energy gap to the VB for a P-type material.

E_A & E_D are the acceptor energy level & donor energy level respectively.

If the temp. of N-type or P-type is increased then E_F moves towards centre of E_g.

The Fermilevel of N-type material is given by

$$E_{F_n} = E_c - KT \ln\left(\frac{N_c}{N_D}\right)$$

N_c → Effective density of states in CB.

N_D → Donor density.

K → Boltzmann const. (in eV/°K).

For p-type

$$E_{F_p} = E_V + KT \ln\left(\frac{N_V}{N_A}\right)$$

$N_V \rightarrow$ Effective density of states in VB

$N_A \rightarrow$ acceptor density.

A p-type Si has $N_V = 1 \times 10^{22}/cm^3$. An impurity from 3rd group with conc. of $1 \times 10^{19}/cm^3$ is added. If bandgap for Si is 1.1 eV. Find the closeness of fermilevel with VB at temp of 27 K.

$N_V = 1 \times 10^{22}/cm^3$

$E_g = 1.1$ eV.

$T = 27°C = ~~300~~ = 300K$

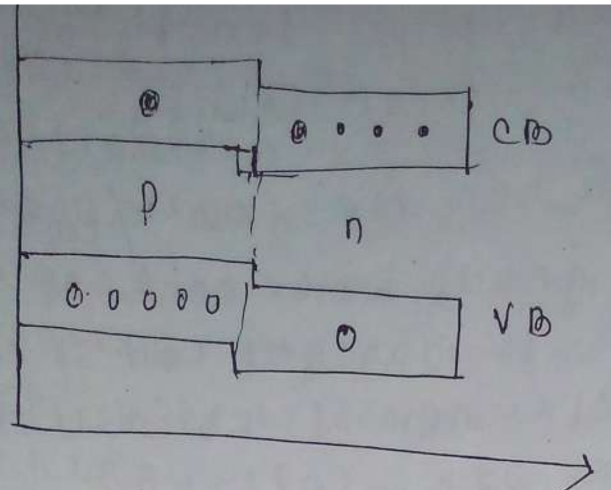
$N_A = 1 \times 10^{19}/cm^3$

$K = 8.62 \times 10^{-5}$ eV

$$E_F - E_V = KT \ln\left(\frac{N_V}{N_A}\right)$$

$$= 8.629 \times 10^{-5} \times 300 \ln\left(\frac{10^{12}}{10^{19}}\right)$$

$= 0.1788$ eV <u>Ans</u>



[Energy band of an abrupt junction before diffusion]

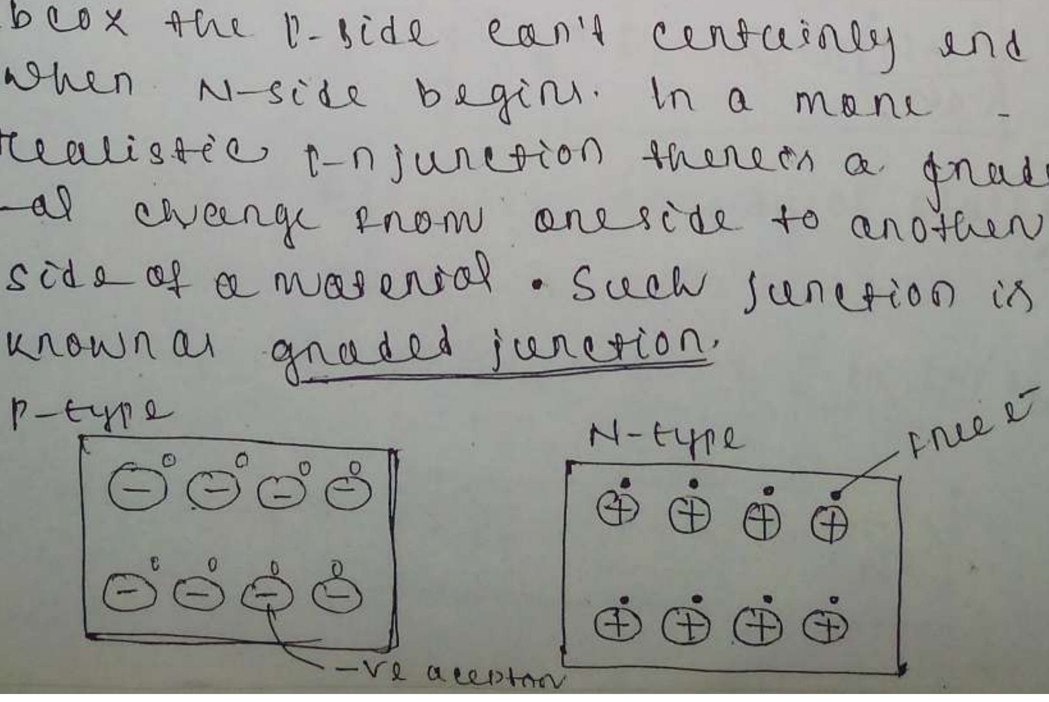
→ The figure shows the energy band of an abrupt junction.

The

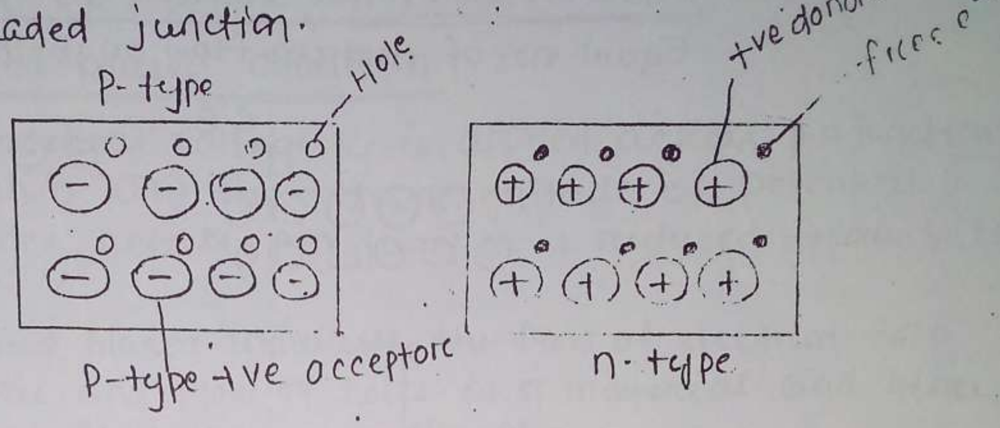
The P-bands are slightly higher than the N-bands because the P-types have slightly larger obits than N-types.

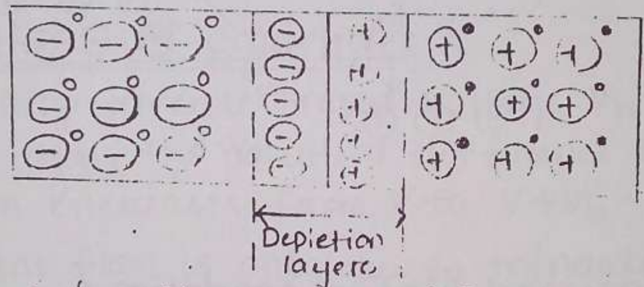
bcox a pentavalent atom with a core charge of +5 more than a trivalent atom of +3.

An abrupt junction is an idlization bcox the P-side can't certainly end when N-side begins. In a more realistic P-n junction there's a gradual change from one side to another side of a material. Such junction is known as <u>graded junction</u>.



- An abrupt junction is an idealisation because the P-type can't suddenly end where the N-side begins. In a more realistic P-N junction, there is a gradual change from one type of material to another. Such junction is called as graded junction.





- When a junction between P & N type material is formed, the carriers (free e⁻s & holes) diffuse from higher conc. side to lower conc. side. After crossing the junction these carriers recombined with all other types of carriers found in majority in other side.
- P-type has higher conc. of holes & N-type has higher conc of free e⁻s. Therefore at junction, there is a tendency for free e⁻s to diffuse over P-side, holes to the N-side This is called diffusion.

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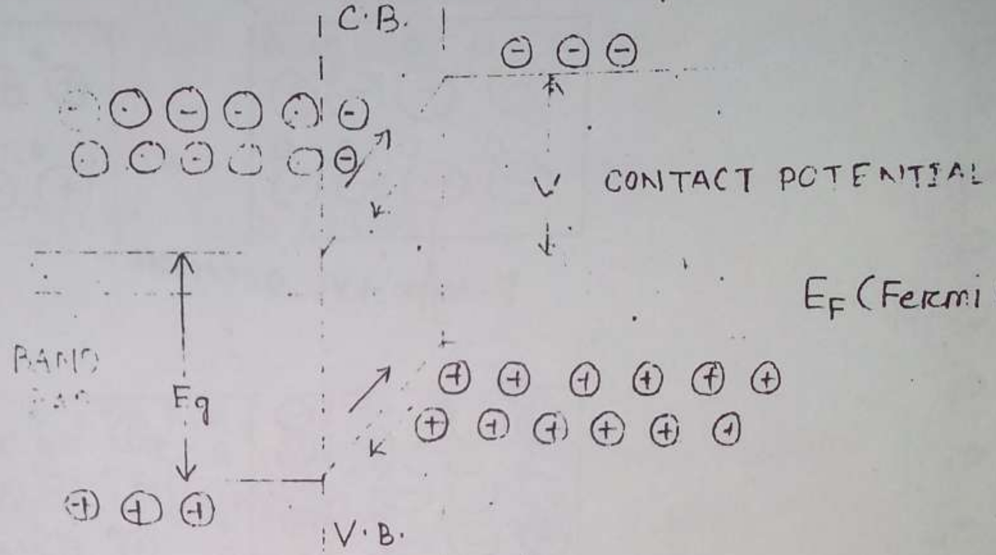
Due to diffusion, a +ve charge is built on the n-side of the junction and a net -ve charge is built on the p-side of the junction. When sufficient no. of donor & acceptor ions are uncovered, further diffusion is prevented because +ve charge on the n-side repels holes to cross from p side & -ve charge from n-side repels free electrons. Thus a barrier is developed against further movement of charge carriers and it is called potential barrier or junction barrier V_0

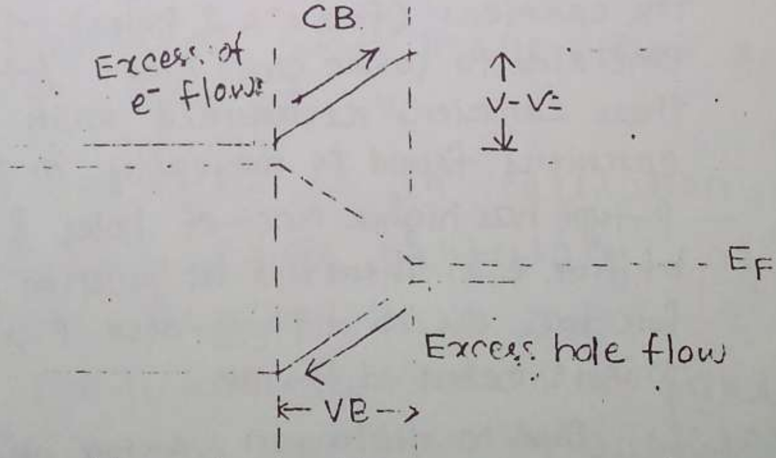
So, potential barrier is set up which gives rise an electric field that region of potential barr is depleted of mobile charges and is called depl layer.

Unbiased condition of P n junction:

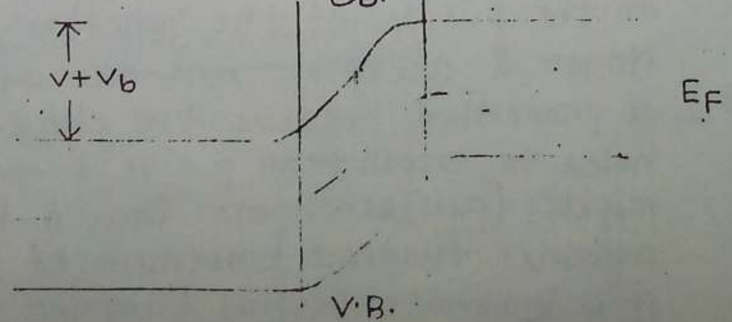
Equal no. of electron flow on both side.



Forward biased condition:



Reverse biased condition:



Unbiased Condition:

1) Electrons on the n side flow into hole of the p side.
2) Diffusion process goes on till the junction potential reaches an equilibrium value. This is the unbiased condition of p-n junction.

Forward biased condition:

1) If an external voltage V_f is applied across p-n junction in such a way that the magnitude of potential difference across p-n junction is reduced from V to $V-V_f$.
2) Forward biased increases the flow of electron in p material and flow of holes in n material and hence current flow increases sharply.

Reverse biased condition:

1) When large reverse biased voltage V_b is applied across the junction, the potential difference across the p-n junction increases from V to $V+V_b$.
2) Current flow is only due to minority carriers i.e. electron from p to n and holes from n to p.
3) Reverse bias makes the inbuilt electric field stronger resulting in negligible flow of electron across the p-n junction.

When there is no illumination (dark), the flow of junction current (I_j) with imposed voltage V in p-n junction is given by,

$$I_j = I_0 \left[\exp\left(\frac{eV}{KT}\right) - 1 \right]$$

Where I_0 = Saturation current (dark current)

e = electronic charge

K = Boltzman's constant

V = p-n junction potential

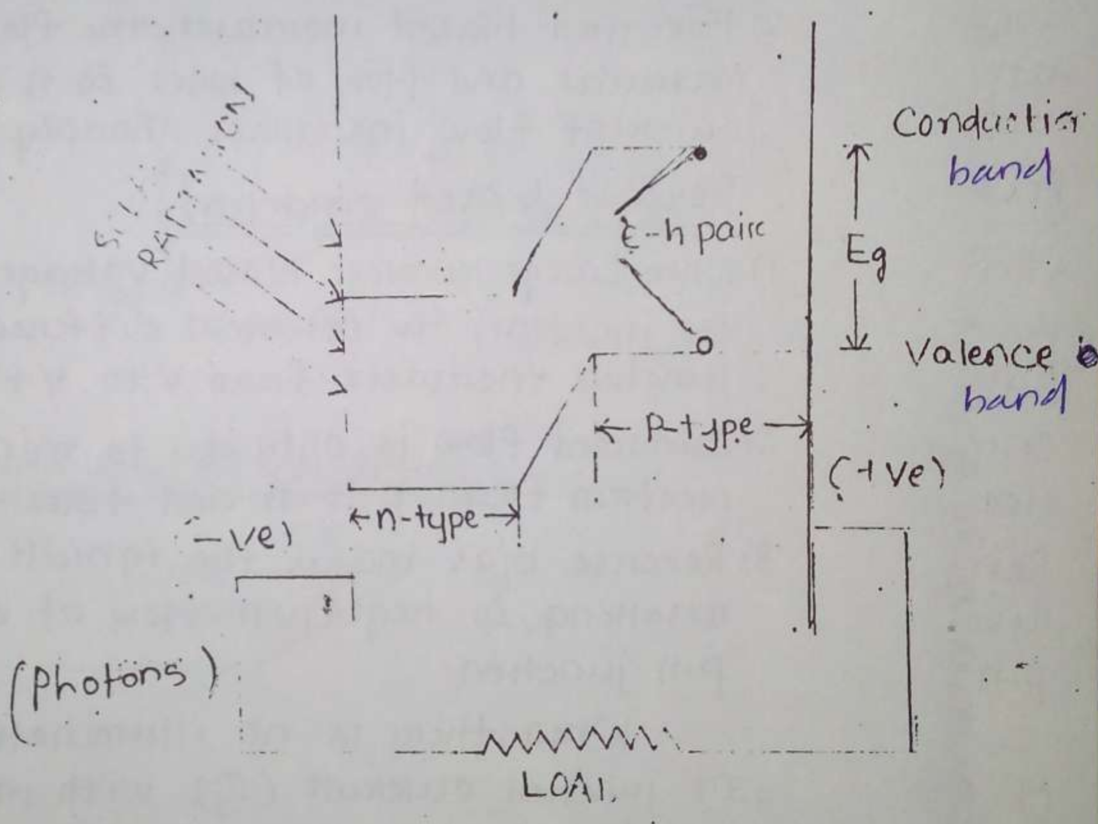
Photo Voltaic Effect :

When a solar cell (P-n junction) is illuminated electron-hole pair are generated and electric current I is the difference between the solar light generated current I_L and diode dark current I_j.

$$I = I_L - I_j$$

$$I = I_L - I_0 \left[\exp\left(\frac{eV}{KT}\right) - 1\right]$$

Semiconductor diode band structure :



Photons of solar radiation processing energy higher than the band energy Eg absorbed by the semiconductor material dislodges some electrons. These electrons possess enough energy to jump over the band gap from the valence band into the conduction band. Thus hole & free electron pairs are created and this enables the current flow through an external circuit.

Photon energy:

Sunlight is composed of tiny energy capsules called photons. The no. of photons present in solar radiation depend upon the intensity of solar radiation. When photons collide on an atom of a semiconductor, they interact with electrons & get absorbed.

This enhanced energy drives off electron to the outer orbit.

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Generation of electron-hole pair by photon absorption:

Energy available in a photon is given by,

$$\boxed{E = h\nu = \frac{hc}{\lambda}}$$

h - Planck's constant $= 6.63 \times 10^{-34}$ J sec.

c - speed of light $= 2.988 \times 10^{8}$ m/s

ν - frequency of photon

λ - wavelength of photon in m.

$$\boxed{1\ eV = 1.6 \times 10^{-19}\ J}$$

Putting the value we get, $\boxed{E = \frac{1.24}{\lambda}\ eV}$

The energy in a photon must exceed the band-gap energy E_g in order to get absorbed & generate an electron-hole pair. For energies less than the band gap energy, no absorption takesplace. The material appears transparent to these low energy photons. If a photon has energy much greater tha the bandgap, it still produces a single electron-h pair. The remaining of photon energy is lossed to the material as heat. The semiconductors used for photo-absorption have band gap energy such that maximum % of solar spectrum is efficiently absorbed.

Ex: Calculate the optimum wavelength of light for photo-voltaic generation in a cell? The bandgap for the cell is 2.48 eV.

Ans: Given data:

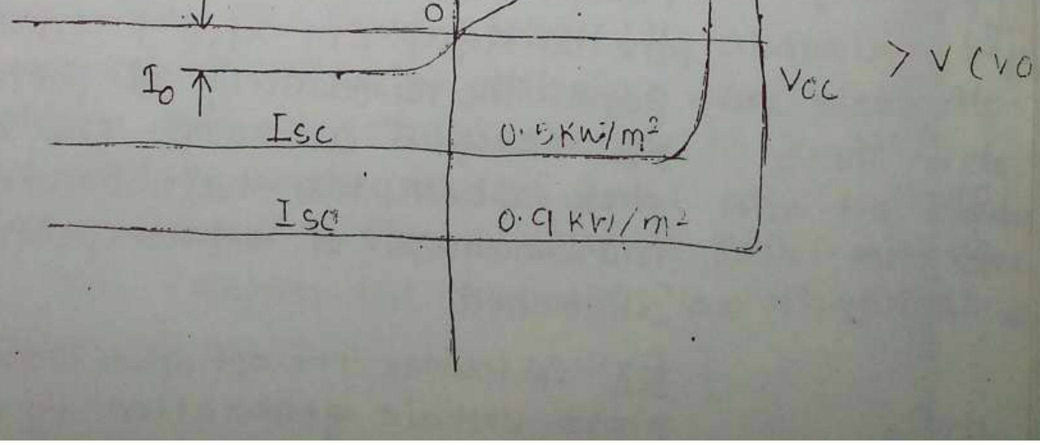
$$E = 2.48\,eV.$$

$$E = \frac{1.24}{\lambda} \Rightarrow \lambda = \frac{1.24}{2.48} = 0.5\,\mu m.$$

Photo-conduction:

When an e-h pair generated within the junction (depletion layer), both carriers will be acted upon the built-in electric field. The field is directed from n to p side. It will cause the holes to move towards the n-side. Once out of the junction region, these carriers become a part of majority carriers in the respective region & diffuse away from the junction region as their concentration near the junction has increased. This addition of excess majority charge carriers on each side of the junction results in a voltage across the external terminal. If a load is connected across this terminal, the photon generated current will flow through the external circuit. This current will be proportional to the no. of e-h pair generated, which depends upon the intensity of illumination. So, an illuminated p-n junction becomes a P-V cell with the +ve terminal on p-side.

Solar-cell characteristics – I V characteristics:



Mathematically, dark characteristics with junction not illuminated is given by

$$I = I_0 \left\{ \exp\left(\frac{V}{V_T}\right) - 1 \right\}$$

I_0 - reverse saturation current

$V_T = \frac{KT}{q}$ = voltage equivalent of temp.

When p-n is illuminated, the characteristics gets modified in shape & shifts downward as a photon generated component is added with reverse leakage current.

$$I = -I_{sc} + I_0 \left\{ \exp\left(\frac{V}{V_T}\right) - 1 \right\}$$

When the junction is short-circuited at its terminal, 'V' becomes zero. So, finite current $I = -I_{sc}$ flows through the external path emerging from p-side.

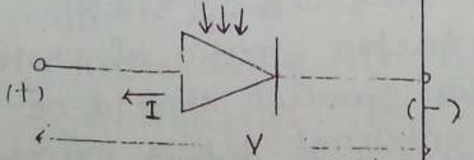
I_{sc} is called short circuit current & its magnitude depends upon solar insolation.

When external voltage is applied in external path with +ve polarity on p-side & its magnitude is increased from zero, the current starts decreasing. The value 'V_{oc}' at which I_{sc} becomes zero is known as open circuit voltage. V_{oc} is given by,

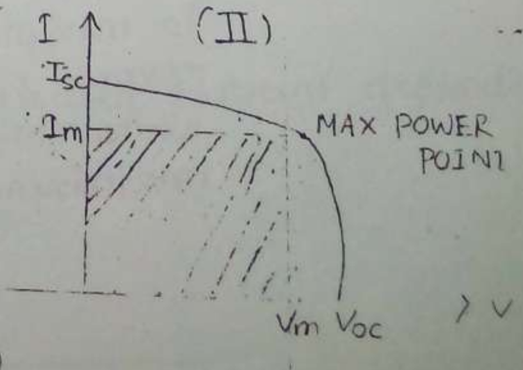
$$V_{oc} = V_T \ln\left\{\left(\frac{I_{sc}}{I_0}\right) + 1\right\}$$

If $I_{sc} = 2A$, $I_0 = 1nA$, at room temp., $V_{oc} = 0.55V$.

Thus illuminated p-n junction can be considered as energy source (PV cell) with open circuit voltage 'V_{oc}' & short circuit current 'I_s'.



(Standard sign convention)
Current coming out of +ve terminal is considered +ve.



As per standard sign convention, I-V characteristics of a solar cell is given by.

$$I = I_{sc} - I_0 \left\{ \exp\left[\left(\frac{V}{V_T}\right) - 1\right] \right\} \quad \text{for (II)}$$

In order to obtain as much energy as possible from a costly PV cell, it is desirable to operate a cell to produce maximum power. The maximum useful power of the cell is represented by the rectangle with largest area. When the cell gives maximum power, the current & voltage are represented by I_m & V_m respectively. Closeness of characteristics to the rectangular shape is a measure of the quality of the cell. An ideal cell will have perfect rectangular characteristics.

Fill factor (FF):

It indicates the quality of cell & is defined as ratio of peak power to the product of open circuit voltage & short circuit current.

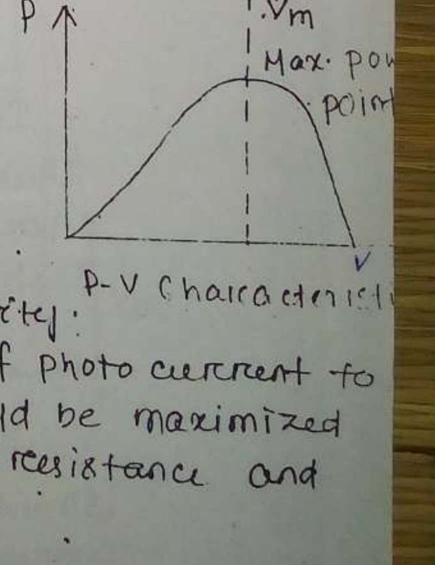
$$FF = \frac{V_m I_m}{V_{oc} I_{sc}}$$

Maximum efficiency of a solar cell is defined as ratio of maximum electric power output to incident solar radiation.

$$\eta_{max} = \frac{I_m V_m}{I_S A_c}$$

I_S - Incident solar flux

A_c - Cell's area

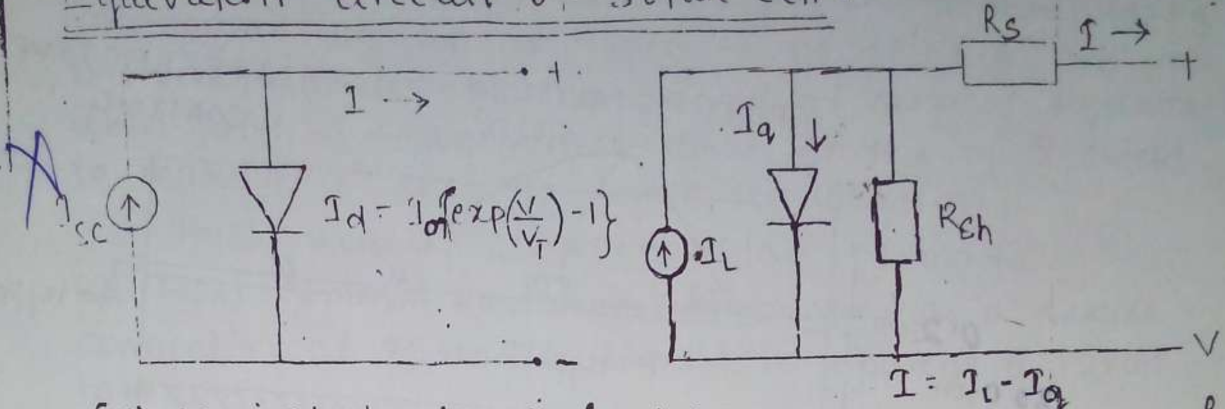


P-V characteristi

Fill factor of an ideal cell is unity.

To maximize fill factor, ratio of photo current to reverse saturation current should be maximized while minimizing internal series resistance and maximizing the shunt resistance.

Equivalent circuit of Solar cell:



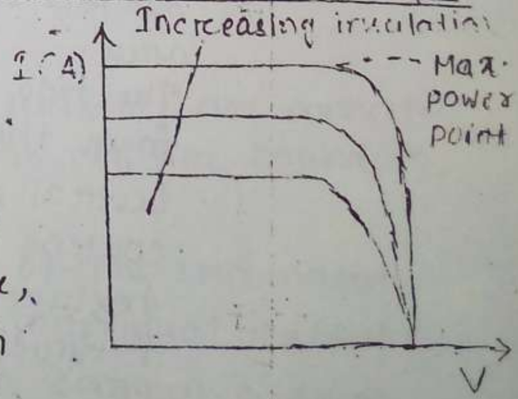
(a) equivalent circuit of practical solar cell

(b) equivalent circuit of ideal solar cell

The I-V characteristics is derived for ideal condition. Considering the internal series resistance of the cell is zero & shunt resistance ∞. In a practical case, both have a finite value which alter the characteristic. In a practical cell, I_{sc} is not equal to the light generated current I_L but is less than by shunt current through I_{sc}. Modified characteristics can be given as

$$I = I_L - I_0 \left[exp\{(V+IR_s)/V_T\} - 1 \right] - (V+IR_s)/R_{sh}$$

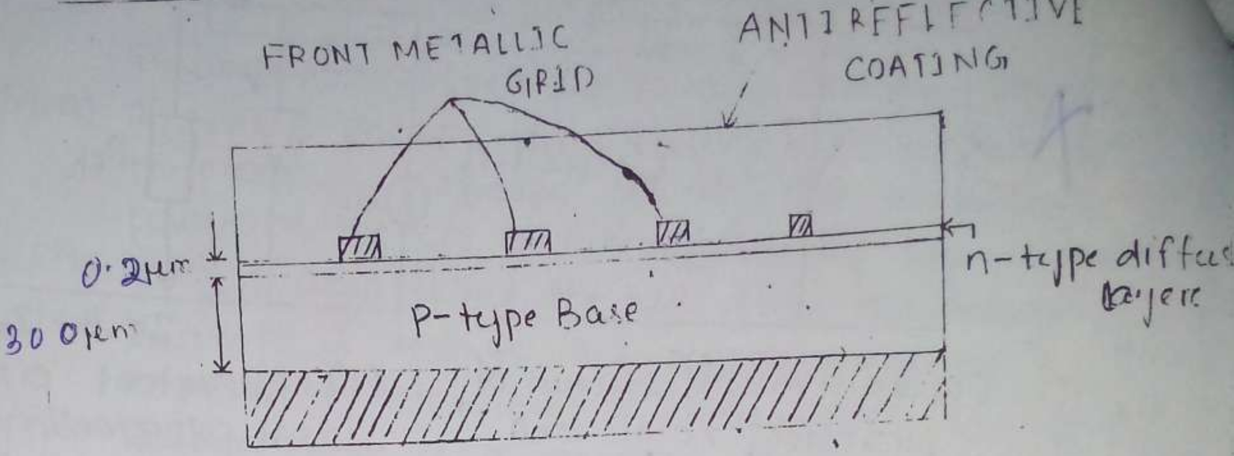
Effect of variation of insulation & temperature:



Solar insulation keeps on varying through out a day. If spectral content of radiation, temperature and all other factor remain same, both I_{sc} & V_{oc} increased with increasing the intensity of radiation. The photo generated current depends directly on insulation.

PV Cell, Module, Panel & Array Construction:

PV Cell:



Basic Cell structure of Si Cell

The ~~back~~ bulk material is P-type silicon of thickness 100-350 microns.
A thin layer of n-type 'Si' is formed at the top surface by diffusing an impurity from fifth group to get a p-n junction.
The top active surface of the n-layer has an ohmic contact with metallic grid structure to collect the current produced by impinging photons. The metallic grid structure covers minimum top surface area (less than 10% of total area) to leave enough uncovered surface area for incoming photons. The bottom inactive surface has an ohmic metallic contact over the entire area.
The two metallic contacts on p & n-layers respectively form the +ve & -ve terminals of the solar cell.
Several other features like providing antireflective coating, texture finish of the top surface & reflective, texture rear surface to capture maximum photons & direct them towards the junction.

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Solar P-V module:

A single cell can't be used for outer energy generation by itself. Because,
(i) Output of one cell is low.
(ii) It requires protection (capsulation against dust, mechanical shock & outdoor harsh condition)

Workable voltage & reasonable power is obtained by interconnecting an appropriate no. of cells. The unit is fixed on a durable back cover of several square field with a transparent cover on the top & shield to make this suitable for outer location.

This assembly is called solar PV module.

Ex: Most common commercial module has a series connection of 32 or 36 Si cells to charge a 12volt battery.

Cell mismatch in a module :

→ In a module, a no. of cells are interconnected and is very important that these cells should match as closely as possible that means V_{oc}, I_{sc}, V_m & I_m for all cells are exactly same.

→ Any mismatch in the characteristics of these cells leads to additional mismatch loss. So, peak power of the combination is always less than the sum of individual peak power of the cell.

→ In an ideal case, when all cells are exactly identical, the resultants peak power will equal to arithmatic sum of its constituents.

Series & Parallel Connection :-

→ When cell with mismatch characteristics are connected in series & load is applied, both cell are bound to carry same current.

→ The composite characteristics of the combination can be obtained by adding the individual output voltage of cell corresponding to a common current for all operating points. At a particular operating point, when one cell is operated at peak power, the other mayn't.

→ Thus, the peak power of the combination is always less than the sum of individual peak power of

each cell & so the composite characteristi[c]
a lower fill factor.

⇒ If such a combination is short circuited, equal & opposite voltage V_1' & V_2' are produced by individual cell and therefore one cell will be generating power while other will be dissipating it.

Parallel combination:

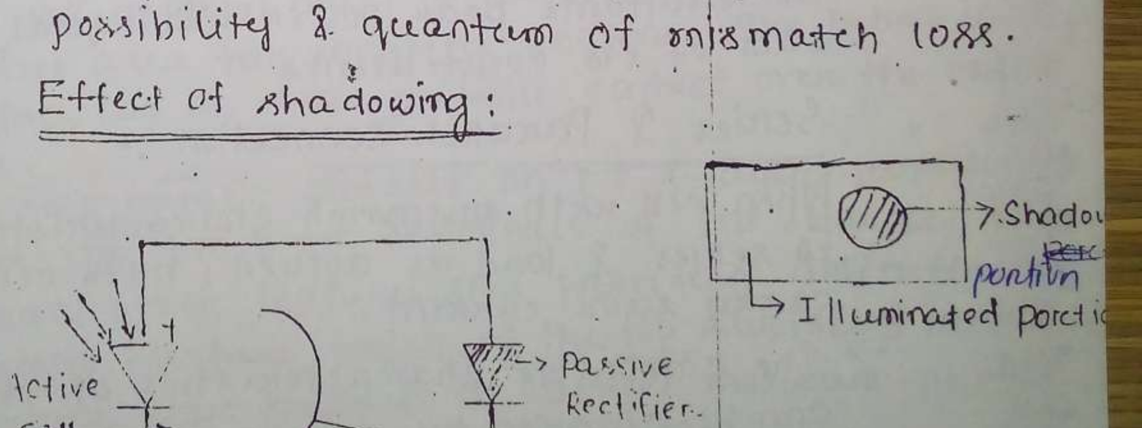
→ When two cells with mismatch characteristics are connected in parallel & voltage of cell are bound to be equal, but the current will be different & hence the maximum power point.

→ So, the conclusion can be drawn for two or more cells connected in series & parallel.

→ To reduce mismatch loss, modules are fabricated from cells belonging to same batch. "cell shorting" is done to catagorise cell having match parameter with specific tolerance.

⇒ Large the no. of cells in module, more is the possibility & quantum of mismatch loss.

Effect of shadowing:



– Partial shadowing may have serious consequences & may completely damage a module due to creation of hot spots.

- When a cell is partially shadowed, the shadowed portion will not produce any power but remaining portion will remain active & produce power. The generated voltage by illuminated portion, the forward biased parallel rectifier corresponding to shadowed portion.
- If the shadowed portion is relatively small, large circulating current flows through it with result in excessive heating at shadowed portion.
- This phenomenon is called "hot spot effect" & may completely damage the module for prolong partial shadow.

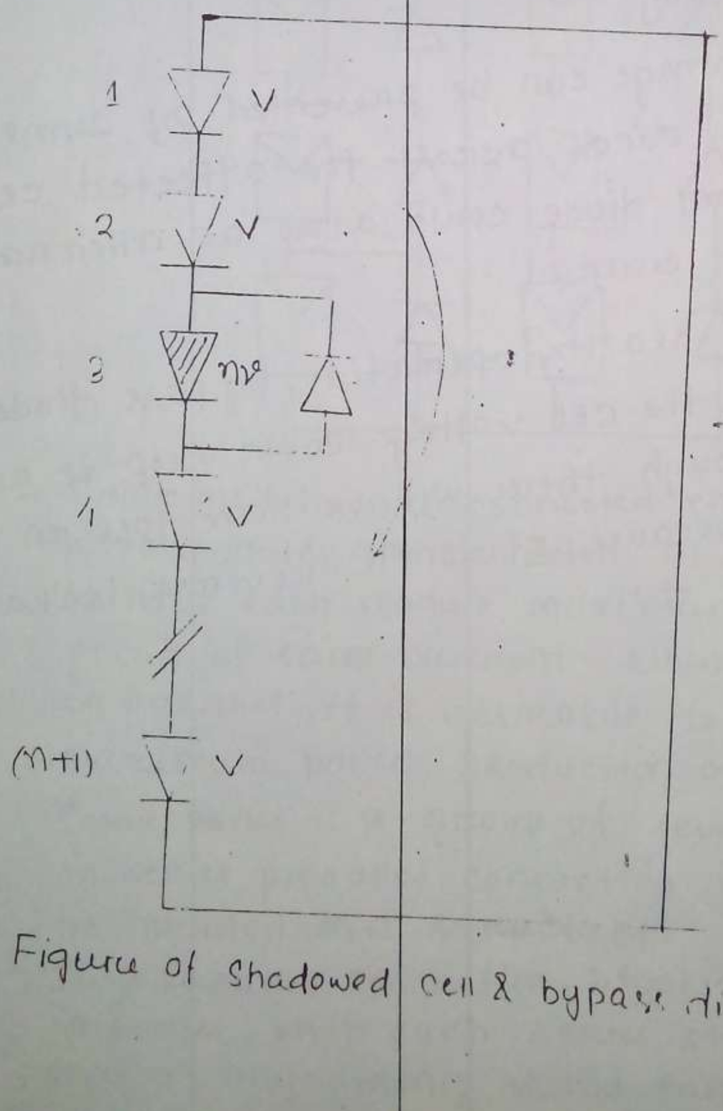


Figure of shadowed cell & bypass diode connection

A short circuited series string of (n+1) with one cell completely shadowed. The voltage produced by n illuminated cells add up & appear as reverse bias voltage of nV volt across the shadowed cell is more than the reverse biased voltage, no current will flow.

- If PIV is less, then total reverse voltage current will flow through the string, dissipating ~~ta~~ large power in the shadowed cell, leaving to a ~~pos~~ possible damage of the module.

The chance of damage to the shadowed cell due to excessive heating increases with no. of ~~cel~~ cell with the string.

The damage can be prevented by connecting a bypass diode across the affected cell. The by-passed diode could allow an alternating ~~pa~~ path of load current.

During healthy operation, bypass diode has ~~n~~ no Role as the cell voltage could keep it reverse baised even though there will be some loss in the ~~byp~~ bypass mode because of finite reverse leakage current through it.

Solar P-V Panel :

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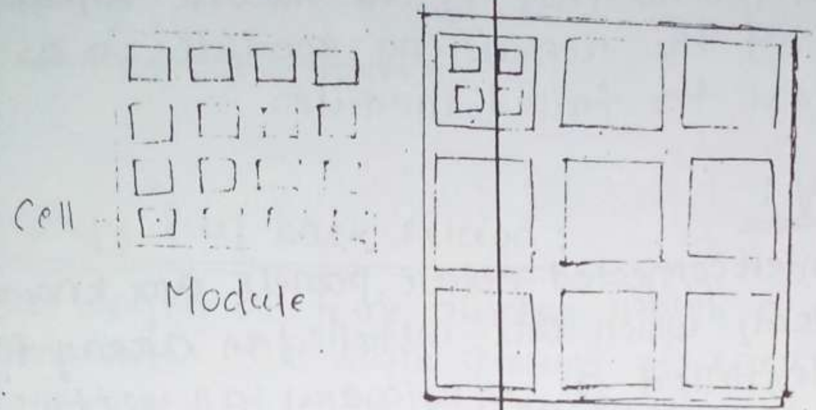
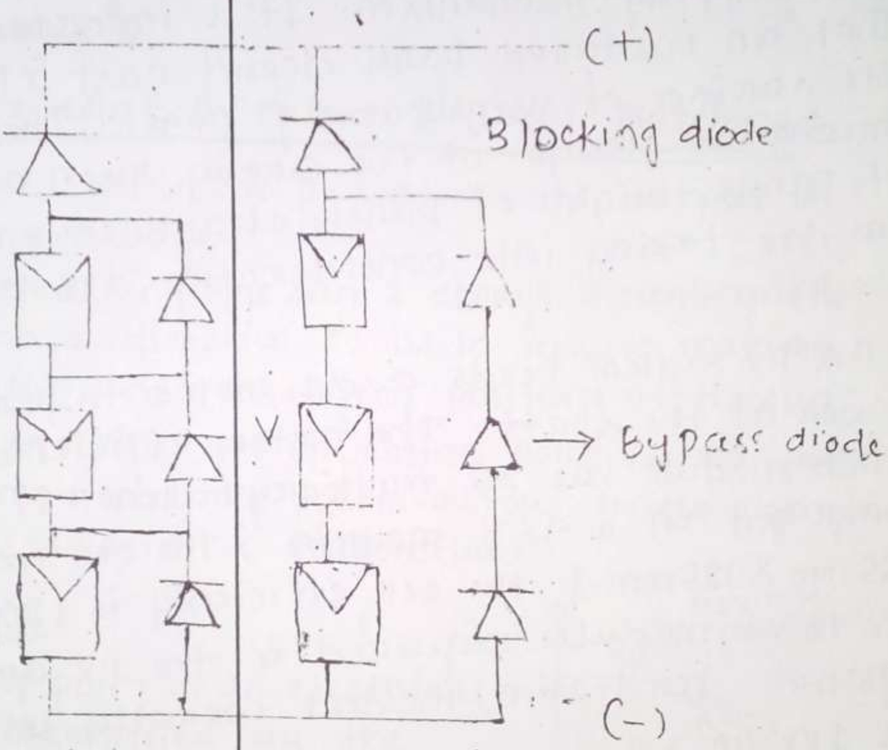




- Solar modules are connected in series & parallel. When modules are connected in series, it is desirable to have each module maximum power production occur at same current. When modules are connected in parallel, it is desirable to have each module maximum power production occur at same voltage. Solar panel is a group of several modules connected in series parallel connection in a frame that can be mounted on a structure.
- In a parallel connection, blocking diodes are connected in series with each series string of modules, so that if any string should fail, the power output

of the remaining series string will not be absorbed by the failed strings. By passed diodes are installed across each module, so that if one module should fail, the output of the remaining module in a string will bypass the failed module.

Solar P-V Array:

A large no. of interconnected solar panels are known as solar PV array which are installed in array field. These must be installed as stationary all with sun tracking mechanism. It is important to ensure that an installed panel doesn't cast its shadow of the surface of neighbouring panel. The layout and mechanical design of the array such as tilt angle of panels, height of panel, clearance among panel are done taking into consideration the local climating condition.

Ex: A PV system feeds a dc motor to produce 1 HP power at the shaft. The motor efficiency is 85%. Each module has 36 multicrystalline Si solar cell arranged in a 9×4 matrix. The cell size gives 125 mm × 125 mm & the cell efficiency is 12%. Calculate the no of modules required in the PV array. Assume global radiation incident normally into the panel is $1 KW/m^2$.

ns: Maximum O/P power = 1 HP ≐ 746 W.

Electrical Power input = $\frac{\text{Max. O/P power}}{\text{efficiency}}$

$= \frac{746}{0.85} = 877.64\ W.$

|| Area in a module $= 9 \times 4 \times 125 \times 125 \times 10^{-6} = 0.5625\ m^2$

Let the no. of modules = N

Solar radiation $= 1 KW/m^2 = 1000\ W/m^2$

Cell efficiency = 0.12

O/P of the Array $= 1000 \times 0.12 \times 0.5625 \times N$

$= 67.5\ N$

$67.5N = 877.64$

$\Rightarrow N = 13$ = No. of modules.

~~Cell Area in a module =~~

Energy Pay back Period:

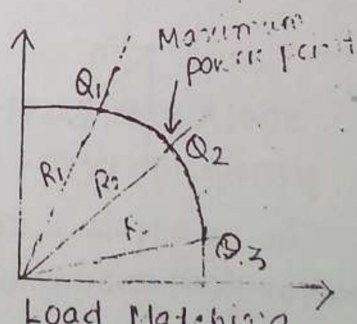
The length of time during which a solar cell generates the same amount of energy that it has consumed during its production is known as energy pay-back period.

Maximizing the solar PV output & Load Matching:

To make best use of solar pv system, the output is maximized in two ways.

- Mechanically tracking the sun & always orienting the panel in such a direction so as to receive maximum solar radiation under changing positions of the sun.
- Electrically tracking the operating point by manipulating the load to maximize the power output under changing conditions of isolation & temperature.

Load Matching:



Load Matching with Resistive load

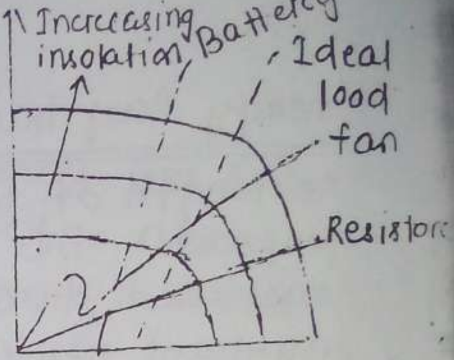
The operating point of an electrical system is determined by the intersection of source characteristics (source line) & load characteristics (Load line). The operation of a solar pv system connected to a resistive load is shown in figure.

For resistance R_1, the system operates at Q_1 & for R_2 & R_3, system appears at Q_2 & Q_3. Maximum power is available from the PV system for a load resistance R_2. This load matching is required for extracting maximum power from a pv system.

Maximum Power Point Tracker (MPPT):

The I-V characteristics of a solar PV system keeps on changing with insolation & temp. In order to receive maximum power, the load must adjust itself according to track maximum power point. An ideal load is the one that tracks the maximum power point.

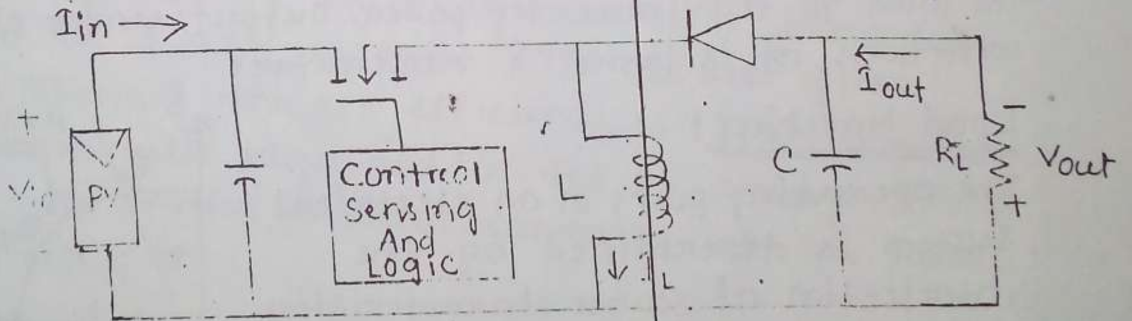
If the operating point departs significantly from the maximum power point, It may be desirable to interpose an Electronic Maximum Power point Tracker (MPPT) between PV system and load.



Characteristics of PV and some loads.

MPPT is an adaptation of dc-dc switching voltage regulator.

The load is coupled for maximum power transfer & as required it provides a higher voltage at a lower current or lower voltage for higher current. In this process, a Bulk-Boost scheme is commonly used with voltage & current sensors tied into a feedback loop using a controller to vary the switching times.



Maximum Power Point Tracker (MPPT): Using Bulk-Boost Converter

The output voltage of Bulk-Boost converter is given by,

$$V_{out} = \frac{D}{1-D} V_{in} \quad (0 < D < 1)$$

where D = Duty cycle of MOSFET

Power output of a PV system is given by,

$$P = VI$$

With change in current & voltage, modified power (P) is given by,

$$P + \Delta P = (I + \Delta I) \cdot (V + \Delta V)$$

$$\Rightarrow P + \Delta P = IV + \Delta I V + \Delta V I + \Delta V \Delta I$$

Neglecting negligible terms,

$$\Delta P = \Delta V I + \Delta I \cdot V \quad \text{———— (1)}$$

At peak point $\Delta P = 0$.

∴ At peak point eqn (1) can be re-written as,

$$dV \cdot I = -dI \cdot V$$

$$\Rightarrow \boxed{\frac{dV}{dI} = -\frac{V}{I}}$$

$\frac{dV}{dI}$ = dynamic impedance of the source which is equal to −ve of $\frac{V}{I}$ = static impedance

There are 3 possible strategies for operation of an MPPT:

(i) <u>By monitoring Dynamic & Static Impedance :</u>

A small signal current is periodically injected into the array bus & dynamic & static bus impedance (Z_d & Z_s) are measured operating voltage is then adjusted until $Z_d = -Z_s$.

(ii) <u>By monitoring Power output :</u>

From P-V characteristics, it is clear that, the slope $\frac{dv}{dt}$ is zero at maximum power point. This property is used to track maximum power point. voltage is adjusted & power output is sensed. The operating voltage is increased as long as $\frac{dP}{dV}$ = +ve, i.e. voltage is increase as long as we get increased output. If $\frac{dP}{dV}$ is sensed −ve, the operating voltage is decreased. The voltage is held unaltered if $\frac{dP}{dV}$ is near zero within a preset dead band.

(iii) <u>By fixing the output voltage as a fraction of Voc :</u>

The method makes use of the concept that most PV cells, the ratio of the voltage at maximum power point to open circuit voltage is approximately constant (K). An additional identical unloaded cell is installed on the array to face same environment as the module & V_{oc} is constantly measured. The operating voltage of the array is then set at KV_{oc}.

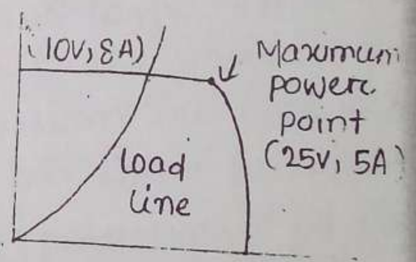
Ex: A PV source having I-V characteristics as shown is supplying power to a load whose load line intersects the characteristics at (10V, 8A). Determine the additional power gained if an MPPT is interposed between the source & the load. If the cost of the MPPT is Rs. 4000.00 for how long does the system need to operate in order to recover the cost of MPPT? The loss of electricity may be assumed to be Rs. 300 per KWh & efficiency of MPPT is 95%.

Soln: Power produced without MPPT $= 10 \times 8 = 80W$.

Maximum power production capability of PV module $= 25 \times 5 = 125W$.

As the efficiency of the MPPT is 95%, actual power produced with MPPT $= 125 \times 0.95 = 118.75W$.

Surplus power produced by use of MPPT $= 118.75 - 80 = 38.75W$.



Surplus energy produce in 't' hours

$= \frac{38.75 \times t}{1000} = 0.03875t$ KWh.

cost of surplus energy $= 3 \times 0.03875t$

Cost of MPPT = 4000

Time (in hrs) required to recover the cost of MPPT

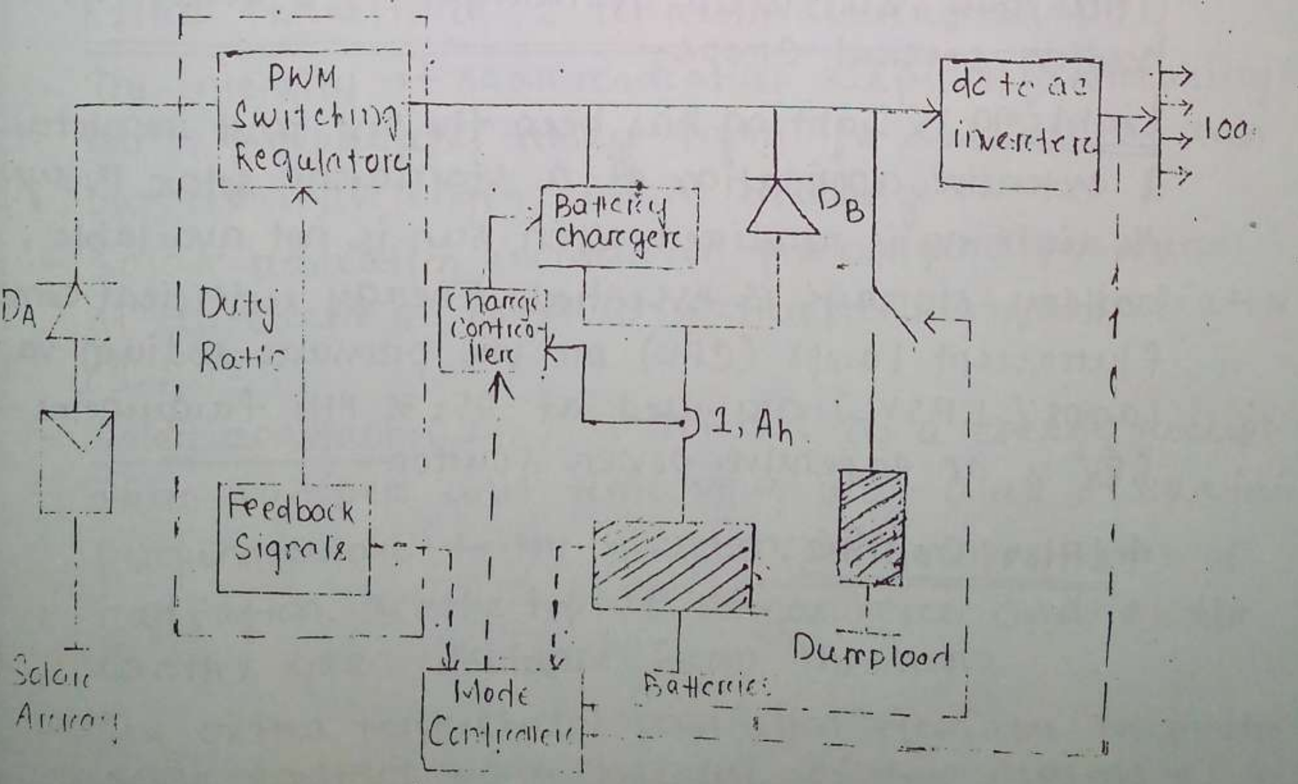
$= \frac{4000}{3 \times 0.03875} = 34408.6$ hours

Applications of Solar PV systems:

Battery Charging: In a stand-alone solar PV system, the output is excess as per the load requirement, which can be used to charge the battery. The MPPT senses the voltage & current outputs of the array & adjusts the operating point to extract maximum power under the

A general stand alone PV system:

- The output of the array after converting to ac is fed to loads. The array output in excess of load requirement is used to charge the battery.
- If excess of power is still available after fully charging the battery, it may shunted to dump heaters.
- When the sun is not available, the battery supplies the load through an inverter. The battery discharge diode D_B prevents the battery from being overcharged after charger is opened.
- The array diode D_A is to isolate the array from the battery to prevent battery discharge through array during nights.
- Mode controller is a central controller for the entire system. It collects the system signals & keeps track of charge / discharge state of the battery matches the generated power & load & commands the charger & dump heater on-off operation.



Water Pumping: Pumping of water for the purpose of drinking or minor irrigation during sunshine hours is a very successful application of a standalone PV system without storage.

- Water pumping appears to be most suited for solar PV application as water demand increases during dry days when plenty of sunshine is available.
- There would be less need of water during the rainy season when the availability of solar energy is also low. Solar PV water pumping systems has been successful all over.
- Three types of motors has generally been used in water pumping :-> Permanent magnet dc motor, Brushless dc motor, variable voltage & variable frequency ac motor.

Ex: A 1800 watt PV array to operate a 2HP dc motor pumpset. It can give water discharge of 140,000 litres/day, sufficient to irrigate 5.8 acres of land holding several crops.

Lighting: Lighting has been the 2nd most important & extensive application of a standalone solar PV system.

- As lighting is required when sun is not available, battery storage is essential. Energy sufficient compact fluorescent lamps (CFL) or low pressure sodium vapour lamps (LPSVL) are used at 25-35 KHz frequencies as SPV is an expensive power source.

Peltier Cooling:

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Solar thermal System:

Solar radiation basics:

The sun radiates energy uniformly in all directions in the form of electromagnetic wave. Solar energy can be used in two ways.

1) By collecting the radiant heat & using it in a thermal system.
2) By collecting & converting it directly to electrical energy by using solar pv system.

Various energy sources find their origin in the sun.
Ex: Wind energy, biomass energy, tidal energy, ocean wave energy, ocean thermal energy, hydro energy etc.

Solar processes:

Extra terrestrial & terrestrial radiation:

- The intensity of solar radiation keeps on decreasing as it propagates away from the surface of sun but the wavelength remain unchanged.
- Solar radiation incident on the outer atmosphere of the earth is known as extra terrestrial radiation (I_{ext}).
- Solar constant (I_{sc}) is defined as a energy receipt from sun per unit time in a unit area of surface perpendicular to the direction of propagation of radiation at the top of atmosphere and at the earth's mean distance from the sun.
- The extra terrestrial radiation deviates from the solar constant value because of two reasons.
  (1) variation in the radiation emitted by the sun itself
  (2) variation of earth - sun distance due to earth's elliptical path.

The extra terrestrial radiation being outside the atmosphere is not changed by changing in atmospheric condition.

The solar radiation reaches the earth surface after passing through the earth's atmosphere is known as terrestrial radiation.

Solar insolation (incident solar radiation) is defined as the solar radiation receipt on a flat horizontal surface on earth.

Spectral energy distribution on solar radiation:

Solar radiation covers a continuous spectrum of electromagnetic radiation in a wide frequency range. About 6.4% of extra terrestrial energy is contained in ultraviolet region ($\lambda < 0.38 \mu m$) 48% is contained in visible region ($0.38 \mu m < \lambda < 0.78 \mu m$) Remaining 45.6% is contained in infrared radiation ($\lambda > 0.78 \mu m$).

- There is almost complete absorption of shortwave radiation in the range ($\lambda < 0.29 \mu m$) & infrared radiation in the range ($\lambda > 2.3 \mu m$) in atmosphere.
- So, it can be concluded from the point of view of terrestrial application of solar energy, the radiation only in the range of wavelength between 0.29 & 2.3 is significant.

Depletion of solar radiation:

The solar radiation is depleted during its passage through atmosphere due to presence of various gaseous constituent, suspended dust particles and other minute solid & liquid particulated matter.

Ex: C, N, CO_2, CO, water vapour.

Absorption:

The absorbed radiation increase the energy of the absorbing molecule. Thus raising the temp.

(1) N & molecular O absorb the x-rays & extreme ultraviolet radiation.

(2) Ozone absorb the ultraviolet radiation in the range ($\lambda < 0.38\ \mu m$)

(3) Water vapour & CO_2 absorb almost complete infrared radiation ($\lambda > 2.3\ \mu m$)

(4) Dust particle & air molecules also absorb a part of solar radiate energy irrespective of their wavelength.

Scattering:

Scattering by dust particle & air molecules involves redistribution of incident energy.

Beam radiation:

Solar radiation propagating in a straight line & receive at the earth's surface without change of direction i.e. in the line with the sun is called beam or direct radiation.

Diffused radiation:

Solar radiation scattered by aerosols, dust and molecules is known as diffused radiation. It doesn't have a unique ~~radiation~~ direction.

Global radiation:

The sum of beam & diffused radiation is referred as total or global radiation.

Sun at Zenith:

It is the position of sun directly overhead.

Irradiance:

The rate of incident energy per unit area of surface is termed as irradiance.

Albedo:

The earth reflects back nearly 30% of the total solar radiate energy to the space by reflection from clouds, by scattering & by reflection at the earth's surface. This is called albedo of earth's atmospheric system.

Solar Collectors:

A solar thermal energy collector is an equipment in which solar energy is collected by absorbing radiation in an absorber & then transferring to a fluid.

- The classification of solar collector is based on the way they collect solar radiation.
- Non-concentratic type absorb radiation as it receive on the surface of collector.
- Concentratic type first increase the concentration of radiation per unit area before absorbing it.

Solar Collectors

- Non-Concentratic type
  - Flat plate Collector:
    - a) Liquid flat plate collector
    - b) Flat plate air heating Collector
- Concentratic type
  - Focus type
  - Non-focus type
    - a) Modified flat plate Collector
    - (b) Compound parabolic concentratic (CPC type)

Focus type Collectors are 2 type

Focus type

- Line focus (One axis tracking)
  - i) Fixed mirror solar Concentration
  - i) Cylindrical parabolic Concentration
  - ii) Linear fraesnel lens collector
- Point focus (Two axis tracking)
  - (i) Paraboloidal dish Collector
  - (ii) Hemispherical bowl mirror concentration
  - (iii) Circular fraesnel lens concentration
  - (iv) Central tower receiver

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Flat Plate Collectores:

- A flat plat collector is simple in construction & doesn't require sun tracking. Therefore, it can be properly secure on a rigid platform & thus becomes mechanically stronger than those requiring flexibility for tracking purpose. As a collector is installed outdoores, the flat plate type is exposed to atmospheric disturbances & withstands harsh outdoor condition, due to simple stationary design, a flat plate collector requires little maintainance.
- The main disadvantage of F.P.C. is that because of optical concentration, the area from which heat is lossed is large & high temp. can be attained

Concentrating type Solar Collectors:

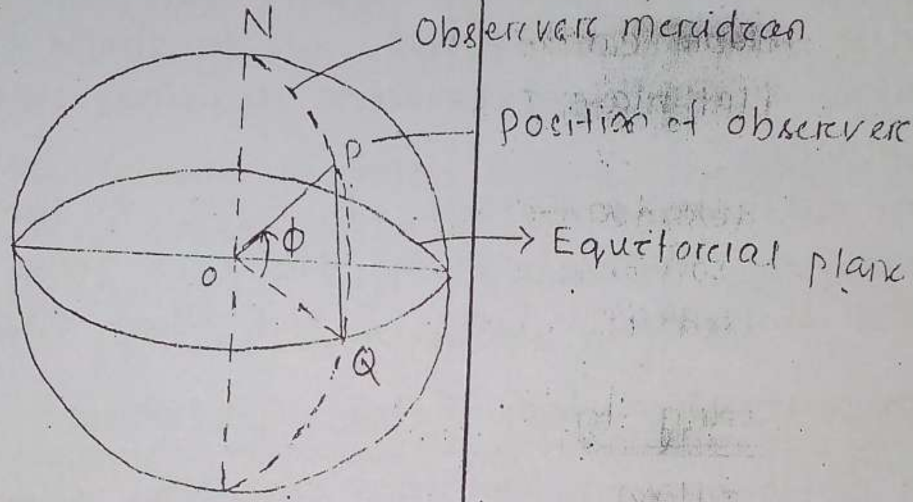
In concentrating type solar collectors, solar radiation is conversed from a larger area into a smaller area using optical means. Beam radiation which has unique direction & travel in a straight line can be converted by a reflection or refraction techniques. Diffused radiation has no unique direction and so don't obey optical principle. So, concentrating type solar collector mainly make use of beam radiation component (plus very little diffused component coming directly over the absorber) while non-concentrating type (flat plate) collectors absorb both beam as well as diffused radiation - a advantage of flat plate collector.

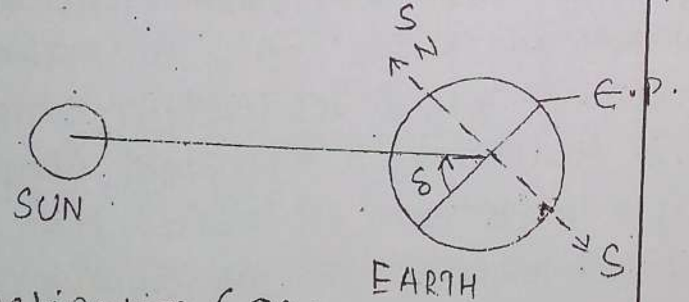
- The main advantage of concentratic type collectors is that high temp. can be attained due to conc. of radiation. This also yields high temperature thermal energy.

Solar radiation geometry :

Latitude (Angle of Latitude) 'φ' :

The latitude of a location on earth's surface is the angle made by a radial line joining the given location to the centre of the earth with its projection on the equator plane. The latitude is +ve for northern hemisphere & −ve for southern hemisphere.





Declination (δ) :

It is defined as the angular displacement of sun from the plane of earth's equator. It is +ve when measured above the equitorial plane in the northern hemisphere.

Mathematically, it is given by,

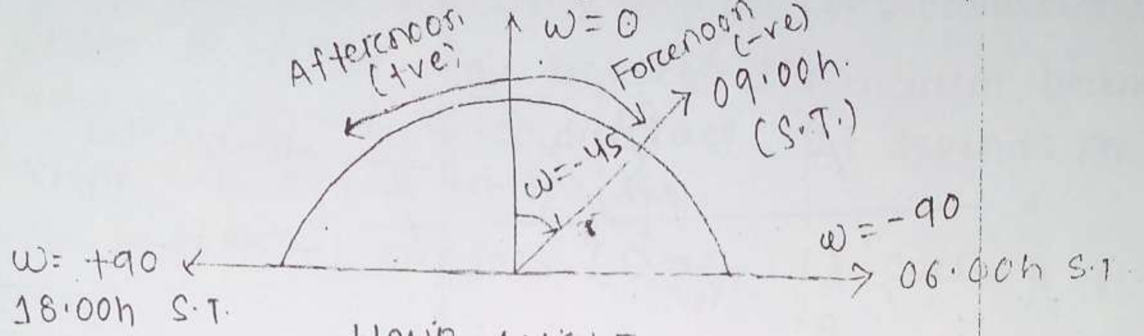
$$\delta = 23.45 \times \sin\left[\frac{360}{365}(284+n)\right] \text{ degrees}$$

when n is the no. of days in a year counted from 1st january.

(c) Hour angle (ω):

The hour angle at any moment is the angle through which the earth must turn to bring the meridian of the observer directly in line with the sun's rays.

$\omega = [\text{Solar time} - 12:00]$ in hrs × 15 degrees



HOUR ANGLE

(d) Inclination Angle (Altitude) 'α':

The angle between sun's ray & its projection on a horizontal surface is known as inclination angle.

(e) Zenith Angle (θ_z):

It is the angle between the sun's ray & the perpendicular (normal) to the horizontal plane.

(f) Solar Azimuth Angle: (γ_s).

It is the angle on a horizontal plane between the line due south & the projection of sun's rays on a horizontal plane.

(g) Slope (tilt angle) 'β':

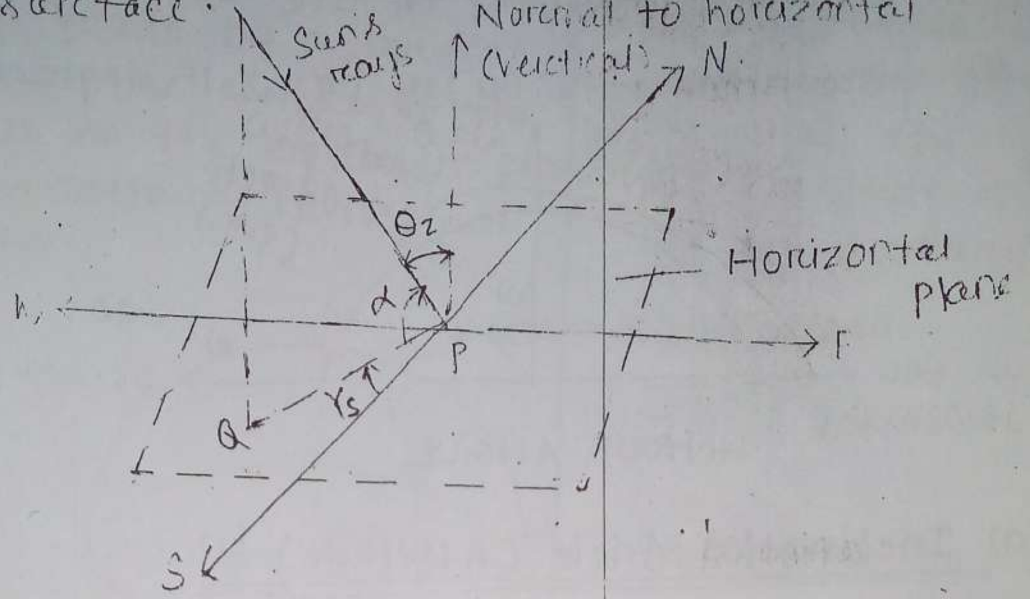
It is the angle between the inclined plane surface (collector) under consideration & the horizontal. It is +ve for surfaces sloping towards south.

(h) Surface Azimuth Angle: (γ):

It is the angle in the horizontal plane between the line due south & the horizontal projection of the normal to the inclined plane surface (collector). It is +ve when measured from south towards west.

(i) Angle of Incidence (θ_I):

It is the angle between the sun's rays incident on plane surface (collector) & the normal to that surface.



QP is the horizontal projection of sun's rays

Solar radiation on an inclined surface:

The total solar radiation incident on a surface has 3 components.

(i) Beam solar radiation

(ii) Diffused solar radiation.

(iii) Reflected solar radiation from ground & surrounding.

→ To obtain maximum solar energy, flat plate collectors always face the sun by using a sun tracking instrument. So, solar radiation collecting appliance are tilted at an angle to the horizontal.

→ Measuring instrument measure the solar radiation falling on horizontal surface. So, mathematically the values measured on horizontal surface should be converted to corresponding values on an inclined surface.

(i) Beam Radiation:

Generally, inclined surface face south to obtain maximum solar radiation even during winter. So, $\gamma = 0°$; $\cos\theta$ is given by

$$\cos\theta = \sin\delta \times \sin[\phi-\beta] + \cos\delta \cos\omega \cos(\phi-\beta)$$

- Where θ is the angle between the incident beam & normal to the tilted surface. It depends on the position of sun in the sky.
- For horizontal surface, $(\theta = \theta_z)$ & $\cos\theta_z$ is given by,

$$\cos\theta_z = \sin\phi \sin\delta + \cos\phi \cos\delta \cos\omega$$

The ratio of beam radiation falling on an inclined surface to that of falling on a horizontal surface is termed as tilt factor for beam radiation. It is denoted as R_b.

$$R_b = \frac{\cos\theta}{\cos\theta_z}$$

(ii) Diffused radiation:

The ratio of diffused radiation falling on a tilted surface to that falling on a horizontal surface is known as tilt factor for diffused readiation (R_d).

$$R_d = \frac{1+\cos\beta}{2}$$

Where $\frac{1+\cos\beta}{2}$ is the radiation shape factor for an inclined surface with reference to sky.

(iii) Reflected radiation:

The tilt factor for reflected radiation (R_r) is

$$R_r = \frac{\rho(1-\cos\beta)}{2}$$

where ρ - Reflectivity

$\left(\frac{1-\cos\beta}{2}\right)$ is the radiation shape factor with respect to the surrounding.

Total radiation:

The total radiation flux falling on an inclined surface at any instant is given by,

$$I_T = I_b R_b + I_d R_d + (I_b + I_d) R_r$$

Dividing this eqn by I_g, we get

$$\frac{I_T}{I_g} = \left(1 - \frac{I_d}{I_g}\right) R_b + \frac{I_d}{I_g} \cdot R_d + R_r \quad (\because I_g = I_b + I_d)$$

Performance indices of solar collector:

The performance of a solar collector is evaluated on the basis of -

(i) Collector efficiency - It is the ratio of the energy actually absorbed & transferred to the heat transport fluid by the collector (useful energy to the energy incident on the collector).

(ii) Concentration ratio - It is defined as the ratio of the area of the aperture of the system to the area of the receiver. The aperture of the system is the projected area of the collector facing normal to the beam.

(iii) Temperature range - It is the range of temp. to which the heat transport fluid is heated up by the collector.

Performance Analysis of a Liquid flat plate Collector:

The performance of a solar collector can be improved by enhancing the useful energy gain from incident solar radiation with minimum losses. Thermal losses include 3 components.

(i) Conductive loss – It is reduced by providing insulation on the rear & sides of the absorber plate.

(ii) Convective loss – It is minimized by keeping an air gap of about 2 cm. between the cover & the plate.

(iii) Radiative loss – It is lowered from the absorber plate by applying a spectrally selective absorber coating.

During normal steady state operation, useful heat delivered by a solar collector is equal to the heat gained by the liquids flowing through the tubes minus the losses.

The energy balance of the absorber is given by

$$Q_u = A_p S - Q_L$$

where Q_u = useful heat delivered by the collector (w

S = Solar heat energy absorbed by the absorb plate (watt/m^2)

A_p = Area of the absorber plate in m^2

Q_L = Rate of heat loss by convection & reradiati from top, by conduction & convection from bottom & sides (watt).

Solar flux falling on an inclined surface is given by,

$$I_T = I_b R_b + I_d R_d + (I_b + I_d) R_r$$

The instantaneous collector efficiency is defined a the ratio of useful heat gain to radiation falling on the collector.

$$\eta_i = \frac{Q_u}{A_p I_T}$$

Depending on given data, the collector aperture area (A_a) or collector gross area (A_L) is used in place of A_p in the given eqn.

Stagnation temperature:

In case the flow of fluid through the collector is stopped, the useful heat gain & the efficiency becomes zero. At this stage, the absorber plate attains a temperature. So that $A_pS = Q_L$. This maximum temp that the absorber plate can attain is called stagnation temperature.

6.09.10

MODULE - III

27·09·10

BIOMASS POWER

Biomass refers to solid carbonious material derived from plants and animals. These include residues of agriculture and forestry, animal waste and discarded material from food processing plants. Biomass being organic matter from terestrial and marine vegetation, renews naturally, in short span of time. So, they are called renewable source of energy. It is a derivative of solar energy as plants grow by the process of photosynthesis by absorbing CO_2 from atmosphere. The energy or power obtained from biomass is called bio-mass energy or bio-mass power.

Operating Principle :

The use of biomass energy, is done - the initial biomass may be transformed by chemical or biological processes to produce more convenient intermediate biophase such as methane, producer gas, ethanol and charcoal. On combustion, it reacts with oxygen to release heat, but the material should be available for recycling in natural ecology or agricultural processes. Thus, the use of biomass may be non-polluting and sustainable.

Biomass is a derivative of solar energy as plants grow by the process of photosynthesis by absorbing CO_2 from atmosphere to form hexose (glucose .... etc). Solar radiation incident on green plants & other photosynthetic organisms perform two basic functions.

(1) Temperature control for chemical reaction to proceed
(2) Photosynthesis process

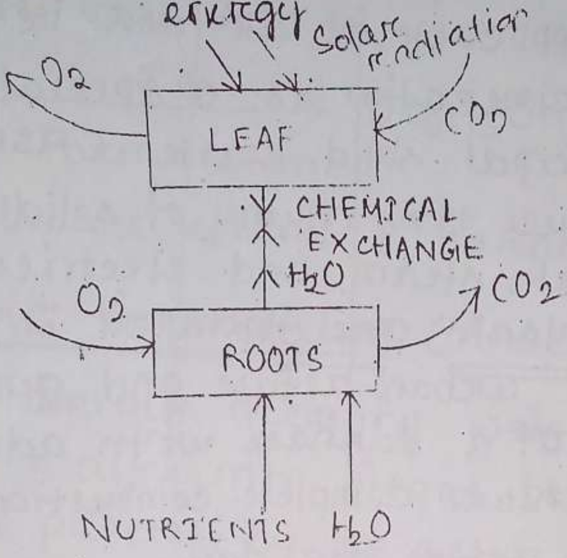
Photosynthesis Process:

$$xCO_2 + yH_2O + \text{light energy} \xrightarrow{\text{Photosynthesis}} xCO_2 + C_x(H_2O)_y$$

$C_x(H_2O)_y$ ↓ Carbohydrade

Basic reaction:

$$6CO_2 + 6H_2O + \text{Light energy} \xrightarrow{\text{Photosynthesis}} 6CO_2 + C_6H_{12}O_6$$



Photosynthesis is a complex process and involves successive stages. Reverse of this process is called respiration. The intake of CO_2 by plant leaves is a function of many factors, especially temperature, CO_2 concentration and intensity and wavelength distribution of light. Solar readiation incident on a leaf is reflected, transmitted & absorbed.

Biomass Conversion Technologies:

There are many different ways of extracting energy from biomass which can be utilised optimally by adopting efficient conversion technologie

(1) Physical method
(2) Incineration & combustion
(3) Thermochemical method
(4) Bio-chemical method

Incineration:

Incineration means direct combustion of biomass for immediate useful heat. It is the process of burning completely the solid biomass to ~~access~~ ashes by high temp. oxidation. The term incineration & combustion are synonymous. But the process of combustion is applicable to all fuels i.e. solid liquid & gases. Incineration is a special process whether dry municipal solid waste (MSW) is incinerated to reduce the volume of solid refuse and to produce heat, steam and electricity. Waste incineration plants are installed in large cities to dispose of urban refuse and generate energy. It consists of a furnace with adequate supply of air to ensure complete combustion upto a capacity of 1000 tonne per day.

Combustion:

Direct combustion is the main process adapted for utilising biomass energy. It is burnt to produce heat utilised for cooking, space heating, industrial processes and for electricity generation. This utilisation method is very inefficient with heat transfer losses of 30-90% of original energy contained in the bio-mass.

Bio-chemical Conversion:

The process make use of metabolic action of micro-bial organism on biomass to produce liquid & gaseous fuels. Two bio-chemical processes are

(a) Ethanol formentation

(b) Anaerobic formentation

(a) Ethanol formentation :

Alcoholic formentation is the decomposition in the absence of aire of simple hexose sugares (sugar containing 6 carbon atom per. molecule, Ex: $C_6H_{12}O_6$), in aqueous solution by the action of an enzyme (a natural catalyst), present in yeast in acidic condition (PH value 4 to 5)

$$C_6H_{12}O_6 \xrightarrow[\text{Formentation}]{32^{\circ}C} 2C_2H_5OH + 2CO_2$$

The products are ethanol & carbon dioxide.

(b) Anaerobic formentation (Anaerobic digestion):

This process converts decaying ~~weight~~ wet biomass and animal wastes into biogas through the decomposition process, by the action of anaerobic bacteria (bacteria that live & grow in absence of oxygen). Carbon present in biomass may be ultimate divided between fully oxidised CO_2 and fully reduc CH_4.

Decaying wet biomass $\xrightarrow[\text{Anaerobic formentation}]{20-55^{\circ}C}$ Biogas (Largely CH_4 & C(

The biomass material in the form of water slurry is digested by the bacteria anaerobically for sevre days in an airtight containere. The reaction are slightly exothermic and a small amount of heat is also generated that helps in maintaining a favoureable temp. The process may be carried or at higher temp. The most useful biomass material appear to be animal manure, algae, plant residu and other organic waste materials with high moisture content.

28.09.10

Thermochemical method:

In this process biomass is converted into a more valuable & convenient product and is known as pyrolysis. Biomass is heated either in absence of oxygen or by partial combustion with limited air supply. Pyrolysis can be processed all forms of organic material like rubber and plastic which can't be handled by other method. The products are of three types.

(i) Gaseous mixture – hydrogen, CO, CO_2, CH_4, N_2.
(ii) Oil like – Water soluable phase including acetic acid, acetone, methanol.
(iii) A nearly pure carbon char.

The distribution of these product depends on the type of feed-stock, temp & pressure during the process, its duration & heating rate.

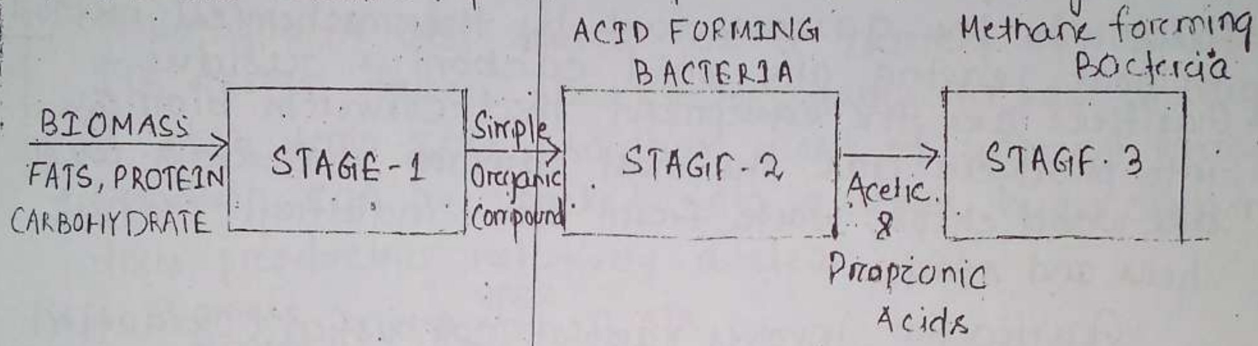
→ High temp. pyrolysis (1000°c) maximizes the gaseous products. The process is known as gasification.
→ Low temp. pyrolysis (upto 600°c) maximizes char output. The process is called carbonisation.
→ A liquid product is obtained through catalytic liquification process. Liquification is a relatively a low temp (250–450°c), high pressure (270 atm) thermochemical conversion of wet biomass. A catalyst is used to enhance the rate of reaction & to improve selectivity of process.

Anaerobic Digester:

Biogas is produced from wet biomass with about 90–95% water content by the action of anaerobic bacteria. Part of the carbon is oxidised and another part reduced to form CO_2 & CH_4. These bacteria live and grow without oxygen. The process is favoured by wet, warm and dark conditions.

The airtight equipment used for the conversion is known as biogas plant or digester. This is constructed & controlled to favour CH_4 production. The conversion process is known as <u>anaerobic formentation</u>. or <u>biodigestion</u>. The energy available from the combustion of biogas is 60-90% of combustion of input drey matter. Thus, the energy conversion efficiency of the process is 60-90%.

→ The bio-chemical process proceed in 3 stages.



- **<u>Stage-1:</u>** 1st the original organic matter containing complex compound carbohydrate, protein, fats is breoken down through the influence of water (known as hydrolysis to simple water soluable compounds. The polymers (large molecules) are reduced to monomers (basic molecules).

→ This process takes about a day at 25°c in an active digester.

- **<u>Stage-2:</u>** Anaerobic bacteria also known as methane formers slowly digest the products available from 2nd stage to produce CH_4, CO_2, small amount of hydrogen & a trace amount of other gases.

→ This process takes 2 weeks time at 25°c. Methane formation stage is strictly carried out by anaerobic bacteria.

- **Stage-2**: The microorganisms of anaerobic and facultative (that can live & grow with or without oxygen) groups together known as acid formers, produce mainly acetic & propionic acid.

→ This stage also takes a day at 25°C. Much of CO_2 is released in this stage.

Biomass gasification:

29.09.10

The word gasification refers to conversion of solid fuels into the gaseous fuel by thermochemical method without leaving any solid carbonious residue. Gasifiers are the equipment that converts biomass into producer gas. The most common materials used are wood chips, waste from wood industry, coconut shells and straw.

Gasification involves partial combustion (oxidation in limited quantity of air/oxidant) and reduction operation of biomass. In a typical combustion process, generally the oxygen is surplus while in gasification process, the fuel is surplus. The combustion products, mainly CO_2, water vapour, nitrogen, CO & H_2 pass through the glowing layer of charcoal for the reduction process to occur. During this stage, both CO_2 & water vapour, oxidises charcoal to form CO, H_2 & CH_4.

Reactions:

$C + O_2 \rightarrow CO_2$ (Combustion)

$C + CO_2 \rightarrow 2CO$ (Boudouard Reaction)

$C + H_2O \rightarrow CO + H_2$ (Water gas Reaction)

$CO + H_2O \rightarrow CO_2 + H_2$ (Water shift Reaction)

$C + 2H_2 \rightarrow CH_4$ (Methane Reaction)

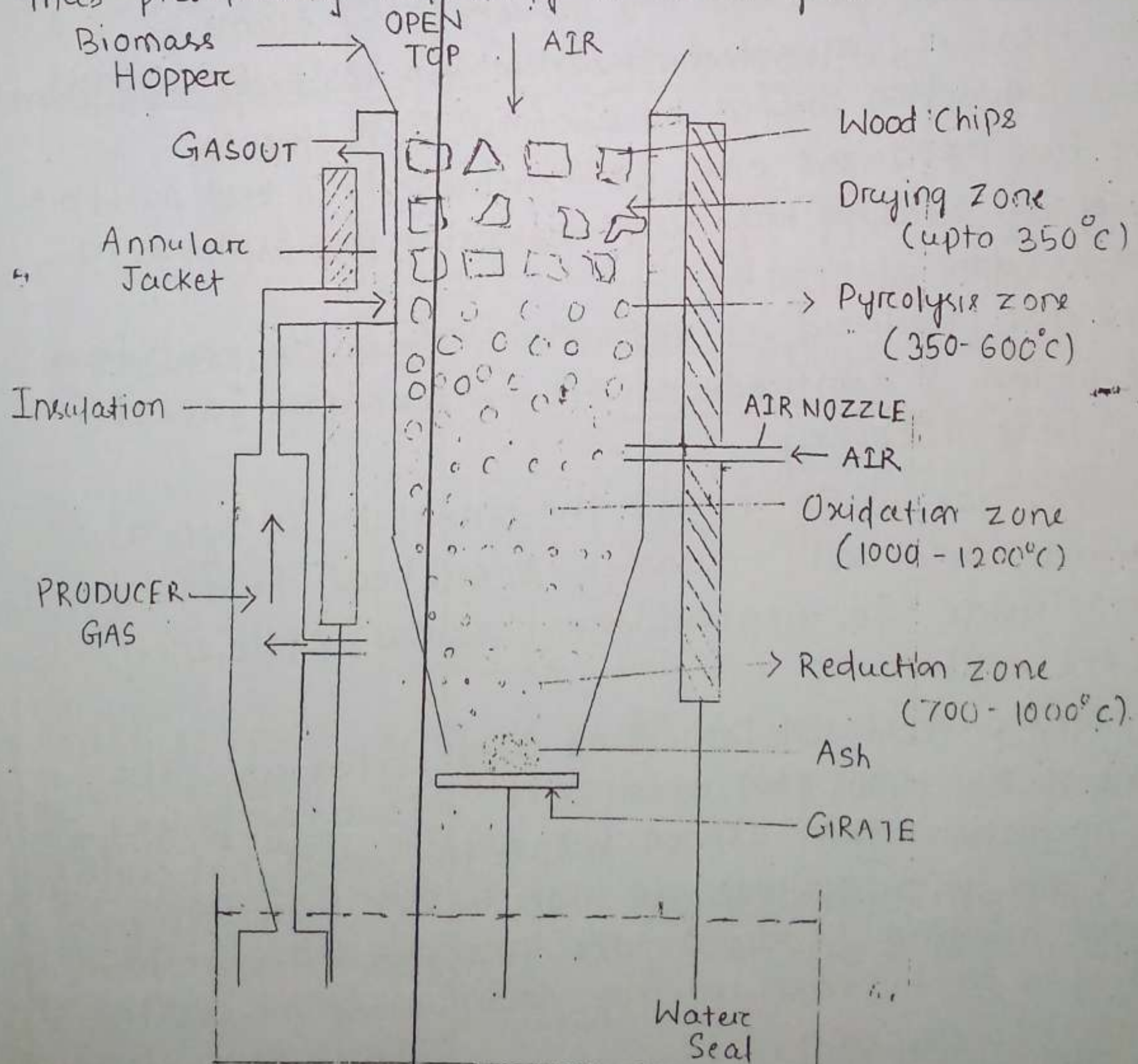
The moisture available in biomass is converted to steam & generally no extra moisture is required.

Gasifiers are classifeed into 2 types.
1) Fixed-bed gasifier
2) Fluidised - bed gasifier.

Fixed-bed gasifiers are further classified as
a) Down-draft
b) Up-Draft
c) Cross-Draft. (type depending upon the direction of airflow)

(a) Down-draft type:

This type is best suited for a variety of biomass. Its design forces the raw products to pass through a high temp. zone, so that most of unburnt pyrolysis product can be cracked into gaseous hydrocarbons, thus producing relatively a clean gas.



In steady state operation, heat from the combustion zone near the air nozzle is transferred upwards by radiation, conduction and convection causing wood chips to pyrolyse and loose 70-80% of their weight. These pyrolysed gases burn with air to form C.O, CO_2, H_2, H_2O, there by raising temp. to 1000-1200°c. The product gases from the combustion zone further undergo reduction reaction with char to generate combustible product like CO, H_2, CH_4. When 40-70% of air is drawn through the open top depending upon the pressure drop condition due to size of wood chips & gas flow rate.

→ The open top & air nozzle helps in stabilising the combustion zone by consuming the uncovered char left. It also prevents the movement of flame to the top. Heat is conducted towards top through radiation and conduction helped by airflow from the top.

30.09.10

→ The tar produced can be eliminated in best possible way by creating high temp. oxidising atmosphere in the reactor.

› The gas produced is withdrawn from an exit ~~from~~ at bottom & reintroduced in the annular jacket, for heat recovery.

The hot gas which enters the annular jacket at around 500°c and transfer some heat to wood chip inside. So, improve the thermal efficiency of the system.

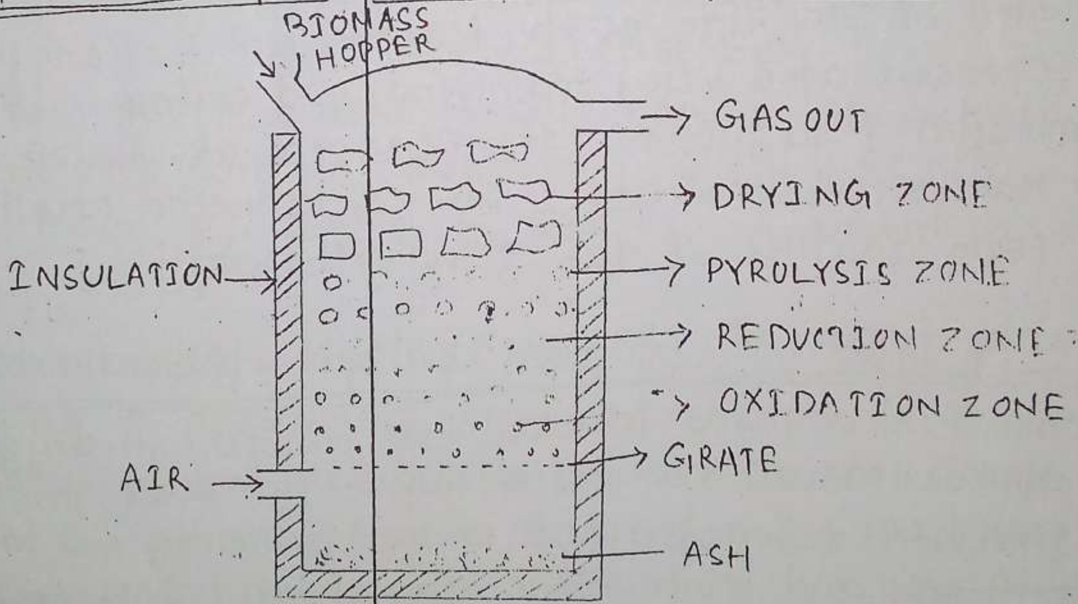
In this process the wood is also dried up. The inner wall temp. goes upto 350°c. after few hours of operation. This aspect helps the use of hot chips with moisture content as higher 25%. This regenerative heating is due to the transfer of heat from hot gas to biomass moving downwards, helps in better tar cracking.

The raw producer gas can be used for thermal application. But to be used in IC engines, further processing is required. Admission of hot gas into the engine decreases the power. So, it has to be cooled.

→ Raw gas also contains various dust (ash, char) particles, moisture & tar. So, the gas has to be cooled & cleaned before using in IC engine. This is done by direct injection of gas in cooling water from a spray tower.

→ A sand-bed filter is used to remove particulated matter by periodic washing of the gas through this sand-bed. This removes large dust from the gas and some part of tar is also deposited in the filter circuit.

(b) Up-Draft type (Counter flow gasifiers):



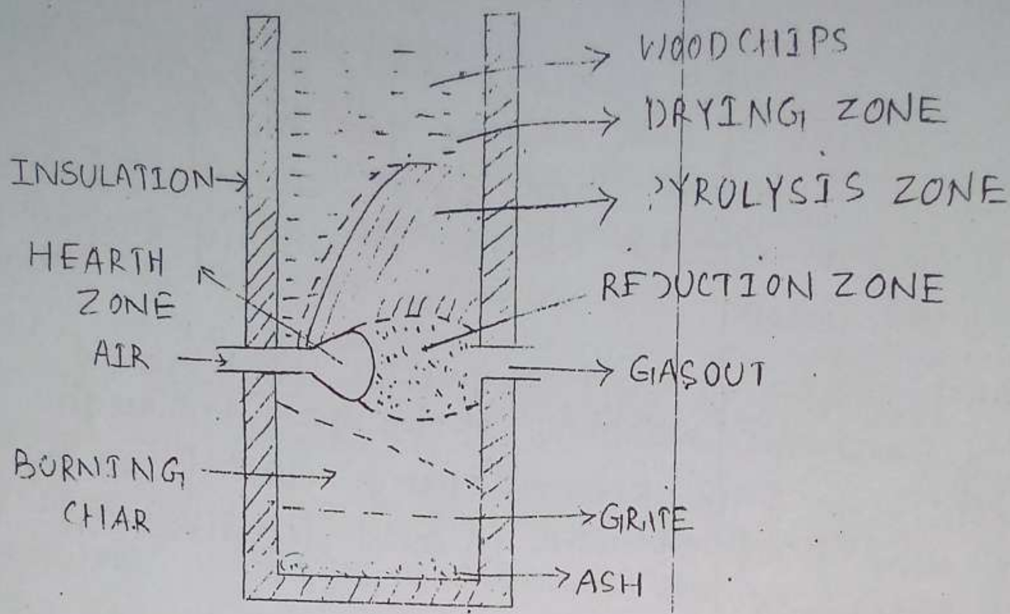
→ It is simplest, easy to built and operate.

→ The air enters below the combustion zone and the gas is drawn off at the top.

→ The updraft gasifier has highest efficiency, as the gas passed through the fuel bed & leave the gasifier at a low temp.

→ The gas produced has practically no ash but contains tar and water vapour because of passing through unburnt fuel.

(C) Cross-Draft Type:



→ Air enters the gasifier through a water cooled nozzle mounted on one side of the firebox.

→ It operates at a very high temp. and confines its combustion & reduction zone near the air nozzle.

→ The high exit temp. of gas & low CO_2 reduction results in poor quality of gas & low efficiency.

Usable form of Biomass & their Applications:

Biomass is organic material that reacts with oxygen in combustion and natural metabolic processes to release heat. Sometimes, it is used in original forms ~~like in wo~~ and more often transformed into modern energy forms such as liquid & gaseous fuels, electricity etc.

1. Wood Stoves:

Wood is the most obvious & oldest source of biomass energy. Direct combustion is the simplest way to obtain heat energy. Specially designed household stoves (chulhas), used wood as fuel and are used for cooking purpose. But, in this process only 5% of heat is utilised. The rest is lossed due to wind, incomplete combustion, radiation losses and other losses such as mis-match of fire and pot size. Considerable energy is also lossed in evaporation from the uncovered pot, and from the use of wet fuels.

→ Smoke, which is a output is the unburnt tar and carbon and creates a health hazard. There is little control over the rate at which wood is burnt.

→ Improved household stoves and use of pressure cooker are making things easy by better fuel consumption.

2. Biogas:

→ Organic waste from plants, animals and humans contain enough energy to contribute significantly to energy supply in many areas.

→ Acquatic biomass is also used.

→ Nitrogen rich sludge (fertilisers) is also produced as a byproduct with improved sanitation.

→ If raw material used is cow manure, the output biogas will contain about 50-60% CH_4, 30-40% CO_2, 5-10% H_2, 0.5-0.7 N_2 with trace amount of O_2 & H_2S.

→ Used in cooking, lighting (using mantle lamps), heating & operating small I.C engines. It is unlikely to be used for mobile vehicle on a large scale due to low pressure and high inert fraction.

3. Bio-diesel: 5.10.10

→ Some vegetable oils edible as well as non-edible can be used (after some chemical processing) in pure form or blended with petroleum

→ Biodiesel is simple to use, biodegradable, non-toxic and free of sulphur and aromatics.

→ Raw vegetable oil is upgraded as biodiesel through a chemical process called trans-esterfication.

→ The process has two products as output,

(i) Methyl (or ethyl) esters :- The chemical name for bio-diesel.

(ii) Glycerin :- a valuable byproduct usually used in soaps and other products.

Biodiesel can be produced from vegetable oils, animal fats or recycled restaurant greases.

→ Jatropha and Karang are most useful bio-diesel resource and are grown on waste lands. The oil extracted from these seeds has high viscosity (20 times that of diesel) which causes serious lubrication, oil contamination and injector chocking problem. This problem is solved by trans-esterification, a process where the raw vegetable oil are treated with alcohols - methanol or ethanol with a catalyst to form methyl or ethyl ester.

→ These monoesters produced by trans-esterifying vegetable oil are called bio-diesel having low fuel viscosity with high octant number and heating value.

→ Biodiesel can be used as an alternative fuel for existing diesel engines without modification.

4) Combustion Engine:

This is an engine in which the combustion of a fuel (normally a fossil fuel) occurs with an oxidiser (usually air) in a combustion chamber.

Ex: Two-stroke, four-stroke piston engines.

The internal combustion (IC) engines are used for mobile application and act as power supply for cars, aircraft and boats.

→ Producer gas can be used as fuel in IC engine (diesel, dual fuel mode engine) for irrigation pumps, motor vehicles and small scale power generations. The commercial diesel engine has to modified to a dual fuel mode engine. Mixture of air with producer gas is used in this process. Limited quantity of diesel is required to initiate the ignation. The engine is started with diesel fuel only and subsiquently the quantity of diesel is reduced as producer gas is mixed with air.

→ 85-87% of diesel replacement can be obtained in this process.

Application:

→ Biomass energy is used in over 90% of rural households and about 15% urban areas.

→ Biodiesel and producer gas are equally important and can be used as fuels to different types of engines and vehicles.

→ Biodiesel is also used in several decentralised energy units like diesel gensets, small scale/home and industries.

→ Transportation sector is an important application area of biomass power. Biomass energy is also used in mechanical agricultural sector like irrigation pumps and agricultural machinery.

HYBRID ENERGY SYSTEM

6.10.10

Need for hybrid energy system:

Stand alone electrical power sources are required at less populated remote areas where demand of power is low. Power distribution lines are not extended to these areas as it becomes highly uneconomical. But the nature of these sources (renewable energy sources) are different from conventional ones. The supply from such sources depend heavily on weather conditions and keeps on fluctuating. So, continuous supply can't be provided over long period of time by using stand alone electrical power sources.

For system reliability rechargable batteries are used for supplying energy during peak load periods. Batteries require periodic charging, for which a separate source of power is required.

Diesel driven alternators provide a reliable continuous source of electrical energy. But it has high running cost, poor fuel efficiency, high transportation cost, high cost of maintenance. All these factors make diesel generation expensive.

So, some efficient systems are designed by combining renewable energy (wind / solar) systems and battery inverter sub-systems into diesel generator sets. This can have a better system efficiency.

The benefits of hybrid systems are:

(i) Improve reliability
(ii) Reduce emission and pollution
(iii) Provide continuous power supply
(iv) Increase operational life

(v) Reduce cost and more efficient use of power.

Case studies :

(1) Diesel - PV system :

Operational concept :

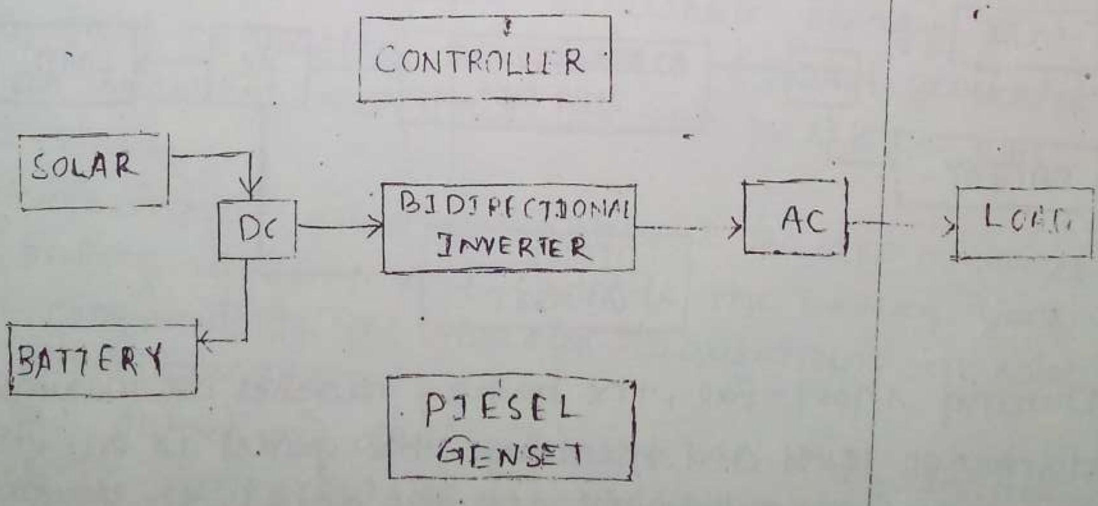
→ The solar will be the 1st choice of supplying load and excess energy produced will be stored in batteries. Diesel gensets will be secondary source of energy.

→ A microprocessor based controller is used to manage the energy supplied and load demands.

→ This hybrid system offers clean and efficient power which is more cost effective than standalone diesel systems.

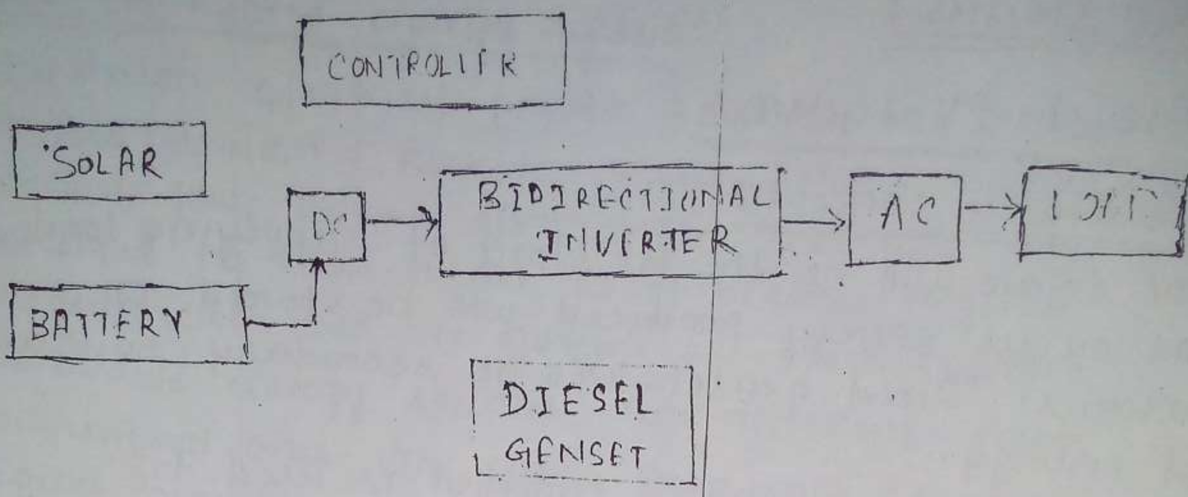
→ The configuration of solar hybrid system is analysed for various photo-voltaic array sizes with respect to a diesel gensets to operate in tandem with the battery system.

(a) System operation during day time :



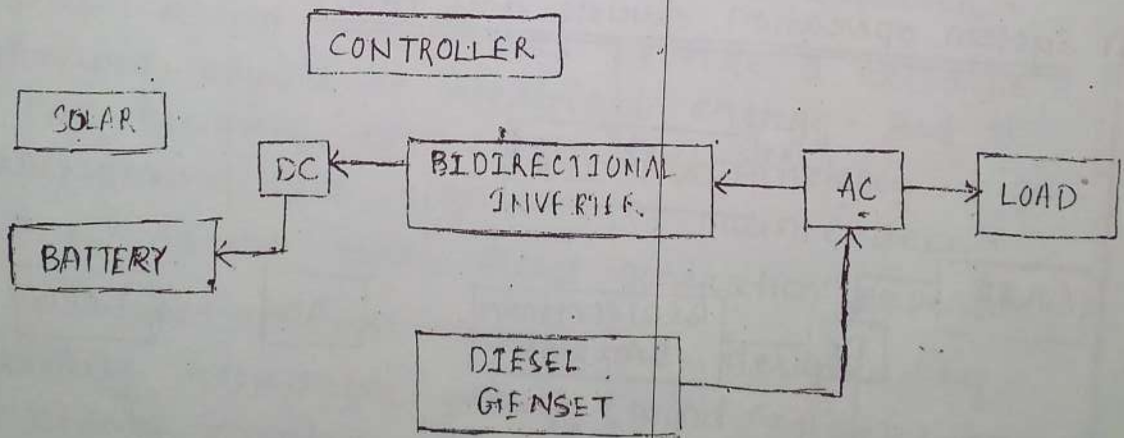
During day time, solar is the 1st choice and only source of energy while the generator is off. The inverter converts dc power from solar pv to ac power for the load. The extra power produced is stored in battery system.

(b) System operation during night time:



During night time, the battery is the only source of energy while the generator & solar pv both are off. The inverter converts dc power from the battery to ac power for the load. The battery will supply the load to its maximum discharge level.

(C) System operation during short fall:



During short-fall, the battery reaches its maximum discharge level and therefore the genset is on. At this time (normally night / cloudy days), the generator serves the load as well as charges the battery. The battery charge rate is adjusted to maintain the generator at full output. The operations which activate or de-activate gensets and charging or discharging battery are managed and done by microprocessor based controller unit. The main objective of solar PV diesel Hybrid system is to reduce the cost of operation and maintenance cost and cost of transport by minimizing diesel run-time and fuel consumption.

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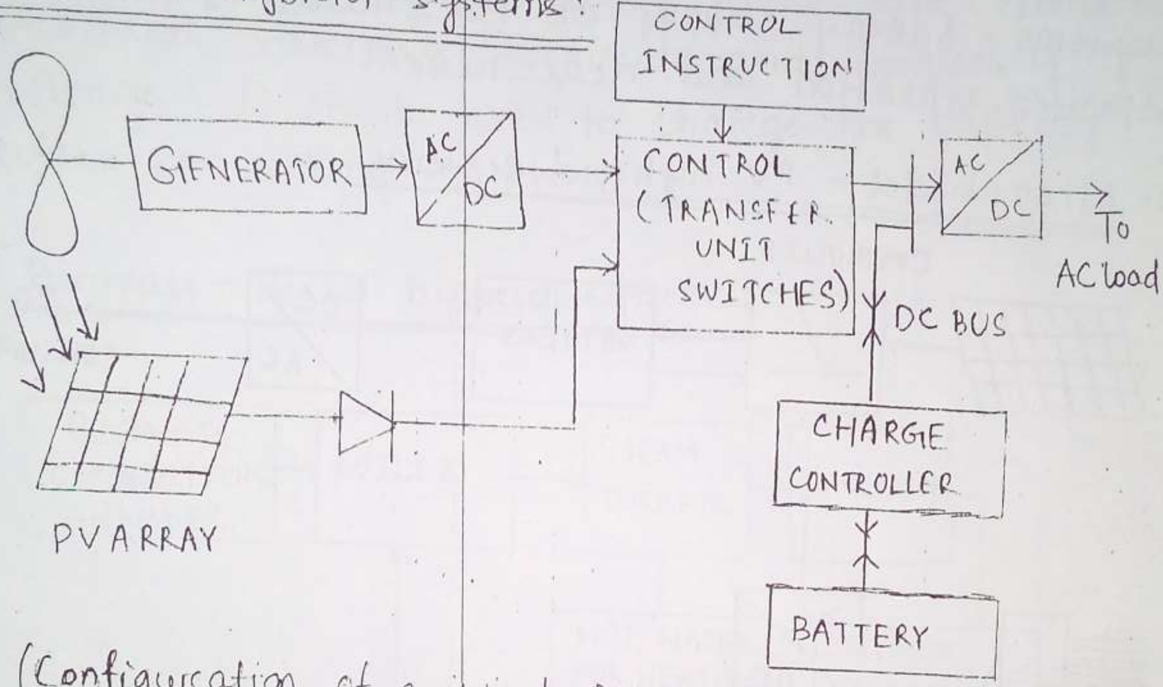
(2) Wind PV hybrid systems:



(Configuration of a wind PV hybrid system)

-> Wind generators & photo voltaic cells are combined to provide year round renewable energy to non-grid connected households. A wind generator is an excellent suppliment to the PV system and vice-versa.

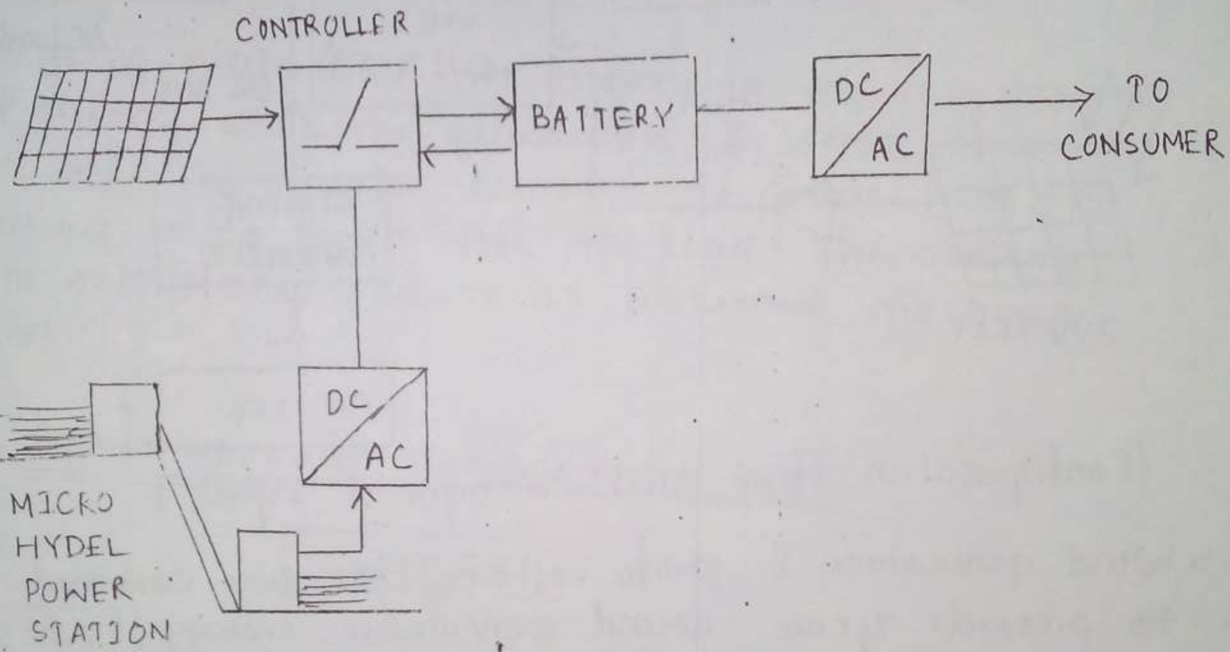
-> Interfacing of wind generators & PV cells minimizes the battery capacity and extends the battery bank life compared to the storage requirement in solar or wind standalone systems.

-> The ac output of wind generator feeds the rectifier which is connected in parallel to the PV array through a controller to a dc bus. The dc bus also serves as a connection point for the battery through a charge controller.

→ The blocking diode protects the pv array from voltage spikes and prevents the flow of current in the reverse direction at low irradiation. (Exposure of an item to radiation).

→ The controller decides the connection of the generating systems / battery supply or its charging, in specific situation and requirement.

(3) Microhydel - PV hybrid systems:



(TYPICAL HYBRID ENERGY SYSTEM CONTAINING SOLAR AND MICRO-HYDEL SOURCES)

→ Microhydel systems - These type of system usually refer to electricity generated by small hydropower. These type of installation produce upto 100kW of power under used to provide power for isolated home or a small community.

→ Microhydel system complement PV solar energy in many area because water flow & thus available hydropower, is highest in the winter when solar energy is at minimum.

→ In this system, there is a small reservoir to store the water. This type of hybrid systems sometimes depends on the geographical conditions where the water at some height is available. System capacity depends upon the water quantity & solar radiation.

→ The power supplied by falling water is the rate at which it delivers energy, and this depends on the flow rate & the waterhead. Hydropower available may be of run-off river type. Hence produces variable amplitude and frequency voltage. It can be used to charge the battery after converting it into dc.

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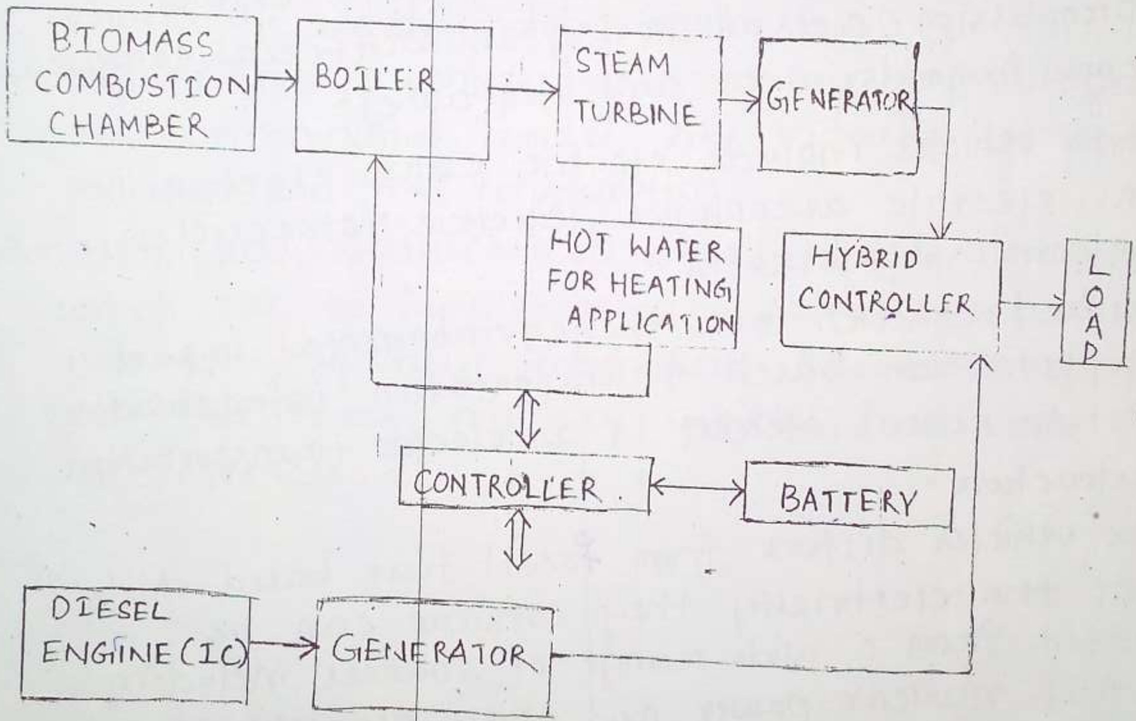
(4) Biomass - diesel hybrid systems:



(BLOCK DIAGRAM OF BIOMASS DIESEL HYBRID SYSTEM)

→ The biomass energy system will be the first choice for supplying load & diesel gensets will be the secondary source of energy.

→ Various type of biomass are dumped into huge hoppers. This is then fed into a furnace where it is burnt. The heat is used to boil water in the boiler and the energy in the steam is used to turn turbines and generators.

→ Diesel energy systems are kept as a back-up source.

→ A hybrid controller is used which maintains the energy balance during the load variation. It assigns the priority among the energy sources (means it allows one source, which has highest priority, to feed the load if that source is capable). It also maintains the synchronizing of voltage signal coming from different sources.

27.10.10

Electric & Hybrid Electric Vehicle:

→ An electric vehicle (EV) also referred as electric drive vehicle uses one or more electric motors for propulsion (act of moving an artificial carrier of people or goods over any distance).

→ Electric vehicles include electric cars, electric trains, electric aeroplanes, electric motorcycles and electric spacecrafts.

→ Increased concern over the environmental impact of the petroleum based transportation infrastructure has let to renew interest in an electric transportation infrastructure.

→ Electric vehicles differs from fossil fuel based vehicle in that the electricity they consume can be generated from a wide range of sources including fossil fuel, nuclear power and other renewable sources.

→ Hybrid vehicles use two or more distinct power sources to move the vehicle.

→ Hybrid electric vehicles (HEV) is a type of hybrid vehicle which combines a conventional internal combustion engine (ICE) propulsion system with an electric propulsion system.

→ The presence of electric powertrain is intended to achieve a better fuel efficiency than a conventional vehicle.

→ Modern HEVs make use of efficiency improving technologies such as regenerative breaking, which converts the vehicle's kinetic energy into battery - restorable electric energy, rather than wasting it as heat energy as conventional brea do.

→ Some HEVs use their IC engine to generate electricity by spinning an electrical generator (This combination is known as motor - generator) to either recharge their batteries or to directly power the electric drive motors.

→ Hybrid electric vehicles have certain advantages as environmental impact like reduction of noise, pollution and fuel consumption.

→ HEVs use NiMH (Nickel metal hydride) batteries which can be fully recycled. Various types of HE' has already been introduced like motor cycles, car, bus, truck, military vehicles & in some aircrafts also.

Peltier Cooling:

Seebeck Effect:

When heat is applied to junction of two dissimilar metals, an emf is generated which can be measured at the other junction.

Peltier effect:

~~A pe~~ It is the inverse of seebeck effect. If voltage is applied at one junction of thermocouple, this causes a temp. difference between the junctions. This results in a small heat-pump also known as thermoelectric cooler (TEC).

Peltier Coolers:

A peltier cooler is a cooler that uses a peltier element (TEC). Peltier coolers consist of the peltier element itself, and a powerful heat sink/fan combination to cool the TEC. Peltier junction is normally used for applications like thermoelectric coolers. The energy input to the peltier junction is made through a solar PV module:

→ Since peltier elements are active heat-pumps, they can be used to cool components below ambient temperature (room temp.) - which is not possible using conventional cooling.

✓

NUMERICALS OF WIND 105

28·10·10

Ex: (1) A horizontal axis wind turbine has a diameter of 5m. When the wind speed unaffected by the wt turbine is 10m/s, the turbine rotates at 300rpm & produce 5 KW. of mechanical power. Find the T.S.R. and power co-efficient ?

Ans: $\rho = 1.225\ Kg/m^3$ at $15°C$ & normal pressure.

$D = 5m$.

$r = 2.5\ m$.

$A = \pi r^2 = 3.14 \times (2.5)^2 = 19.625\ m^2$

$V_\infty = 10 m/s$.

$N = 300 rpm$

$= 300 \times \frac{2\pi}{60} = 31.4\ rad/sec$.

$P_{o/p} = 5 KW.$ = Power output

$P_0 = \frac{1}{2} \rho A V_\infty^3$ = power contained in the wind

$= \frac{1}{2} \times 1.225 \times 19.625 \times (10)^3$

$= 12.02\ KW$.

$C_p = \frac{P_{o/p}}{P_0} = \frac{5}{12.02} = 0.415$

(2) If the turbine of prob-1 is connected to an electrical generator & the variable load, the load is smoothly varied to obtain a maximum power output for the above wind condition. Find the wind speed through the turbine under that condition.

Ans: As per Betz limit, maximum power of a turbine is given by,

$P_{max} = \frac{16}{27} P_0$ when $v = \frac{2V_\infty}{3}$

(12) (15)

$$v = \frac{2 \times 10}{3} = \frac{20}{3} = 6.67 \, m/s.$$

3) A darrieus rotor has the following dimensions, $a = 2.5m$ / $b = 2m$. If it produces 3 KW of mechanical shaft power, $V_\infty = 10 m/s$. Calculate the power co-efficient C_p.

Ans: For darrieus rotor,

$$A = \frac{2DH}{3}$$

where $D = 2a$ — Diameter

$H = 2b$ — Height of Rotor

$$A = \frac{2 \times 2a \times 2b}{3} = \frac{8ab}{3} = \frac{8 \times 2.5 \times 2}{3} = 13.33 \, m^2$$

$\rho = 1.225 \, kg/m^3$ (Given)

$$P_0 = \frac{1}{2} \rho A V_\infty^3$$

$$= \frac{1}{2} \times 1.225 \times 13.33 \times (10)^3$$

$$= 8.16 \, KW.$$

$$C_p = \frac{P_{o/p}}{P_0} = \frac{3}{8.16} = 0.367$$

(4) A two blade HAWT is installed at a location with free wind velocity of 20 m/s. The rotor diameter is 30 m. What rotational speed should be maintained to produce maximum output?

Ans: Given

$V_\infty = 20 \, m/s.$

$\rho = 1.225 \, kg/m^3$

$D = 30m.$, $r = 15m.$

$A = \pi r^2 = 3.14 \times (15)^2 = 706.5\ m^2$

$V_\infty = 20 m/s$.

$\lambda opt = \frac{4\pi}{n} = \frac{4\pi}{2} = 2\pi$

$\lambda = \frac{2\pi RN}{V_\infty} = \frac{\omega R}{V_\infty}$ (where $\omega = 2\pi N$)

Now, $\frac{\omega R}{V_\infty} = 2\pi$

$\Rightarrow \omega = \frac{2\pi V_\infty}{R} = \frac{2 \times 3.14 \times 20}{15} = 8.373$ rps

$\omega = \frac{2\pi N}{60}$

$\Rightarrow N = \frac{\omega \times 60}{2\pi} = \frac{8.373 \times 60}{2 \times 3.14} = 79.996 \approx 80$ rpm

(5) Wind speed is 10m/s at standard atmospheric pressure. Calculate (i) the total power density in wind stream?

(ii) The total power produced by a turbine of 100m diameter with an efficiency of 40%. Air density is 1.226 Kg/m³.

Ans: Given

$V_\infty = 10 m/s$.

$\rho = 1.226\ Kg/m^3$

$P_0 = \frac{1}{2} \rho A V_\infty^3$

(i) Power density $= \frac{P_0}{A} = \frac{1}{2} \rho V_\infty^3$

$= \frac{1}{2} \times 1.226 \times (10)^3 = 613\ W/m^2$

(ii) Total power produced (P) = efficiency × total power contained in wind

$\Rightarrow P = \frac{40}{100} \times \frac{1}{2} \rho A V_\infty^3 = \frac{40}{100} \times \frac{1}{2} \times 1.226 \times 3.14 \times (50)^2 \times (10)^3$

$= 1924.82$ KW.

(6) Design the rotor for a multiblade wind turbine that operates wind turbine 36 kmph to pump water at a rate of 6 m^3/hour with a lift of 6 m. Also calculate the angular velocity of the rotor. Given water density = 1000 kg/m^3. g = 9.8 m/s^2, water pump efficiency = 50%, efficiency of rotor to pump = 80%, $C_p = 0.3$, $\lambda = 1$ & air density = 1.2 kg/m^3.

Ans: Given data:

Water density = 1000 kg/m^3.

$g = 9.8\ m/s^2$

water pump efficiency = 50% = 0.5

efficiency of rotor to pump = 80% = 0.8

$C_p = 0.3$, $\lambda = 1$, air density = 1.2 kg/m^3

Power required to pump water = P.

$$P = 6\,m^3/hr \times 1000\,kg/m^3 \times 9.8\,m/s^2 \times 6\,m$$

$$= \frac{6}{3600}\,m^3/sec \times 1000\,kg/m^3 \times 9.8\,m/s^2 \times 6\,m$$

$$= 98\,kg \cdot m^2/s^3$$

$$= 98\ watts$$

Power required at rotor × efficiency = Power required to pump water

⇒ Power required at rotor $= \frac{98}{0.5 \times 0.8} = 245$ watts

Power contained in wind, P_o

$$P_o = \frac{1}{2} \rho A V_o^3$$

$$= \frac{1}{2} \times 1.2 \times \pi R^2 \times \left(36 \times \frac{1000}{3600}\right)^3$$

$$= 1884.955\,R^2$$

$$C_p = \frac{\text{Power output of the rotor } (P_{out})}{\text{Power contained in wind } (P_0)}$$

$$\Rightarrow P_{out} = C_p \times P_0$$

$$\Rightarrow 245 = 0.3 \times 1884.955 \, R^2$$

$$\Rightarrow R^2 = \frac{245}{0.3 \times 1884.955}$$

$$\Rightarrow \boxed{R = 0.66 \text{ m.}}$$

$$\lambda = \frac{2\pi R N}{V_\infty} = \frac{\omega R}{V_\infty}$$

$$\Rightarrow 1 = \frac{\omega R}{V_\infty} = \frac{\omega \times 0.66}{\left(36 \times \frac{1000}{3600}\right)} = 0.066\omega$$

$$\Rightarrow \omega = \frac{1}{0.066} = 15.1 \text{ rps}$$

$$= \frac{15.1 \times 60}{2\pi}$$

$$= 144.19 \approx 144 \text{ rpm}$$