Module-I

Classification of Energy Resources:..

→ Energy resources can be classified in the following ways

1. **Based on Usability of Energy**

(a) **Primary Resources**

→ These are resources in nature prior to undergoing any human made conversions or transformations
Examples of primary energy resources are coal, crude oil, sunlight, wind, running rivers, uranium etc

→ These resources are generally available in raw forms and are therefore known as raw energy resources

→ These are located, extracted, processed and are converted to a form as required by the consumer

→ The energy yield ratio of an energy extraction process is defined as

$$\text{Energy yield ratio} = \frac{\text{Energy received from raw energy source}}{\text{Energy spent to obtain raw energy source}}$$

(b) **Intermediate Resources**

→ These are obtained from primary energy by one or more steps of transformation and are used as vehicles of energy

(c) **Secondary Resources**

→ The form of energy which is finally supplied to a consumer for utilization is known as secondary or usable energy ie electrical energy, thermal energy (in the form of steam) chemical energy (in the form of hydrogen or fossil fuels) etc

(2)

Based on Traditional use

(a)

Conventional:- Energy resources which are being traditionally used for many decades and were in common use around the oil crisis of 1973 are called conventional energy resources ie fossil fuels, nuclear and hydro resources

(b)

Non-conventional:- Energy which are considered for large-scale use after the oil crisis of 1973 are called non-conventional energy source ie solar, wind, biomass etc

(3)

Based on Long-term Availability

(a) **Non-renewable:-**

→ Resources which are finite and do not get replenished after their consumption are called non-renewable ie Fossil fuels, Uranium etc

(b)

Renewable:-

→ Resources which are renewed by nature again and again and their supply is not affected by the rate of their consumption are called renewable ie solar, wind, biomass, ocean (tidal, hydro etc:

(4) <u>Based on commercial Application</u>

(a) <u>commercial Energy Resource:-</u>

→ The secondary usable energy forms such as electricity, petrol, diesel, gas etc are essential for commercial activities and are categorized as commercial energy resources.

→ The economy of a country depends on its ability to convert natural raw energy into commercial energy.

(b) <u>Non- commercial Energy:-</u>

→ The energy derived from nature and used directly without passing through a commercial outlet is called a non - commercial resource i.e wood, animal dung cake, crop residue etc

(5) <u>Based on origin</u>

(a) Fossil fuels energy
(b) Nuclear energy
(c) Hydro energy
(d) Solar energy
(e) wind energy
(f) Biomass energy
(g) Tidal energy etc

Fossil Fuels as a Source of Energy

→ Fossil fuels are energy-rich substances that have formed from long-buried plants and microorganisims

→ coal, crude oil, natural gas are example of fossil fuels

→ these are undergo combustion producing significant amount of energy per unit weight

→ These are the work main part of our energy Sector because of many advantages

→ **Advantages**

(1) easily combustible and produce high amount of energy

(2) well established and stable extraction storage, distribution and service infrastructure

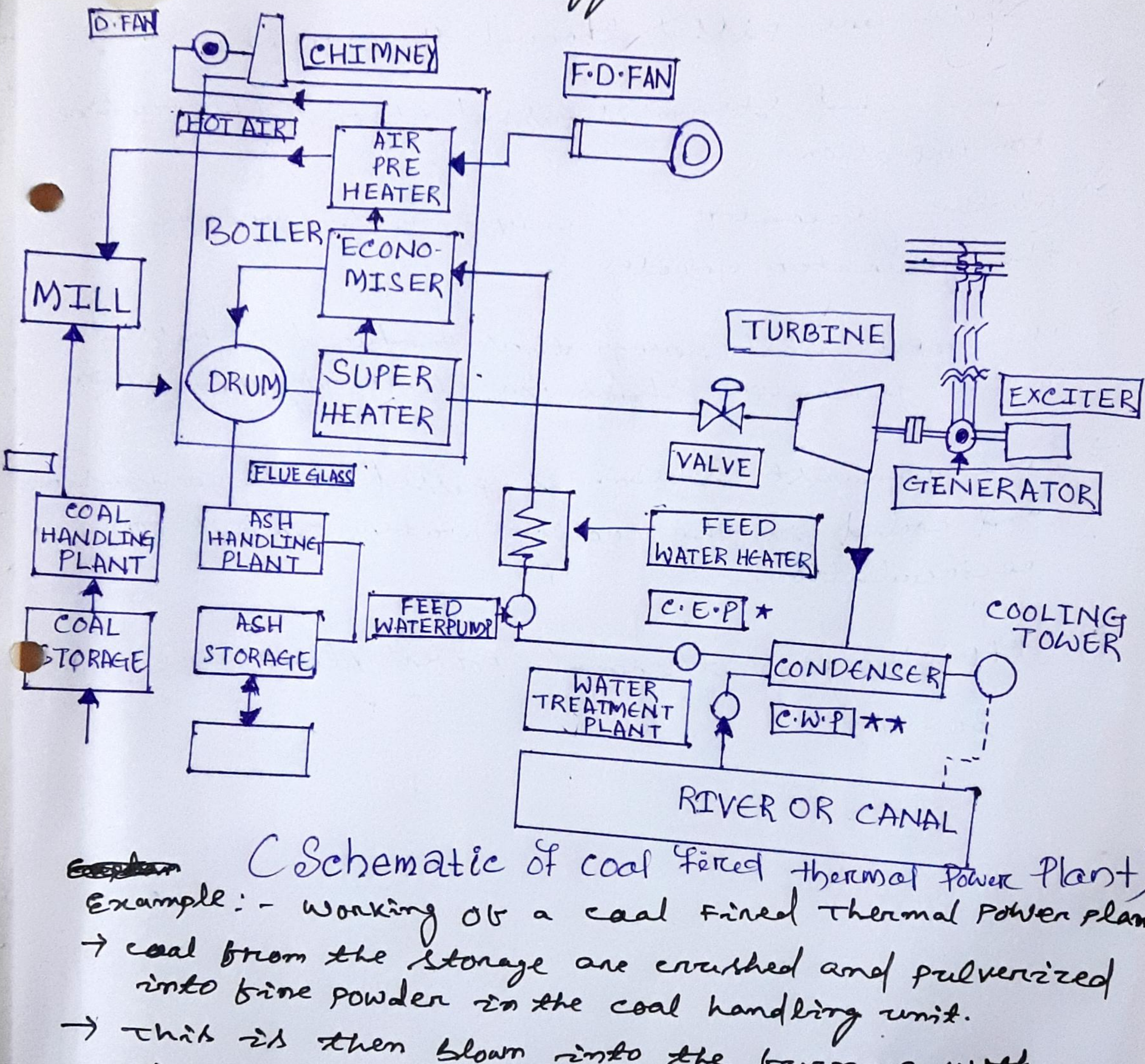
(3) Generation of electricity and various other forms of energy

(4) inexpensive compared to other energy forms

(5) commercial availability

Fossil Fuel Based system :-

→ A Fossil-fuel based system is one that uses fossil fuels such as coal, natural gas or petroleum (oil) to produce electricity or other usable form of energy



(Schematic of coal fired thermal Power Plant)

Example :- Working of a coal fired Thermal Power plant

→ coal from the storage are crushed and pulverized into fine powder in the coal handling unit.

→ This is then blown into the furnace with air where it is burnt with the help of oil guns

→ Ash produced is the disposed by the ash handling unit

→ The flue gases are forced out through the chimney

→ water is pipes on the furnace wall called risers is converted into steam and fed to the boiler drum at high pressure

→ water is also fed to boiler drum through feed water pump through the economiser

→ These are passed through the superheater

→ superheated steam is passed through the turbine for expansion

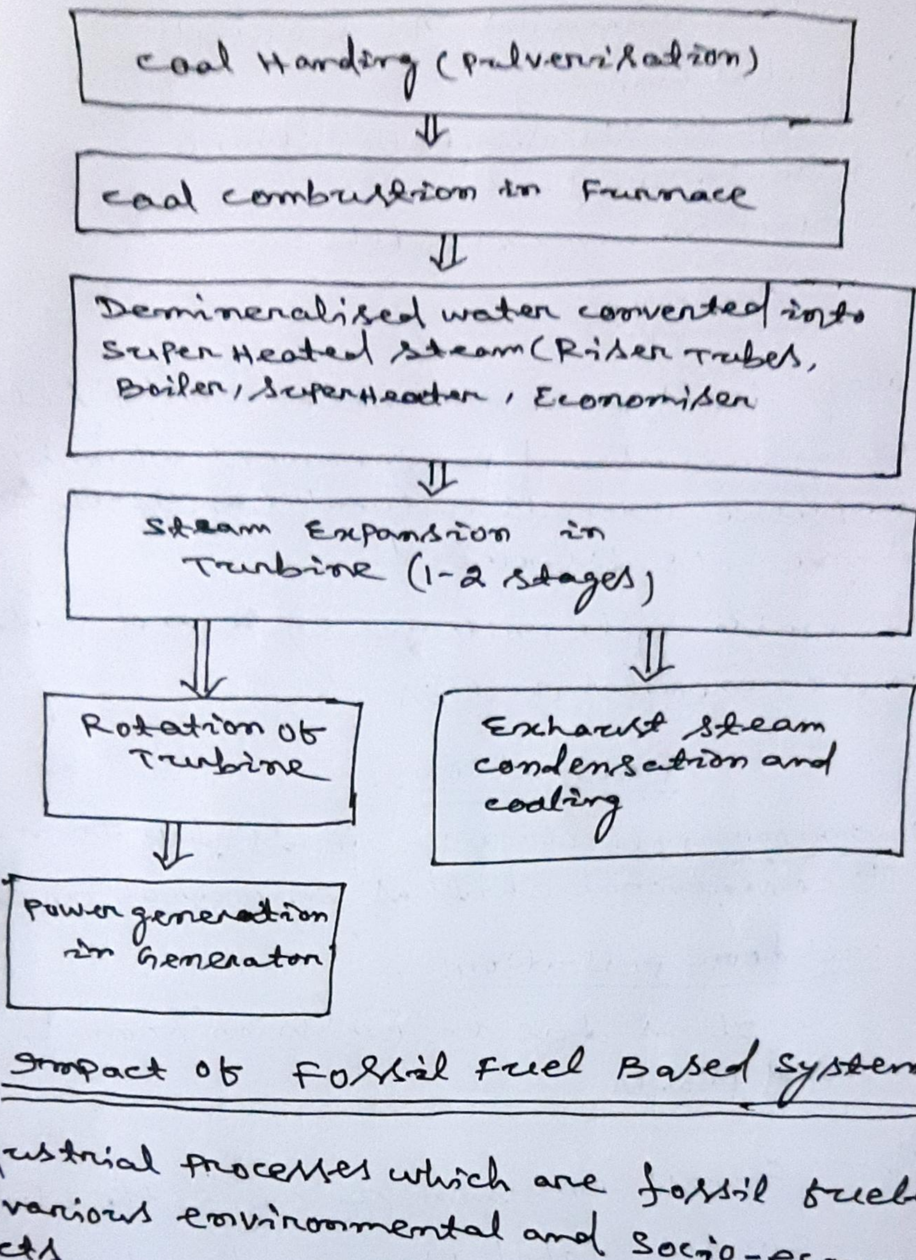
→ As the generator is couple with turbine so the generator rotate

→ the mechanical energy thus produced is passed to the generator shaft for electricity production

→ the exhaust steam is passed to the condensor and cooled in the cooling water circuit for recirculation.

→ Efficiency of thermal power plant are 30-40%.

simplified process flow of the thermal power plant



Impact of Fossil Fuel Based System

→ Industrial processes which are fossil fueled have various environmental and socio-economic impacts

Green House Effect :-

→ carbon dioxide, nitrous oxide, methane, chloro floro carbon (CFC). A green house is an enclousure having transparent glass plates or sheets

→ Due to increase emission from fossil fuel based system the green house gases in the atmosphere increases. As a result

→ Global warming
→ change in the rain fall pattern
→ Rise in sea level
→ Impact on human health

Ecology:-

→ Ecology deals with the relationship between living organisms and environment. when human interference exceeds natural limits the ecological balance gets disturbed.

→ The water cycle, nitrogen cycle and carbon cycle are the examples of this

Pollution:-

1 → Indoor pollution:- It is due to mainly use of conventional chulhas in rural areas

2 → outdoor pollution:-

It is due to emission from fossil fuel based plants

CO_2:- Excess emission of CO_2 in the atmosphere causes global warming due to green house effect

CO:- It is formed due to incomplete burning of coal inadequate air.

It mainly affects the oxygen dependent tissues in the body

SO_x: combustion of fuel containing sulphur causes asthma, acid rains, corrosion of metals

NO_x: Oxides of nitrogen such as N_2O, NO, NO_2, N_2O_3 are commonly referred as NO_x

Environmental impacts

(i) Emissions: -

→ Fossil fuels must be burned to release energy for utilization

→ Fossil fuels being rich in carbon concentration release CO_2

→ CO is also released from boilers and furnaces by incomplete (incoming) combustion of carbon

→ combustion in air comprising 78% nitrogen by volume produces nitrogen oxides NO, NO_2, N_2O collectively known as NO_x

→ Any sulfur content of fuel result in SO_x emissions

(ii)

Effects

→ The increase in the CO_2 concentration in the atmosphere makes it warmer and leading to global warming effect

→ These are resulting in the drastic change in atmosphere condition

→ Pollution endangers our health resulting premature death

→ Air pollutants such as NO_x and SO_x can travel long distances, chemically react in the atmosphere to produce secondary pollutants such as acid rain or ozone

Socio - Economic Impacts

→ Fossil fuel drive our life styles and a nations economy

→ Energy infrastructure building need to be fast enough to keep pace with economic and social changes

→ Increased competition for limited fossil resources is pushing the prices up

Importance of Non-conventional Energy Sources

→ concern for the environment due to ever-increasing use of fossil fuels and rapid depletion of natural resources have led to development of alternative and environment friendly

→ the following points may be mentioned in this connection

1. The demand of energy is increasing by leaps and bound due to rapid industrialization and population growth and hence the conventional source of energy will not be sufficient to meet the growing demand
2. conventional sources (except hydro) are non-renewable and are bound to finish up oneday
3. conventional sources (fossil fuels, nuclear) also cause pollution, thereby their use degrades the environment
4. Large hydro resources affect wildlife, cause deforestation and cause various social problem

Due to these reasons it has become important to explore and develop non-conventional energy resources to reduce too much dependence on conventional resources

Salient features of Non-conventional Energy sources:

merits:-

→ 1. Non-conventional sources are available in nature free of cost

2. They produce no or very little pollution

3. They are inexhaustible (incapable of being used up)

Demerits

→ 1. In general, the energy available in dilute form from these sources

2. Though available freely in nature, the cost of harnessing (extract) energy from non-conventional sources is generally high

3. Availability is uncertain, the energy flow depends on various natural phenomena beyond human control

4. Difficulty in transporting such forms of energy

Non conventional Energy - Seasonal variations and Availability :-

→ Non-conventional technologies are presently under the development stage. At present their share is very small

(i) Solar Energy

→ Solar energy can be major source of power and can be utilized by using thermal and photovoltaic conversion systems.

→ The solar radiation received on the surface of the earth on a bright sunny day at noon is approximately 1KW/m2

→ The earth continously intercepts solar power of 178 billion mw, which is about 10,000 times the world demand

→ But so far it could not be developed on a large scale

→ According to one estimate if all the building of the world are covered with solar photovoltaic PV panels, it can fulfill electrical power requirements of the world

→ Solar PV power is considered an expensive of power

→ At present the capital cost of a solar PV system is 200.00 per watt (20 crore/mw as against Rs 4 crore/mw for coal-fired thermal plant, (1 crore = 10 million)

(ii) Wind Energy

→ The power available in the winds blowing over the earth surface is estimated to be 1.6×10^7 MW, which is more than the present energy requirement of the world.

→ Wind power has emerged as the most economical of all renewable energy sources

→ The installation cost of wind power is Rs 4 crore/MW (which is comparable to that of conventional thermal plants)

→ There has been remarkable growth of wind power installation in the world.

→ Wind-power generation is the fastest growing energy source

→ Wind-power installations worldwide have crossed 94,100 MW (at the end of 2007) which is about 1% of the world electrical power generation capacity

→ Germany is the world leader in wind power with an installed capacity of 22,247 MW

(iii) Biomass Energy

→ Energy resources available from animal and vegetation are called biomass energy resources

→ This is an important resource for developing countries, especially in rural areas

→ The biomass resources are

1. Tree (wood and forest industry waste)
2. cultivated plants grown for energy
3. Urban waste (municipal and industrial waste)
4. Rural waste (Agricultural and animal wastes, crop residue etc)

→ Solar energy absorbed by plants (through the Photosynthesis process) is estimated to be 2×10^{21} J/year

→ Biomass material may be transformed by chemical or biological processes to produce intermediate bio-fuels such as biogas (methane) producer gas, ethanol and charcoal

→ At present there are millions of biogas plants in the world and most of them are in china

(iv) Geothermal Energy:-

→ Geothermal energy is derived from huge amount of stored thermal energy in the interior of the earth, through its economic recovery on the surface of the earth is not feasible every where

→ its overall contribution in total energy requirement is negligible

→ At the end of 2005 the world's total ~~installe~~ installed electrical power-generating capacity from geothermal resources was about 8932 MW

→ The oldest geothermal power generation is located at Lardarello in italy and presently producing 460 MW of power

(V) Ocean Tidal Energy

→ Tidal energy is a form of hydro power that converts energy of ocean tides into electricity or other useful forms of power

→ It is in the developing stage and although not yet widely used, tidal power has potential for future electricity generation

→ Tides are more predictable than wind energy and solar power

→ There are at present only a few operational tidal power plants

→ The first and the biggest a 240MW tidal power plant was built in 1966 in France at the La Rance river

→ Many sites have been indentified in USA, Argentina, Europe, India and China for development of tidal power

(Vi) Ocean wave Energy

→ Wave power refers to the energy of ocean surface waves and the capture of that energy to do useful work.

→ Good wave power locations about 50KW/m of shoreline

→ As per an estimate the potential for shoreline-based wave power generation is about 50,000MW

→ The world's first 2250MW commercial wave form is based in portugal

(viii)

Ocean Thermal Energy conversion (OTEC)

→ OTEC Technology is still in its infant stages

→ conceptual designs of small OTEC plants have been finalized

→ Their commercial prospects are quite uncertain

→ The potential is likely to be more than that of tidal or wave energy

Features of Renewable or Non-conventional Energy source :-

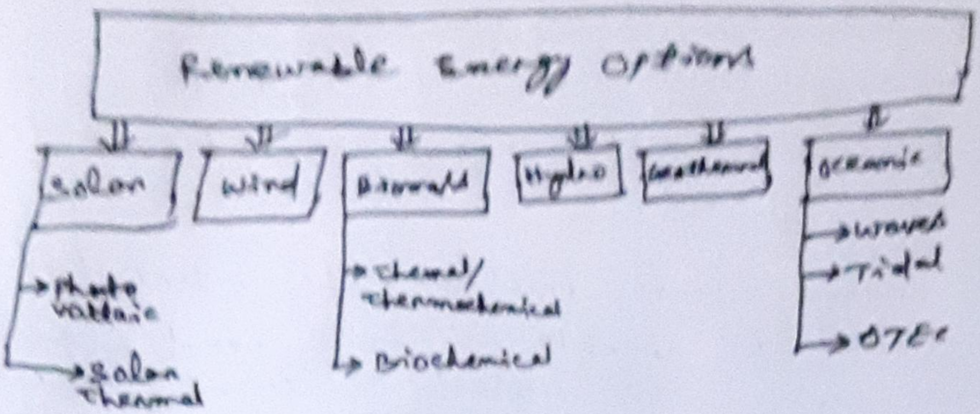
→ Renewable Energy sources are the need of the present global scenario of energy and environmental crisis

→ The technological and economical aspects of harnessing these energy sources have needed

features

→ (1) Large inexhaustible source
(2) clean source of energy
(3) Availability varies w.r.to time, geographic location
(4) Need for storage
(5) can be developed into modular units
(6) Technology is not yet fully matured
(7) capital cost is more

→ The various renewable energy options available are mentioned below most of the renewable energy sources have their origin is Sun.



Hybrid Energy systems

→ Hybrid systems may be used to harness or exploit and upgrade available renewable resources which are presently unutilised or under utilised in rural Areas

→ In addition to developing various Hybrid Systems biomass gasification based cogeneration systems are proposed for peak load demands

→ The required biomass will be obtained from high yielding and high density plantation.

→ In decentralised system the power from micro-hydel system (small hydro and bio-mass system) is preferably fed to the village for meeting their requirements of power for domestic and street lighting, irrigation

→ Small hydro can be developed to the available resources to meet rural energy requirements

→ The peak load carries a special significance in utility generation industry.

→ Higher the peak load, greater will be capacity of power generation.

→ If the total load of the system is taken by a single power plant. This induces higher initial investment, low efficiency of generation and higher generating cost

→ To overcome above problems the micro-hydel system is proposed to operate as base load plant and biomass gasification based electrical generation system as peak load plant.

→ The first combined system (300KW micro-hydel and 200KW biomass gasification based co-generation is coming up at Kakroi (Haryana)

→ the integrated system also meets the entire energy requirement

Distributed Generation :-

→ Distributed generation covers a local energy source to generate power for distribution to consumer in a particular area.

→ Distributed generation complements central power by

(1) providing a relatively low capital cost
(2) Avoiding T & D capacity
(3) Having the flexibility to put power back into the grid at user sites

Distributed generation also referred as cogeneration
cogeneration of heat and electricity can be deal with two ways

* Topping cycle
* Bottoming cycle

→ In the topping cycle mode, fuel is burn to generate electric power and the discharged heat from the turbine is supplied as process heat

→ In bottoming cycle fuel is consumed to produce process heat and waste is then utilized to generate power

The efficiency of a cogeneration plant is given by

$$\eta_{co} = \frac{E + \Delta H_S}{Q_A}$$

where E = Electric energy generated
ΔH_S = Heat energy utilized from process steam (hot water)
QA = Heat added to plant

For separate generator of electricity and process steam, the heat added per unit of total energy output is

$$\frac{e}{\eta_e} + \frac{1-e}{\eta_b}$$

where e = electrical fraction of total energy output

$$e = \frac{E}{E + \Delta H_S}$$

η_e = efficiency of electric plant
η_b = " " process steam generator plant

The overall efficiency of separate generator of electricity and process heat is given by

$$\eta_{so} = \frac{1}{\left(\frac{e}{\eta_e}\right) + \frac{(1-e)}{\eta_b}}$$

→ cogeneration is economical only if the efficiency of the cogeneration plant exceeds that of the overall efficiency of separate generating plants for electricity and heat.

Dispersed Generation

→ Dispersed generation refers to the use of generating units of less than 25kW output to serve individual homes, business and defence installation in remote areas

→ Diesel generators, solar PV installations, mini hydro plants, fuel cells and small wind generators come under this category.

→ Dispersed power and distributed generation is cleaner. Greener power and energy that

* Ends: power problems, electric grid problem and black-out
* Increases: profits through decreased energy expenses
* Improves: Air quality through significantly reduced emissions
* Conserves: Natural resources
* Reduces: Dependance on foreign oil

Benefits of Distributed Generation

→(i) provides the right energy solution at the right location

(ii) provides the power quality needed in many industrial applications dependent upon sensitive electronic instrumentation and controls

(iii) Reduces green house gas emissions

(iv) Avoids unnecessary capital expenditure by closely matching capacity increases to growth in demand.

[illegible]

Solar photovoltaic systems :-

Solar photovoltaic cell concept :-

→ The sun radiates energy uniformly in all directions in the form of electromagnetic waves. The sun provides the energy needed to sustain life in our solar system

→ Solar energy can be utilized directly in ~~two~~ ways

(i) By collecting the radiant heat and using it in thermal system

(ii) By collecting and converting it directly to electrical energy using a photovoltaic system

→ Solar photovoltaic is a semiconductor device which converts ~~[illegible]~~ sunlight directly into electricity. Therefore a solar PV panel or a solar PV module when exposed to sunlight generates voltage and current at its output terminal

→ This voltage and current can be used for our electricity requirements

*→ The amount of electricity a solar PV module can generate depends on the amount of sunlight available ~~to~~ it. The higher the intensity of the sun light, ~~the~~ more the electricity generated from it. When no sunlight ~~the electricity~~ falls on a solar PV module, no electricity is generated

→ The amount of electricity generated from a PV module also depends on the size of the module. The larger the size of the module higher will be the amount of electricity generated from it.

→ The electricity that is generated from a PV module is DC in nature

→ The conversion of D.C power to A.C power can be achieved using a device called inverter (or DC to AC converter). It is also possible to convert AC power into D.C power using a rectifier

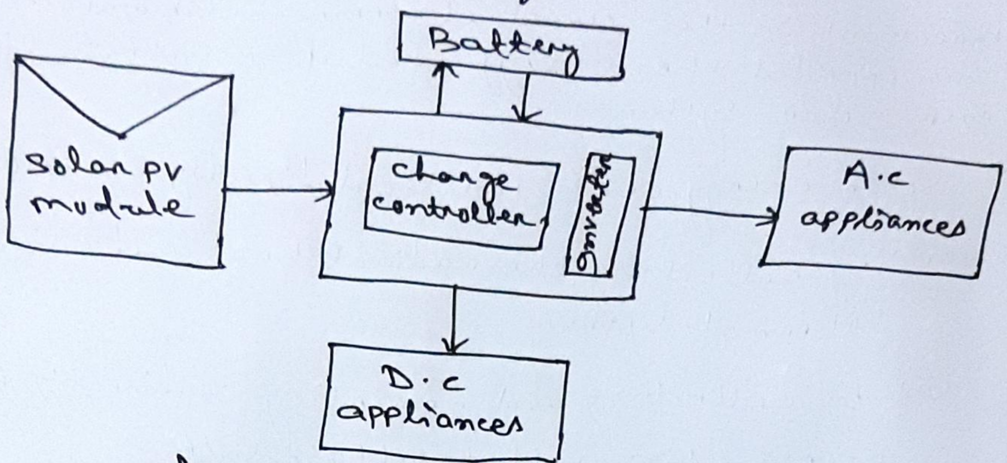


fig [Block diagram of a PV system]

Application

* Space sattelights
* Remote radio-communication booster stations
* marine warning lights
* Solar powered vehicles
* Battery charging

Solar PV Application

(i) Battery charging
(ii) Water pumping
(iii) Lighting
(iv) Thermoelectric cooling or peltier cooling

(i) **Solar Battery charging system:-**

→ The solar Battery charging system is a complete PV power generation, processing, storage and conversion system in a convenient compact package. The kit consists of a main system case, a large storage case with wheels and a 12V DC storage battery case. The power suitcase with external connectors can be operated in dusty and adverse environments

(ii) **Water pumping:-**

→ In solar water pumping system, the pump is driven by motor run by solar electricity. A Solar Photovoltaic (SPV) water pumping system consists of a photovoltaic array mounted on a stand and a motor pump set compatible with the photovoltaic array. It converts the solar energy into electricity, which is used for running the motor pump set.

Three types of motors have generally been used

→ permanent magnet have generally been used i.e permanent magnet dc motor (in low capacity pumping system)

→ Brushless dc motors

→ variable voltage and variable frequency a.c motors

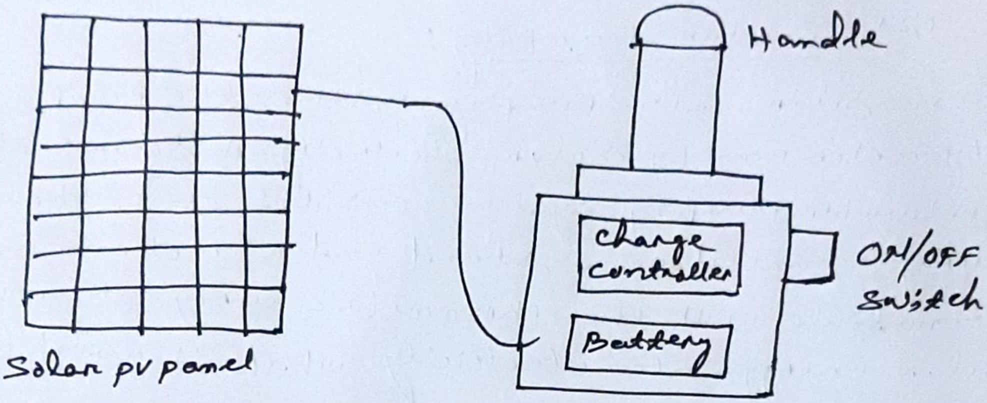
The pumping system draws water from the open well, bore well, stream, pond, canal etc

In Punjab 500 solar pumps has been installed for agricultural use. Under this project 1800 watt PV array was coupled with a 2 HP D.C motor pump set. The system is capable of delivering about 140,000 litres water every day from a depth of about 6-7 meters. This quantity of water is considered adequate for irrigating about 5-8 acres land holding for most of the crops

(iii) Lighting:-

→ As lighting is required when the sun is not available battery storage is essential

→ A solar PV patern is an example of a very simple PV based system that is used for lighting during darkness. It replaces the need of a kerosene based system



A solar PV lantern comprises of a small PV panel, a rechargable battery, a charge controller and a CFL

The purpose of providing charge controller is to protect the battery from over charging and discharging

(iv) Peltier cooling:-

Thermo electric commercial TEC consists of a number of P and n type semiconductor couples connected electrically in series and thermally in parallel. These couples are sandwiched between two thermally conductive and electrically insulated substrates

The heat pumping direction can be altered by altering the polarity of changing D.C current

The typical materials used for constructing TEC are

(1) Substrate: Aluminium oxide (Al_2O_3), Aluminium nitride (AlN), Barium oxide (BaO)

(2) conductor: copper

(3) Thermo electric semiconductor

(i) n-type: Bismuth-telluride-~~antimony~~ selenium (Bi Te Se) compound

(ii) P type: Bismuth-telluride-antimony (Bi Te Sb) compound

(4) Assembled and joined by solder

TEC can be used in different application where cooling or temperature control of an object is required.

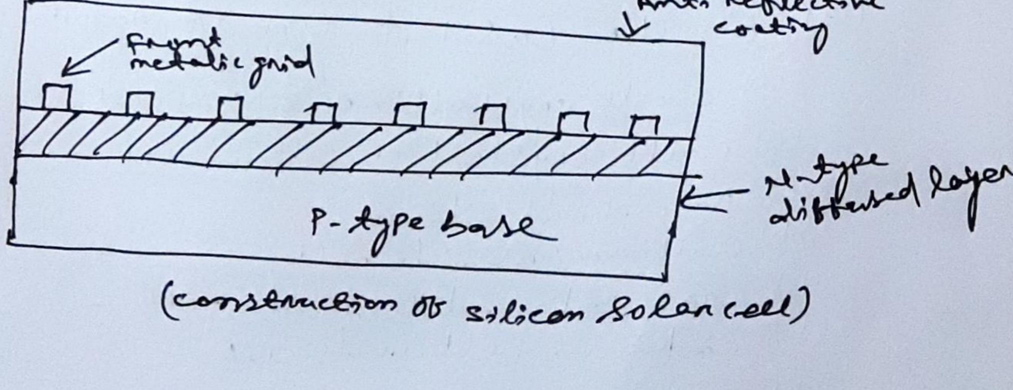
Solar cell

→ Solar cells are made of semiconductor material mainly silicon

→ A solar cell must have a junction between two different semiconductors

→ In case of Si solar cell, the junction is made between p-type silicon and n-type silicon

→ When light falls on this p-n junction, a voltage across p-n junction is generated



(construction of silicon solar cell)

→ The function of metallic grid is to collect the current produced by the photons. Anti reflecting coating gives to capture maximum photons and direct them towards the junction.

→ For Silicon p-n junction, the voltage generated is about 0.5 to 0.6 volts. This generated voltage is then capable of supplying current in the circuit, which can be used for any electrical application.

→ The voltage across a solar cell is generated as long as light is falling on it. As soon as there is no sunlight voltage generated across the solar cell is zero. Thus under sunlight, a solar acts like a charged battery

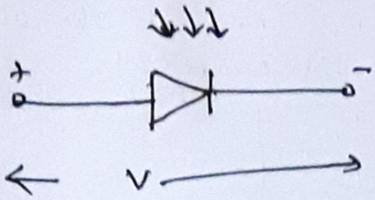
Solar cell classification:-

(1) On the basis of thickness of Active material
   (a) Bulk-material cell
   (b) Thin-film cell

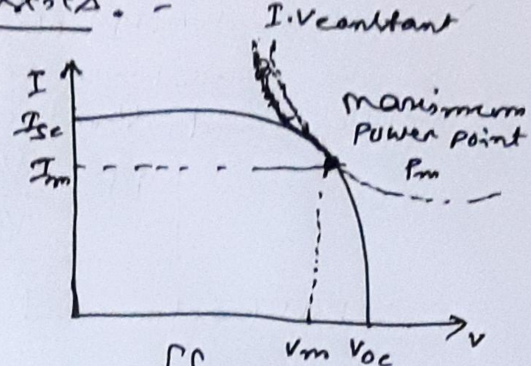
(2) On the basis of junction structure
   (a) pn homo junction cell
   (b) pn hetero junction cell
   (c) pn multi junction cell
   (d) metal semiconductor junction
   (e) ~~p.~~

(3) On the basis of type of Active material
   (a) single crystalline silicon cell
   (b) multi crystalline silicon cell
   (c) Amorphous silicon
   (d) Gallium arsenide cell
   (e) Copper indium diselenide cell
   (f) cadmium telluride cell
   (g) organic PV cell

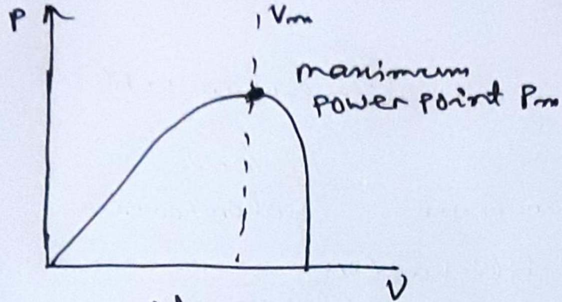
Solar cell characteristics :-



[fig (a)]



[fig-b]



(fig-c)

→ fig-(a) schematic symbol of a photo voltaic cell
fig-(b) V-I characteristics, maximum power point figure
fig-(c) P-V characteristic

mathematically the V-I characteristics of a solar cell may be written as

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

where I_0 = Reverse saturation current
V_T = voltage equivalent at room temp (20°) is 26mV

$V_T = \frac{KT}{q}$ where K is Boltzman constant, T is temperature in °K and q is charge of an electron

I_{sc} = Short circuit current

Open circuit voltage is given by

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

→ Fill factor (FF) of a cell is defined as the ratio of the peak power to the product of open circuit voltage and short circuit current

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

Fill factor indicates the quality of a cell

→ conversion efficiency, η of a solar cell is given by

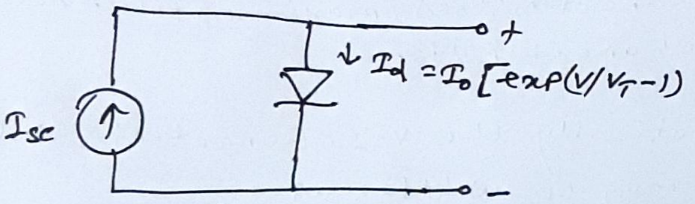
$$\eta = \frac{V_m I_m}{\text{Solar power}} = \frac{FF\, V_{oc} I_{sc}}{\text{Solar power}}$$

where FF is fill factor

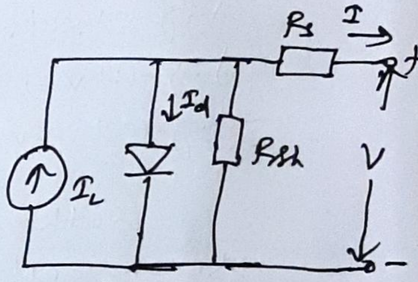
V_{oc} = open circuit voltage

I_{sc} = short circuit current

<u>Equivalent circuit</u>



(fig-a)



[fig-b]

[Equivalent circuit of solar cell (a) ideal (b) practical]

For a practical cell, the characteristic is modified as

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

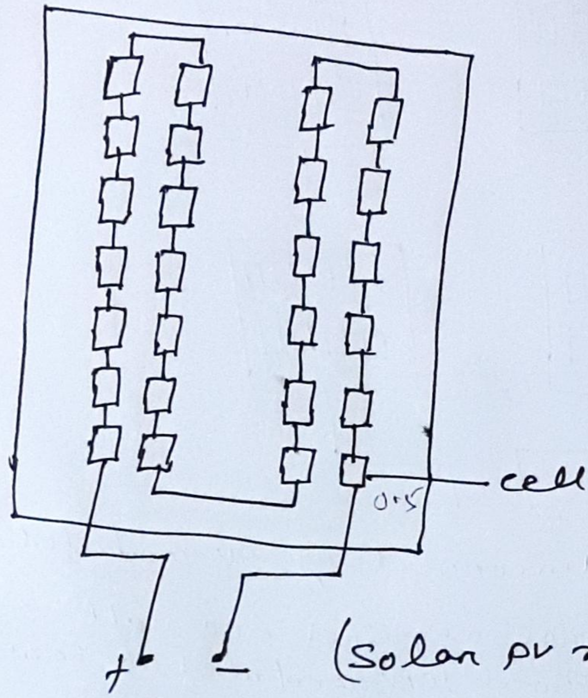
where I_L = light generated current

IR_s = internal voltage drop

R_{sh} = shunt resistance

Solar PV module:-

→ For generation more power many solar cells are connected together to make a solar PV module. Usually there are 36 solar cells connected in series and laminated together to make solar PV module of 12 volt which is required to charge a battery



(Solar PV module)

$0.5 \times 24 = 12V$

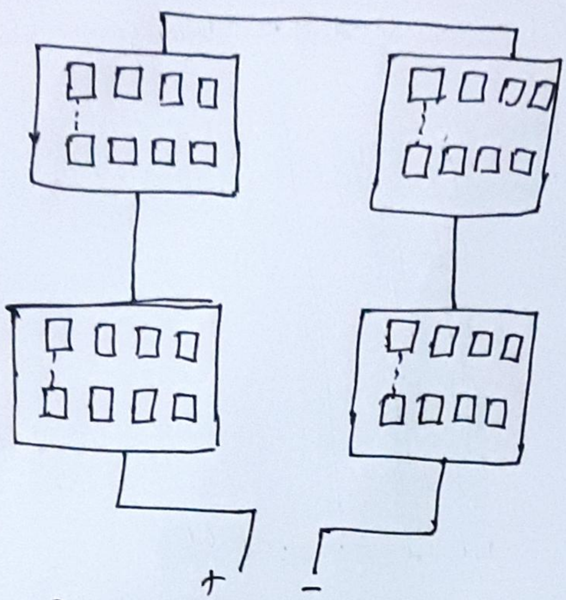
Typically a silicon solar PV module of one square feet given peak output power of 10 to 12 watt

Solar PV modules are available in market in the size of 3W, 5W, 10W, 20W, 40W, 60W, 75W, 120W

Solar PV Array

→ In most of the cases the power generated by a single PV module is not enough

→ Therefore one needs to connect more PV modules in series and parallel to get large power



By interconnecting PV modules we get a PV array

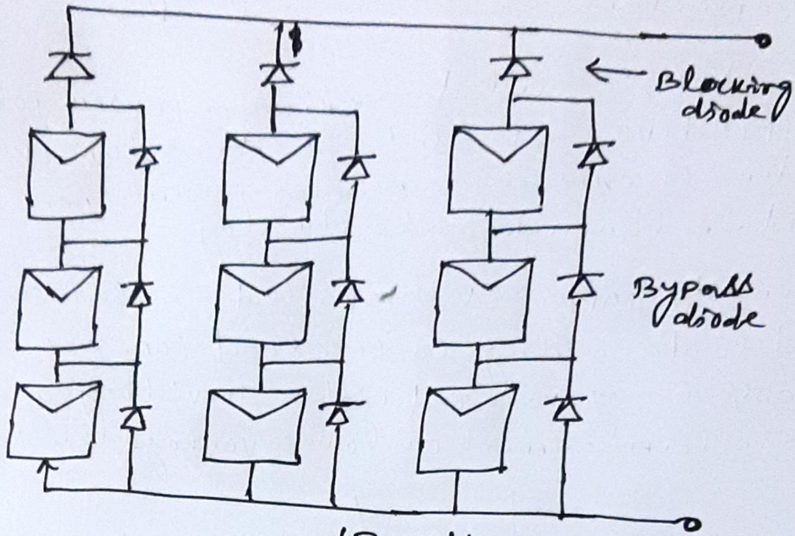
→ If a house requires 600 watt of power it will have to use about 10 PV modules of 60 watt each

Solar panel (OR) Series and parallel connections of solar PV modules :-

→ Solar pannel is a group of several modules connected in a series - parallel combination in a frame that can be mounted on a structure to increase the voltage/current rating.

→ When modules are connected in series, it is desirable to have each module's maximum power production occur at the same current.

→ When modules are connected in parallel, it is desirable to have each module's maximum power production occur at the same voltage.



(Panel)

→ 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 strings will not be absorbed by the failed string.

→ Also bypass diodes are installed across each module, so that if one module should fail, the output of the remaining modules in a string will bypass the failed module

Maximum power point Tracking:-

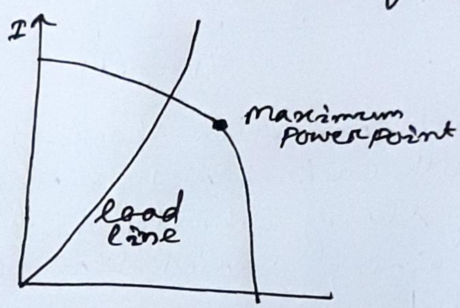
To make best use of the solar PV system the output is maximized in two ways

→ The first is mechanically tracking the sun and always orienting the panel in such a direction as to receive maximum solar radiation under changing positions of the sun

→ The second is electrically tracking the operating point by manipulating the load to maximize the power output under changing conditions of temperature

→ A device called maximum power point tracking (MPPT) device is used in solar PV system in order to extract maximum power from solar PV module through out the day

→ Generally MPPT is installed in between PV system and load. coupling to the load for maximum power transfer may required either providing a higher voltage at a lower current or lower voltage for higher current



[PV system – load characteristics]

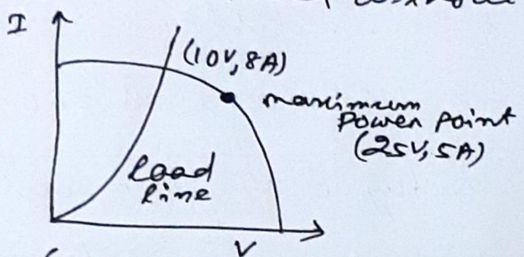
With the help of this device about 20 to 30% more energy can be generated

problem

A PV source having VI characteristics as shown in figure 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 and 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 cost of electricity may be assumed as Rs 3.00 per kWh. Assume the efficiency of the MPPT is 95%.

Ans

Power produced without MPPT = 10×8 = 80 watt



(PV system - load characteristics)

maximum power production capability of the PV module
= 25×5 = 125 watt

As the efficiency of the MPPT is 95%.

Actual power produced with MPPT
= 125×0.95 = 118.75W

surplus power produced by use of MPPT = 118.75 - 80 = 38.75W

Surplus energy produce in t hours

$$= \frac{38.75 \times t}{1000} \text{ kWh}$$

$$\text{cost of surplus energy} = \frac{3 \times 38.75 \times t}{1000} \text{ kWh}$$

cost of MPPT = 4000

Time (in hours) required to recover the cost of

$$\text{MPPT} = \frac{4000 \times 1000}{3 \times 38.75} = 34408.6 \text{ hours}$$

Solar processes and spectral composition of solar Radiation :-

→ Solar radiation incident on the outer atmosphere of the earth is known as extra terrestrial radiation I_{ext}.

→ The solar constant I_{sc} is defined as the energy received from the sun per unit time, on a unit area of surface perpendicular to the direction of propagation of the radiation at the top of the atmosphere and at the earth's mean distance from the sun

$$I_{ext} = I_{sc}\left[1.0 + 0.033\cos(360n/365)\right] \; W/m^2$$

where n is day of the year counted from 1st January

Beam Radiation or Direct Radiation :-

Solar radiation propagating in a straight line and received at the earth surface without change of direction.

Diffused Radiation :-

Solar radiation scattered by dust and molecules is known as diffused radiation.

Global Radiation :-

The sum of beam and diffused radiation is referred as total or Global radiations

Measurements of solar radiation :-

Solar radiation data are measured by

(a) Pyranometer :- A pyranometer is designed to measure global radiation.

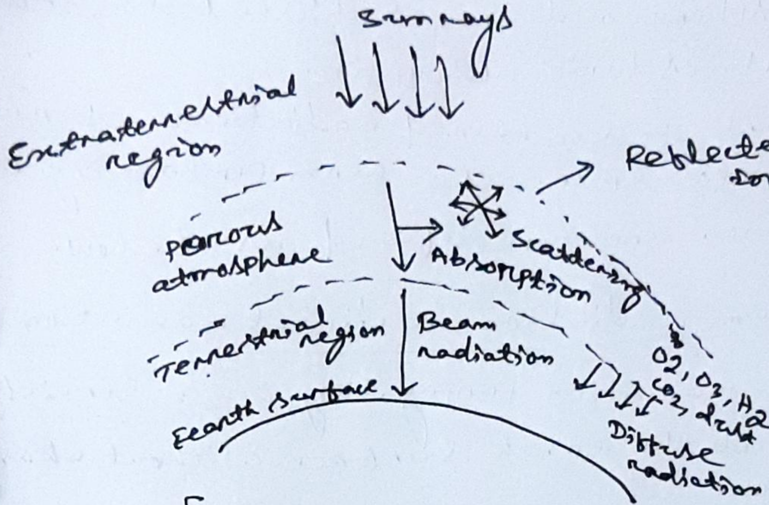
(b) pyrheliometer:-

An instrument that measures beam radiation is called pyrheliometer

(c) Sunshine recorder:-

It measures the sunshine hours in a day

Extraterrestrial and Terrestrial Solar radiations:-



[Solar radiation atmospheric mechanisms]

Extraterrestrial radiation:-

Solar radiation incident on the atmosphere of the earth is known as extra terrestrial radiation I_{ext}

Solar constant:-

→ The solar constant, I_{sc} is defined as the energy received from the sun per unit time on a unit area of surface perpendicular to the direction of propagation of the radiation at the top of the atmosphere and the earth's mean distance from the sun

$$I_{ext} = I_{sc}[1.0 + 0.033 \cos(360n/365)] \ W/m^2$$

Where n is day of the year counted from 1st January

Terrestrial solar radiation:-

→ The solar radiation that reaches the earth surface after passing through the earth's atmosphere is known as Terrestrial solar radiation

→ Solar radiations pass through the earth's atmosphere and are subjected to scattering and atmospheric absorption.

→ A part of scattered radiations is reflected back into space. The term pertaining to solar radiation are now defined as below:

Beam radiation or direct radiation (I_b):-

Solar radiation propagating in a straight line and received at the earth surface without change of direction.

Diffused radiation (I_d):

solar radiation scattered by dust and molecule is known as diffused radiation.

Total radiation (I_T):-

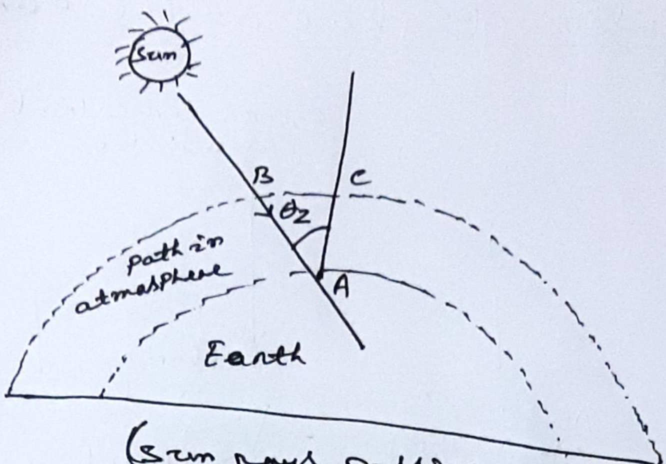
The sum of beam and diffuse radiations ($I_b + I_d$) is referred to as Total radiation. When measured at a location on the earth's surface it is called solar insolation at the place. When measured on a horizontal surface it is called global radiation (I_g).

Sun at zenith:-

It is the position of the sun directly overhead

Air mass:-

It is the ratio of the path length of beam radiation through the atmosphere to the path length if the sun were at zenith



(Sun rays passing through atmosphere)

$$\text{Air mass, } AM = \frac{AB}{AC} = \sec\theta_z$$

where θ_z is zenith angle

At sea level AM = 1, when the sun is at zenith or directly overhead.

AM = 2, when the angle subtended by zenith and line of sight of the sun is 60°.

AM = 0 just above the earth's atmosphere

During winter, the sun is low and hence air mass is higher and vice versa during summer

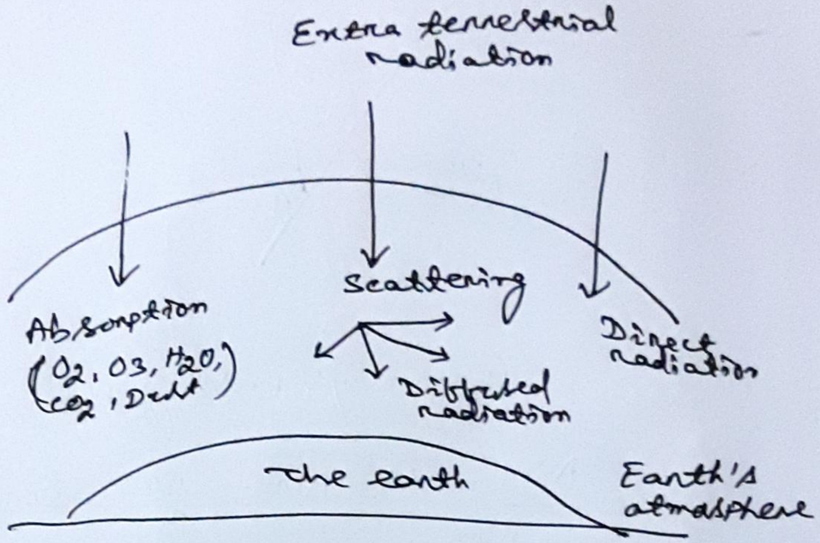
Irradiance (W/m2):

The rate of incident energy per unit area of a surface is termed irradiance.

Albedo:-

The earth reflects back nearly 30% of the total solar radiant energy to the space by reflection from clouds, by scattering and by reflection at the earth's surface. This is called the albedo of the earth's atmosphere system

Radiation of Flux at the earth's surface:-



→ The sun rays outside the earth atmosphere travel parallel to each other. when the solar radiation passes through earth's atmosphere, it undergoes several interactions (absorption and scattering) with the gaseous molecules and other particles in the atmosphere.

→ In the absorption, the energy of the solar radiation is given to the gaseous molecules and other particles in the atmosphere. This is a loss of radiation, due to scattering interaction, the direction of sun rays changes. This results in redistribution of scattered radiation randomly in all directions.

The scattered radiation is called diffuse radiation.

→ These radiation which does not go through either absorption or scattering interaction reaches the earth's surface directly and is known as direct radiations or beam radiation.

→ Thus the total radiation reaching the earth surface should be the sum of diffuse radiation and direct radiation. The sum is known as Global radiation.

→ Thus the total radiation reaching the earth surface should be the sum of diffuse radiation and direct radiation.

→ On a normal sunny day the diffuse radiation is about 15 to 20 percent of that of direct solar radiation. During cloudy days, the percentage of diffuse radiation increases with respect to direct radiation.

Solar collectors :-

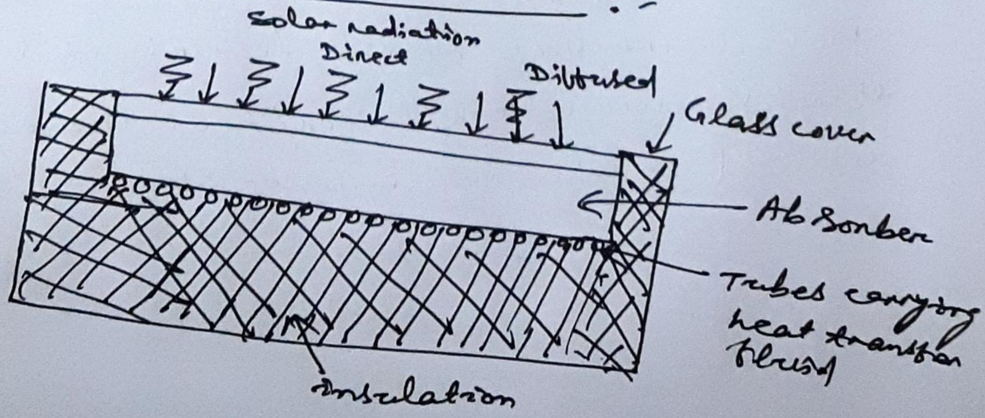
→ It absorbs solar energy as heat and then transfers it to the heat transport fluid efficiently. The heat transport fluid delivers this heat to a thermal storage tank/boiler/heat exchanger to be utilized in the subsequent stages of the system.

Classification of Solar collectors

Solar collectors

- 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 collector
    - Point Focus (TWO axis tracking)
      - (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

(i) Liquid flat plate collector :-

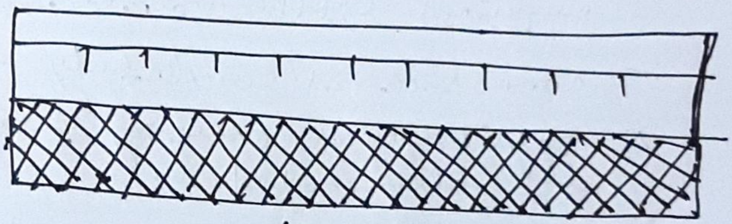


→ The liquid flat plate collector consists of

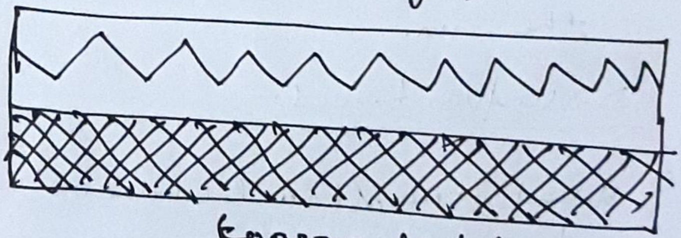
* Transparent cover (one or two sheets) of glass or plastic
* Blackened absorber plate usually of copper allumininum or steel
* Tubes, channels or passages in thermal contact with the absorber plate
* weather tight, insulated container to enclose the above components

(ii) <u>Flat plate air heating collector</u>

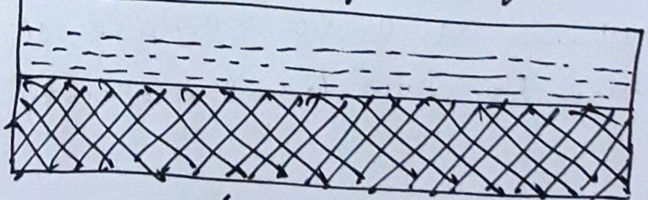
(Solar Air heater, Solar air collector)



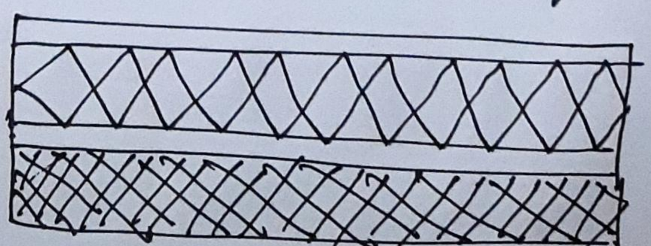
(fin type)



(corrugated type)



(metal matrix type)



(thermal-trap type)

→ A solar air heating collector is similar to a liquid flat plate collector with a change in the configuration of the absorber and tube

→ The variation of shapes of the absorber plate are fin type, corrugated type, metal matrix type and thermal trap type

The application of these collectors are drying for agricultural and industrial purposes and space heating.

Advantages :-

* It is compact, simple in construction and requires little maintenance

* corrosion is completely eliminated

* possibility of freezing of working fluid is also eleminated

* They do not require orientation towards the sun.

Disadvantages :-

* Heat transfer between the absorber plate and air is poor.

* There is less storage of thermal energy due to low heat capacity.

Problem-1

calculate the angle made by beam radiation with the normal to a flat collector on December 1. at 9.00 AM. solar time for a location at 28° 35' N. The collector is tilted at an angle of latitude plus 10°, with the horizontal and is pointing due South.

Ans

Since collector is pointing due South $\gamma = 0$

$$\cos\theta_i = \cos(\phi - \beta) \cdot \cos\delta \cdot \cos w + \sin\delta \cdot \sin(\phi - \beta)$$

$n = 335$ (no of days starting from 1st Jan to 1st December)

$\phi = 28.35'$

$\beta = (\phi + \text{tilt})$
$= 28.35 + 10$
$= 38.35$

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

$$= 23.45 \sin\left[\frac{360}{365}(284 + 335)\right]$$

$$= -22.11$$

Hour angle w corresponding to 9.00 hours $= 45°$

$(9^{00} - 12.00) \times 15° = (-3) \times 15° = 3 \times 15 = 45$

Hence

$$\cos\theta_i = \cos(28.58° - 38.58°)\cos(-22.11)\cos 45° + \sin(-22.11)\sin(28.58 - 38.58) = 0.7104$$

$$\Rightarrow \theta_i = \cos^{-1}(0.7104) = 44.72$$

Problem-2

For a parabolic collector of length 2m, the angle of acceptance is 15°. Find the concentration ratio of the collector

Ans

concentration ratio, $CR = \frac{1}{\sin\phi_{max}}$

where $\phi_{max} = \frac{\text{acceptance angle}}{2} = \frac{15}{2} = 7.5$

So $CR = \frac{1}{\sin 7.5} = 7.66$

Module - II

Wind Energy

Wind Energy conversion system (WECS) :-

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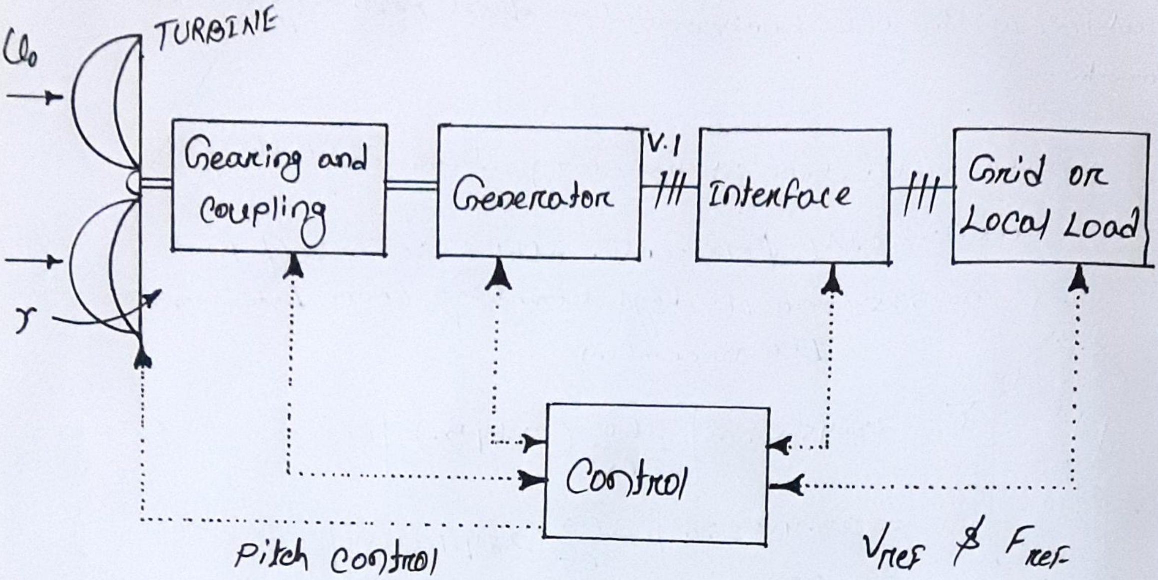
B.H. Khan
fig-7.23



→ A wind-energy conversion system converts wind energy into some form of electrical energy

→ In particular medium and large scale WECs are designed to operate in parallel with a public or local ac grid, feeding only to a local load is known as autonomous

→ A general block diagram of a grid-connected WECs is shown in fig-1

→ The turbine shaft speed is stepped up with the help of gears, with a fixed gear ratio to the electrical generator and fine-tuning of speed is incorporated by pitch control.

→ This block acts as a drive for the generator

→ DC, synchronous or induction generators are used for mechanical to electrical power conversion depending on the design of the system.

→ The interface conditions the generated power to grid-quality power

→ It may consists of a power electronic converter, transformer and filter etc.

→ The control unit monitors and controls the interaction among various blocks

→ It derives the reference voltage and frequency signals from the grid and receives wind speed, wind direction, wind turbine speed signals etc processes them and accordingly controls various blocks for optimal energy balance

→ The main features of various type generators

(i) DC Generators:-

→ Conventional d.c generators are not favoured due to their high cost, weight and maintenance problems of the commutator.

→ However permanent-magnet (brushless and commutator-less) d.c machines are considered in small-rating (below hundred kW) isolated systems

(ii) Synchronous Generator:-

→ Synchronous generators produce high-quality output and are universally used for power generation in conventional plants.

→ However they have rigid requirement of maintaining constant shaft speed and any deviation from synchronous value immediately reflects in the generated frequency

→ Also precise rotor speed control is required for synchronization, due to this reason synchronous machine is not well suited to wind power generation.

→ Requirement of d.c current to excite rotor field, which needs sliding carbon brushes on the slip ring.

(iii)

Induction Generator :-

→ The primary advantages of an induction machine are the rugged (hard), brushless construction, no need of separate d.c field power and tolerance of slight variation of shaft speed ±10% as these variations are absorbed in the slip.

→ Compared to d.c and synchronous machines, they have low capital cost, low maintenance and better transient performance

→ For these reasons induction generators are extensively used in wind and micro-hydroelectric plants.

→ The machine is available from very low to several megawatt ratings

→ The induction machine requires ac excitation current which is mainly reactive.

→ In case of grid connected system, the excitation current is drawn from the grid. The network must be capable of supplying this reactive power. The voltage and frequency are determined by the grid.

→ In a stand alone system, the induction generator is self excited by shunt capacitors

→ Based on one generator drive two schemes have been developed for the operation of wind energy conversion system

(i) Fixed speed drive schemes
(ii) variable speed drive schemes

Fixed speed drive schemes

→ In this scheme, constant speed is maintained at one shaft of a generator by pitch control

→ Two types of fixed speed drive schemes are possible

(a) one fixed speed drive
(b) Two fixed speed drive

(a) one fixed speed drive

→ The shaft speed is held fixed for the whole range of wind speed.

→ The major disadvantages of the fixed speed drive is that it never captures the wind energy at the peak value of the power coefficient cp.

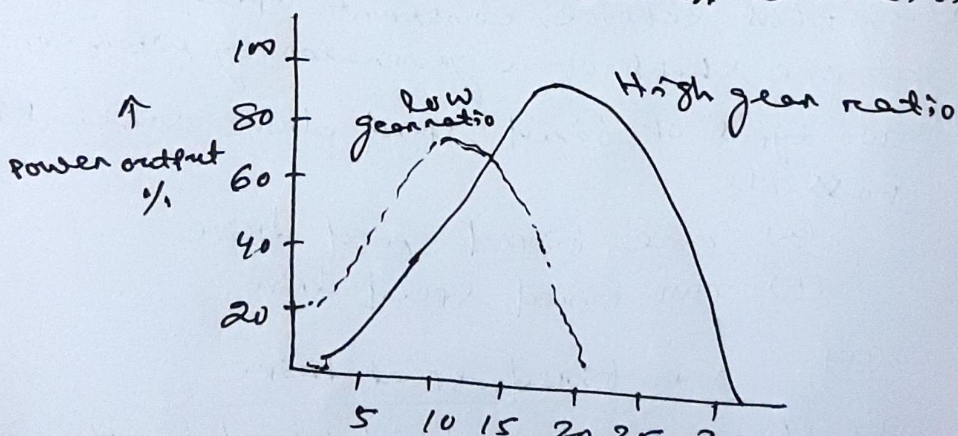
→ Wind energy is wasted when wind speed is higher or lower than the optimal value, corresponding to C_{Pmax}. Because of the low annual energy yield, the use of on fixed speed drive is limited to small machines

(b) Two fixed speeds drive:-

→ Two fixed speed drive increases the energy capture, reduces the electrical losses and reduces the gear noise.

→ The speed setting is changed by changing the gear ratio.

→ The two operating speeds are selected to optimize the annual energy production with expected annual wind-speed distribution at the site



[Power output ~ wind speed for two fixed-speed drives]

→ The power production from a typical WECS using two fixed speed drive is shown in figure.

→ In this particular example, the gear ratio is changed at a wind speed of 10m/s

→ The induction generator is designed to operate at two speed. This is achieved by either

* having two stator windings with different number of poles or
* Using single winding with pole changing arrangement by connecting the winding coils in series and parallel

Variable speed drive schemes :-

→ In this scheme, rotor speed is allowed to vary optimally with wind speed to capture maximum power

→ Three types of variable speed drive schemes are possible

(a) variable speed drive using power Electronics
(b) Scherbius variable speed drive
(c) variable speed direct drive

(ii) Variable speed drive schemes :-

Extra

→ In this scheme, rotor speed is allowed to vary optimally with the wind speed to capture maximum power.

→ As a result it can capture about one third more power per year as compared to a fixed speed drive system. The following types of variable speed-drive systems are possible

(a) Variable speed-drive using power Electronics :

→ modern variable speed-drive schemes make use of power-electronic converters for power conditioning.

→ the variable voltage and variable frequency output available from a generator (synchronous or self-excited induction generator) is first rectified to dc and then converted to fixed frequency and fixed voltage using an inverter.

→ The harmonics are filtered out to get grid quality output before connecting the grid.

→ the rectifier, inverter, filter and transformer constitute the main parts of the interface.

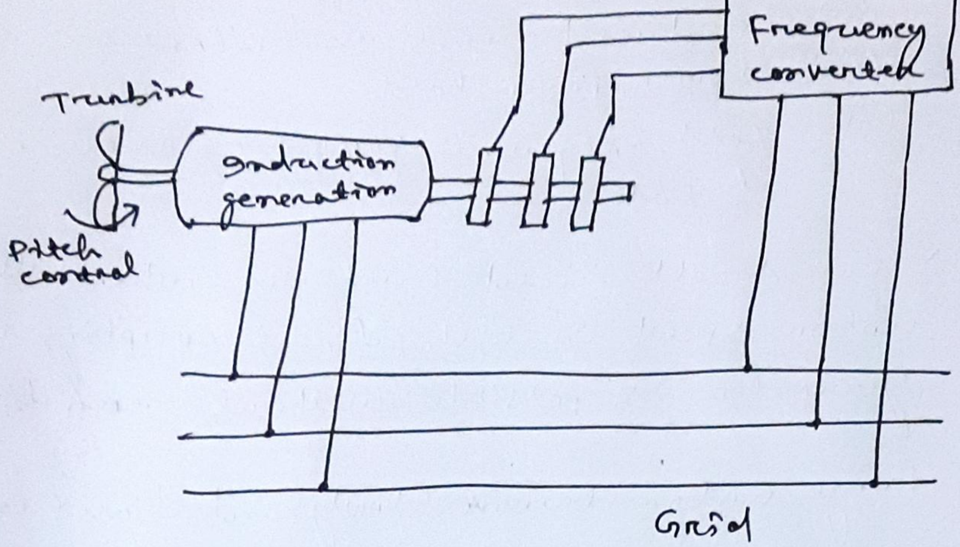
→ Apart from higher energy yield use of power electronics offers remotely adjustable and controllable quality of power. This has two major benefits not available in other systems

(i) Opportunity for remote control which makes it attractive for application.

(ii) and fine tuning for superior grid connection to make it better suited for meeting the demand of weak grids

Use of power electronics adds to the cost electrical, noise and losses of the system. However the cost and benefit trade is generally positive for large machines.

(b) Scherbius variable speed drive



→ Scherbius drive makes use of wound rotor induction machine.

→ The stator is connected to the grid and rotor is connected to variable frequency source via slip rings.

→ The speed is controlled by controlling the frequency of the external voltage injected into the rotor.

→ It offers lower cost and eliminates the power quality disadvantages. However sliding contacts at the slip rings lead to increased maintenance and the range of speed control is generally limited to 2:1

(c) Variable speed direct drive:-

→ In this scheme, the generator is directly coupled to the turbine shaft without gear and operates at turbine speed. Also it does not make use of power electronics

The main benefits are

(i) The lower weight
(ii) reduced noise and vibration
(iii) lower power loss
(iv) Less frequent servicing requirement.

→ For small sized turbines, where the rotor speed is high, direct coupling to the generator is possible without much difficulty.

→ Large rotor turns slowly and direct coupling requires large number of poles on electrical machines, which impose design limitations

→ To overcome such limitations the permanent magnet synchronous machine with large number of poles are being considered

→ <u>Advantages of wind energy conversion system</u>:-

(1) Wind energy is renewable source of energy and free of fuel cost.

(2) It produces electricity in an environmentally friendly way.

(3) It can supply electric power to remote in accessible areas like the upper Himalayan range, Andaman and Nicobar islands.

(4) Wind power Generation is cost effective.

Disadvantages of wind energy conversion system:-

(1) Wind energy has low energy density and normally available at only selected geographical locations away from cities and load centres

(2) Wind speed being variable, wind energy is irregular unsteady and erratic.

(3) Wind energy system require storage battery which contribute to environmental pollution

(4) Wind energy systems are noisy in operation, a large unit can be heard many kilometers way.

Classification of Wind Turbines:-

→ Wind turbines are classified as horizontal-axis turbines or vertical-axis turbines depending upon the orientation of the axis of rotation of their rotors.

→ A wind turbine operates by slowing down the wind and extracting a part of its energy in the process

→ For a horizontal-axis turbine, the rotor axis is kept horizontal and aligned parallel in the direction of the wind stream

→ In a vertical-axis turbine, the rotor axis is vertical and fixed and remains perpendicular to the wind stream

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→ In a vertical-axis turbine, the rotor axis is vertical and fixed and remains perpendicular to the wind stream

→ In general, wind turbines have blades sails or buckets fixed to a central shaft

→ The extracted energy causes the shaft to rotate.

→ This rotating shaft is used to drive a pump to grind seeds or to generate electric power.

→ Wind turbines are further classified into 'lift' and 'drag' type

Lift Type and Drag Type Wind Turbines:-

→ Two important aerodynamic principles are used in wind turbine operations i.e lift and drag.

→ Wind can rotate the rotor of a wind turbine either by lifting (lift) the blades or by simply passing against the blades (drag)

→ Wind turbines can be identified based on their geometry and the manner in which the wind passes over the blades

→ Slow-speed turbines are mainly driven by the drag forces acting on the rotor.

→ The torque at the rotor shaft is comparatively high which is of prime importance for mechanical applications such as water pumps

→ For slower turbines a greater blade area is required so the fabrication of blades is undertaken using curved plates

→ High speed turbines utilise lift forces to move the blades, which phenomenon is similar to acts on the wings of aeroplane

→ Faster turbines require aerofoil-type blades to minimize the adverse effect of the drag forces

→ The blades are fabricated from aerofoils sections with a high-thickness-to-chord ratio in order to produce a high lift relative to drag.

→ For electric power generation, the shaft of the generator requires to be driven at a high speed

→ For the same swept area, the energy extracted by a wind turbine operating on lift forces is several times greater than the energy from the drag-type turbine

→ The lift-type turbines are more suitable compared to drag type turbines for electric power generation.

Types of Rotors:

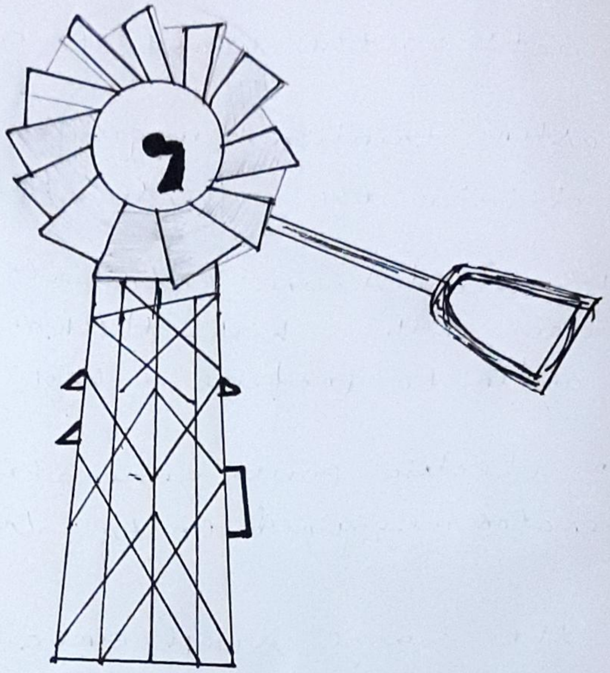
Different types of rotors used in wind turbines are

(i) Multiblade Type
(ii) Propeller Type
(iii) Savonious Type
(iv) Darrieus Type

→ The first two are installed in horizontal-axis turbines while the last two in vertical-axis turbines.

(i) Multiblade Rotor :-

Page-149(Phi)
fig. 7.2



→ The multiblade rotor is fabricated from curved sheet metal blades

→ The width of blades increases outwards from the centre

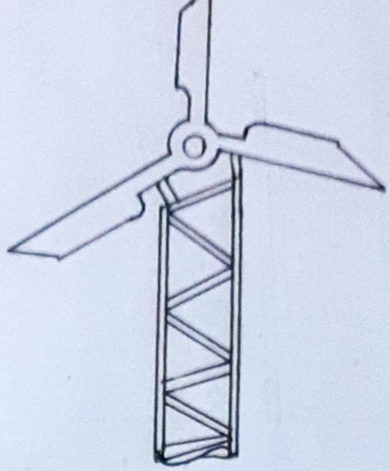
→ Blades are fixed at their inner ends on a circular rim.

→ They are also welded near their outer edge to another rim to provide a stable support

→ The number of blades used ranges from 12 to 18 as shown in fig.

(ii) **Propeller Rotor :-**

Page-150(PhS)
fig - 7.3



→ The propeller rotor comprises two or three aerodynamic blades made from strong but lightweight material such as fibre glass reinforced plastic

→ The diameter of the rotor ranges from 2m to 25m shown in fig.

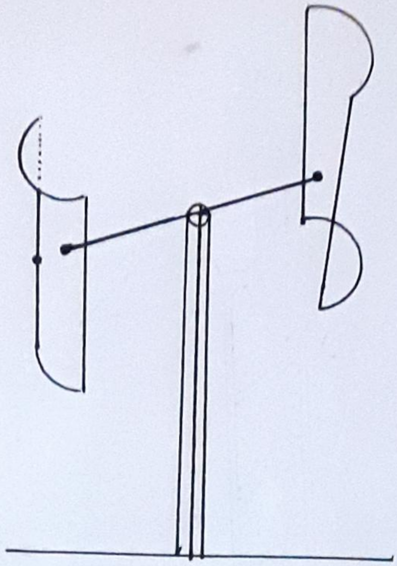
→ The blade slope is designed by using the same aerodynamic theory as for air craft

(iii) **Savonious Rotor :-**

→ The savonious rotor comprises two identical hollow semi-cylinders fixed to a vertical axis.

→ The inner side of two half-cylinders face other to have as 'S' shaped cross section as detailed in fig.

Page-150(Phi)
fig-7.4



→ Irrespective of wind direction, the rotor rotates due to pressure difference between the two slides.

→ This vertical axis rotor was develored by an engineer Savonious of Finland in the year 1920.

→ It is self starting and driving force is mainly of drag type.

→ The rotor possesses high solidity so as to produce a high starting torque, hence this rotor is suitable for water pumping.

(iv)

Darrieus Rotor :-

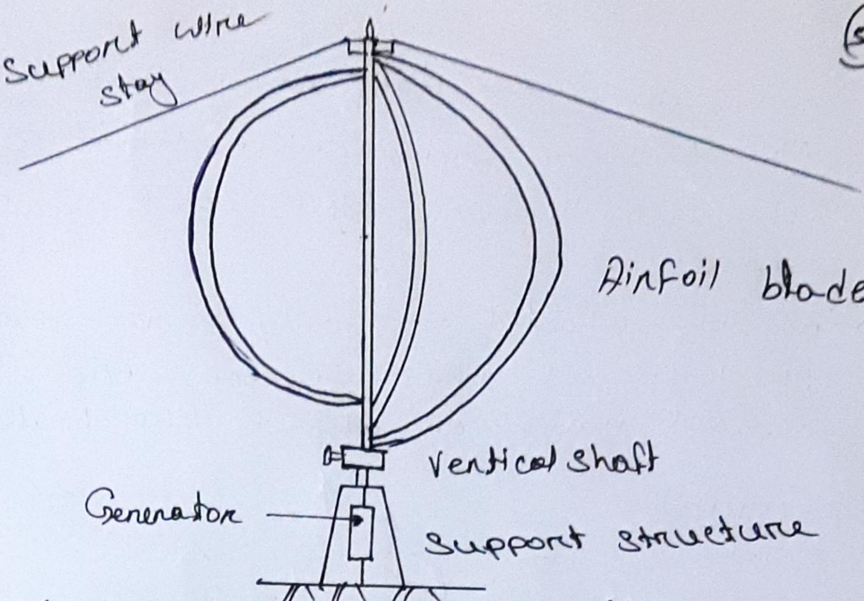
→ This rotor has two or three thin curved blades of flexible metal strips.

→ It looks like an egg beater and operates with the wind coming from any direction

→ Both the ends of the blades are attached to a vertical shaft as shown in fig.

→ It has an advantage that it can be installed close to the ground eliminating the cost of the tower structure.

page-151(Phi)
fig-7.5



→ Lift is the driving force, creating maximum torque when the blade moves across the wind.

→ This rotor was designed by a French engineer G.M Darrieus in 1925.

→ It is used for decentralized electricity generation.

Aerodynamic operation of wind Turbines:-

→ Aerodynamics deals with the movement of solid bodies through the air.

→ In wind turbines aerodynamics provides a method to explain the relative motion between airfoil and air

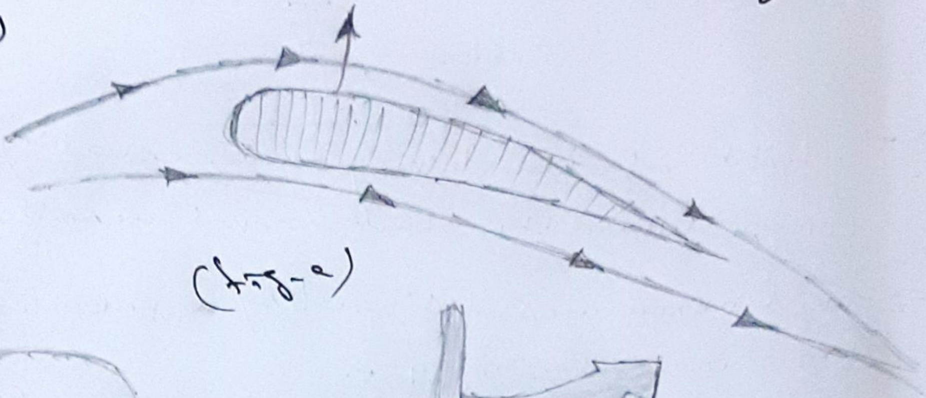
→ Airfoil is the cross-section of the wind turbine blade.

→ When the wind passes over the surface of the rotor blade, it automatically passes over the longer or upper side of the blade creating a low pressure area above the airfoil as shown in fig-(a)

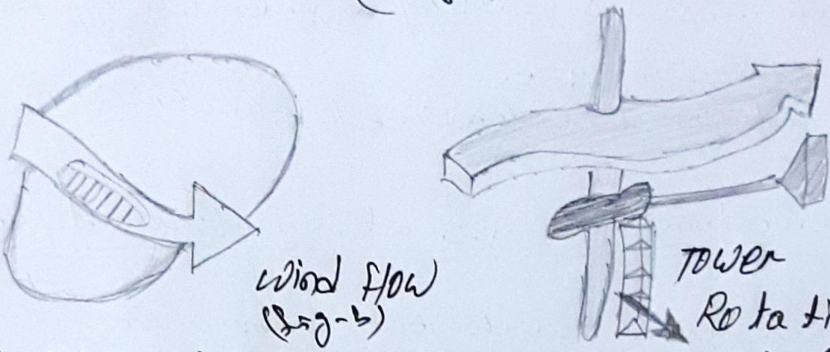
→ The pressure difference between the top and the bottom surfaces results in a force called the aerodynamic lift that causes the airfoil to rise.

→ As the blades can only move in a plane with the hub as their centre, the lift force causes rotation about the hub fig-(b)

page-154 (Phi)
fig-7.7



(fig-a)



(fig-b)

→ The turbine thus extracts energy from the wind stream by converting the wind's linear kinetic energy into rotational motion.

→ In addition to the lift force, a drag force perpendicular to the lift force also acts on the blade which impedes rotor rotation.

→ The prime objective in wind turbine design is the desired lift-to-drag ratio of the blade.

→ When air flows over Solid bodies, several physical phenomena are noticed such as drag force acting on objects like trees and electric towers, the lift force developed by airplane wings, the lifts force experienced by dust particles in a wind storm and the blade motion developed by a turbine.

Drag:-

→ It is the resistance which a body experiences when a fluid moves over it.

→ Flood water washes away animals, vehicles and buildings

→ Wind storm and hurricane knocks down transmission towers, trees etc.

These are a few undesirable examples of drag forces

→ The force that a flowing fluid exerts on a body in the direction of flow is called drag force.

→ Drag may bring an undesirable effect of friction, such as burning of space vehicles on entering into the earth's atmosphere.

Lift:-

→ When a body is immersed in a standstill fluid only the normal pressure force is exerted on it.

→ A flowing fluid in addition exerts tangential shear forces on the surface

→ Both these forces have two components one is drag in the flow direction, the other is perpendicular to the fluid flow called lift.

→ It causes the body to move in the upward direction.

→ The relative magnitudes of drag and lift forces depend completely on the shape of the object

→ Airfoils of a wind turbine are especially shaped to produce lift force on coming in contact with the moving air

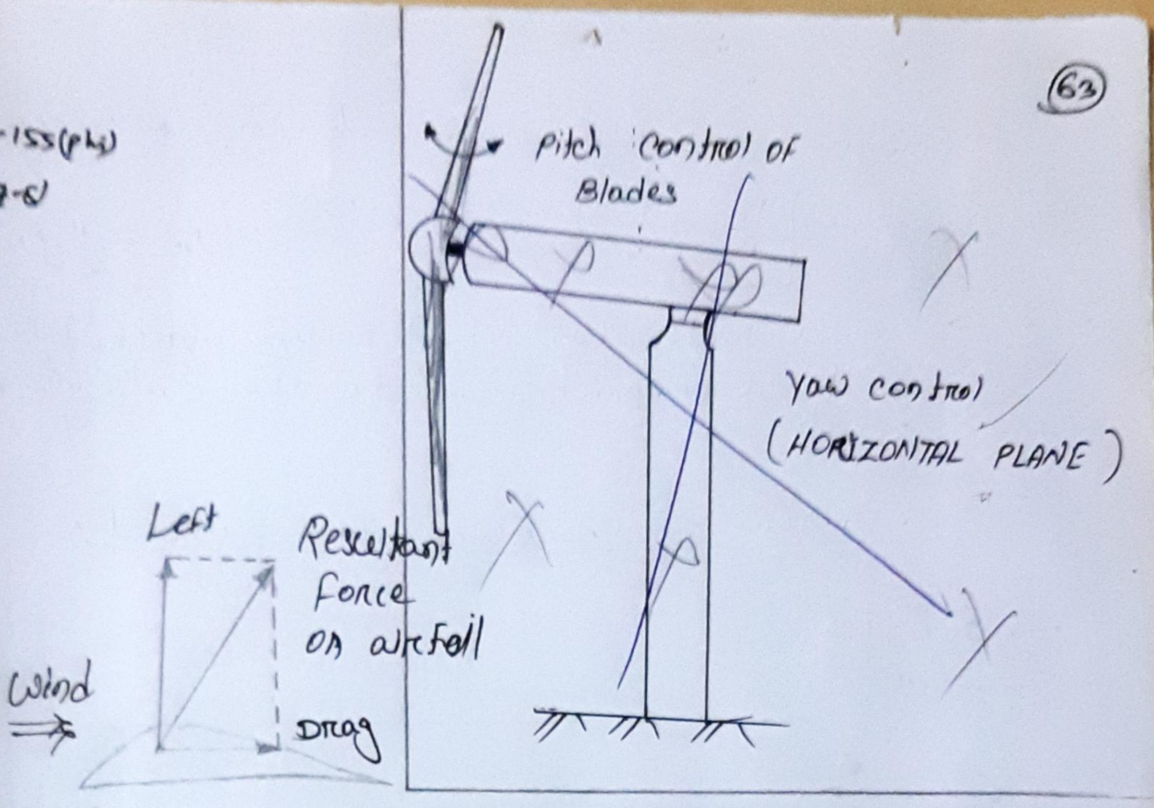
→ It is achieved by fabricating the top surface of the airfoil as curved and the bottom surface nearly flat.

→ Air flowing over the airfoil travels a longer distance to reach the tip-end of airfoil in contrast to air flowing under the foil shown in fig.

→ It creates a pressure difference that generates an upward force which tends to lift the airfoil causing rotation of the wind turbine rotor.

→ Good airfoils can have lift 30 times greater than drag.

Page-155(PK)
fig(8-6)



Wind Turbine Aerodynamics

(1) Energy Estimation of wind :-

→ If u_0 is the speed of free wind in unperturbed (not disturbed) state the volume of air column passing through an area A per unit time is given by Au_0.

→ If ρ is the density of air the air-mass flow rate, through area A is given as $\rho A u_0$.

→ Power (P_0) available in wind is equal to kinetic energy associated with the mass of moving air i.e

$$P_0 = \frac{1}{2}(\rho A u_0) u_0^2$$

$$\Rightarrow \boxed{P_0 = \frac{1}{2}(\rho A) u_0^3} \quad \text{— eq}^n (1)$$

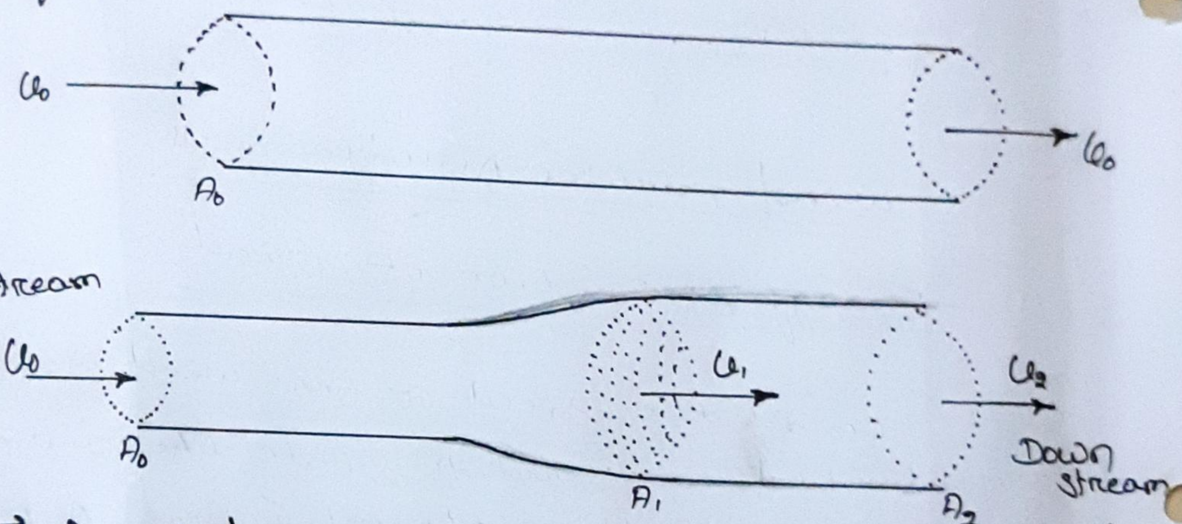
Power available in wind per unit area is

$$\boxed{\frac{P_0}{A} = \frac{1}{2}\rho u_0^3} \text{ — eq}^n \text{ (2)} \Rightarrow P_0 = \frac{1}{2}\rho A u_0^3$$

→ This indicates that power available in wind is proportional to the cube of wind speed.

(2) <u>Power Extraction from wind</u>: -

Pag-209 (Khan)
fig-7.10



→ A wind turbine is used to useful mechanical power from wind.

→ The rotor of the turbine collects energy from the whole area swept by the rotor.

→ In fig-7.10 the stream tube area of constant air mass is A_0 upstream, which expands to A_1 while passing through the rotor becomes A_2 downstream

→ The wind speed is u_0 upstream, which reduces to u_1 while passing through the rotor and becomes u_2 downstream.

→ The air-mass flow rate remains same throughout the stream tube

Therefore

$$\dot{m} = \rho A_0 u_0 = \rho A_1 u_1 = \rho A_2 u_2 \quad \text{— eq}^n \text{ (3)}$$

→ If u_0 and u_2 are wind speeds upstream and downstream respectively, the force or thrust on the rotor is equal to the reduction in momentum per unit time from the air mass flow rate $\dot{m}$

So $$F = \dot{m} u_0 - \dot{m} u_2 \quad \text{— eq}^n \text{ (4)}$$

→ This force is applied by the air at uniform air-flow speed of u_1, passing through the actuator disk (turbine). The power extracted by the turbine is.

$$P_T = F u_1 = \dot{m} (u_0 - u_2) u_1 \quad \text{— eq}^n \text{ (5)}$$

→ The power extracted from wind is also equal to loss in KE per unit time

$$P_w = \frac{1}{2} \dot{m} (u_0^2 - u_2^2) \quad \text{— eq}^n \text{ (6)}$$

equating eq^n (5) and eq^n (6) we have

$$u_1 = \frac{u_0 + u_2}{2} \quad \text{— eq}^n \text{ (7)}$$

→ An extreme case considering u_2 to be zero i.e $u_1 = \frac{u_0}{2}$

→ An interference factor 'a' is defined as fractional wind speed decrease at the turbine

$$a = \frac{u_0 - u_1}{u_0} \quad \text{— eq}^n \ (8)$$

$\Rightarrow u_1 = (1-a)u_0$

$\Rightarrow a = \frac{u_0 - u_2}{2u_0}$

'a' is also known as induction or perturbation factor

using eq^n (3), (4), (7) and (8)

Power extracted by the turbine may be written as

$$P_T = 4a(1-a)^2\left(\frac{1}{2}\rho A_1 u_0^3\right) \quad \text{— eq}^n \ (9)$$

or $P_T = C_p . P_0$ — eq^n (9*)

→ Where C_p is the fraction of available power in the wind that can be extracted and is known as power coefficient

$$C_p = 4a(1-a)^2 \quad \text{— eq}^n \ (9^{**})$$

(3) <u>Axial Thrust on Turbine, F_A :-</u>

→ With no energy extraction, Bernoulli's equation for upstream and down stream

$$\frac{P_0}{\rho_0} + gz_0 + \frac{u_0^2}{2} = \frac{P_2}{\rho_2} + gz_2 + u_2^2/2$$

as $z_0 = z_2$ and variation in air density is negligible compared to other terms, considering ρ as average ~~to other terms~~ air density, the static pressure difference across the turbine may be written as

[∵ z is height to relative height is]

$$\Delta P = P_0 - P_2 = (u_0^2 - u_2^2)\rho/2$$

→ The maximum value of static pressure difference occurs when u_2 approaches zero

$$\Delta P_{max} = \frac{\rho u_0^2}{2}$$

$P = \frac{F}{A}$ $F = P \times A$

$$F_{Amax} = A_1 (\rho u_0^2/2) \quad \text{— eq}^n \text{ (10)}$$

→ On a horizontal machine, this thrust acts along the turbine axis and therefore is known as axial thrust F_A

→ This axial thrust must be equal to loss of momentum of the air stream as given in eq^n (9)

$$F_A = \dot{m} u_0 - \dot{m} u_2$$

using eq^n (1), (7) and eq^n (8)

we can write

$$F_A = 4a(1-a) A_1 \cdot \rho u_0^2/2 \quad \text{— eq}^n \text{ (11)}$$

or
$$F_A = C_F \cdot F_{Amax} \quad \text{— eq}^n \text{ (12)}$$

where $C_F = 4a(1-a)$ — eq^n (13)

→ maximum axial thrust occurs when $C_F = 1$ which is achieved when $a = 0.5$, equivalent to $u_2 = 0$

(4) Torque developed by Turbine, T :-

→ The maximum conceivable torque T_m on an ideal turbine rotor would occur if maximum circumferential force acts at the tip of the blade with radius R thus

$$\boxed{T_m = F_{cir\,max}\, R} \quad \text{— eq}^n \;(14)$$

$$\boxed{T_m = \frac{P_0}{u_0} R} \quad \text{— eq}^n \;(15)$$

where P_0 → wind power
u_0 → speed of oncoming air
R → blade Radius

Now if the tip-speed ratio λ is defined as

$$\lambda = \frac{\text{speed of tip of the rotor blade}}{\text{speed of oncoming air}} = \frac{R\omega}{u_0}$$

[∵ ω → Angular velocity]

So $$\boxed{T_m = \frac{P_0 \lambda}{\omega}} \quad \text{— eq}^n \;(16)$$

→ For a particular machine, where circumferential force is not concentrated at the tip but spread throughout the length of the blade.

The shaft torque T_{sh} is given by

$$\boxed{T_{sh} = C_T\, T_m} \quad \text{— eq}^n \;(17)$$

where C_T → Torque coefficient

→ As the product of shaft torque and angular speed equals power developed by the turbine

$$T_{sh} \cdot \omega = P_T$$

$$\Rightarrow C_T\, T_m \cdot \omega = C_p P_0$$

[∵ C_p → Power coefficient
P_0 → wind power

Substituting T_m from eqn (16) we get

$$C_T P_0 \lambda = C_p P_0$$

$$\Rightarrow \boxed{C_T = \frac{C_p}{\lambda}} \text{ — eqn (18)}$$

$$\boxed{C_{T\,max} = \frac{C_{p\,max}}{\lambda}} \text{ — eqn (19)}$$

Problem-1

A propeller-type wind turbine has the following data.

Speed of free wind at a height of 10m = 12 m/s
air density = 1.226 kg/m³
$\alpha = 0.14$
Height of tower = 100m
Diameter of rotor = 80m
wind velocity at the turbine reduces by 20%
Generator efficiency = 85%

Find
(i) Total power available in wind
(ii) Power extracted by the turbine
(iii) Electrical power generated
(iv) axial thrust on the turbine
(v) maximum axial thrust on the turbine

Ans

Given data

$u_H = 12\ m/s$ $H = 10m$ $Z = 100m$
$\rho = 1.226\ kg/m^3$ $\alpha = 0.14$
$D = 80m$ $A_1 = 5026.55 m^2$
$u_1 = 0.8 u_0$ $\eta_{Gen} = 0.85$

(reduce by 20% → 100−20 = 80%)

$$\boxed{u_Z = u_H \left(\frac{Z}{H}\right)^{\alpha}} \text{ standard eqn}$$

$$= 12\left(\frac{100}{10}\right)^{0.14}$$

$$= 12 \times (10)^{0.14}$$

$$= 16.565\ m/sec$$

[∵ wind speed u_Z at a height Z to available standard reference height H]

[∵ diameter 80m]

$u_2 = 16.565 \ m/s = u_0$

$u_1 = 0.8 \times 16.565$

$= 13.252 \ m/sec$

(i) From eqn - (2)

$$\frac{P_0}{A} = \frac{1}{2} \rho u_0^3$$

$$\Rightarrow P_0 = A \cdot \frac{1}{2} \rho u_0^3$$

$$= 5026.55 \times \frac{1}{2} \times 1.226 \times (16.565)^3$$

$$= 14 \ MW$$

(ii) Interference factor 'a'

from eqn (8)

$$a = \frac{u_0 - u_1}{u_0}$$

$$= \frac{16.565 - 13.252}{16.565}$$

$$= 0.2$$

from eqn (9**) C_p is

$$C_p = 4a(1-a)^2$$

$$= 4 \times 0.2 (1 - 0.2)^2$$

$$= 0.512$$

from eqn (9*) P_T is

$$P_T = C_p \cdot P_0$$

$$= 0.512 \times 14 = 7.168 \ MW$$

(iii) Electrical power generated

$$= 0.85 \times P_T$$

$$= 0.85 \times 7.168 = 6.09 \ MW$$

(iv) From eqn (11)

axial thrust on the turbine

$$F_A = 4a(1-a)A_1 \rho u_0^2/2$$

$$= [illegible] = 5.4 \times 10^5 N$$

(v) maximum axial thrust occurs where $a = 0.5$ and $C_F = 1$

$$F_{A(max)} = A_1 \rho u_0^2/2 = 8.455 \times 10^5 N$$

$$= [illegible]$$

$$\approx [illegible]$$

Problem-2

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

Ans

Given

Rotor diameter = 80m, R = 40m

$u_0 = 15 m/s$, $n = 3$

tip-speed ratio for optimum output

$$\lambda_0 \approx \frac{4\pi}{n} = \frac{4\pi}{3} = 4.188$$

tip-speed ratio is given by $\lambda_0 = \frac{R\omega}{u_0}$

$$\Rightarrow 4.188 = \frac{40 \times \omega}{15}$$

$$\omega = 1.57$$

If N is rotor speed in rpm $\omega = \frac{2\pi N}{60}$

$$N = 15 \text{ r.p.m}$$

Therefore for optimum energy extraction rotor speed should be maintained at 15 r.p.m

Wind characteristics

→ Power in the wind is proportional to the cube of the wind speed i.e

$$\boxed{P_{max} = 0.593 \left(\frac{1}{2} \rho A V_u^3\right)}$$

and is highly site specific

→ It is necessary to carry out wind measurement if the performance of wind turbines is to be estimated accurately.

→ The highest wind speed sites are on exposed hill tops, off shore or on coastal sites

→ For developing wind energy at any site the different parameters required are

(i) mean wind speed

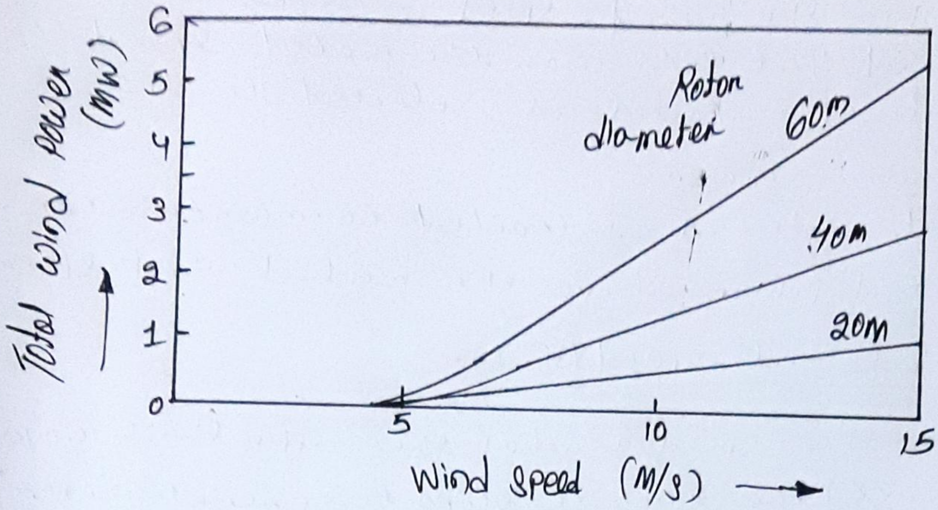
(ii) Daily, seasonal and annual variations in wind speed. wind speed frequency distribution generally described by probability distribution.

(iii) wind speed variation with height above ground (power in the wind increases with height)

→ meterological Department microprocessor-based anemometers are used at wind mapping stations.

→ These instruments can make highly accurate wind measurement for the estimation of power production

Page-160 (PNS)
fig-7.11 (...)



wind power generation curve:-

→ The power curve of a wind turbine indicates power output as a function of wind velocity hub height as shown in fig

→ The curve shows the steady idealized characteristic but in practice the wind speed constantly varies.

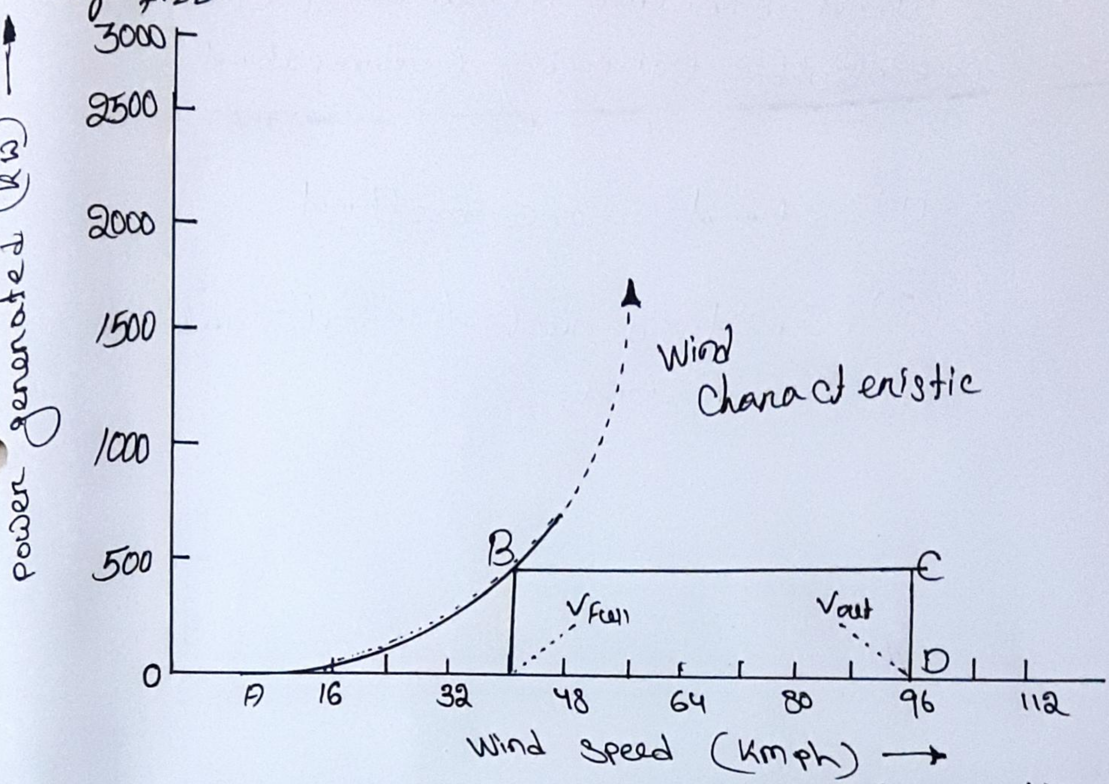
→ A wind turbine develops less power than the wind's stream power due to friction and spillage and the curve in fig 7-22 shows the following limiting speeds

(i) cut-in speed (V_{in}) :- (start)

→ It is the wind speed (14 km/h or 4m/s) at which the turbine output begins.

→ It is higher than the speed at which the turbine starts rotating. Before starting to rotate, the turbine remains in the braked position.

Page-177 (Phi)
fig - 7.22



Modes of wind Power Generation

Wind Electric Generators operate in one of the following two modes

(1)

Modes of Wind Power Generation:-

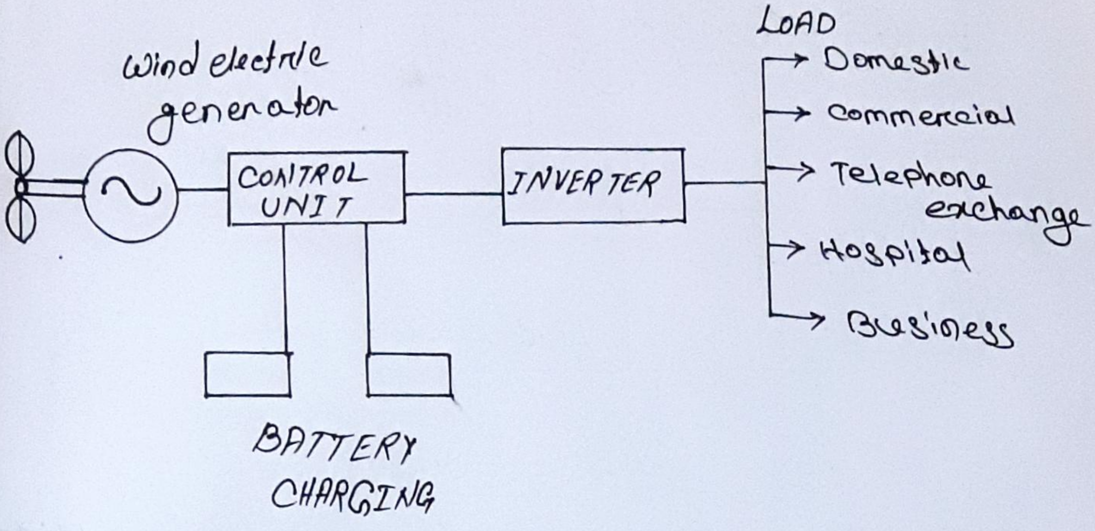
Wind Electric Generators operate is one of the following two method

(1) Stand alone method

(2) Grid connected wind Turbine Generators

(1) Stand alone method

→ The diagram of stand alone method shown in fig-1



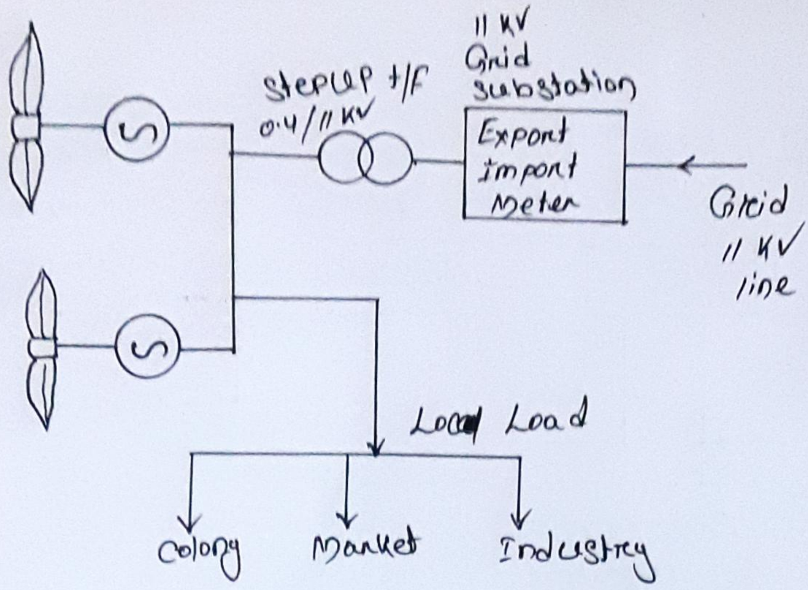
(fig-1)

→ This type of aero-generator represents decentralized application of wind energy and is characterized by the situation where an individual energy consumer or a group of consumers install their own wind turbine

→ The generating capacity of the WTG is matched with the energy requirement

→ A WEG with a capacity of 2.5kW to 5kW is useful for domestic power supply

(2) Grid connected wind Turbine Generators



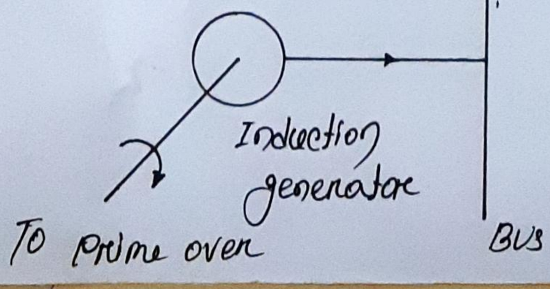
→ In India a grid connected WEG constitute wind farms where the generated power is distributed among the nearby consumers and the excess power is exported to the grid.

→ Electrical energy is purchased (imported) from the grid during periods of no wind.

Grid connected and Self-excited induction generator operation.

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

(a) constant-voltage, constant frequency generator



→ In the constant voltage, constant frequency category, the generator derives its excitation from the utility bus as shown in the figure

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

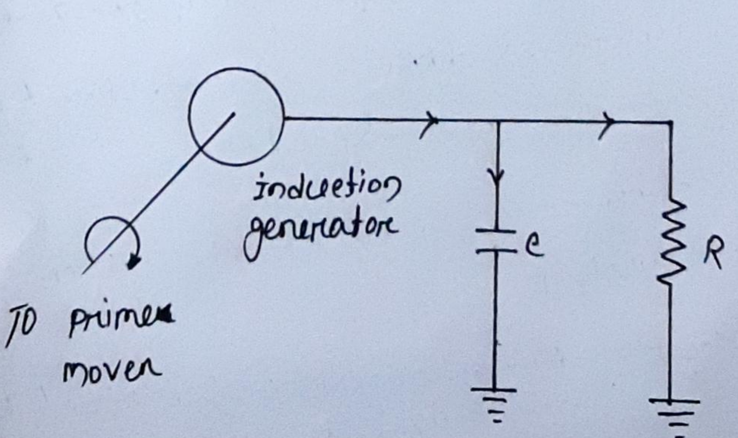
→ Machines with a cage-type rotor feed only through the stator and generally operate at low negative slip

But wound rotor machines can feed power through the stator and generally operate at low negative slip.

But wound rotor machines can feed power through the stator as well as the rotor to the bus over a wide speed range

(b) Variable-voltage, variable frequency generators :-

→ Variable-voltage, variable frequency generators is analogous to a self excited dc generator.



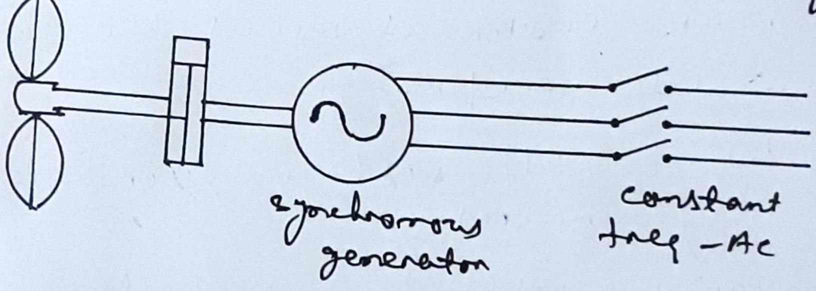
→ when a capacitor is connected across the induction machine, helps build up the terminal voltage
→ But the building up of the voltage also depends on factors such as speed capacitor value and load
→ The squirrel cage machine is generally used as a self-excited induction generator.

Schemes for electric generation:-

There are three schemes for electric generator have been developed

(i) constant speed constant frequency system (CSCF)
(ii) variable speed constant frequency system (VSCF)
(iii) variable speed variable frequency system (VSVF)

(i) constant speed constant frequency system.



→ The synchronous generator delivers electrical energy to the load/grid at grid frequency (50Hz) only if its rotor is driven at constant speed called the synchronous speed.

At synchronous speed of the rotor

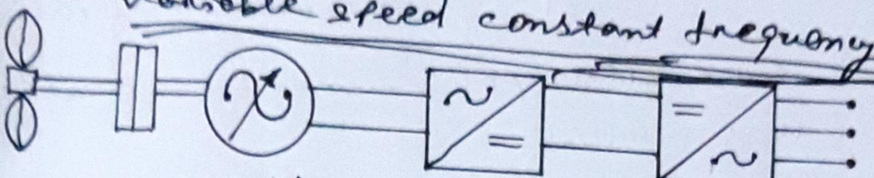
$F = 120 N_s \cdot P$

where F = Frequency of electrical voltage and current.

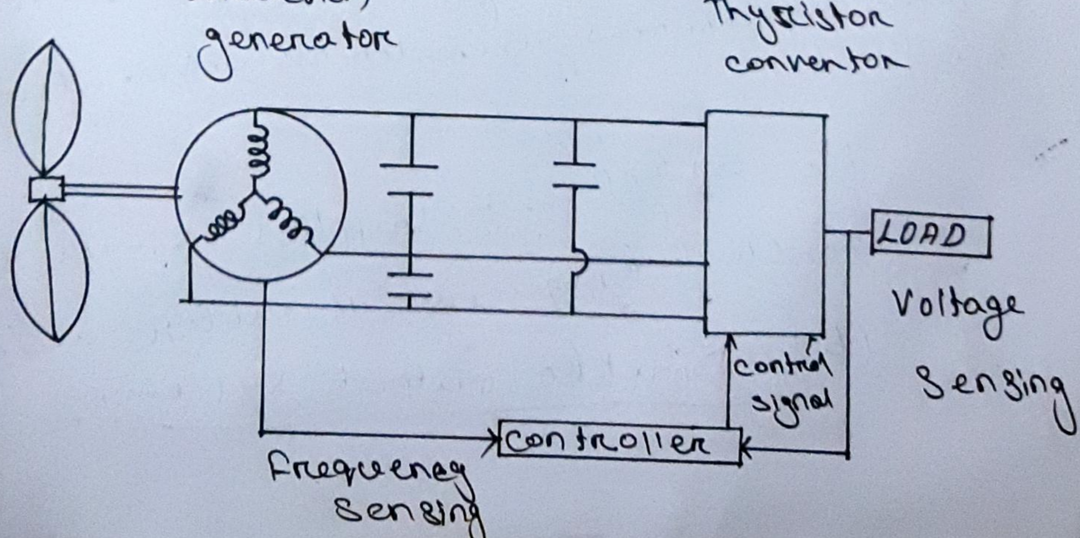
n_s = synchronous speed
P = no of poles
n = 2 pole machine needs n_s = 3000 rpm
4 pole machine needs n_s = 1500 rpm
6 pole machine needs n_s = 750 rpm
and likewise

When a synchronous generator is driven at constant speed n_s, it supplies power at constant frequency of voltage and current.

(ii) variable speed constant frequency system:-



→ The rotor speed is allowed to vary with the wind speed. The generator produces variable frequency output (FAM) Rectifier-inverter combination delivers constant frequency electrical output can be delivered to the load on the grid



→ chopper is a device which converts fixed dc input voltage to a variable dc output voltage.

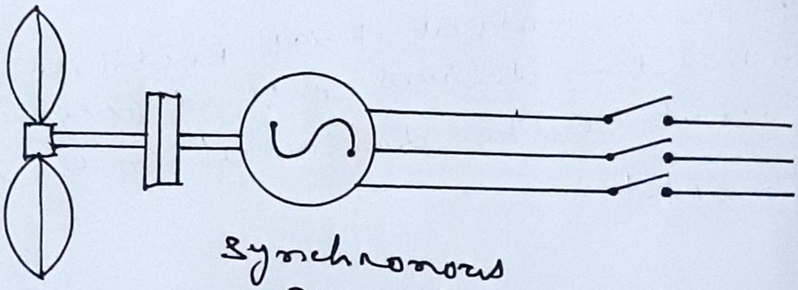
→ In this system capacitor excited (self excited) squirrel cage induction machines can be used.

→ This system otherwise known as Stand alone

→ The magnitude and frequency of the emf depends on the value of the load impedance, prime mover speed and excitation capacitance

Computer programmes have also formulated for this purpose

(a) Single output system

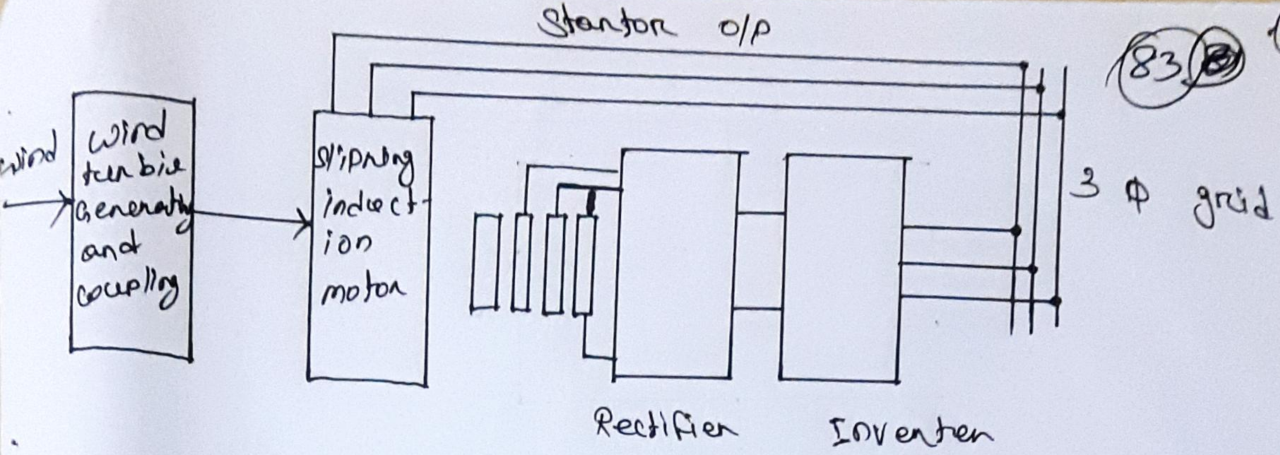


synchronous generator

→ In this system a synchronous generator is used when a synchronous generator is driven at constant speed

$N_s = \frac{120F}{P}$ it supplies single output at constant frequency of voltage and current

(b) Double output system:-



→ In this system a slipring induction motor is used. Rotor power at slip frequency is converted to sine frequency power by rectification and inversion.

Output power is obtained both from Stator and rotor and hence this device is known as double output induction generator.

(4) Reactive power compensation:

(i) The switched capacitor scheme

→ The switched capacitor scheme comprises a ~~b~~ bank of parallel capacitors which are switched ON and OFF by contactors in response to present voltage levels.

Module - III

Biomass Power

Biomass:-

→ Biomass is organic matter produced by plants, both terrestrial (those grown on land) and aquatic (those grown in water) and their derivatives.

→ It includes forest crops and residues crops grown especially for their energy content on "energy farms" and animal manure.

Solar energy → Photosynthesis → Biomass → Energy Generation

→ Out of several sources of renewable energy like solar, wind, ocean thermal energy, tidal wave energy, Geothermal energy, ~~tidal~~ energy through biomass are important feature in our country. Biomass resources fall into three categories.

→ (i) Biomass in its traditional solid mass (wood and agriculture residue)

(ii) Biomass in non-traditional form (converted into liquid fuels)

→ The first category is to burn the biomass directly and get the energy.

In the second category, the biomass is converted into ethanol (ethyl alcohol) and methanol (methyl alcohol) to be used as liquid fuels in engines.

(iii) The third category is to ferment the biomass anaerobically to obtain a gaseous fuel called biogas

Biomass conversion Technologies:

→ There are many different ways of extracting energy from biomass

(i) Physical method
(ii) Incineration (direct combustion)
(iii) Thermochemical method
(iv) Biochemical method

(i) Physical method :—

→ The simplest form of physical conversion of biomass is through compression of combustible material.

→ Its density is increased by reducing the volume by compression through the processes called briquetting and pelletization

→ Fuel oils can be extracted from plant products by expelling them.

(a) Pelletization:-

→ Pelletization is a process in which waste wood is pulverized dried and forced under pressure through an extrusion device

→ The extracted mass in the form of pellets (rod, 5 to 10mm dia and 12mm long) facilitating its use in steam power plants and gasification system.

→ pelletization reduces the moisture to about 7 to 10% and increases the heat value of the biomass

(b) Briquetting:-

→ Biomass briquettes are made from woody matter (i.e agricultural waste and saw dust) are a replacement for fossil fuels such as oil or coal and can be used to heat boilers in manufacturing plants.

→ Burning a wood briquette is far more efficient than burning firewood.

→ The moisture content of a briquette can be as low as 4% whereas for green firewood, it may be as high as 65%.

→ Briquetting is brought about by compression and squeezing out moisture and breaking down the elasticity of the wood and bark

→ If elasticity is not sufficiently removed the compressed wood will regain its pre-compression volume.

→ Densification is carried out by compression under a die at high temperature and pressure

→ It is a process similar to forming a wood pellet but on a larger scale.

There are no binders in this process. The natural lignin in the wood binds the particles of wood together to form a solid piece.

(c) Expelling agro products:-

→ Concentrated vegetable oils may be obtained from certain agro products and may be used as fuel in diesel engines.

→ However difficulties arise with direct use of plant oil due to high viscosity and combustion deposits.

→ Therefore, these oils are upgraded by a chemical method known as transesterification.

→ Categories of certain materials with examples are as follows.

Seeds sunflower, rapeseed, soya beans etc.

(d) Fuel Extraction:-

→ Occasionally milky latex is obtained from freshly cut plants.

→ The material is called exudates and is obtained by cutting (tapping) the stems or trunks of living plants (a technique similar to that used in rubber production)

→ Some plants are not amenable to tapping and in such cases, the whole plant (usually a shrub) is crushed to obtain the product.

→ ~~Some plants are cool rare~~
→ For example, the Euphorbia lathyris plant is crushed to extract hydrocarbons of less molecular weight than rubber, which may be used as a petroleum substitute.

(ii) Incineration:-

→ Incineration means direct combustion of biomass for immediate useful heat.

→ The heat or steam produced are either used to generate electricity or provide the heat for industrial process, space heating, cooking etc

→ Furnaces and boilers have been developed for large-scale burning of various types of biomass such as wood, waste wood, black liquid from pulp industry, food industry waste.

→ The moisture content in the biomass and wide range of composition tends to decrease the efficiency of conversion.

(iii) Thermochemical:-

→ The basic thermochemical process to convert biomass into a more valuable and/or convenient product is known as pyrolysis

OR

Thermo-chemical conversion is a process to decompose biomass with various combinations of temperatures and pressures. It includes pyrolysis and gasification.

(a) Pyrolysis :-

→ Biomass is heated in absence of oxygen, or partially combusted in limited Oxygen supply, to produce a hydrocarbon, rich in gas mixture (H_2, CO_2, CO, CH_4 and lower hydrocarbons) an oil like liquid and a carbon rich Solid residue (charcol)

→ The pyrolitic or bio-oil produced can easily be transported and refined into a series of products similar to refining crude oil.

→ There is no waste product, the conversion efficiency is high (82%) depending upon the feedstock used the process temperature in reactor and the fuel/air ratio during combustion

(b) Gasification :-

→ Gasification is conversion of a Solid biomass, at a high temperature with controlled air, into a gaseous fuel.

→ The output gas is known as producer gas, a mixture of H_2 (15-20%), CO (10-20%), CH_4 (1-5%), CO_2 (9-12)% and N_2 (45-55%)

→ The gas is more versatile (charge) than the Solid biomass, it can be burnt to produce process heat and Steam or used in internal combustion engines or gas turbines to generate electricity.

→ The gasification process renders the use of biomass which is relatively clean and acceptable in environmental terms.

(c) <u>Liquefaction</u>:.

→ Liquefaction of biomass can be processed through fast or flash pyrolysis called pyrolytic oil which is a dark brown liquid of low viscosity and a mixture of hydrocarbons, pyrolysis liquid is a good substitute for heating oil.

→ Another liquefaction method is through methanol synthesis.

→ Gasification of biomass produces synthetic gas containing a mixture of H_2 and CO

→ The gas is purified by adjusting the hydrogen and carbon monoxide composition

→ Finally the purified gas is subjected to liquefaction process, converted to methanol over a zinc chromium catalyst. Methanol can be used as liquid fuel.

Biochemical conversion

There are two forms biochemical conversions

1. Anaerobic digestion
2. Ethanol fermentation

1. Anaerobic Digestion (Anaerobic fermentation)

→ This process converts the cattle dung, human wastes and other organic waste with high moisture content into biogas (gobar gas) through anaerobic fermentation in absence of air.

→ Fermentation occurs in two stages by two different metabolic groups of bacteria.

→ Initially the organic material is hydrolyzed into fatty acids, alcohol, sugars H_2 and CO_2

→ Methane forming bacteria then converts the products of the first stage to CH_4 and CO_2 in the temperature range 30-55°C

→ Biogas produced can be used for heating or for operating engine driven generators to produce electricity

→ Fermentation occurs in a sealed tank called digester. where the sludge left behind is used an enriched fertilizer

(b) Ethanol Fermentation:

→ Ethanol can be produced by decomposition of biomass containing sugar like sugarcane, cassave sweet Sorghum, beet, potato, grape etc into sugar molecules such as glucose ($C_6H_{12}O_6$) and Sucrose ($C_{12}H_{22}O_{11}$)

→ Ethanol fermentation involves biological conversion of sugar into ethanol and CO_2

$$C_{12}H_{22}O_{11} + H_2O \rightarrow 2C_6H_{12}O_6$$

$$C_6H_{12}O_6 \xrightarrow{\text{fermentation}} 2C_2H_5OH + 2CO_2$$

Ethanol has emerged as the major alcohol fuel in blended with ~~petro~~ petrol.

Biomass Gasification

→ Biomass gasification is thermo-chemical conversion of solid biomass into a combustible gas fuel through partial combustion with no solid carbonaceous residue,

→ Gasifiers use wood waste and ~~a~~ agriculture residue

Wood Gasifiers

→ The word gasification or thermal gasification implies converting solid fuel into a gaseous fuel by thermochemical method without leaving any solid carbonaceous residue.

→ Gasification is an established technology the first commercial application of which dates back to 1830.

→ During world war-II biomass gasification systems appeared all over the world to power vehicles to keep the basic transport systems running.

→ The most common raw materials used are wood chips and other wastes from wood industry, coconut shells and straw.

→ Biomass that has high ash content such as rice husk can also be handled with some difficulty.

→ Gasification involves partial combustion (Oxidation in restricted quantity of air/oxidant) and reduction operations of biomass.

→ In a typical combustion process, generally the oxygen is surplush, while in a gasification process, the fuel is surplus.

→ The combustion products, mainly carbon dioxide, water vapour, nitrogen, carbon monoxide and hydrogen pass through the glowing layer of charcoal for the reduction process to occur.

→ During this stage, both carbon dioxide and water vapour oxidize the char to form CO, H_2 and CH_4

→ The following are the typical reactions which occur during gasification.

$$C + O_2 \rightarrow CO_2 \text{ (combustion, 240 KJ/mole)}$$

→ The moisture available in the biomass is converted to steam and generally no extra moisture is required.

→ Thus the product of combustion of pyrolysis gases results in CO_2 and H_2O (steam), which further react with char

$$C + CO_2 \rightarrow 2CO \text{ (Boundary reaction, } -164.9 \text{ KJ/mole)}$$
$$C + H_2O \rightarrow CO + H_2 \text{ (water gas reaction, } -122.6 \text{ KJ/mole)}$$
$$CO + H_2O \rightarrow CO_2 + H_2 \text{ (water shift reaction, } 40.2 \text{ KJ/mole)}$$
$$C + 2H_2 \rightarrow CH_4 \text{ (methane reaction, } 83.3 \text{ KJ/mole)}$$

→ The composition of the gas produced depends on the degree of equilibrium attained among various reactions.

→ Gasifiers are broadly classified into

(i) Fixed-bed gasifier

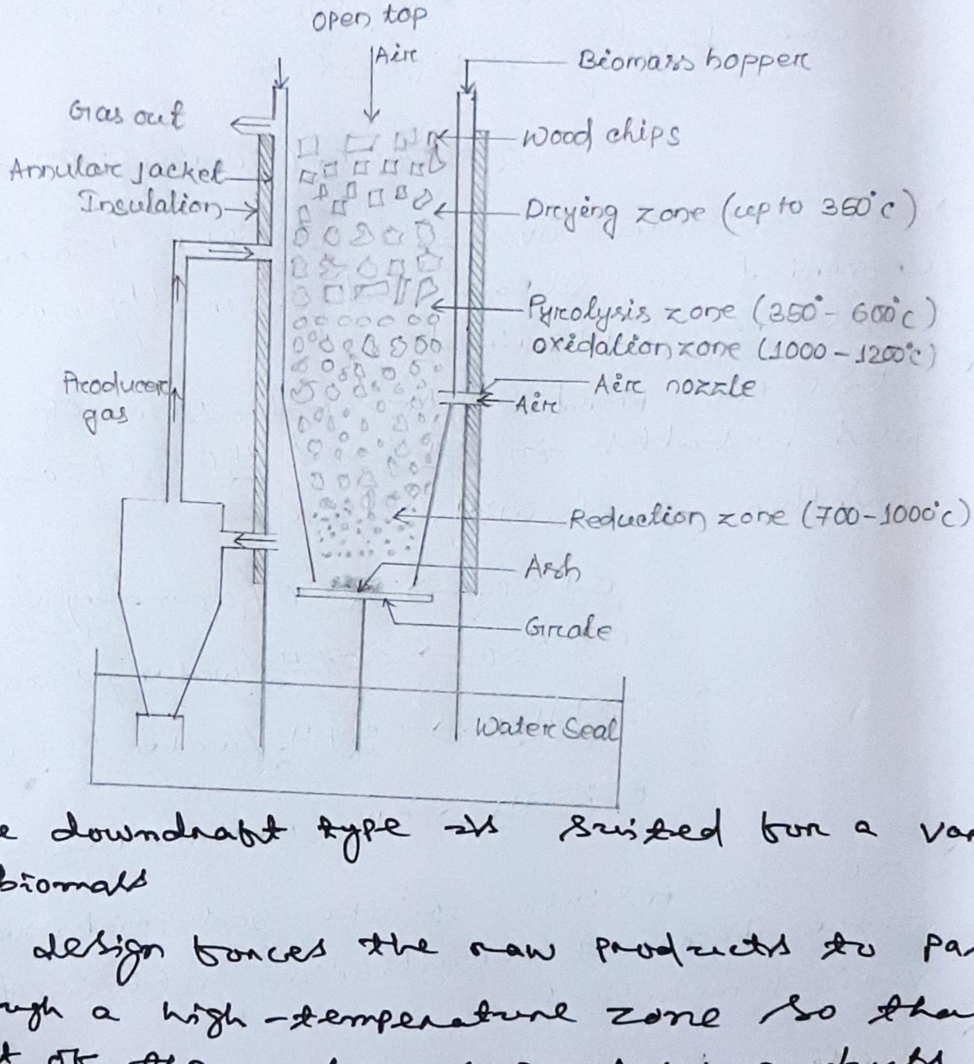
(ii) Fluidized-bed gasifier

The fixed-bed gasifiers are further classified as

(a) down draft
(b) updraft
(c) cross-draft types, depending upon the direction of air flow.

Down draft Type

fig-8.4



→ The downdraft type is suited for a variety of biomass

→ It's design forces the raw products to pass through a high-temperature zone so that most of the unburnt pyrolysis products (especially tars) can be cracked into gaseous hydrocarbons, thus producing a relatively clean gas.

→ A recently developed open-top downdraft type gassifier is shown in fig - 8.4

→ 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 lose 70-80% of their weight.

→ These pyrolysed gases burn with air to form CO, CO_2, H_2 and H_2O, thereby raising the temp to 1000-1200°c.

→ The product gases from the combustion zone further undergo reduction reaction with char to generate combustible products like CO, H_2 and CH_4

→ Generally about 40-70% air is drawn through the open top depending on the pressure drop conditions due to the size of wood chips and gas-flow rate.

→ This flow of air opposite to the flame front helps in maintaining homogeneous air/gas flow across the bed.

→ combining the open top with the air nozzle towards the bottom of the reactor helps in stabilizing the combustion zone by consuming the unconverted char left and also by preventing the movement of the flame front to the top

→ As a consequence the high-temp zone spreads above the air nozzle by radiation and conduction aided by air flow from the top.

→ The tar thus is eliminated in the best possible way by creating a high temp oxidising atmosphere in the reactor itself

→ The gas produced is with drawn from an exit at the bottom and reintroduced in the annular jacket for heat recovery.

→ The hot gas which enters the annular jacket around 500°c, transfers some heat to the wood chips inside, improving the thermal efficiency of the system in addition to drying the wood in this zone.

→ The inner wall temp reaches more than 350°c after a few hours of operation.

→ This aspect enables the use of wood chips with moisture content as high as 25%.

→ The regenerative heating due to the transfer of heat from hot gas to the biomass moving downwards also increases its residence time in the high-temp zone. This leads to better tar cracking.

→ The raw producer gas thus obtained can be used as such for thermal applications for use in IC engines, further processing is required.

→ Admission of hot gas into an engine results in loss of power and hence the gas has to be cooled.

→ Raw gas contains varying amount of dust (ash and char) particles, moisture and tar

→ Dust and tar are reduce to the life of an engine. Hence the gas has to be cooled and cleaned before admitting to the engine

→ The upper limit of allowable tar is about 50mg/m3 and that for particulate content is about 50mg/m3.

→ The gas may be cooled to the ambient temp by direct injection of cooling water from a spray tower.

→ A sand-bed filter may be deployed to remove the particulate collected by the cooling tower.

→ periodic washing of this sand bed is adequate to keep the operation smooth.

→ For filtering of the gas a sand-bed filter with specific particle size distribution is used.

→ The filter is divided into a coarse (sand particle size 0.5 to 2mm) and fine sections (particle size 0.2 to 0.6mm)

→ The size of the filter area is so chosen that the gas velocities through the filter bed do not exceed 0.1 m/sec

→ This low velocity coupled with a tortuous path causes the removal of a large part of the dust from the gas.

→ Some part of the tar also gets deposited in the filter circuit, particularly when the moisture carried over from the cooler causes slight wetting of the sand

problem 1

calculate the volume of a cow-dung based biogas plant required for cooking needs of a family of five adults and lighting needs with two 100 CP lamps for three hours daily. Also calculate the required number of cows to feed the plant. Assume standard values of data where required.

Ans

Assume Retention time = 50 days

Density of Slurry = 1090 kg/m³

Biogas yield = 0.34 m³/kg of dry matter

percentage of dry matter in cow dung = 18%.

Biogas required per cooking = 0.227 m³/person/day

Gas required per lighting a 100 CP (candle power) lamp = 0.126 m³/hour

Gas required for cooking for the family

$= 5 \times 0.227 = 1.135\ m^3/day$

Gas required for lighting $= 0.126 \times 2 \times 3$

$= 0.756\ m^3/day$

Total daily gas requirement of the family

i.e $1.135 + 0.756 = 1.89\ m^3/day$

cowdung production rate = 10 kg/day/cow

Let 'n' be the number of cows

cow dung produced = 10n kg/day

collectable cow dung (70%) = 7n kg/day

weight of dry solid mats (18%) in cow dung

$= 0.18 \times 7n$ kg/day

Gas production per day = 0.34 X 0.18 X 7 n m³/day

$0.34 \times 0.18 \times 7n = 1.891$

$n = 4.41 \approx 5$

Thus, five cows are required to feed the plant.

Daily feeding of cow dung = 7X5 = 35 kg

This will be mixed with equal quantity of water to make the slurry.

Thus daily feed of slurry = 70 kg = 70/1090 = 0.0642 m3

(slurry density = 1090 kg/m3)

For a 50-day retention time, volume of slurry the digester = 50 X 0.0642

= 3.21 m3

As about 90% volume is occupied by the slurry the required volume of the digester

= 3.21/0.9 = 3.56 m3

problem-2

A school in a remote place has the following energy requirements

- Ten lamps each of 100cp that operate for 4 hours daily.
- Six computers, each of 250W, that operate for 6 hours daily by a dual fuel-engine driven generator
- 2hp water pump driven by dual fuel engine for two hours daily.

calculate the size of the biogas plant and the number of cows required to feed the plant. Assume standard values of data where required.

Ans

Gas required for lighting $= 10 \times 0.227 \times 4$
$= 9.08\, m^3/day$

Electrical energy required by ten computers
$= 10 \times 250 \times 6 \times 60 \times 60 = 54M$

Assuming the conversion efficiency of generator to be 80% and the thermal efficiency of the engine to be 25%, the thermal input to the engine to generate 54MJ electrical energy $= \frac{54}{0.25 \times 0.80} = 270MJ$

mechanical energy required for water pumping
$= 2 \times 746 \times 2 \times 60 \times 60 = 10.74MJ$

Assuming the thermal efficiency of engine to be 25%, the required thermal input
$= 42.96MJ$

As only 90% of the digester volume is occupied by the slurry, the net volume of the digester

$$= \frac{34.035}{0.9} = 37.82 m^3$$

Module-IV

Hybrid systems

Need for Hybrid systems:-

→ Solar water heaters, air heaters, solar distillation and wax melters, PV arrays, PV pumps, operate at optimal efficiency for the months of April to September when solar radiation contain high energy flux.

→ To meet the load demand during night and cloudy days, battery bank is provided.

→ During winter, load demand shoots up and solar energy reduces, so designer is compelled to select large size equipment, PV arrays and battery bank.

→ Similar situation is faced for a stand alone wind power generating system, when wind speed drops below cut-in speed and wind Turbine Generator (WTG) stops.

→ For emergency, loads of hospitals, defense installations and communication services a back up source

(1) Diesel generator
(2) Gas turbine generator
(3) biogas
(4) small hydro
(5) Fuel cell is required

→ Two different energy systems installed at a location to ensure continuity of electrical supply is known as hybrid energy system.

→ These hybrid energy system provides an edge over the stand-alone and even grid interactive systems for reliability of energy supply and lower capital cost.

→ However engineer's selection of the back up source is done by maximum capacity of the prime energy source at peak energy source at peak energy demand period.

Types of Hybrid systems

→ Few hybrid energy systems that are operative in prevailing Indian conditions in various states are given.

→ It is assumed that a battery bank of a ~~battery bank of a~~ suitable size is installed as the storage ~~bank~~ for the period of low wind speed, during no sun' cloudy day and night period.

→ Correct choice for an option will include the parameters

(i) Available solar insolation at optimum array tilt.

(ii) Free wind velocity at 10m or 20m height.

(iii)

number of cattle available in available in a village or a cluster community

(A) PV-Diesel
(B) wind-Diesel
(C) Biomass-Diesel
(D) wind-PV
(E) micro Hydel-PV
(F) Biogas-Solar thermal
(G) Solar-Biomass
(H) Electric and Electric Hybrid vehicles

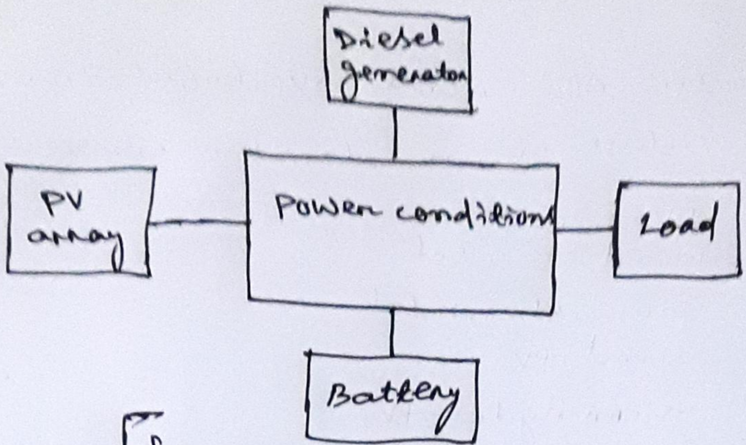
PV Hybrid with Diesel Generator:-

→ Renewable energy technologies are possible for electrification of remote villages including small hydro, wind, biomass and solar energy, yet solar PV-lighting remains the most preferred

→ Such systems are used in Orissa, Assam, Sikkim, Jammu and Kashmir and Uttarakhand

→ This power plant contains one PV array with a Diesel electric generator and a battery bank

→ Energy generated keeps the battery fully charge and some time supplies load demand when PV output is not sufficient and battery charge is low to supplement



[fig : Block diagram of PV – Diesel hybrid power plant]

→ fig-1 is a block diagram of such a power plant where power conditioner perform three functions.

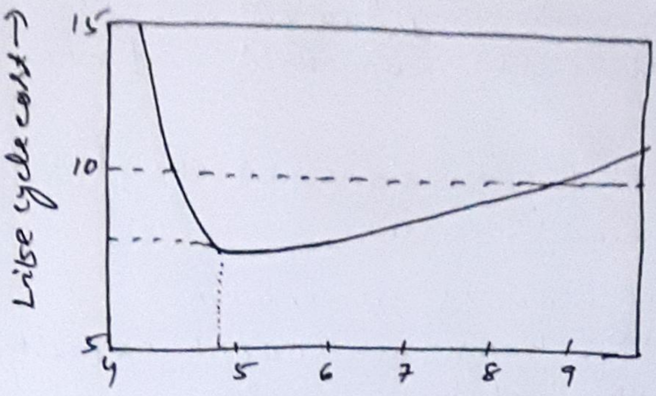
(i) To convert alternating current (A.C) diesel generated output into direct current (D.C) for charging battery bank.

(ii) To invert direct current (D.C) from PV array and battery bank into A.C for feeding load.

(iii) To regulate battery current and voltage for input from generator and output for load.

→ Several experiments have been carried out to find where 10 percent diesel fuel would be required with a given solar PV array area to replace 90 percent of diesel fuel that would be consumed for a diesel system only.

→ Experimental values have been used to draw a graph fig-2 shows "life cycle cost" versus array area ($10^3 \times m^2$)



[fig: graph of photo voltaic-diesel system i.e life cycle cost and array area]

→ Graph indicates a minimum cost point corresponding to a cost effective design for a PV-diesel hybrid power plant where PV has replaced 90 percent of the diesel fuel.

→ Thus a PV-diesel hybrid power plant ensures continuous power supply and is more cost effective as compared to stand alone PV system or stand alone diesel

Biomass-Diesel Hybrid system

→ combustion is a common process in biomass conversion technology.

→ Application of combustion process is for solid fuels either from cultivated biomass or waste biomass.

→ Biomass is widely available in hills and remote forest areas but becomes scarce during snowy winter.

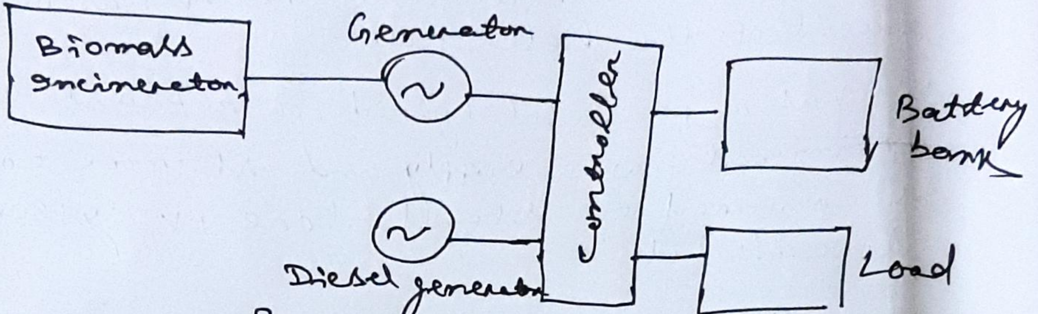
→ when its supply stops and stock dwindles energy route of biomass to electrical energy by incineration suffers a set back.

→ This system needs a back up by diesel power electric generator to meet the known lighting and plug loads of residences commercial establishments, hospitals and other life sustaining loads.

→ Essential components of this hybrid configuration are

(a) 25KW biomass generator
(b) Battery bank of 1000Ah capacity
(c) 15 KVA diesel generator

→ A biomass-fired steam power plant is made hybrid with a diesel generator along with a controller, battery bank and load is shown in fig-1



[fig: Biomass-diesel hybrid system]

→ TO operate this system, economic viability is necessary by utilising biomass generation to the full capacity and minimum use of diesel generator, for essential and life saving load during crisis period of biomass availability

Wind PV Hybrid system

→ Wind and Solar hybrid energy systems are located in open terrains away from multi storey buildings and forests

→ Locations are selected in those areas where the sunshine and wind are favourable for more than 8 months during a year.

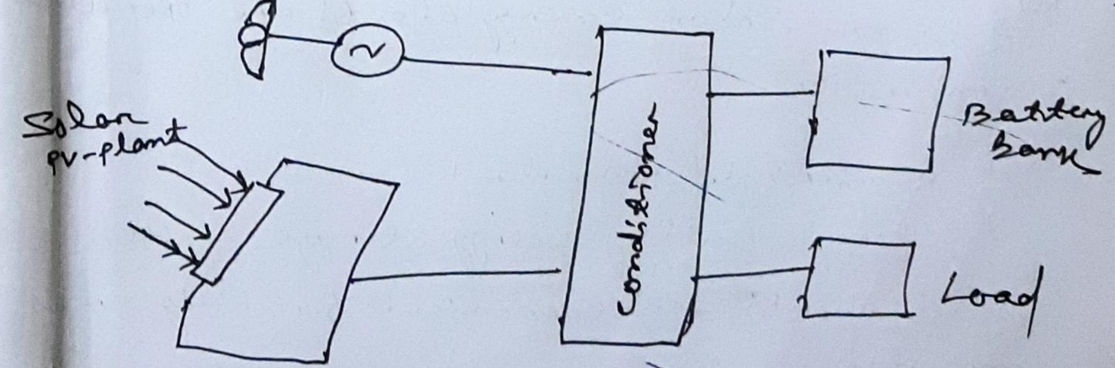
→ A schematic wind-PV hybrid system is shown in fig-1

→ During the day when sun shines, the solar photovoltaic plant generate D.c electric energy conditioner provided, converts D.c to A.c and supplies power to the load.

→ During favourable wind speed, wind turbine generator produce A.c electrical power

→ It supplies power to the load and excess energy after conversion to D.c is stored by the battery bank.

→ The plant may operate as stand alone load or may be connected to the state grid.



[fig Wind-PV hybrid system]

Micro Hydel-PV Hybrid System

→ Micro hydel (up to 100KW) power stations are low head (less than 3m) installations and provide decentralised power in mountain regions

→ In remote areas of J&K, boarder districts of Arunachal pradesh micro hydro power plants are the only source of energy.

→ With the help of micro hydro power, rural electrification can be achieved besides providing power for pumped irrigation and grinding mills.

→ In Arunachal pradesh, 425 villages are being electrified by completing 46 small/micro hydro power projects.

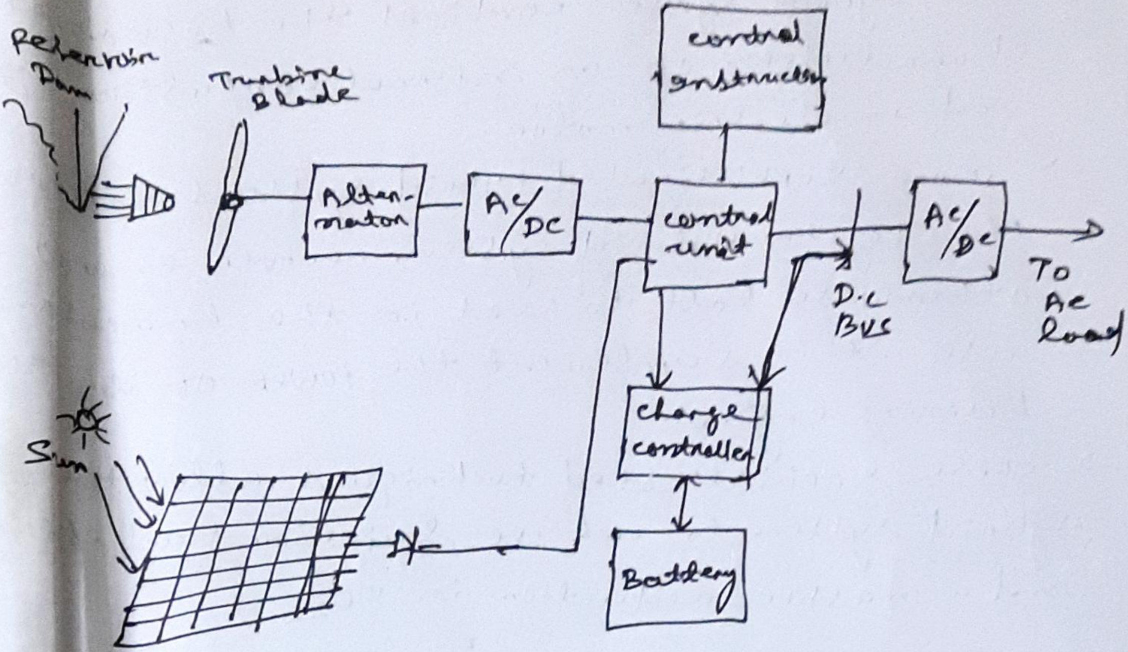
→ However, there are 1058 villages which cannot be illuminated by micro hydel projects as at several locations, head is very low, while at other quantity of water is small.

→ Solution is to provide micro hydel-PV hybrid system as sunshine is available practically at all locations.

→ Hence solar energy plants are operated in conjunction

* a microhydel powerplant
* storage battery energy storage system

Such plants are economical for hilly areas, mountain



[fig microhydel - PV hybrid system]

Hybrid Electric vehicle system

→ Rapid population growth and economic development in recent decades have resulted in a sharp increase in fossil fuel consumption on a global scale.

→ Faced with the challenges to create an earth-friendly vehicle.

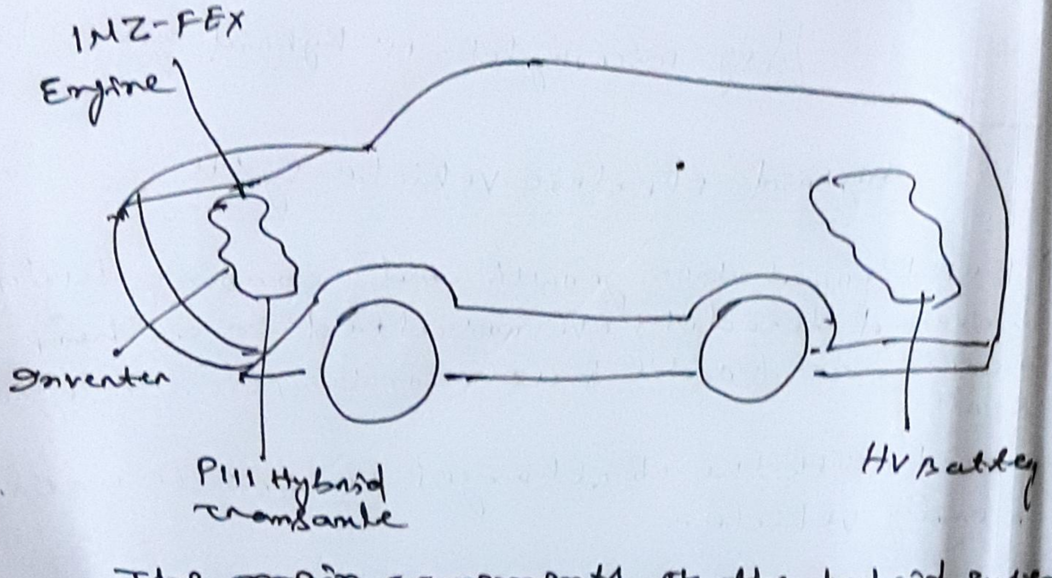
→ Toyota has produced the world's first mass produced hybrid automobile named prius (prius is a Latin word meaning "to go before"

→ The hybrid system is the wave of the future and now there are more incentives to purchase one

→ A hybrid system combines the best operating characteristic of an internal combustion engine and an electric motor.

→ More sophisticated hybrid systems such as the Toyota Hybrid system, recover energy otherwise lost to heat in the brakes and use it to supplement the power of its fuel burning engines.

→ These sophisticated techniques allow the Toyota Hybrid system to achieve superior fuel efficiency and a massive reduction in CO_2



The main components of the hybrid system are

* IC Engine
* Motor Generator-1 (MG1)
* Motor Generator-2 (MG2)
* Planetary Gear set
* Inverter
* HV Battery
* HV ECU (Electric control unit)

Hybrid Electric vehicle control mode:-

→ when starting and travelling at low speeds, MG-2 provides the primary motive force. The engine may starts immediately in the HV battery start of charge is low as speed increased above 15-20 mph the engine will start.

→ when driving under normal condition the engine energy is devided in to two part one portion drives the wheels another portion drive mg-1 to produced electricity the HV ECU controll the energy destribution radio for maximum efficiency. During full exellation power generator by the engine and mg-1 is supplemented by power by the battery. Engine torque combine with mg-2 torque delevors the power required to evaluate the vecile during dislaration or brakeing the wheel drives mg-2. And the mg-2 acts as a generator for regenerative power recovory the recovored energy from the braking is stored in the HV battery back.

5Th Semester

Renewable Power Generation Systems

(15 Hours)

Module I:
Introduction: Conventional energy Sources and its Impacts, Non conventional energy–seasonalvariations and availability, Renewable energy – sources and features, Distributed energy systemsand dispersed generation (DG). Solar Energy: Solar processes and spectral composition of solar radiation. Solar Thermal system-Solar collectors, Types and performance characteristics, Applications-Solar water heating systems(active & passive) , Solar space heating & cooling systems , Solar desalination systems, Solar cooker.Solar photovoltaic system-Operating principle, Photovoltaic cell concepts, Cell, module, array,Losses in Solar Cell, Effects of Shadowing-Partial and Complete Shadowing, Series and parallelconnections, Cell mismatching, Maximum power point tracking, Applications-Battery charging,Pumping, Lighting, Peltier cooling. Modelling of PV cell.

(10 Hours)

Module II:
Wind Energy: Wind energy, Wind energy conversion; Wind power density, efficiency limit for windenergy conversion, types of converters, aerodynamics of wind rotors, power ~ speed and torque speed characteristics of wind turbines, wind turbine control systems; conversion to electricalpower: induction and synchronous generators, grid connected and self excited induction generatoroperation, constant voltage and constant frequency generation with power electronic controlsingle and double output systems, reactive power compensation, Characteristics of wind powerplant, Concept of DFIG.

(9 Hours)

Module III:
Biomass Power: Principles of biomass conversion, Combustion and fermentation, Anaerobic digestion, Types of biogas digester, Wood gassifier, Pyrolysis, Applications. Bio gas, Wood stoves,Bio diesel, Combustion engine, Application.

(6 Hours)

Module IV:
Hybrid Systems: Need for Hybrid Systems, Range and type of Hybrid systems, Case studies ofDiesel-PV, Wind-PV, Microhydel-PV, Biomass-Diesel systems, electric and hybrid electric vehicles.

Text Books:

[1] Godfrey Boyle"Renewable Energy- Power for a Sustainable Future",Oxford University Press.
[2] B.H.Khan, "Non-Conventional Energy Resources",Tata McGrawHill, 2009.
[3] S. N. Bhadra, D. Kastha, S. Banerjee, "Wind Electrical Systems",Oxford University Press, 2005.

Reference Books:

[1] S. A. Abbasi, N. Abbasi, "Renewable Energy Sources and Their Environmental Impact", Prentice Hall of India, New Delhi, 2006

Digital Learning Resources:

Course Name: Energy Resources and Technology
Course Link: https://nptel.ac.in/courses/108/105/108105058/
Course Instructor: Prof. S Banerjee, IIT Kharagpur