CMR Institute of Technology, Bangalore			
Department(s): Electrical and Electronics Engineering			
Semester: 07	Section(s): A &B	Lectures/week: 04	
Subject: Solar and Wind Energy		Code: 18EE731	
Course Instructor(s): Prof. Nithara P V			
Course duration: 01 Oct 2021 to 31 Jan 2022			

Module 1

1(a). Explain the following terms i) Energy policy ii)Energy planning iii)Energy management iv) Energy audit v)energy conservation vi)Energy efficiency

IMPORTANT TERM & DEFINITION

- **Energy policy**
  - Overall guidelines for the effort to achieve greater energy efficiency
- **Energy planning**
  - Setting of concrete energy target complying with overall energy policy & elaborate action plan to achieve the target

- **Energy management**
  - The judicious & effective use of energy to maximize the profit
- **Energy audit**
  - Is an inspection, survey & analysis of energy flows for energy conservation in a building, process / system to reduce amount of energy input into the system without affect the output

- **Energy conservation**
  - Act of saving energy by reducing service . Conserve energy by cut back the usage
- **Energy efficiency**
  - Saving energy, but keeping same level of service(Eg: using LED instead of incandescent lamp)

- **Energy intensity**
  - Measure of the energy efficiency of a nation economy
  - It is calculated an amount of energy consumed for generating one unit of gross domestic product(GDP).

- **Energy elasticity**
  - Percentage change in energy consumption to achieve one percentage change in national GDP in specific country over time

1(b) Write advantages and limitations of non-Conventional energysources

1.9 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. Thus, by and large, they are environment friendly.
3. They are inexhaustible.
4. They have a low gestation period.

Demerits

1. In general, the energy is available in dilute form from these sources.
2. Though available freely in nature, the cost of harnessing 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.

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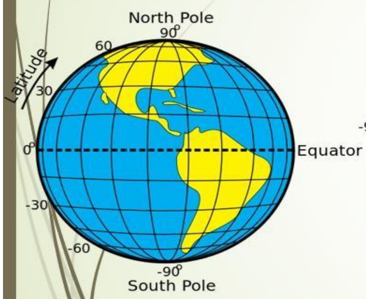
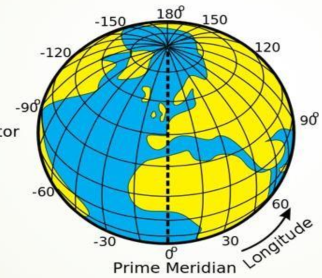
6a) Define the following terms with respect to solar radiation

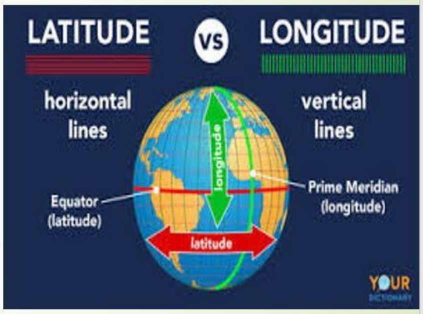
a. Latitude; b. Longitude; c. Declination Angle; d. SolarNoon; e. Hour Angle;

f. Altitude Angle; g. Zenith Angle; h. Solar Azimuth Angle; i. Tilt Angle; j. Surface Azimuth Angle; k. Angle of Incidence.

Latitude & longitude



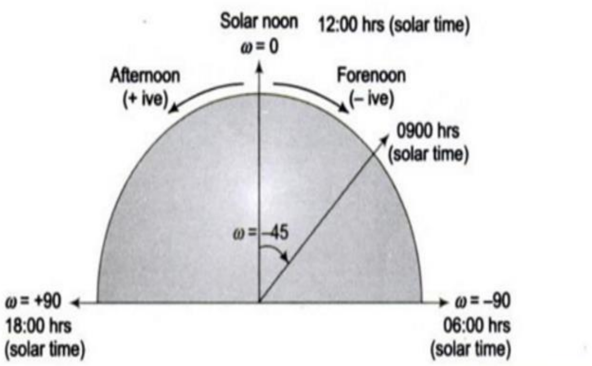




Hour angle ω

- Hour angle at any moment Is the angle through which Earth must turn to bring the **meridian of the observer** directly in line with **sun's ray**

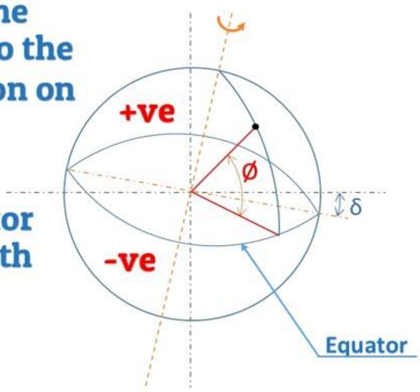
$$\omega = [\text{Solar Time} - 12{:}00]\ (\text{in hrs}) \times 15\ \text{degrees} \quad (4.6)$$



Angle of Latitude (Ø):

It is the vertical angle between the line joining that point of location to the centre of the earth and its projection on an equatorial plane.

When the point is north of equator the angle is positive and when south it is negative.

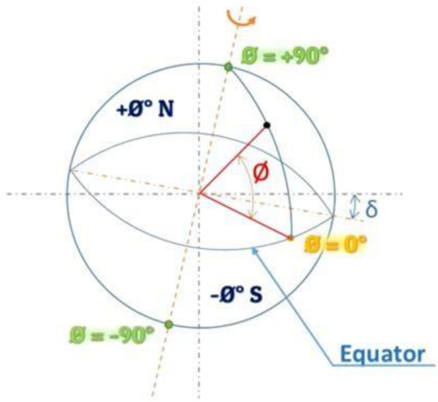


Angle of Latitude (Ø):

Angles are represented as Ø° N or Ø° S of equator.

Also,

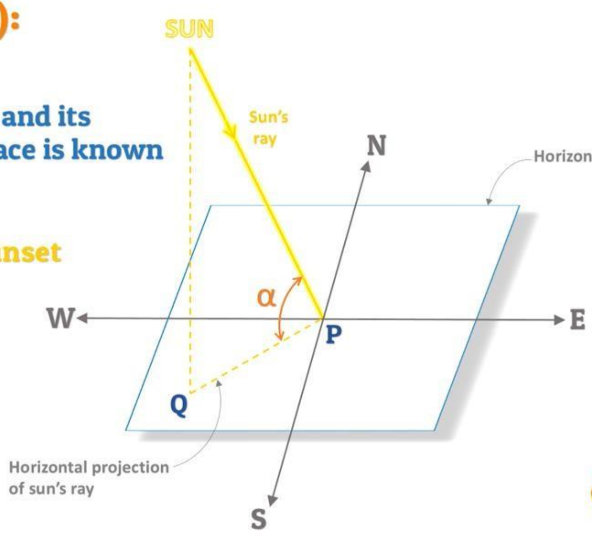
Ø = 0° for point on the equator
Ø = ±90° for a point at the poles



Inclination angle (α):

The angle between sun's ray and its projection on a horizontal surface is known as the inclination angle (α).

➔ $\alpha = 0°$ at sunrise and sunset



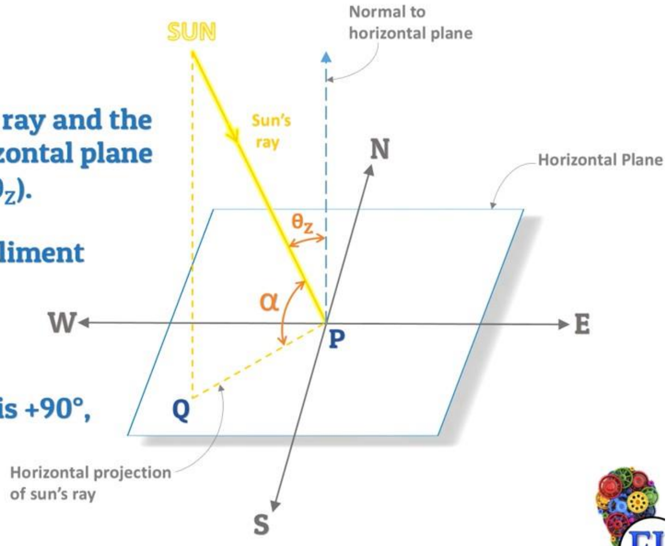
Zenith angle (θ_Z)

The angle between the sun's ray and the perpendicular (normal) to horizontal plane is known as the Zenith angle (θ_Z).

Also, Zenith angle is compliment of inclination (altitude) angle,

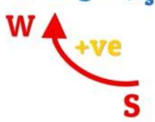
i.e. $\alpha + \theta_Z = 90°$

Hence, at sunrise zenith angle is +90°, whereas -90° at sunset.

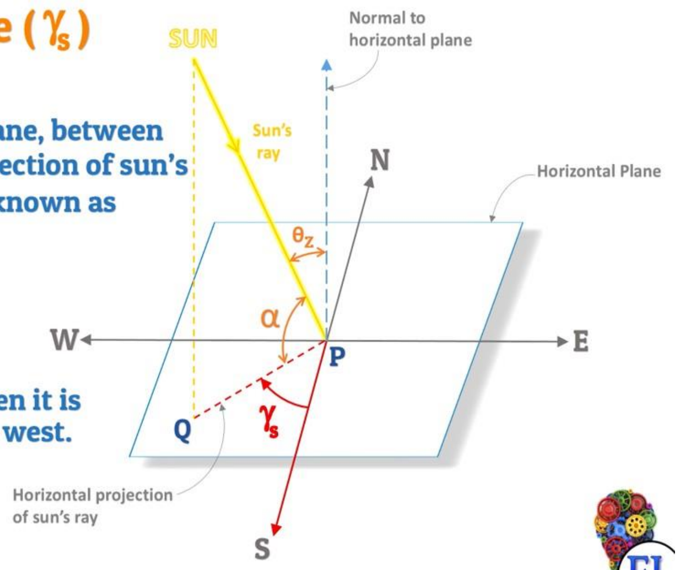


Solar azimuth angle (γ_s)

The angle on a horizontal plane, between the line due south and the projection of sun's ray on the horizontal plane is known as Solar azimuth angle (γ_s).

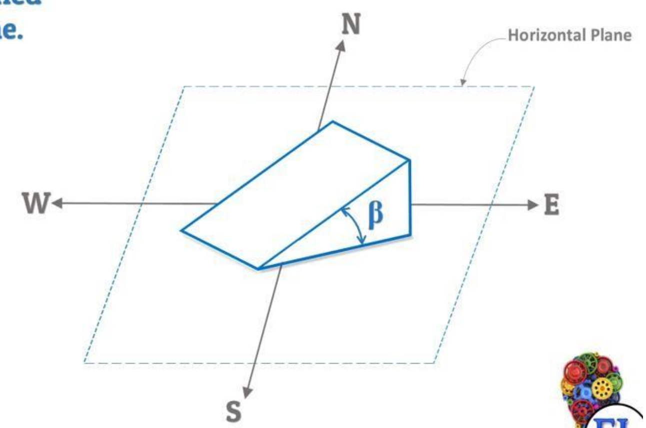


It is considered as positive when it is measured from south towards west.



Tilt angle or slope (β)

It is an angle between the inclined surface and the horizontal plane.



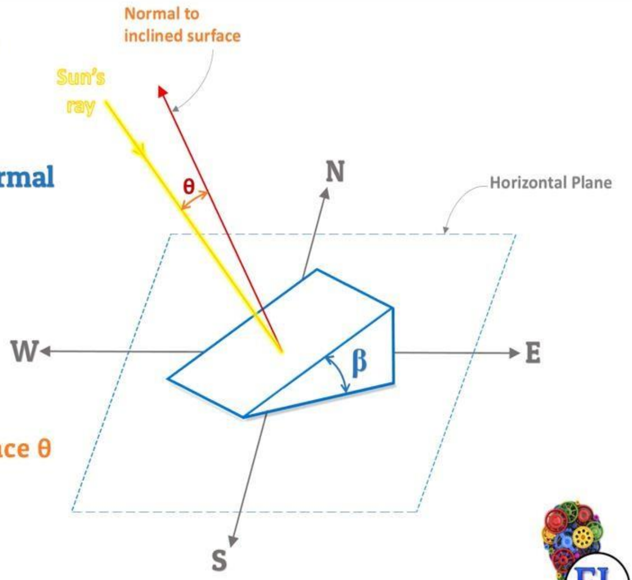
Angle of incidence (θ)

It is an angle between sun's ray incident on plane surface and normal to that surface.

For Horizontal Surface,

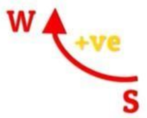
Slope, $\beta = 0°$

Zenith Angle θ_Z = Angle of Incidence θ

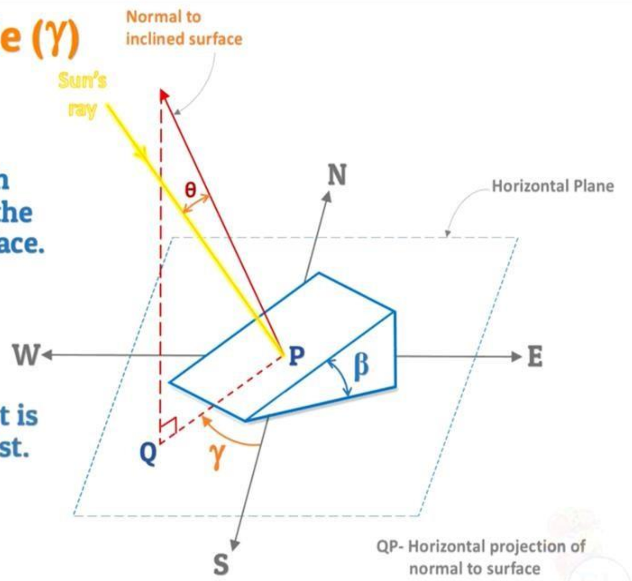


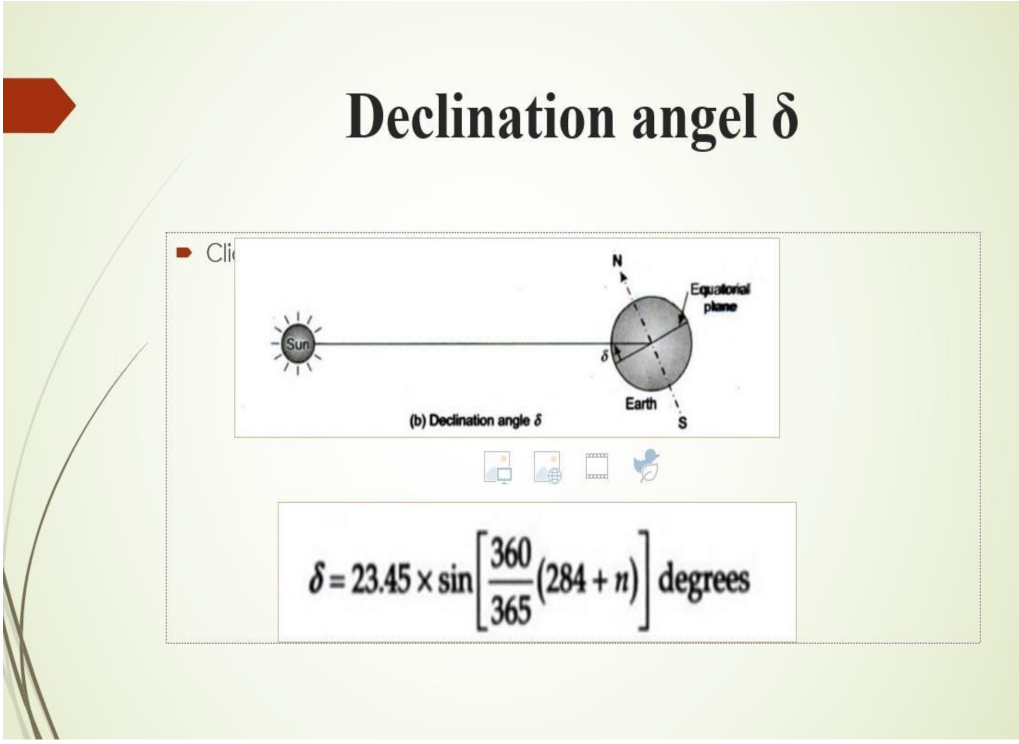
Surface azimuth angle (γ)

It is the angle in the horizontal plane, between the line due south and the horizontal projection of the normal to the inclined plane surface.



It is considered as positive when it is measured from south towards west.





Module 2

Solar Energy – Basic Concepts

3(a).Calculate the number of day light hours (sunshine hours) in Srinagar on January 1 and on July 1. The latitude of Srinagar is 34^0 05’ N.

Jan 1

$n = 1$

$\delta = 23.45^\circ \sin\left[360^\circ \left(\frac{284+n}{365}\right)\right] = -23.01^\circ$

$\phi = 34^\circ 05' = 34.083^\circ$

$t_d = \frac{2}{15} \cos^{-1}\left[-\tan\phi \tan\delta\right] = 9.77h = 9h\ 46m\ 25s$

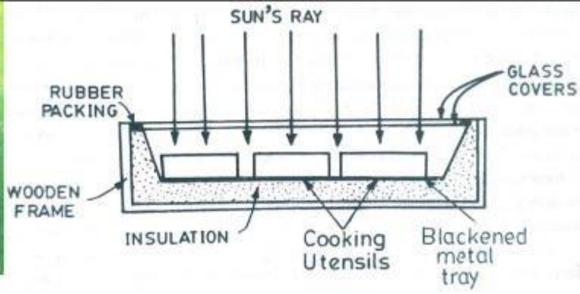
July 1

$n = 182$

$\delta = 23.45^\circ \sin\left[360^\circ \left(\frac{284+n}{365}\right)\right] = 23.12^\circ$

$t_d = \frac{2}{15} \cos^{-1}\left(-\tan\phi \tan\delta\right) = 14.238h = 14h\ 14m\ 20.$

3(b). With a neat sketch, explain box type of solar cooker.



- Used to
  - Cook food
  - Pasteurize water
  - Drying fish and grains

Basic Principle (Diagram on right top corner depicting box type solar cooker principle)

- Concentrating Sunlight
  - Reflective mirror (polished glass, metal or metalized film)
  - Reflective mirror concentrates sunlight on cooking area
- Converting Light to Heat
  - Black surface on food container or inside of a solar cooker
  - Absorbs light and heats the content
- Trapping Heat
  - Plastic bag or tightly sealed glass cover traps heat
- Greenhouse Effect
  - Glass transmits visible light
  - Blocks escaping of infrared thermal radiations
  - In turn amplifies heat trapping effect

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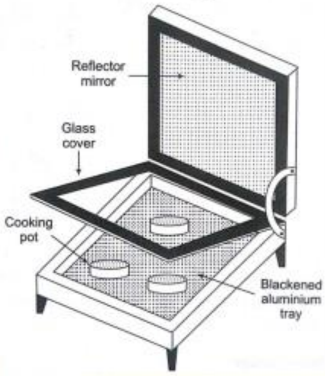
TYPES OF SOLAR COOKERS

Box Type Solar Cooker

- Well insulated box
- Double glass lid
- Reflector cover on inside
- External dimension of a typical family size (4 dishes) box cooker is 60 x 60 x 20 cm
- Simple in construction and operation
- Box receives direct radiation and reflected radiation from reflector mirror fixed on inner side of box cover hinged to one side of the box
- Angle of reflector is adjusted accordingly
- With addition of reflector temperature rise of 15 to 25 °C is achieved
- Glass cover consisting of two layers of clear window glass sheets serves as box door
- Box cover traps heat due to green house effect
- With single reflector temperature in solar cooker in maintained from 70 to 110 °C
- Maximum air temperature obtained inside the box is 140 °C in winter to 160 °C in summer
- This is enough to cook boiling type food slowly in 1 to 4 hours



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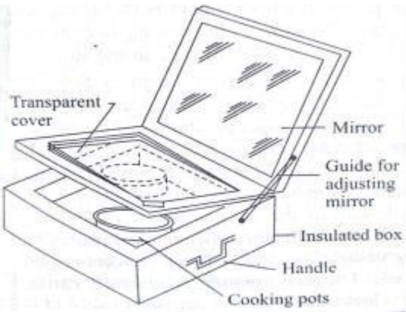
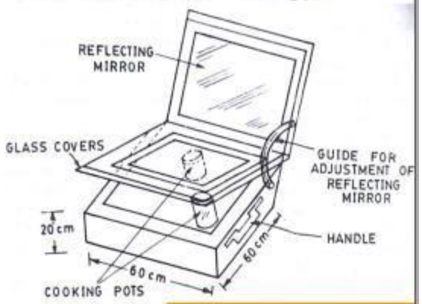
- Meat should be allowed to cook for 3 to 4 hours, vegetables form 1 ½ to 2 ½ hours, all types of dals can be cooked in 1 ½ to 2 hours, rice is cooked between 30 min to 2 hours Best time of day to cook is between 11 am to 2 pm
- Cooking is faster in summer than in winter
- Can cook 2 kg of food and can save 3 to 4 LPG cylinder fuel a year
- Electrical back up is provided to use during non sunshine hours
- Cost varies between Rs. 5000/- to Rs. 6290/- depending on type, size, quality, and electrical backup facility
- More affordable, folding type solar cooker made of cardboard is also developed
- In India a typical good quality cooker with a mirror varies between Rs. 1000/- to Rs. 2500/- and can be used for at least 250 days in a year with a pay back period of 3 to 4 years
- Keeps food warm in afternoon and evening
- Most widely used
- It is estimated that more than 600,000 cookers have been sold and the number is growing at a rate of about 20,000 to 30,000 every year



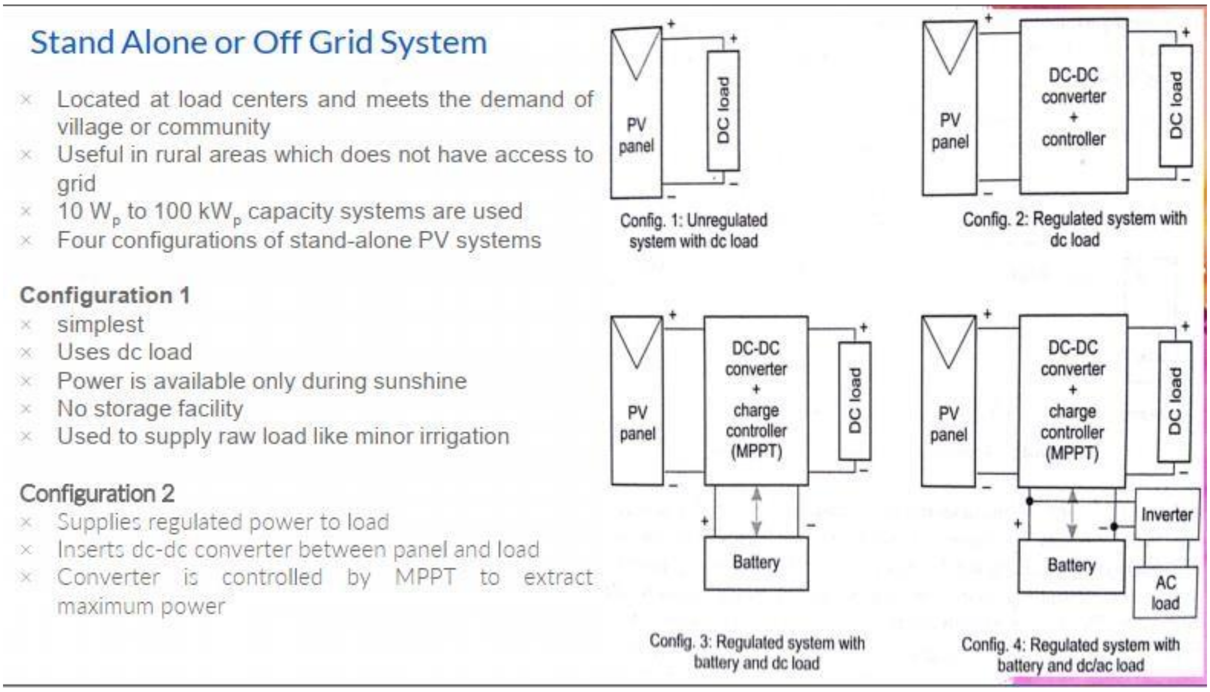


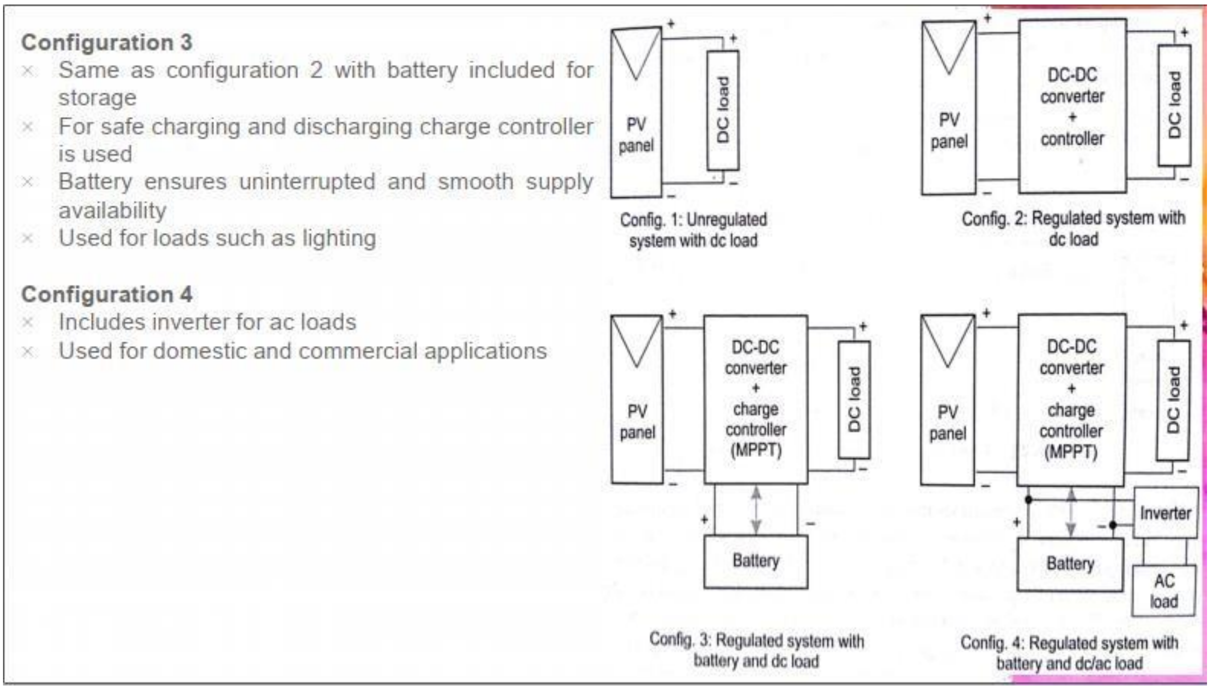
ADVANTAGES
- No attention during cooking
- No fuel required
- Negligible maintenance
- No pollution
- No problem of charring of food and no over flowing
- Vitamins of food are not destroyed and food cooked is nutritive and delicious with natural taste

DISADVANTAGES
- Should cook according to sunshine and menu has to be planned
- More time for cooking
- Food cannot be cooked in cloudy days or night
- Box type cookers with no reflector or with one reflector cannot be used for cooking chapatis and purees as they require high temperatures

Module 3. Solar Photovoltaic Systems

4. With the help of block diagrams, explain the different configurations of stand-alone solar PVsystems.



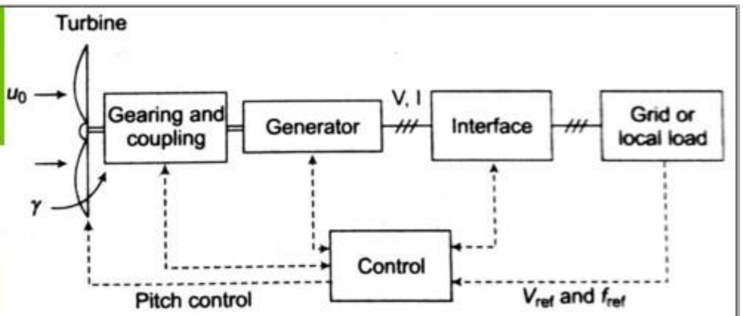


M4.a. Wind Energy

5(a). With a neat block diagram, explain the basic principle of wind energy conversion system.

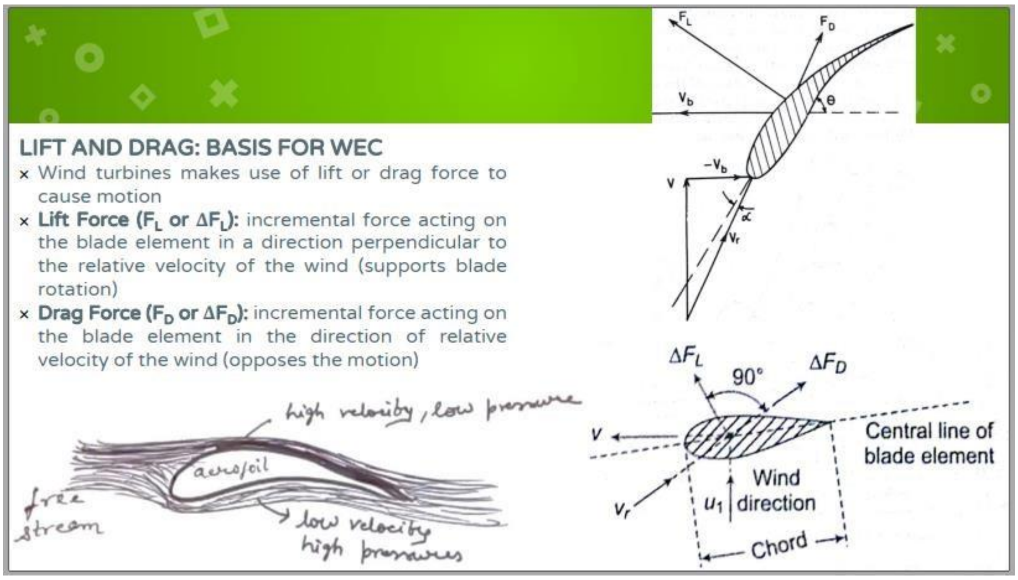
- Basic principle of wind energy conversion is to convert kinetic energy of the wind to mechanical energy
- This mechanical energy is used in farm appliances, water pumping or is converted to electricity using aero generator
- Aero generator/wind generator/ wind energy conversion system (WECS) is a generator coupled wind turbine
- A step up transmission is required to match relatively slow speed of the wind rotor to the higher speed of an electric generator

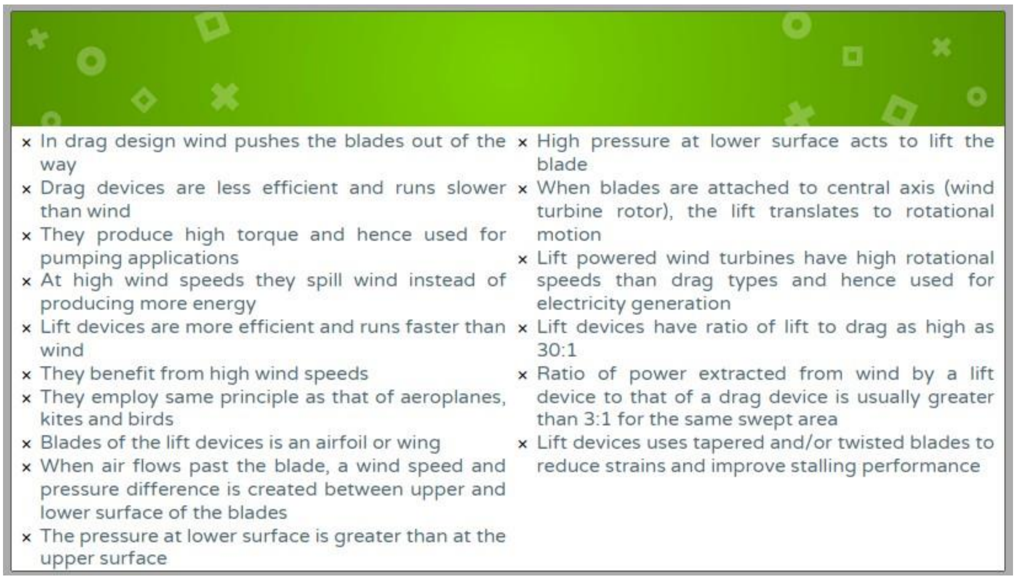
- General block diagram of WECS is shown in figure
- Turbine shaft speed is stepped up with the help of gears, with fixed gear ratio, to suit the electrical generator
- Fine tuning of the speed is incorporated by pitch control
- Variable gear ratio is not preferable as it creates problems
- Depending on the design of the system DC, Synchronous or Induction generators are used for mechanical to electrical power conversion



- Function of the interface section is to condition the generated power to grid quality power by using power electronic converter, transformer and filter
- Control unit monitors and controls interaction between various blocks
- The control unit drives the reference voltage and frequency signals from the grid and receives wind speed, wind direction, wind turbine speed etc. processes them and accordingly controls various blocks of optimal energy balance

5(b) With the help of a neat diagram, explain the terms lift force and drag force.





6. Wind at a velocity of 20 m/s flows through a HAWT having a diameter of 10 m. Calculate (i) total power available in wind; (ii) total power density; (iii) maximum power which can be extracted; and (iv) torque at maximum efficiency if rotor speed is 30 rpm. Assume ρ = 1.293 kg/m3 and $g_c = 1$.

$V_1 = V = 20$ m/s $\quad D = 10$ m ; $\quad N = \frac{30}{60} = 0.5$ rps ;

$\rho = 1.293$ kg/m^3

(i) $P_a = \frac{1}{8}\rho \pi D^2 V^3 = \frac{1}{8} \times 1.293 \times \pi \times (10)^2 \times (20)^3$

$= 406.208$ KW

(ii) $\frac{P_a}{A} = \frac{1}{2}\rho V^3 = \frac{1}{2} \times 1.293 \times (20)^3$

$= 5172$ W/m^2

(iii) $P_{max} = 0.593 \, P_a = 240.881$ KW

OR

$P_{max} = \frac{8}{27} \rho A V_1^3 = \frac{8}{27} \rho \left(\frac{\pi D^2}{4}\right) V_1^3$

$= \frac{8}{27} \times 1.293 \times \frac{\pi \times (10)^2}{4} \times (20)^3$

$= 240.715$ KW

(iv) $T_{max} = \frac{2}{27} \frac{\rho D V_1^3}{N} = \frac{2}{27} \times \frac{1.293 \times 10 \times (20)^3}{0.5}$

$= 15324.44$ N

M5 – Basic Components of WECS

7(a) List and explain various classification of wind energy conversion systems.

Broad Classifications
- Horizontal Axis Wind Turbines (HAWT)
- Vertical Axis Wind Turbines (VAWT)

According to Size
- Small size machine (up to 2 kW) – used in farm, remote applications and places requiring low power
- Medium size machine (2 kW to 100 kW) – residential or local use
- Large size machine (100 kW and above) – used to generate power for distribution in central power grids. Two subclasses – (a) Single generator at single site (b) Multiple generator sited at several places over an area

According to Output Power
- DC Output – (a) DC generator (b) Alternator Rectifier
- AC Output – (a) Variable frequency, variable or constant voltage AC (b) Constant frequency, variable or constant voltage AC

According to Rotational Speed of Aeroturbines
- Constant speed with variable pitch blades – uses synchronous generator with constant frequency output
- Nearly constant speed with fixed pitch blades – uses induction generator
- Variable speed with fixed pitch blades – uses constant frequency output system such as Field Modulated System, AC-DC-AC Link, Double Output Induction Generator, AC Commutator generators etc.

According to Utilization of Output
- Battery storage
- Direct connection to an electromagnetic energy converter
- Other forms such as thermal potential etc. of storage
- Interconnection with conventional electric utility grids

7(b). Derive the relationship between the torque coefficient (C_T), power coefficient (C_P) and the tipspeed ratio (λ).

❖ RELATIONSHIP BETWEEN C_T, C_P, and TSR (λ)

$$C_T = \frac{T}{T_{max}}$$

$$T = C_T\, T_{max} \quad (1)$$

Maximum torque occurs if maximum thrust is applied at the blade tip furthest from the axis

$$T_{max} = F_{max}\, R; \qquad \text{where R is radius of propeller turbine}$$

$$F_{max} = \frac{1}{2}\rho A\, V_1^2$$

$$T_{max} = \frac{1}{2}\rho A\, V_1^2\, R \quad (2)$$

$$\text{Tip speed ratio (TSR) } \lambda = \frac{V_{tip}}{V_1} = \frac{R\omega}{V_1}$$

Where R is outer blade radius and ω rotational frequency

$$R = \frac{\lambda V_1}{\omega} \quad (3)$$

(3) In (2)

$$T_{max} = \frac{1}{2\omega}\rho A\, V_1^2\, \lambda V_1 = \frac{1}{2}\rho A\, V_1^3\, \frac{\lambda}{\omega} = P_a \frac{\lambda}{\omega} \quad (4); \quad \text{where } P_a = \text{available power in wind}$$

Shaft power is the power derived from the turbine P_t , so

$$P_t = \tau\, \omega = T\, \omega \quad (5)$$

Also,

$$P_t = C_P\, P_a \quad (6)$$

Putting (6) and (1) in (5)

$$C_P\, P_a = C_T\, T_{max}\, \omega$$

From (4)

$$C_P\, P_a = C_T\, P_a\, \lambda$$

$$C_P = \lambda C_T$$

Note that in practice C_P and C_T will be function of λ and not constants

By Betz criterion for ideal case C_P maximum value if 0.593 hence,

$$C_{T\,max} = \frac{0.593}{\lambda}$$

- High solidity machines have high starting than running torque while starting torque of low solidity machine is lower than their already low running torque