RENEWABLE & NON CONVENTIONAL ENERGY

NOTE:

MAKAUT course structure and syllabus of 5th Semester has been changed from 2020. Previously **RENEWABLE & NON CONVENTIONAL ENERGY** was in 7th semester. This subject has been shifted in 5th semester in present curriculum. Subject organization has been changed slightly. Taking special care of this matter we are providing chapterwise relevant MAKAUT university solutions, so that students can get an idea about university questions patterns.

INTRODUCTION TO ENERGY SOURCES

Multiple Choice Type Questions

1. Which of the following is not renewable energy source? [WBUT 2009, 2010, 2011, 2012, 2013, 2014, 2018]
a) hydropower b) tidal power c) geothermal d) fuel cell
Answer: (d)

2. Global warming is mainly caused due to [WBUT 2011, 2015]
a) emission of heat from engine
b) emission of CO_2 due to burning of fossil fuels
c) use of nuclear energy d) air pollution
Answer: (b)

3. Harmful nuclear radiation includes [WBUT 2016]
a) alpha particles b) beta particles
c) gamma particles d) all of these
Answer: (d)

4. The temperature in the crust increases with depth at a rate of about [WBUT 2018]
a) 300°C/km b) 10°C/km c) 1°C/km d) 30°C/km
Answer: (c)

5. Which energy accounts for largest share in the renewable energy basket of India? [WBUT 2019]
a) Wind b) Nuclear c) Hydel d) Solar
Answer: (c)

Short Answer Type Questions

1. How economic are the non-conventional sources with respect to the conventional energy sources? Considering that, how do you rate the future of non-conventional energy source? [WBUT 2011, 2013]

Answer:
The variety of ways to collect, convert, store and use non-conventional energy is enormous. Non-conventional energy systems produce electricity, thermal energy and mechanical power derived directly from the sun on wind or indirectly through solid, liquid or gaseous fuels.
Three criteria can be used to assess the potential of non-conventional energy
1. quality of energy produced
2. regardless of form
3. level of power production (kW or MW) and whether such power is suitable for base load, intermediate on peaking uses.

The cost of commercially available non-conventional energy have been the subject of a great deal of investigation but much of this work can be summarized in two statements.

1. There are a number of systems that currently produce energy or a electricity at prices competitive with those of oil-fired systems, especially in locations that are richly endowed with non-conventional energy sources and where fuel transportation costs are high. These systems, which can be installed relatively quickly including wind machines in good wind regions, bagassee or wood-fired electric power generation units, small hydro stations, biogas units and charcoal production from forestry residues or sustained yield plantations. The site specific nature of these resources means that the total contribution from such systems may have a large local but a much smaller national or regional impact.
2. Systems that could have a large national and international impact (e.g., solar photovoltaic cells, solar thermal collectors and utility-scale electric batteries) are not yet economic in comparison with conventional energy system terms and energy efficient measures, except in very special markets. Certain cost goals must be achieved if the first two technologies are to make a major contribution to the energy sectors of either developed or developing countries.

2. Discuss different renewable sources of energy with reference to Indian context.
[WBUT 2015]

Answer:

India is endowed with abundant natural and renewable resources of energy namely, solar, wind and biomass. The available renewable resources need to be exploited by giving a commercial orientation, wherever possible. Efforts are being made to make the renewable sources cheaper and more efficient. The main attention has to be directed to the following sources of renewables, namely, i) wind energy ii) Solar energy iii) Bio-mass energy iv) Small hydro resources v) Geothermal Energy v) Ocean Tidal energy.

(i) Wind Energy: The highly successful wind power programme in India was initiated in 1983-84 and is entirely market driven. The current (July 2008) installed capacity for wind power stands at 8,696 MW, and is mostly located in Tamil Nadu, Gujarat, Maharashtra and Rajasthan.

(ii) Solar Energy: India receives a solar energy equivalent of more than 5,000 trillion kWh per year, which is far more than its total annual consumption. The daily global radiation is around 5 kWh per sq. m per day with sunshine ranging between 2300 and 3200 hours per year in most parts of India.

(iii) Biomass Energy: A large quantity of biomass is available in our country in the form of dry waste like agro residues, fuel wood, twigs, etc., and wet wastes like cattle dung, organic effluents, sugarcane bagasse, banana stems, etc. The potential for generation of electric power/cogeneration is 16,881 MW from agro residues and 5000 MW from bagasse through cogeneration. The potential from urban waste is 2,700 MW.

(iv) Small Hydro Resources: The total potential is 15,000 MW out of which 2,015 MW has been realized by approximately 611 plants in India.

(v) Geothermal Energy: The potential in geothermal resources in the country is 10,000 MW As a result of various resource assessment studies/surveys, nearly 340 potential hot springs have been identified throughout the country. Most of them are low-temperature hot-water resources and can best be utilized for direct thermal applications. Only some of them can be considered suitable for electrical power generation. The geothermal reservoirs suitable for power generation have been located at Tattapani in Chhattisgarh and Puga valley of Ladakh, Jammu and Kashmir. A 300 kW demonstration electric-power-production plant is being installed at Tattapani.

(vi) Ocean Tidal Energy: There is no functional tidal plant at present and the total potential has been estimated as 9,000 MW, Three sites have been identified for development of tidal energy.

- Gulf of Kutch: potential = 900 MW, tidal range = 5 m
- Gulf of Cambay (Khambat): Potential = 7,000 MW, tidal range = 6 m
- Sundarbans: potentials 1,000 MW, tidal range- 3.9 m

Long Answer Type Questions

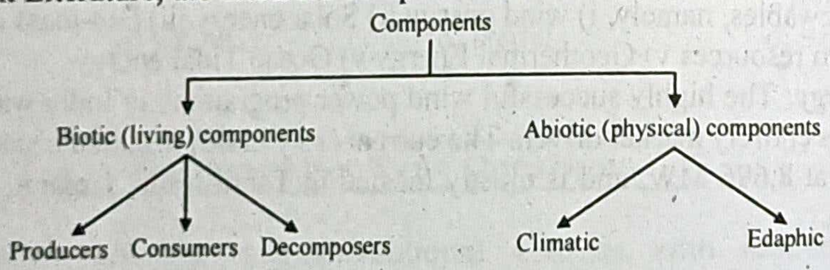
1. What are the different components of environment? What environmental hazards are created by the conventional power plants? Explain the importance of non-conventional energy sources in the context of global warming. [WBUT 2011]

Answer:

1st Part:

Different components of environment

As per British Literature, the different components of environment are



As per American Literature, the different components of environment are

1. Hydrosphere (Water)
2. Atmosphere (Air)
3. Lithosphere (Land)
4. Biosphere (Flora/Fauna/Microbes)
5. Anthrophere (Man made things).

2nd Part:

Greenhouse Effect: A greenhouse is an enclosure having transparent glass panes or sheets. It behaves differently for incoming visible (short wave) radiations and outgoing infrared (long wave) radiations. It is transparent for incoming solar radiation, allows entry of sunlight and becomes largely opaque for reflected infrared radiation from the earth's surface, thus preventing the exit of heat. Hence, it maintains a controlled warmer environment inside for growth of plants in places where the climate is very cold.

Consequences of Global Warming: Global warning is caused mainly due to the emission of excessive CO_2 due to agricultural practices. This trend is leading to the melting of polar snowcaps, which accounts for more than 90% of the world's ice. Melting of the polar snowcaps would, in turn, increase the level of oceans and would possibly redefine ocean boundaries inundating low-lying areas and smaller islands. During the last 100 years, the earth's temperature has increased about half a degree Celsius and sea levels have risen 6 to 8 inches (15 to 20 cm). Experts have predicted more frequent and severe heat waves, more intense tropical cyclones, change in rainfall patterns, melting of ice and glaciers at mountains, thus causing floods, followed by decline of water supplies and an increased incidence of vector-borne deceases like malaria.

Pollution:

(a) **Indoor Pollution:** Indoor pollution is mainly caused due to use of conventional chulhas in rural areas. About 5,00,000 children and women die from diseases caused due to indoor air pollution each year. This requires the need of improved household stoves to reduce indoor pollution.

(b) **Outdoor Pollution:** Outdoor pollution is mainly caused due to use of fossil fuels. Emissions from fossil fuel based plants degrade the environment and cause various other problems. Coal and oil are more pollutant than gas.

Remedy:

1. Use of fossil fuels should be slowly curtailed. Less-polluting technologies should be employed for use instead of fossil fuels, i.e., gasified coal, which is less polluting, should be used in power plants.
2. Clean alternative fuels such as hydrogen should be used. Hydrogen should be used. Hydrogen is the cleanest fuel and does not cause pollution during power conversion.
3. Electric vehicles or battery-operated vehicles should be used in place of IC-engine-based vehicles.

Various Pollutants and their Harmful Effects:

1. **Particulate matter:** The presence of particulate matter
    - reduces sunlight
    - reduces visibility
    - A level above 100 $\mu g/m^3$ (yearly average) results in respiratory problems
    - A level above 300 $\mu g/m^3$ (yearly average) results in bronchitis (inflammation of mucus membrane inside the bronchial tubes, branches of the wind pipe)

The annual average permissible limit is 75 $\mu g/m^3$.

2. CO_2: Carbon dioxide is ordinarily not considered a toxic gas. It is essential for photosynthesis and production of essential oxygen and organic matter in nature. But increased concentration of CO_2 adversely affects the global climate. Excess emission of CO_2 in the atmosphere causes global warming due to greenhouse effect.
3. CO: CO is formed due to incomplete burning of carbon in inadequate air. It seriously impairs the oxygen-dependent tissues in the body, particularly the brain, heart and skeletal muscles. CO concentration of 100 ppm causes headache, 500 ppm causes collapse and 1000 ppm is fatal. Smokers inhale Co concentrations of 400 to 450 ppm.
4. SO_X: The presence of SO_2 in the air is mainly due to manmade reasons involving combustion of fuels containing sulphur. The contribution from various sources is as follows:

Power plants	70%
Industry	15%
Motor vehicles	8%
Solid waste disposal	5%
Others	2%

SO_2 can further oxidize to form sulfur trioxide, which in turn forms sulphuric acid when absorbed in water.
Harmful Effects
(a) Causes respiratory deceases including asthma, and the irritates eyes and respiratory track
(b) Causes acid rains, which are harmful to agriculture, forest, vegetation, soil and stones (and thus to buildings)
5. NO_X: Oxides of nitrogen such as N_2O, NO, NO_2, N_2O_3 are commonly referred as NO_X. About 80% of nitrogen oxides in the atmosphere are produced due to natural causes (biological reactions) and about 20% due to manmade causes – mostly due to combustion process in air at high temperature. NO_X is formed by the interaction of nitrogen and oxygen at high temperature. Manmade causes include:

(a) Motor vehicles	7%
(b) Industry	7%
(c) Power plants	4%
(d) Solid waste	2%

Harmful Effects
(a) Causes respiratory and cardiovascular illness
(b) It deprives the body tissues of oxygen
(c) It also forms acid in lungs and, therefore, is more toxic than CO
The safe limit is 100 $\mu g/m^3$.

3rd Part:
The term green power is used to explain sources of energy, which are considered environmental friendly, non-polluting; and therefore may provide a remedy to the systemic effects of certain forms of pollution and global warming. This is in fact, the renewable energy sourced from the sun, the wind, water, biomass and waste.

Green energy is commonly thought of in the context of electricity, heating and cogeneration and is becoming increasingly available. Consumers, businesses and organizations may purchase green energy in order to support further development, help reduce the environmental impacts associated with conventional electricity generation and increase their nation's energy independence. Renewable energy certificates (green certificates, or green tags) have been one way for consumers and businesses to support green energy.

Concern for the environment due to ever-increasing use of fossil fuels and rapid depletion of natural resources have led to development of alternative sources of energy, which are renewable and environment friendly. The following points may be mentioned in this connection:

1. The demand of energy is increasing by leaps and bounds due to rapid industrialization and population growth and hence the conventional sources 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 one day.
3. Conventional sources (fossil fuels, nuclear) also cause pollution, thereby their use degrades the environment.
4. Large hydro resources affect wildlife, cause deforestation and pose various social problems.
5. In addition to supplying energy, fossil fuels are also used extensively as feed stock materials for the manufacture of organic chemicals. As reserve deplete, the need for using fossil fuels exclusively for such purposes may become greater.

2. What is greenhouse effect? Write down the consequences of global warming.
[WBUT 2017]

Answer:

Refer to Question No. 1(2nd part) of Long Answer Type Questions.

3. Write short notes on the following:
a) NCES potential: Indian perspective **[WBUT 2008, 2013]**
b) Advantages of non-conventional sources over conventional sources **[WBUT 2009, 2012]**
c) Kyoto protocol **[WBUT 2015, 2017]**
d) Greenhouse Effect **[WBUT 2018]**

Answer:

a) NCES potential: Indian perspective:

Non-conventional energy sources in India comprise those energy sources that are natural, inexhaustible as well as renewable. Like for instance, solar energy, tidal energy and wind energy. Interestingly, wind and running water were in use as sources of energy long before the conventional sources of energy like coal, mineral oil and natural gas came to be used widely. Initially, windmills were used for grinding grains as well as for pumping water. Wind and running water were also used for navigation. In present times, some of the major and extensively used non-conventional sources energy includes wind, tides,

solar geo-thermal heat, biomass including farm and animal waste as well as human excreta. Like for instance, sewage from large cities can be used for generating biogas. All these sources are renewable or inexhaustible. They are inexpensive in nature.
Located in the tropical region, India is endowed with abundant renewable energy resources, i.e., solar, wind and biomass including agricultural residue which are perennial in nature. Harnessing these resources is best suited to meet the energy requirement in rural areas in a decentralized manner. India has the potential of generating more than 1,00,000 MW from non-conventional resources. Up to June 30, 2008, the electrical power generation by non-conventional resources has reached 12,194 MW, which is about 8.4% of total installed electrical power-generation capacity. The government plans to increase this share to 10% by 2012.

(i) Wind Energy: The highly successful wind power programme in India was initiated in 1983-84 and is entirely market driven. This sector has been growing at over 35% in the last three years. India currently (year 2008) stands fourth *m* the world among countries having installed large capacity wind generators, after Germany, USA and Spain. The current (July 2008) installed capacity for wind power stands at 8,696 MW, and is mostly located in Tamil Nadu, Gujarat, Maharashtra and Rajasthan. The government aims to add 10,000 MW from wind during Xlth plan period (2007-2012).

(ii) Solar Energy: India receives a solar energy equivalent of more than 5,000 trillion kWh per year, which is far more than its total annual consumption. The daily global radiation is around 5 kWh per sq. m per day with sunshine ranging between 2300 and 3200 hours per year in most parts of India. Though the energy density is low and the availability is not continuous, it has now become possible to harness this abundantly available energy very reliably for many purposes by converting it to usable heat or through direct generation of electricity. The conversion systems are modular in nature and can be appropriately used for *decentralized* applications.

Solar Thermal Energy Programme: Use of solar thermal energy is being promoted for water heating, cooking, drying and space heating through various schemes. The government is proposing to make solar-assisted water heating mandatory in certain categories of buildings through amendments in the building bylaws. Bangalore has been declared a solar thermal city with special attention to popularize solar water heaters, and Thane in Mumbai is to follow soon. Several large projects are under consideration at the Ministry of New and Renewable Energy Sources. India is planning on developing 60 'Solar Cities' based on a model already practiced in New York, Tokyo and London. The target is to reduce the use of the conventional energy resources by at least 10% over the next five years. Recently, the idea of an Integrated Solar City with ambitious 5 GW solar projects has been mooted by The Clinton Foundation for Gujarat.

Solar Photovoltaic Programme: Solar PV energy is being used for solar lanterns, home-lighting systems, street lighting systems, solar water pumps and power plants. A number of 100-kW grid interactive plants are already in operation at various places in the country. A 200 kW plant is installed recently at the native village of Sardar Bhagat Singh (Village Khatkar Kalan, Dt. Nawanshahar, Punjab).

Aditya Solar Shops: The ministry is promoting the establishment of special sales outlets under the name Aditya Solar Shops in major cities (104 cities so far). Different models of solar-system devices from various manufacturers are sold through these shops in order to provide the customer a wide choice.

(iii) Biomass Energy: A large quantity of biomass is available in our country in the form of dry waste like agro residues, fuel wood, twigs, etc., and wet wastes like cattle dung, organic effluents, sugarcane bagasse, banana stems, etc. The potential for generation of electric power/cogeneration is 16,881 MW from agro residues and 5000 MW from bagasse through cogeneration. The potential from urban waste is 2,700 MW. Also, there is a vast scope for production of bio-diesel from some plants. These plants require little care, can be grown on fallow land and can survive in harsh climatic conditions. Energy farming may be adopted in marginal and infertile lands of the country.

(iv) Small Hydro Resources: Hydro resources of capacity less than 25 MW are called small, less than 1 MW are called mini and less than 100 kW are called micro hydro resources. The total potential is 15,000 MW out of which 2,015 MW has been realized by approximately 611 plants.

(v) Geothermal Energy: The potential in geothermal resources in the country is 10,000 MW As a result of various resource assessment studies/surveys, nearly 340 potential hot springs have been identified throughout the country. Most of them are low-temperature hot-water resources and can best be utilized for direct thermal applications. Only some of them can be considered suitable for electrical power generation. The geothermal reservoirs suitable for power generation have been located at Tattapani in Chhattisgarh and Puga valley of Ladakh, Jammu and Kashmir. A 300 kW demonstration electric-power-production plant is being installed at Tattapani. Hot-water resources are located at Badrinath, Kedarnath and a few other locations in the Himalayan ranges and elsewhere. They are being used mostly for heating purposes and very little has been developed.

(vi) Ocean Tidal Energy: There is no functional tidal plant at present and the total potential has been estimated as 9,000 MW, Three sites have been identified for development of tidal energy.

- Gulf of Kutch: potential = 900 MW, tidal range = 5 m
- Gulf of Cambay (Khambat): Potential = 7,000 MW, tidal range = 6 m
- Sundarbans: potentials 1,000 MW, tidal range- 3.9 m

The Ministry of Non-conventional Energy Sources has sponsored the preparation of a feasibility report by the West Bengal Renewable Energy Development Agency (WBREDA) to set up a 3.6 MW capacity demonstration tidal power plant at Durgaduani Creek in the Sunderbans area of West Bengal.

(vii) Ocean Wave and OTEC Resources A 150-kW pilot plant has been installed at Vizhingum harbour hear Thiruvananthapuram, Kerala. The average potential (annual basis) for Indian coasts has been estimated at around 0.02 MW/m of wavefront. There is a proposal for an OTEC plant at the Minicoy island of Lakhshdweep.
Emerging technologies like 'fuel cell' and 'hydrogen energy' are suited for stationary and portable power generation, which suits transportation purposes. In view of the growing importance of fuel cells and hydrogen, a National Hydrogen Energy Board has been created. The board will provide guidance for the preparation and implementation of the National Hydrogen Energy Road Map, covering all aspects of hydrogen energy starting from production, storage, delivery, applications, safety issues, codes and standards, public awareness and capacity building. Eco-friendly electric vehicles for transportation are being field tested for improving their performance.

b) Advantages of non-conventional sources over conventional sources:
Though non-conventional energy don't provide substantial amount of energy has certain advantages.

1) It is available in considerable quantities to all developing nations and capable. The use of renewable energy could help to conserve foreign exchange and generate local employment if conservation technologies are designed, manufactured locally.
2) Several renewable options are financially and economically competitive for certain applications, such as in remote locations where the costs of transmitting electrical power or transporting conventional fuels are high, or in those well endowed with biomass hydro or geothermal resources.
3) Conversion technology tends to be flexible and modular, it can be rapid deployed.
4) Rapid scientific and technological advantages are expected to expand the economic range of renewable energy applications.

c) Kyoto protocol:
The Kyoto protocol is a legally binding agreement on international level accepted by most of the countries to reduce greenhouse gas emission and risk of global warming. It came into force on 16 February 2005. The greenhouse gases are carbon dioxide, methane, nitrous oxide, hydrofluoro carbons, hexafluoride and perfluorocarbons. About 183 countries including India have ratified this protocol.
The major feature of the Kyoto protocol is that it sets binding targets for industrialised countries to reduce greenhouse gases emission so that global warming can be monitored and controlled. The protocol recognises and accepts that the developed countries are principally responsible for the current high concentration of greenhouse gases in the outer atmospheric layer of the earth as a result of more than 150 years of industrial activities. Hence, Kyoto protocol places a heavier burden on the developed countries under the principle of "common but differentiated responsibilities". The Kyoto protocol lies down that the developed countries are required to reduce their emission of greenhouse gases by an average of 5.2% below the year 1990 levels by the year 2012.

The Kyoto Protocol Mechanism:
The agreement lies down those member countries must meet their target to reduce greenhouse gases primarily through their own measures. However, the Kyoto protocol offers them several other means or measures to meet their targets using any of the following three market-based mechanisms:
i) Emissions trading or carbon trading mechanism
ii) Clean development mechanism (CDM)
iii) Joint implementation (JI) mechanism.

Emission trading or carbon trading: The member countries of the protocol have accepted emission targets for limiting or reducing the greenhouse gas emissions. These emission targets are called allowed emission or assigned amounts. Therefore, every member country has been assigned allowed emissions as assigned amount units (AAUs). A country cannot generate greenhouse gases more than the assigned amount units. The countries are allowed to use the option of emission trading or carbon trading to meet their obligations if they maintain or increase their greenhouse gas emissions. Emission or carbon trading allows nations that can easily meet their targets to sell emission credits to those that cannot meet their emission targets.
The Kyoto protocol sets specific emission targets to each industrialised nation, but it excludes developing countries from any emission target. To meet their targets, most member nations have to adopt the following measures.
i) Place restrictions on the industry causing major pollution problems
ii) Manage transportation to reduce emission from automobiles
iii) Adopt renewable energy sources in place of fossil fuels.

Clean development mechanism: This mechanism is laid down in Article 12 of the protocol and it allows a country with the emission reduction or limitation commitment to implement an emission reduction project in developing countries. Such projects can earn saleable certified emission reduction (CER) credits. Each CER credit is equivalent to the reduction of 1 ton of CO_2 emission and this can be counted towards meeting assigned GHG (greenhouse gases) emission targets. A clean development mechanism activity may be a rural electrification project using solar panel or it may be the adoption of more energy efficient boilers, thereby reducing the greenhouse gas emissions. The clean development mechanism must ensure a sustainable development to provide reduction in emission. However, every nation has flexibility in deciding the procedure or means to meet its emission limitation targets.
Joint implementation: The joint implementation has been defined in Article 6 of the Kyoto protocol. It allows a country with an emission reduction or limitation commitment under the protocol to earn emission reduction units (ERUs) by executing an emission reduction or removal project in another country. Each ERU is equivalent to the reduction of 1 ton of CO_2 gas. The ERUs are counted towards the emission limitation target of a country.

d) Greenhouse Effect:

- **Impact of global warming on climate:** Emission of green house gases in the atmosphere in increasing rates may affect the climate to a large extent. Due to increase of average global temperature, water from various sources on Earth may evaporate more rapidly and as a result of which the overall amount of **rainfall** may increase. But this phenomenon will not occur evenly in all the parts of the Earth, there may be heavy rainfall in some parts and **drought** in some other parts of the world. In some region, the **summer** may be hotter & prolonged, and **winter** becomes shorter & warmer.
- **Impact of global warming on Sea water level:** If the global temperature increases, the **ice-caps** and **glaciers** of the polar regions of the Earth may be melted partially, the floating ice on the water of the seas may also melt partially or completely. Due to an increase in temperature there may be an expansion of volume of sea water and as a result of which the level of sea water may rise. If the global temperature increases by 3°C-5°C on average, then a vast populated low-land area of the world specially coastal areas may be **flooded.**
- **Impact of global warming on Agriculture:** An increase in the amount of CO_2 in air is favourable for an increasing rate of photosynthesis of plants, therefore increase in CO_2 may increase the production of crops in some cases and on the other hand crop production may be reduced in some cases due to **dry soil having higher temperature**. There may be **acute scarcity of water for irrigation** in some places. In some regions, again, production of crops may decrease due to **soil erosion** rate becoming faster due to heavy rainfall and **washing away of fertile top soil** reducing thereby the available cropland area.
- **Impact of global warming on marine food:** Due to increase in temperature, the ice-caps, glaciers melt and as a result, expansion of volume of sea-water takes place. This expansion reduces the concentration of salts and changes the pH of the sea water. The average temperature of sea water is also changed. This changed environment is not suitable for the existence of different marine living organisms, especially fish. Different marine algae that are considered as food also die due to this disturbed condition.

SOLAR ENERGY

Multiple Choice Type Questions

1. Fill factor indicates the [WBUT 2007, 2009, 2011, 2016]
   a) solar radiation
   b) energy of a solar cell
   c) quality of solar cell
   d) none of these

Answer: (c)

2. For a polar PV cell dark current is because of [WBUT 2007, 2010, 2016]
   a) minority carriers
   b) majority carriers
   c) both (a) & (b)
   d) none of these

Answer: (c)

3. The greenhouse gas is [WBUT 2008, 2009, 2012, 2016]
   a) carbon dioxide b) methane c) nitrous oxide d) all of these

Answer: (a)

4. Photo-voltaic (PV) cell is basically a [WBUT 2010, 2012, 2016, 2019]
   a) p-n junction
   b) photo-transistor
   c) Amorphous p-n junction
   d) none of these

Answer: (a)

5. Which process is responsible for production of energy the sun? [WBUT 2010, 2011, 2014]
   a) nuclear fission reaction
   b) nuclear fusion reaction
   c) exothermal reaction
   d) all of these

Answer: (b)

6. The standard value of solar constant is [WBUT 2011, 2012]
   a) 1150 W/m^2 b) 1367 W/m^2 c) 2100 W/m^2 d) 1825 W/m^2

Answer: (b)

7. Solar photo-voltaic panel consists of photo-voltaic cells connected in [WBUT 2011, 2014]
   a) series b) parallel c) series parallel d) none of these

Answer: (a)

8. A solar cell is basically [WBUT 2011, 2014, 2018]
   a) a voltage source controlled by flux of radiation
   b) a current source controlled by flux of radiation
   c) an uncontrolled current source
   d) an uncontrolled voltage source

Answer: (b)

9. Main components of a concentrating type solar collector is [WBUT 2012]
a) reflecting mirrors
b) refracting lenses
c) both (a) and (b)
d) none of these
Answer: (c)

10. Which process is responsible for production of energy in sun? [WBUT 2012]
a) nuclear fission
b) nuclear fusion
c) exothermal reaction
d) none of these
Answer: (b)

11. The standard value for solar constant as per NASA standard is [WBUT 2013]
a) 1150 W/m^2
b) 1353 W/m^2
c) 2100 W/m^2
d) 1825 W/m^2
Answer: (b)

12. An illuminated solar cell is [WBUT 2013, 2019]
a) constant voltage device
b) constant current device
c) constant power output device
d) none of these
Answer: (b)

13. Photo-voltaic cell is basically a/an [WBUT 2013]
a) p-n junction
b) photo-transistor
c) amorphous p-n junction
d) none of these
Answer: (a)

14. In a solar panel, the metal used is [WBUT 2013, 2019]
a) gold
b) copper
c) silver
d) nickel
Answer: (b)

15. The greenhouse gas is [WBUT 2013]
a) carbon dioxide
b) methane
c) nitrous oxide
d) all of these
Answer: (a)

16. Which process is responsible for production of energy in sun? [WBUT 2014]
a) nuclear fission
b) nuclear fusion
c) exothermal reaction
d) all of these
Answer: (b)

17. A solar cell is basically [WBUT 2014]
a) a voltage source controlled by flux of radiation
b) a current source controlled by flux of radiation
c) an uncontrolled current source
d) an uncontrolled voltage source
Answer: (b)

18. A typical open circuit voltage of a solar cell is [WBUT 2015, 2019]
a) 0.45 V DC
b) 3 V DC
c) 1.5 V DC
d) 0.05 V DC
Answer: (a)

19. Which material has the highest solar cell efficiency? [WBUT 2015]
a) Amorphous Silicon b) Poly Crystalline Silicon
c) Thin Filmed Silicon d) Single Crystalline Silicon
Answer: (a)

20. A solar thermal water pump [WBUT 2015]
a) use solar thermal energy to evaporate water
b) uses solar thermal energy to circulate hot water
c) uses electric powered pump to circulate water heated by solar energy
d) uses solar thermal energy for production of power to drive the pump
Answer: (c)

21. The energy radiated by sun on a bright sunny day is about [WBUT 2015]
a) 200 W/m^2 b) 500 W/m^2 c) 1 kW/m^2 d) 2.5 kW/m^2
Answer: (c)

22. The output f a solar cell is of the order of [WBUT 2016]
a) 0.5 W b) 1.0 W c) 5.0 W d) 10.0
Answer: (a)

23. At maximum power point of the solar cell [WBUT 2017]
a) product of voltage and current is maximum
b) both voltage and current are maximum
c) current is maximum
d) voltage is maximum
Answer: (b)

24. Which material has the highest solar cell efficiency? [WBUT 2017]
a) Amorphous silicon b) Thin-filmed silicon
c) Poly crystalline silicon d) Single crystalline silicon
Answer: (a)

25. The greenhouse gas is [WBUT 2017]
a) carbon dioxide b) methane c) nitrous oxide d) all of these
Answer: (a)

26. Output of solar cell depends on [WBUT 2017]
a) ultraviolet radiation b) heat component of solar radiation
c) intensity of solar radiation d) infrared radiation
Answer: (c)

27. Which process is responsible for production of energy in the Sun? [WBUT 2017]
a) Nuclear fission b) Nuclear fusion
c) Exothermal reaction d) All of these
Answer: (b)

28. The payback period of an ordinary passive solar water heater is [WBUT 2018]
a) 20-60 years b) 1 year c) 2-6 years d) 6-10 years
Answer: (d)

29. The ratio of the beam radiation flux falling on a tilted surface to that falling on a horizontal surface is called the [WBUT 2019]
a) Radiation shape factor b) Tilt factor
c) Slope d) None of these
Answer: (b)

30. The angle made in the horizontal plane between the horizontal line due south and the projection of the normal to the surface on the horizontal plane is
a) Hour angle b) Declination angle
c) Surface Azimuth angle d) Solar altitude angle [WBUT 2019]
Answer: (a)

Short Answer Type Questions

1. a) Describe a single crystalline solar cell with constructional details. [WBUT 2011, 2016]
b) What is 'fill factor' of a PV cell? [WBUT 2011, 2014]

Answer:

a) The first silicon PV cells were of the single crystal array. Single crystal silicon cells are the most efficient and most robust of the silicon PV family. Their main drawbacks are: (i) they are most energy intensive in their production and (ii) the unit consumption of silicon to produce one unit of PV electricity is also quite high. Other variations of PV cells are being developed to overcome mainly these two drawbacks. Let us have a brief overview of the main steps involved in their production.

The first step is the production of metallurgical grade (99% pure) silicon, MgSi from its ore, SiO_2 by reduction reaction with carbon in an arc furnace. The energy cost of this step is 50 kWh/kg of silicon. Also, in this process CO_2 is produced as a byproduct, which is a greenhouse gas. Electronic grade pure (an impurity of about 1 part in 10^7) polysilicon (or polycrystalline silicon) is then obtained by refining it further through various complex operations at an energy cost of 200 kWh/kg of silicon. These two steps are highly energy intensive.

The polysilicon is then melted and the IIIrd group impurity (generally boron) in a desired quantity is introduced in the melt to get a *p*-type base material. The bulk resistivity of this material is chosen appropriately by controlled doping. Low doping or high resistivity should result in a wider depletion layer and increased short-circuit current. But this would also result into lower open-circuit voltage and a large series resistance leading to reduction of fill factor. On the other hand, too low resistivity, or a high doping leads to lower photocurrent due to larger carrier recombination. Such considerations have lead to selection of resistivity in the range 1 to 3 ohm-cm as an optimum value for bulk silicon solar cells. The molten mass is recrystallized into a single crystal ingot as large as 4 to 6 inches in diameter and 3 to 5 feet long, using a silicon seed crystal. Special saws are then used to cut the ingots into wafers of thickness between 200 to 400 microns. Again, this crystal growth and wafering processes are quite energy intensive. Also about 40–50% of this expensive material is lost in this slicing operation. Efforts are on to fabricate a thin ribbon-shaped crystal to avoid the need of wafering. The edges of the wafers are then trimmed to make it closer to a square so as to increase the packing density, as circular wafers mounted on a module would leave a large amount of space between them. After preparation of the surface, on each wafer a V^{th} group impurity (usually phosphorus) is diffused to get a thin (fraction of a micron) layer of *n*-type material and thus a *pn* junction is formed. Low-resistance ohmic contacts are made on both sides for external connection. The most common commercially produced silicon cell has an *n*-on-*p* structure, where the base material is *p*-type, which has a thin diffused *n* layer on top of it. Since the diffused layer is relatively heavily doped, it is likely to have a large number of unwanted recombination centres. Therefore, the diffusion length of minority carriers in this region is quite small and they are not expected to contribute significantly to photocurrent. The major contribution would normally come from the base region. The minority carrier diffusion length for electron is about twice that of a hole in silicon. Therefore, a *p*-type silicon base material, which has electrons as its minority carriers are preferred for making single crystalline bulk silicon solar cell.

b) *Fill Factor* of a PV cell indicates the quality of a cell which is defined as the ratio of the peak power to the product of open-circuit voltage and short-circuit current, i.e.,

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

2. What are the advantages of an Evacuated tube solar water heater over Flat plate collector type solar water heater having the same capacity? [WBUT 2011]

Answer:

Advantages of Evacuated tube Solar water heater over flat plate collector

1) Due to the cylindrical shape of the evacuated tube, the solar tubes are able to passively track the sun throughout the day. Flat plate collector only provides peak energy output at midday when the sun is perpendicular to the collector's surface.

2) Air is evacuated from the solar tube to form a vacuum. This greatly reduces conductive and convective heat loss from the interior of the tube. As a result wind and cold temperatures have less effect on the efficiency of the evacuated tube collector.

3) Evacuated solar collectors can often be used in subzero temperatures without the system sustaining damage. Flat plate systems often require expensive and complicated "antifreeze" systems to be installed.

4) Evacuated tubes are strong, long lasting, and should one be broken, inexpensive and easy to replace. If a flat plate collector panel is damaged the whole panel must be replaced.

5) Due to the high efficiency absorption of solar radiation even during overcast conditions, combined with excellent insulative properties of the solar tube, solar tube collectors can heat water all year round(backup from gas and electricity is still required).

6) Due to the various advantages of evacuated tube collector over flat plate collectors, a smaller collector can be used to provide the same heating performance. For example, a standard household of 4-5 people would usually require a 250-300L water storage tank. Depending on your location, only 30 evacuated tubes would be required to provide all summer hot water needs and a large percentage in other seasons. Flat plate solar collectors can produce similar heat output to evacuated tube collectors, but generally only during hot, sunny conditions. When averaged over an entire year, evacuated tube collector heat output per net m^2 of absorber area is between 25% to 40% greater than a flat plate collector.

3. Define Fill factor. Write down the major limitations of solar energy. [WBUT 2012]

Answer:

Fill Factor: ***Refer to Question No. 1(b) of Short Answer Type Questions.***

Limitation of Solar Energy

1. The solar energy that reaches the earth is in a very diffused form.
2. The solar energy is not uniformly available all the time & at all the places.
3. It cannot be used during the night or cloudy days.

4. Define latitude, declination, hour angles with proper diagram. Calculate the day length in Srinagar on 1st July, 2012. The latitude of Srinagar is 34°05'N.

[WBUT 2014]

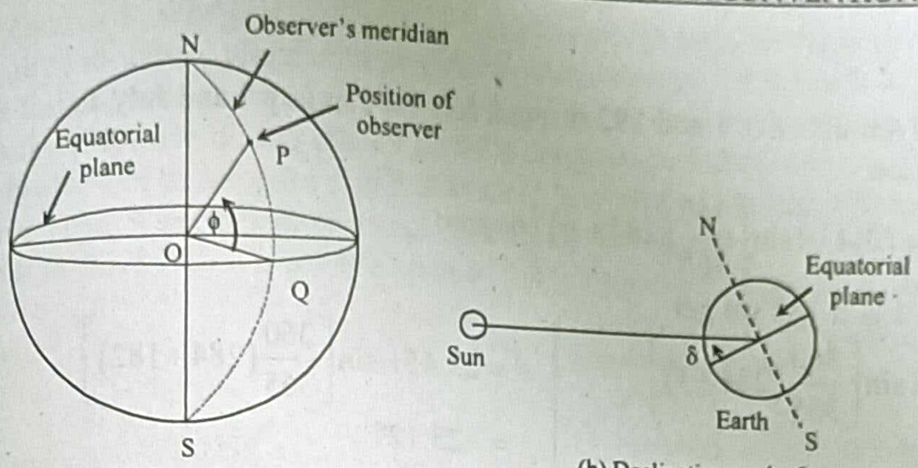
Answer:

1st part:

Latitude (Angle of Latitude), (ϕ): The latitude of a location on the earth's surface is the angle made by a radial line joining the given location to the centre of the earth with its projection on the equator plane, as shown in Fig. 1 (a). The latitude is positive for northern hemisphere and negative for southern hemisphere.

Declination, (δ): It is defined as the angular displacement of the sun from the plane of the earth's equator, as shown in Fig. 1(b). It is positive when measured above the equatorial plane in the northern hemisphere. The declination δ can be approximately determined from the equation.

$$\delta = 23.45 \times \sin\left[\frac{360}{365}(284+n)\right] \text{degrees} \quad \dots (1)$$



(a) Latitude (b) Declination angle, δ

Fig: 1 Latitude and declination angle

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

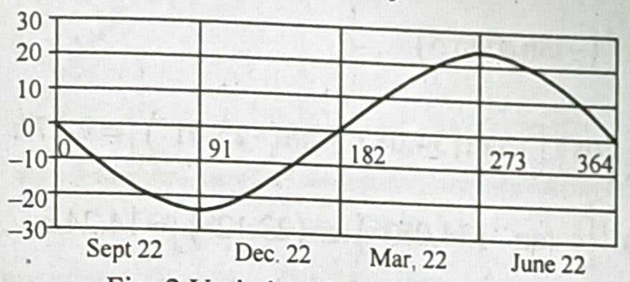


Fig: 2 Variations in sun's declination

Hour Angle, (ω): The hour angle at any moment is the angle through which the earth must turn to bring the meridian of the observer directly in line with the sun's rays.

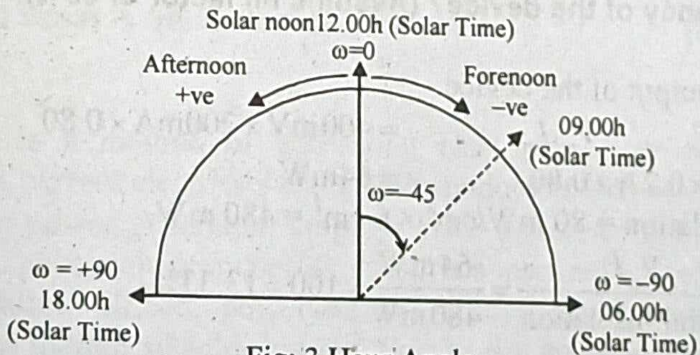


Fig: 3 Hour Angle

In other words, at any moment, it is the angular displacement of the sun towards east or west of local meridian (due to rotation of the earth on its axis). The earth completes one rotation in 24 hours. Therefore, one hour corresponds to 15° of rotation. At solar noon, as the sun's rays are in line with the local meridian, the hour angle is zero. It is –ve in the forenoon and +ve in the afternoon. Thus, at 0.6:00 h it is –90° and at 18:00 h it is +90° as shown in Fig. 3.

It can be calculated as:

$$\omega = [\text{Solar Time} - 12{:}00] \text{ (in hours)} \times 15 \text{ degrees} \qquad \dots (2)$$

2nd part:
From the given data $n = 1$ and 182 respectively for January 1 and July 1.
From equation

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

Putting $n = 1$ and 182 we get

$$\delta = 23.45 \times \sin\left[\frac{360}{365}(284+1)\right] = -23.01°$$

$$\delta = 23.45 \times \sin\left[\frac{360}{365}(284+182)\right] = -23.12°$$

Respectively for January 1 and July 1
From equation

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

On January 1, $t_d = \frac{2}{15}\cos^{-1}\left[-\tan(34.083°)\tan(-23.01°)\right] = 9.77\,h$

On July 1, $t_d = \frac{2}{15}\cos^{-1}\left[-\tan^{-1}(34.083°)\tan(23.12°)\right] = 14.24\,h$

5. A solar cell of active area 6cm² gave the following results: $V_{oc} = 400mV$, $I_{sc} = 200mA$, incident intensity 80 mW/cm². What is the energy conversion efficiency of the device? (Assume fill factor of 80%). **[WBUT 2014]**

Answer:
Maximum power output of the device

$$= V_{oc}I_{sc}.FF \qquad = V_m.I_m \qquad = 400\,\text{mV} \times 200\,\text{mA} \times 0.80$$

$$= 400\,\text{mV} \times 0.2\,\text{A} \times 0.80 \qquad = 64\,\text{mW}$$

Total incident Insolation = 80 mW/cm² × 6 cm² = 480 mW

$$\therefore \text{Efficiency} = \frac{V_m I_m}{\text{Total Insolation}} = \frac{64\,\text{mW}}{480\,\text{mW}} \times 100 = 13.33\%$$

6. Discuss solar water heating system with antifreeze with a neat sketch. **[WBUT 2016]**

Answer:
The details of the most common type of solar water heater are shown in Fig. 1. A tilted flat-plate solar collector with water as a heat-transfer fluid is used. A thermally insulated hot-water storage tank is mounted above the collector. The heated water of the collector rises up to the hot water tank and replaces an equal quantity of cold water, which enters the collector. The cycle repeats, resulting in all the water of the hot water tank getting heated up. When hot water is taken out from the hot water outlet, the same is replaced by cold water from a cold-water make up tank fixed above the hot water tank. The scheme is known as passive heating scheme, as water is circulated in the loop naturally due to

thermo-siphon action. When the collector is fixed above the level of the hot-water tank, a pump is required to induce circulation of water in the loop and the scheme will be known as active (or forced) solar thermal system. An auxiliary electrical emersion heater may be used as a back-up for use during cloudy periods. In average Indian climate conditions, a solar water heater can be used for about 300 days in a year. A typical 100-litres per day (LPD) rooftop solar water heater costs approximately Rs.18,000–21,900 (year 2008) and delivers water at 60–80°C. It has a life span of 10–12 years and a payback period of 2–6 years.

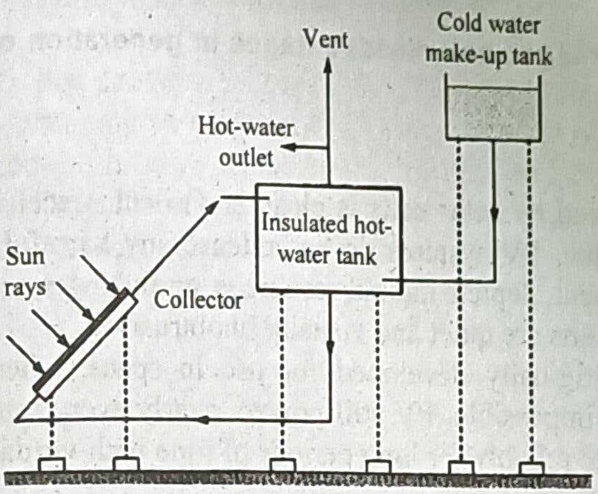


Fig: 1 Solar water heater

In other schemes, the hot water from the collector delivers heat to service water through a heat exchanger. In this scheme, an anti-freeze solution may be used as the heat-transport medium to avoid freezing during cold nights.

7. What is *PV* cell? What is 'fill factor' of a PV cell? **[WBUT 2016, 2017]**

Answer:

1st part:

Photovoltaic (PV) is a method of generating electrical power by converting solar radiation into direct current electricity using semiconductors that exhibit the photovoltaic effect. Photovoltaic power generation employs solar panels comprised of a number of cells containing a photovoltaic material. Materials presently used for photovoltaics include monocrystalline silicon, polycrystalline silicon, amorphous silicon, cadmium telluride and copper indium selenide/sulfide. Due to the growing demand for renewable energy sources, the manufacture of solar cells and photovoltaic arrays has advanced considerably in recent years.

As of 2010, solar photovoltaics generates electricity in more than 100 countries and while yet comprising a tiny fraction of the 4800 GW total global power-generating capacity from all sources, is the fastest growing power-generation technology in the world. Between 2004 and 2009, grid-connected PV capacity increased at an annual average rate of 60 percent, to some 21 GW. Such installations may be ground-mounted (and sometimes integrated with farming and grazing) or built into the roof or walls of a building, known as Building Integrated Photovoltaics or BIPV for short. Off-grid PV accounts for an additional 3–4 GW.

Driven by advances in technology and increases in manufacturing scale and sophistication, the cost of photovoltaics has declined steadily since the first solar cells were manufactured. Net metering and financial incentives, such as preferential feed-in tariffs for solar-generated electricity, have supported solar PV installations in many countries.

2^{nd} part: *Refer to Question No. 1(b) of Short Answer Type Questions.*

8. Discuss the advantages and disadvantages in generation of power by solar P.V. Cell. **[WBUT 2018]**

Answer:

Advantages

- Electricity produced by solar cells is clean and silent. Because they do not use fuel other than sunshine, PV systems do not release any harmful air or water pollution into the environment, deplete natural resources, or endanger animal or human health.
- Photovoltaic systems are quiet and visually unobtrusive.
- PV cells were originally developed for use in space, where repair is extremely expensive, if not impossible. PV still powers nearly every satellite circling the earth because it operates reliably for long periods of time with virtually no maintenance.

Disadvantages

- Some toxic chemicals, like cadmium and arsenic, are used in the PV production process. These environmental impacts are minor and can be easily controlled through recycling and proper disposal.
- Solar energy is somewhat more expensive to produce than conventional sources of energy due in part to the cost of manufacturing PV devices and in part to the conversion efficiencies of the equipment. As the conversion efficiencies continue to increase and the manufacturing costs continue to come down, PV will become increasingly cost competitive with conventional fuels.
- Solar power is a variable energy source, with energy production dependent on the sun. Solar facilities may produce no power at all some of the time, which could lead to an energy shortage if too much of a region's power comes from solar power.

9. Define latitude, declination, hour angles with proper diagram. Calculate the declination angle (δ) for March 31 in a leap year. **[WBUT 2019]**

Answer:

1^{st} **Part:** *Refer to Question No. 4 (1^{st} part) of Short Answer Type Questions.*

2^{nd} **part:**

No. of days from Jan 1 to March 31^{st} is 90.

From given data $n=1$ and 90.

$$\delta = 23.45 \times \sin\left[\frac{360}{366}(284+n)\right] \text{ degree}$$

Putting $n=1$ and 90, we get,

$$\delta = 23.45 \times \sin\left[\frac{360}{366}(284+1)\right] = -23.08°$$

$$\delta = 23.45 \times \sin\left[\frac{360}{366}(284+91)\right] = 3.206°$$

Angle of declination is 3.206°

10. What is solar cooling and where is it used? **[WBUT 2019]**

Answer:

Solar cooling is a system that converts heat from the sun into cooling that can be used for refrigeration and air conditioning. A solar cooling system collects solar power and uses it in a thermally driven cooling process which is in turn used to decrease and control the temperature for purposes like generating chilled water or conditioning air for a building. There are many different cooling cycle techniques using various different principals to function. Three of the most popular techniques include:

- Absorption cycles
- Desiccant cycles
- Solar mechanical cycles

Regardless of the technique being used, a solar cooling system typically includes three core components:

- A solar collector, such as a solar panel, which is used to convert solar radiation into heat or mechanical work.
- A refrigeration or air conditioning plant that is used to produce the cooling.
- A heat sink that collects any rejected heat and radiates it away from the system.

Applications of solar cooling:

Solar cooling is primarily intended for two main purposes: refrigerating food storage and space cooling, or air conditioning. Solar cooling can be seen in vehicles like RVs and campers which use the system for refrigeration. Vapor absorption refrigeration systems, which are used in industries where extremely low process temperatures are required as well as large thermal capabilities, also display the use of solar cooling.

Long Answer Type Questions

1. a) Briefly describe a silicon solar cell along with its constructional features and the equivalent circuit. Show graphically its spectral response and I-V characteristics. **[WBUT 2007]**

OR,

Write down the basic operating principle of a solar cell with proper diagram. **[WBUT 2012]**

OR,

Draw the equivalent circuit of a solar cell. **[WBUT 2014]**

OR,

Draw the equivalent circuit of a practical solar cell and describe its I-V characteristics. Also give a brief idea about the effect of variation of insolation and temperature.
[WBUT 2016]

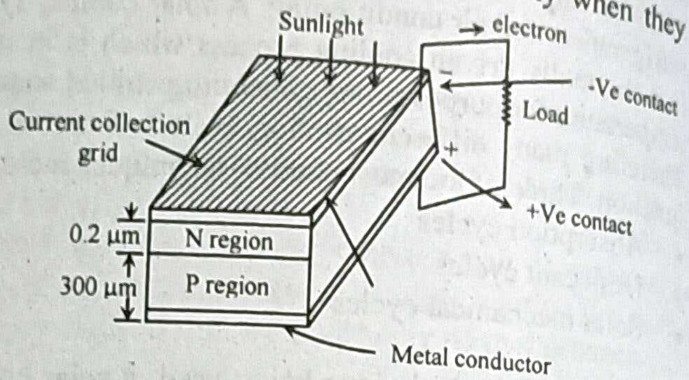
OR,

Draw and explain the equivalent circuit diagram and I-V characteristics of a solar cell.
[WBUT 2019]

Answer:

Constructional features:

An Photovoltaic cells are made of semiconductors that generate electricity when they absorb light. A photovoltaic cells for electrical power generation has been in space craft, for which silicon solar cell is the most highly developed type. The silicon cell consists of a single crystal of silicon into which a doping material is diffused to form a semiconductor. Many improvements have been made in crystal growing and doping, electrical contact and cell assembly and production methods. Large no. of cells have been manufactured with areas 2×2cm. efficiency approaching 10% and operating temperature 28°C. The efficiency is the power developed per unit area. Though silicon is one of the earth's most abundant material, it is expensive to extract photovoltaic effect of a silicon call can be described easily for p-n junction in a semiconductor. In an intrinsic semiconductor such as silicon each one of the four valance electrons of the material atom is tied in a chemical bond and there are no free electrons at absolute zero. A material is doped on one side by a five valance electron material. Such as arsenic or phosphorus, there will be an excess electrons in that side, becomes an n-type semiconductor. The excess electrons in that side, becomes an n-type semiconductors.



Equivalent Circuit:

$$I = I_0\{\exp(V/V_T)-1\} \quad \dots (1)$$

The *I-V* characteristic of solar cell given in Eq. (1), is derived for ideal condition, the. internal series resistance of the cell as zero and shunt resistance as infinite.

In actual practice, however, both have finite values, which would alter the characteristics. The ideal and practical equivalent circuits of the solar cell are shown in Fig. 1. In practical cells, I_{sc}, is no longer equal to the light generated current I_L, but is less by it current through R_{sh}. Further, an internal voltage drop of IR_s is also included terminal voltage. Thus, for a practical cell, the characteristic is modified as

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

For a typical, high-quality, one square inch silicon cell, R = 0.05 to 0.10 ohms
R_{sh} = 200 to 300 ohms.

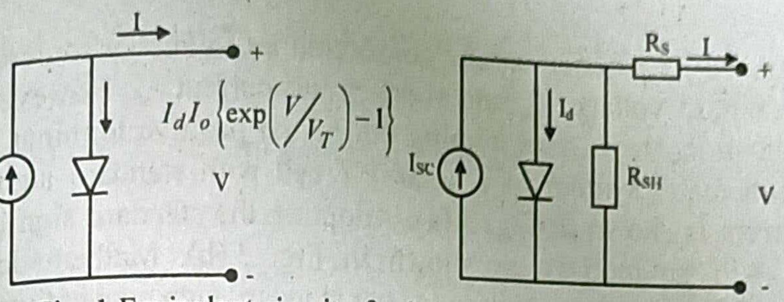


Fig: 1 Equivalent circuit of solar cell (a) ideal (b) practical

The well-known characteristic of an ordinary silicon pn junction is shown in Fig.2 as a dark characteristic with the junction not illuminated. Mathematically this is given by

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

where I_o is the reverse saturation current, V_T is known as the voltage equivalent 'of temperature and at room temperature (20 °C), its approximate value is 26 mV.

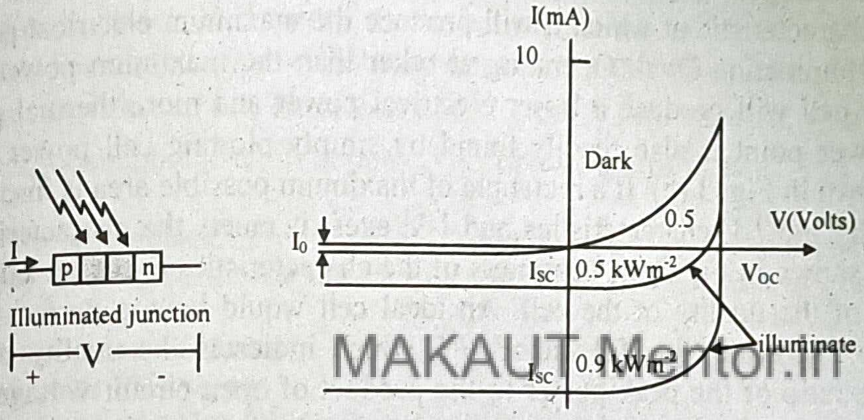


Fig: 2 I-V Characteristic of dark and illuminated p-n junction

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

where k is Boltzman's constant, Tis temperature in °K and q is a charge of an electron When *the pn* junction is illuminated, the characteristic gets modified in shape **and** shifts downwards as the photon-generated component is added with reverse current as shown in Fig. 2. The above diode Eq. 2is modified as

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

When the junction is short-circuited at its terminals, V becomes zero and a finite current I $= -I_{sc}$ flows through the external path emerging from *the p* side. I_{sc} known as *short-circuit current* and its magnitude will depend on solar insolation, a voltage source is inserted in the external path with positive polarity on the/) As the magnitude of this external voltage is increased from zero, the current starts decreasing. The value V_{oc} of this voltage at which the current becomes zero; is known as *open-circuit voltage.*

Thus, $V_{OC} = V_T \ln\left\{\left(I_{sc}/I_o\right)+1\right\}$

Typically for I_{sc} = 2 A, I_o = 1 nA and at room temperature, V_{oc} is found to be 0.55 V.

Thus, an illuminated *pn* junction can be considered as an energy source, (a photovoltaic cell) with open circuit voltage V_{oc} and short-circuit current I_{sc}. However, for an energy source, by convention, the current coming out of the positive terminal is considered as positive. The schematic symbol of a solar PV **cell** with standard sign convention for voltage and current is shown in Fig. 3.(a). Adopting the standard sign convention for a solar PV cell, will be redrawn as shown in Fig. 3.(b). Mathematically, the I— V characteristic a solar cell may be written (as per standard sign convention) as:

$$I = I_{sc} - I_o\{\exp(V/V_T) - 1\}$$

In order to obtain as much energy as possible from the rather costly PV cell, it is desirable to operate the cell to produce maximum power. The maximum power (*PJ* point can be obtained by plotting the hyperbola defined by V×I =constant, such that it is tangential to the *I-V* characteristic. The voltage and current corresponding to this point are peak-point voltage, V_m and peak point current I_m respectively. Thus, there is only one point on the characteristic at which it will produce the maximum electrical power under the incident illumination level. Operating at other than the maximum power point will mean that the cell will produce a lesser electrical power and more thermal power. The maximum power point is also readily found by simply plotting cell power versus cell voltage as shown in Fig. 3.(c). If a rectangle of maximum possible area is inscribed in the area defined by the *I-V* characteristics and I-V axes, it meets the characteristics at the peak point as shown in Fig. 3.a). Closeness of the characteristics to the rectangular shape is a measure of the quality of the cell. An ideal cell would have a perfect rectangular characteristic. Therefore, the 'fill factor', *FF* which indicates the quality of a cell, is defined as the ratio of the peak power to the product of open-circuit voltage and short-circuit current, i. e.,

$$FF = \frac{V_m I_m}{V_{oc} I_{sc}} \qquad \text{.... (1)}$$

An ideal cell will have a fill factor of unity. In order to maximize the fill factor, the ratio of the photocurrent to reverse saturation current should be maximized while minimizing internal series resistance and maximizing the shunt resistance. Typically, its value for a commercial silicon cell is in the range of 0.5 to 0.83, conversion efficiency of a solar cell is given by

$$\eta = \frac{V_m I_m}{\text{Solar Power}} = \frac{FF V_{oc} I_{sc}}{\text{Solar Power}} \qquad \text{.... (2)}$$

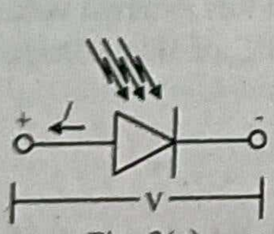


Fig: 3(a)

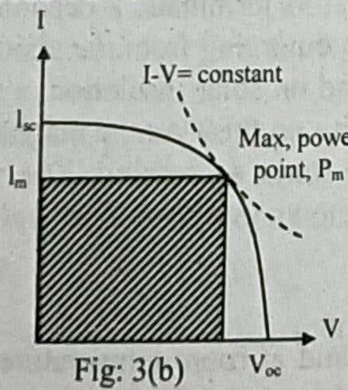


Fig: 3(b)

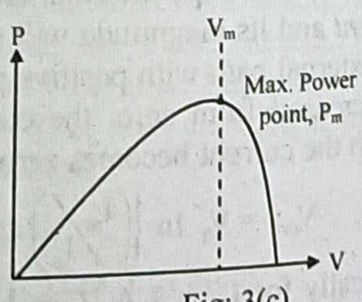


Fig: 3(c)

b) How can you get the maximum power output from a solar cell?

[WBUT 2007, 2009]

OR,

Explain how we can get maximum power from a solar cell and deduce expression for that. **[WBUT 2014]**

Answer:

Maximum power output can be got from the solar cells when they are connected in parallel. Efficiency = Power developed per unit area. In this condition when they are kept in full sunlight and we get maximum power output.

Desirable features of a solar cell are – maximum values of V_{oc} *and* I_{sc}, low series resistance that will lead to high fill factor and high shunt resistance. I_{ac} is related to photocurrent and V_{oc} depends on the ratio of I_{sc} to I_o. Shunt resistance is maximized by ensuring that no leakage occurs at the perimeter of the cell. This is done by passivating the surface. Reduction of series resistance requires high doping of semiconductor. But high doping will also decrease the width of depletion layer, which in turn decreases the photocurrent. Therefore, both V_{oc} and I_{sc} are affected. Therefore, trade-off is made in choosing the level of doping to get optimal performance.

2. a) Draw the equivalent circuit of a practical solar cell and describe its I-V characteristics. Also give a brief idea about the effect of variation of insolation and temperature.
b) Describe briefly the following:
i) Stand alone solar PV system
ii) Grid interconnected solar PV system. **[WBUT 2011]**

Answer:

a) 1st Part: ***Refer to Question No. 1(a) of Long Answer Type Questions.***

2nd Part:

As the insolation keeps on varying throughout the day, it is important to observe its effects on *PV* characteristics. If the spectral content of the radiation remains unaltered and temperature and all other factors remain same, both I_{sc} and V_{oc} increase with increasing the intensity of radiation. The photo-generated current depends directly on insolation. Therefore, the short-circuit current depends linearly while the open-circuit voltage depends logarithmically on the insolation. This is shown in Fig. 1 (a, c).

If I_{sc} is known under standard test conditions, i.e., radiation of $G_0 = 1\,\text{kW/m}^2$ at AM 1.5, then the short-circuit current I'_{sc} at any other insolation level G can be calculated to a very good approximation, as $I'_{sc} = \dfrac{G}{G_0} \times I_{sc}$.

An illuminated PV cell converts only a small fraction (approx. less than 20%) of irradiance into electrical energy. The balance is converted into heat, resulting into heating of the cell. As a result, the cell can be expected to operate above the ambient temperature.

Keeping insolation level as constant, if the temperature is increased, there is a marginal increase in the cell current but a marked reduction in the cell voltage. An increase in temperature causes reduction in the band gap. This, in term, causes some increase in photo-generation rate and thus a marginal increase in current. However, the reverse saturation current increases rapidly with temperature. Due to this, the cell voltage decreases by approximately 2.2 mV per °C rise in its operating temperature, depending on the resistivity of the silicon used — higher the silicon resistivity, more marked is the temperature effect. Also, the fill factor decreases slightly with temperature. This is shown in Fig. 1(b, d).

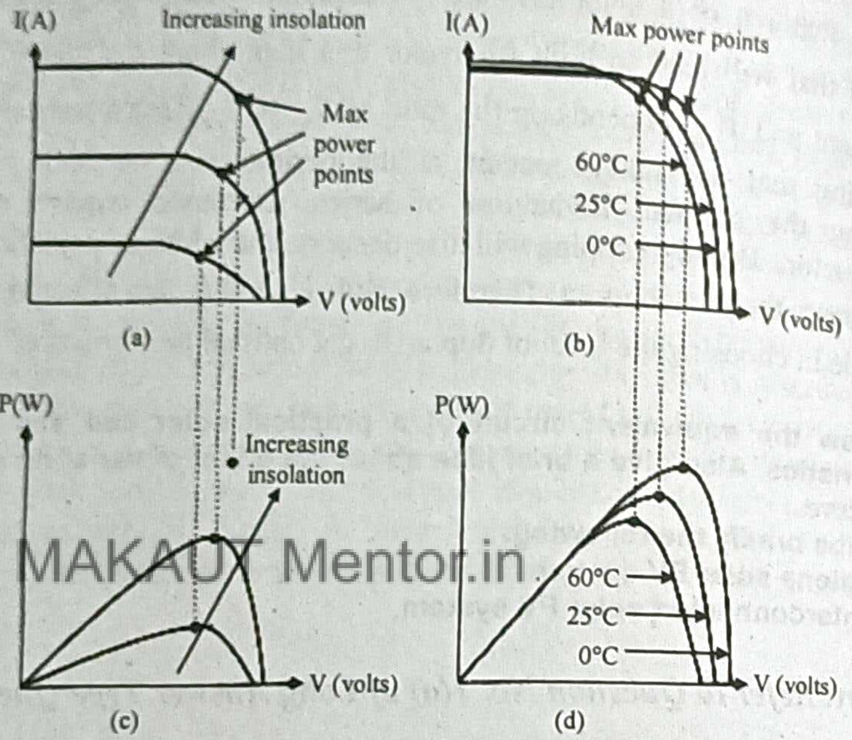


Fig: 1 Effect of variation of (a) and (c) insolation and (b) and (d) temperature on the characteristic of solar cell

The $I-V$ characteristic is generally provided by the manufacturer for standard test conditions. The internationally accepted Standard Test Conditions (STC) refer to an incident AM1.5 irradiance of 1 kW/m^2, with operating temperature of 25°C and wind speed of 1 m/s.

b)

i) The main components of a general stand-alone solar PV system are shown in figure 1. The MPPT senses the voltage and current outputs of the array and adjusts the operating point to extract maximum power under the given climatic conditions. The output of the array after converting to ac is fed to loads. The array output in excess of load requirement is used to charge the battery. If excess power is still available after fully charging the battery, it may be shunted to dump heaters. When the sun is not available, the battery supplies the load through an inverter. The battery discharge diode D_B prevents the battery fro being overcharged after the charger is opened. The array diode D_A is to isolate the array from the battery to prevent battery discharge through array during nights. A mode controller is a central controller for the entire system. It collects the system signals and keeps track of charge/ discharge state of the battery, matches the generated power and load and commands the charger and dump heater on-off operation.

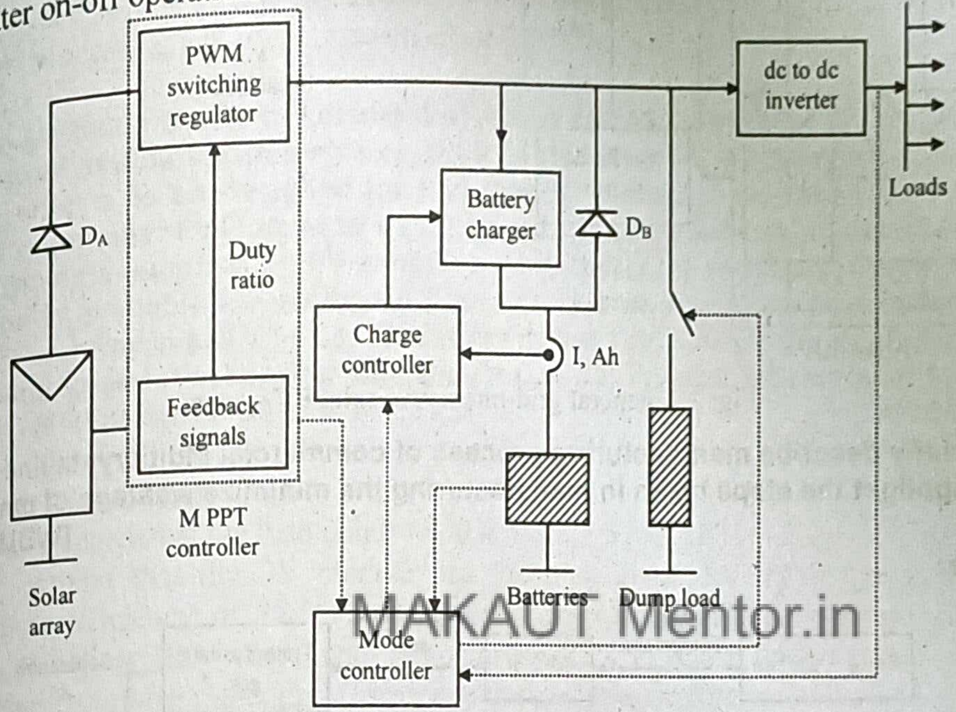


Fig: 1 A general stand-alone solar PV system

ii) In a grid-interactive system, all excess power is fed to a grid and dump heaters are not required. Also, during absence or inadequate sunshine, supply of power is maintained from the grid and thus battery is eliminated. The mechanism for synchronized operation is incorporated. The dc power is first converted to ac by inverter, harmonics are filtered and then only the filtered power is fed into the grid after adjusting the voltage level. Recently, PV modules are being made with inverters as an integral component in the junction box of the module, what is known as ac-PV modules. It provides utility grade 60 Hz power directly from the module junction box. This greatly simplifies the design of a PV system. The schematic diagram of a general grid-interactive solar PV system is given in figure 2.

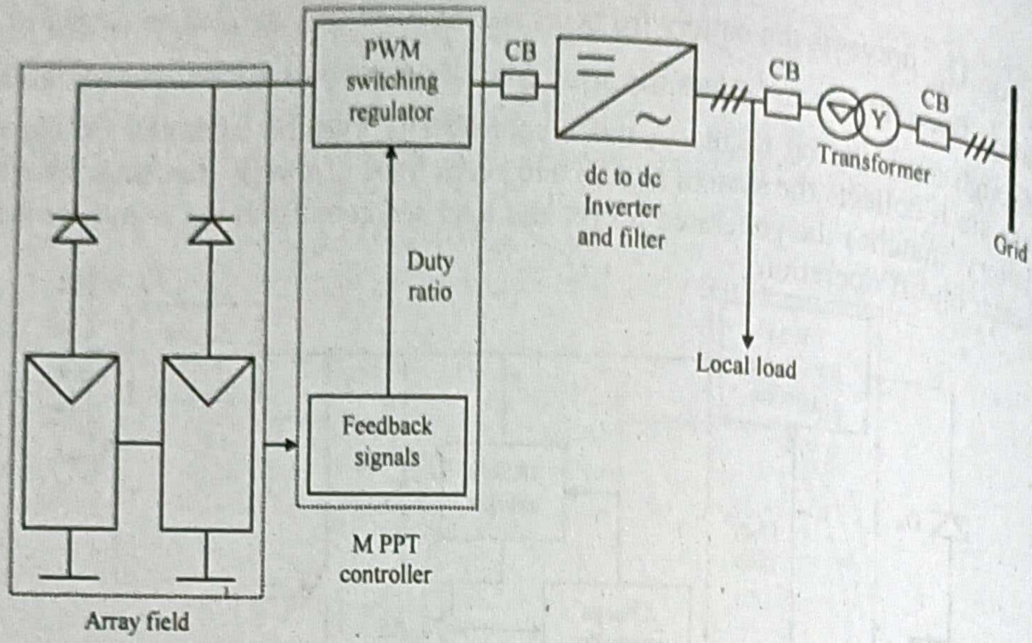
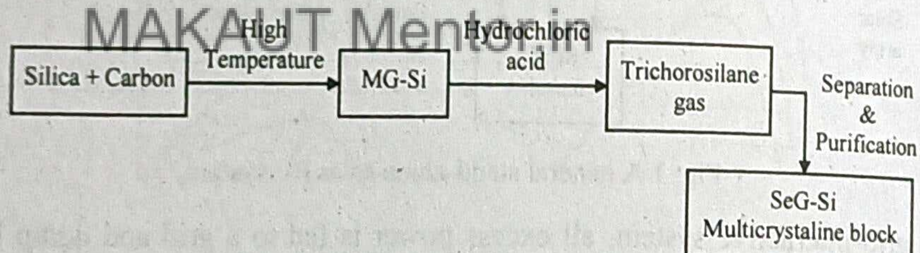


Fig: 2 A general grid-interactive solar PV system

3. a) Briefly describe manufacturing process of commercial Multicrystalline Silicon Cell. Highlight the steps taken in manufacturing the minimize wastage of material. [WBUT 2012]

Answer:



Most of the current commercial modules are made from multicrystalline silicon. The cells are made from wafers by a process very similar to that of single crystal silicon.

Multicrystalline wafers are prepared from large grained multicrystalline ingots. The grains are generally much larger than the wafer thickness. Consequently the grain boundaries do not interfere much with the flow of electrons. Thus, the cells yield efficiencies not very interior to those obtained with single crystal cells and have the advantage of a lowercost cell efficiencies up to 20.3%.

Methods have been developed to prepare multicrystalline silicon in the form of a ribbon directly in order to remove the cost of wafering as well as reducing the wastage of silicon source material. One such method is EFG (Edge defined film-fed growth) process. In the present commercial implementation, a long octagonal tube of multicrystalline silicon with an average wall thickness of 280μm is grown from a melt of silicon and wafers are cut out of this tube. It is expected that the wall thickness would be reduced to 100μm in order to achieve further material savings. Another process, which is commercialised, is the string ribbon process. Two wires are drawn through a molten bath of silicon. A film of molten silicon is trapped between the wires and the film then solidifies to make a multicrystalline silicon ribbon. Both EFG process and the string ribbon process are suitable from the point of view of continuous production.

Multicrystalline silicon solar cells have a great potential for further development in terms of increased cell efficiency and reduced cost. They can be manufactured easily in square shapes and hence when used in modules, a more complete utilization of the module area is realised. Consequently the lower efficiency of the cell is compensated at the module level. Several technological advancements have been made to reduce impurities during solar cell processing and to increase efficiency.

b) A house has a power requirement of 400 W for 4 hours every night. A PV array made up of modules with single crystalline silicon cells, a battery storage system and inverter is to be designed for this load. It is also to be taken care that one night's requirement will have to be taken care even if there is no sunshine in the day. Calculate number of PV modules and batteries required. Given (i) Solar radiation is available for average 6 hours daily and average global radiation flux incident on array is 650 W/M sq. (ii) Battery rating 12V, 120AH, depth of discharge = 0.7, charging and discharging efficiency = 0.9, (iii) Inverter efficiency at full load = 0.85, (iv) Module size = 1.191 M ×0.533 M. [WBUT 2012]

Answer:

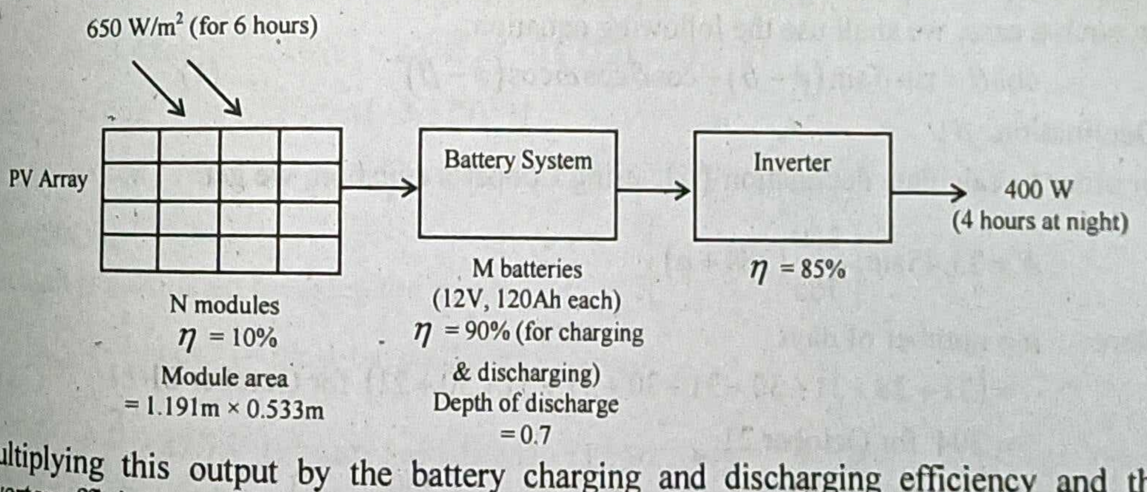
A solar cell is basically a/ an

Thus energy needed at the load point = 400 × 4 × 2 = 3200 Ah

Let we assume that the PV module has the area given for the single crystal. The conversion efficiency of 12.5% mentioned there corresponds to standard conditions (global radiation $1000 W/m^2$, cell temperature 25°C). Since under actual operating conditions, the global radiation is lower and the cell temperature is likely to be higher, we will assume a module conversion efficiency of 10%. If N be the number of PV modules, daily energy output from PV array.

$= 650 \times 6 \times N \times (1.191 \times 0.533) \times 0.1$

$= 247.57317\ NWh$



Multiplying this output by the battery charging and discharging efficiency and the inverter efficiency, we have

$247.57317N \times 0.9 \times 0.9 \times 0.85 = 3200$

$N = 18.7733$ i.e., 19 modules

Energy supplied by one battery to the load = $(12 \times 120) \times 0.7 \times 0.9 \times 0.85 = 771.12$ Wh

Therefore number of batteries (M) required $= \dfrac{3200}{771.12} = 4.149$ i.e., 4

4. a) Explain beam and diffuse radiation. **[WBUT 2013, 2019]**

b) Calculate the angle made by beam radiation with the normal to a flat collector on 21st October at 9:00 AM, solar time for a location at 18°35′N. The collector is titled at an angle of latitude plus 10°, with the horizontal and is pointing due South. **[WBUT 2013]**

c) Calculate the sun-set hour angle and day length at a location latitude of 35°N, on March 14. **[WBUT 2013]**

Answer:

a) The global solar radiation incident on the earth surface comprises both beam (direct) and diffuse solar radiation. The intensity of global radiation on one square meter of the earth surface in a unit time depends on the geographical latitude, season of the year, time of the day and on weather conditions especially cloud cover of the sky.

The annual global solar radiation varies widely from 800 kWh/m^2 to 2400 kWh/m^2 depending upon the location. Another parameter of solar radiation at a particular location is the daily and annual sunshine hours. The value can be anything from 1400 to 3500 hours per year. Solar radiation data for various selected cities of the world have been measured and recorded.

b) Given $\phi = 18°35' = 18.58°$

Day of the year = October 21

Local Solar Time (LST) = 9.00 AM

Tilt Angle, $\beta = 18.58° + 10° = 28.58°$

Angle made by the beam radiation, θ

Since collector is pointing due south, therefore $r = 0$

In such a case, we shall use the following equation:

$$\cos\theta = \sin\delta\sin(\phi-\beta) + \cos\delta\cos\omega\cos(\phi-\beta) \qquad \text{.... (1)}$$

Declination, δ:

In order to calculate declination (δ), using Cooper's equation, we get:

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

Here n = number of days

$= (31+28+31+30+31+30+31+31+30+21)$ for October 21

$= 294$ for October 21.

$$\delta = 23.45\sin\left[\frac{360}{365}(284+294)\right] = 23.45\sin\left(\frac{360}{365}\times 578\right)$$

$$= 23.45\sin 570.082° = 23.45(-0.501) = -11.754°$$

Also $\omega = 15(12 - \text{LST}) = 15(12-9) = 45°$

Putting the various values in the above equations we obtain

$$\cos\theta = \sin(-11.754°)\sin(18.58 - 28.58°)$$
$$+\cos(-11.754°)\cos 45° \cos(18.58° - 28.58°)$$
$$= -0.2037\sin(-10.00°) + 0.979 \times \frac{1}{\sqrt{2}} \times \cos(-10.00°)$$
$$= -0.2037 \times (-0.1736) + (0.979 \times 0.707 \times 0.9848)$$
$$= 0.03536 + 0.6816 = 0.71696$$
$$\theta = \cos^{-1}(0.71696) = 44.195° \text{ (Ans.)}$$

c) 35°N March 14

Given latitude $\phi = 35°$ Day the year = March 14

Sunset hour angle ω_s

Sunset hour angle is calculated by using the relation

$$\omega_s = \cos^{-1}(-\tan\phi \tan\delta) \qquad \text{.... (1)}$$

Let us first calculate the value of δ by using the relation

$$\delta = 23.45\sin\left[\frac{360}{365}(284+n)\right] \qquad \text{.... (2)}$$

Here n = number of days

= 73 for March 14

$[n = 31 + 28 + 14 = 73]$

$$\delta = 23.45\sin\left[\frac{360}{365}(284+73)\right] = 23.45\sin\left[\frac{360}{365} \times 357\right]$$
$$= 23.45\sin[352.1095] = 23.45 \times (-0.1372) = -3.2191°$$

Hence $\omega_s = \cos^{-1}(-\tan 35° \cdot \tan(-3.2191°))$

$$= \cos^{-1}(-0.700 - 0.056) = \cos^{-1} 0.03921 = 87.75° \text{ (Ans.)}$$

Day length, t_{day} (hours):

Day length is calculated by using the relation

$$t_{day} = \frac{2}{15}\left[\cos^{-1}(-\tan\phi \cdot \tan\delta)\right] \text{hours}$$
$$= \frac{2}{15} \times 87.75° \text{ (already calculated)} = 11.700 \text{ hours.} \qquad \text{(Ans.)}$$

5. a) What are photovoltaic device?
b) Outline briefly the principle of operation of a photovoltaic device.
c) Describe the different types of solar energy collectors in common use along with diagram. **[WBUT 2013]**

Answer:

a) Photovoltaic systems are simple, convenient dependable without the need of moving parts. The basic unit of a photovoltaic system is called a solar cell. These are assembled in arrays of identical modules to produce different power capacities. The power plants may range from small residential systems installed on rooftops to large central systems.

Photon Energy: Light is radiant energy. This is transferred in discrete pieces and not continuously. The smallest unit of energy is called quantum. The quantum of radiant energy is called a photon. The photon energy is proportional to the frequency of radiation. This is called Planck's law.

$$E_p = h\nu = h\frac{c}{\lambda}$$

where E_p = photon energy

h = Planck's constant

$= 6.6256 \times 10^{-34}$ [J.s] $= 4.13576 \times 10^{-15}$ [eVs]

ν = frequency of radiation, [hertz]

c = speed of light $= 2.997925 \times 10^{8}$ m/s

λ = wavelength of radiation, [m]

Light has dual characteristics. It consists of photons, which have energy, and it is also waves having a frequency and wavelength. The radiation from the sun is composed of the photons, each carrying a quantity of energy exactly equal to its frequency times Planck's constant.

b) A solar cell is composed of pn semiconductor junction as shown in Fig. 1. Solar cells can be manufactured from different semiconductor materials and their combinations. The voltage generated by a solar cell depends on the semiconductor material. The electric current produced depends upon the intensity of solar radiation and the cell surface area receiving the radiations. The maximum achievable power is about 100 W/m^2 of solar cell surface area. Pure semiconductor materials are needed for achieving high energy conversion efficiency.

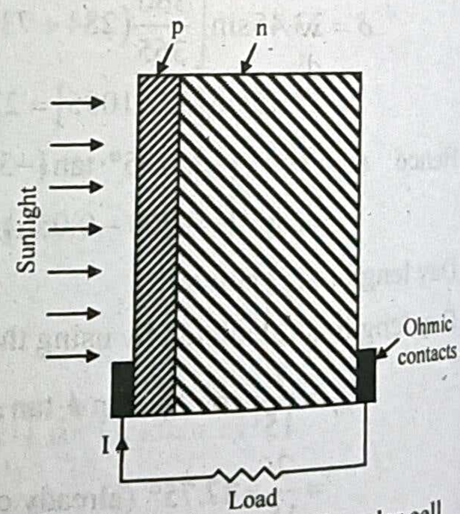


Fig: 1 Cross-section of a solar cell

Direct conversion of solar radiation into electricity can be studied with the help of solid-state principles. In order not to disturb the continuity of the subject.

Types of Solar Cells: the main types of solar cells along with brief performance specifications are:

1. Monocrystalline silicon cells
   Band gap: 1.12 eV
   Maximum efficiency: 24%
2. Polycrystalline silicon cells
   Band gap: 1.12 eV
   Maximum efficiency: 17.8%
3. Amorphous silicon cells
   Band gap: 1.75 eV
   Maximum efficiency: 13%
4. Gallium arsenide (GaAs)
5. Copper indium diselenide (CID) cells
6. Multi-junction cells
7. Cadmium telluride (CdTe) cells
   Band gap: 1.44 eV
   Maximum efficiency: 15.8%
8. Concentrator cells
   Maximum efficiency: 32.3%

At present, silicon solar cells occupy 60% of the world market.

For single-crystal silicon, *p* is obtained by doping silicon with boron and is typically 1 μm thick; *n* is obtained by doping silicon with arsenic and is typically 800 μm thick. Thin film cells are composed of copper sulphide for *p*, typically 0.12 μm thick and cadmium sulphide for *n*, typically 200 μm thick.

Operation of Cell:

The sun's photons strike the cell on the microthin *p* side and penetrate to the junction. There they generate electron-hole pairs. When the cell is connected to the load, the electron will diffuse from *n* to *p*. The direction of current *I* is conventionally in the opposite direction of the electrons.

Performance Characteristics:

Typical voltage-current characteristics are shown in Fig. 2 at two different solar radiation levels. For each

V_0 = Open –circuit voltage

I_0 = Short-circuit voltage

P_m = Point of maximum power,

$= (VI)_{max}$

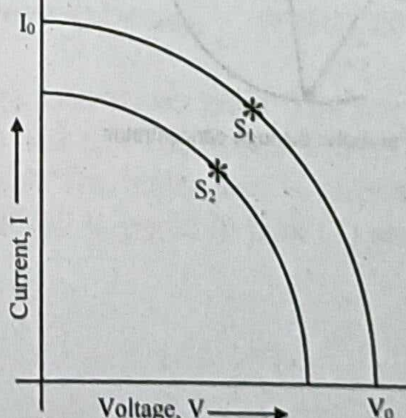


Fig: 2 Performance characteristics of solar cells

c) A solar collector is a receiving device, which absorbs the incident solar radiation and heat a fluid like water or air. The solar radiation is converted into useful heat, which can be used as such or can be converted into electrical power. The collectors can be classified into low temperature, medium temperature and high temperature collectors. Mainly there are two types of collectors.

1. Flat plate collector
2. Concentrating collector

Flat Plate Collectors:

Flat plate collectors are used for temperatures below 100°C. These can use both beam and diffuse solar radiation. They are installed in a fixed tilted position optimally oriented towards the equator.

The main components of a flat plate collector are shown in Fig. 1.

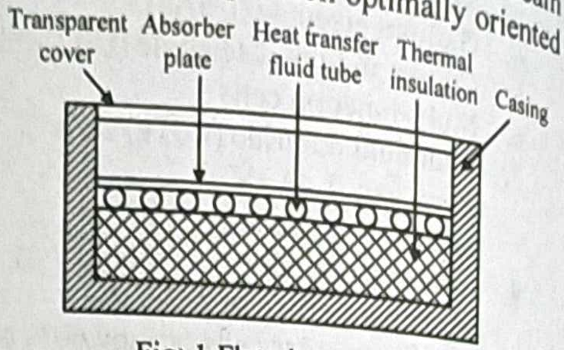
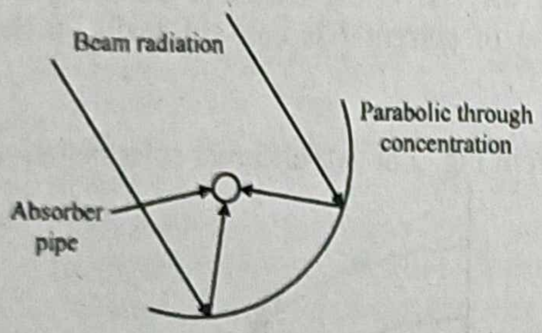


Fig: 1 Flat plate collector

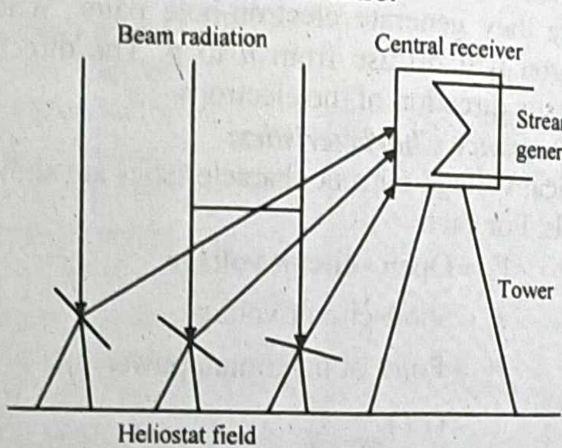
Flat plate collectors used for water heating and space heating can produce 250 to 400 kWh per year and per square meter of useful heat. Evacuated tube collectors can produce useful heat at a temperature upto 250°C. The efficiency of the collector reduces with the increase of fluid temperature.

Concentrating Collector: These are used for medium and high temperature applications. Various types of concentrating solar collectors are shown in Fig. 2. It consists of a concentrating device, which may be a reflecting mirror or Fresnel lenses. The beam radiations are concentrated and focussed on to the absorber.

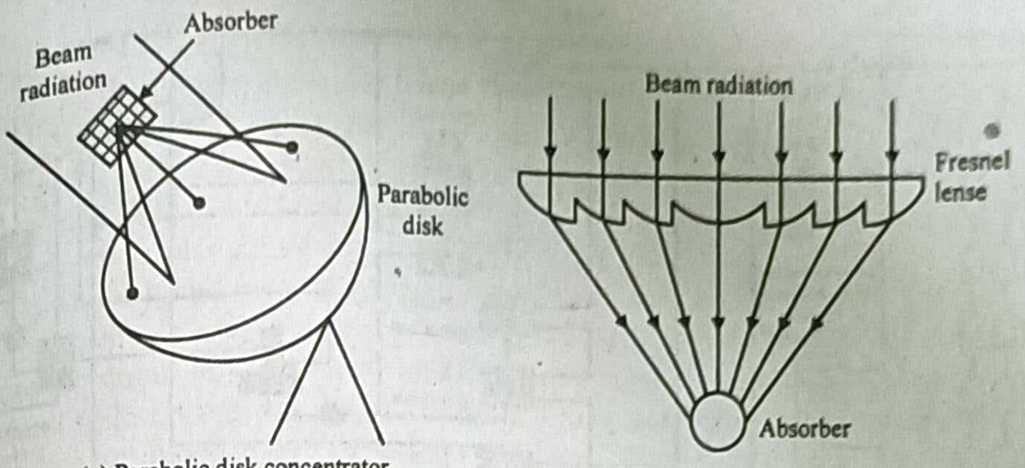
Different types of collectors have different values of concentration ratio.



(a) Parabolic through concentrator



(b) Central receiver with heliostat field



(c) Parabolic disk concentrator

(c) Fresnel lenses concentrator

Fig: 2 Concentrating solar collectors

The concentration ratio,

$$C = \frac{A_a}{A_r}$$

where A_a = Aperture area of the concentrator

A_r = Area of absorber

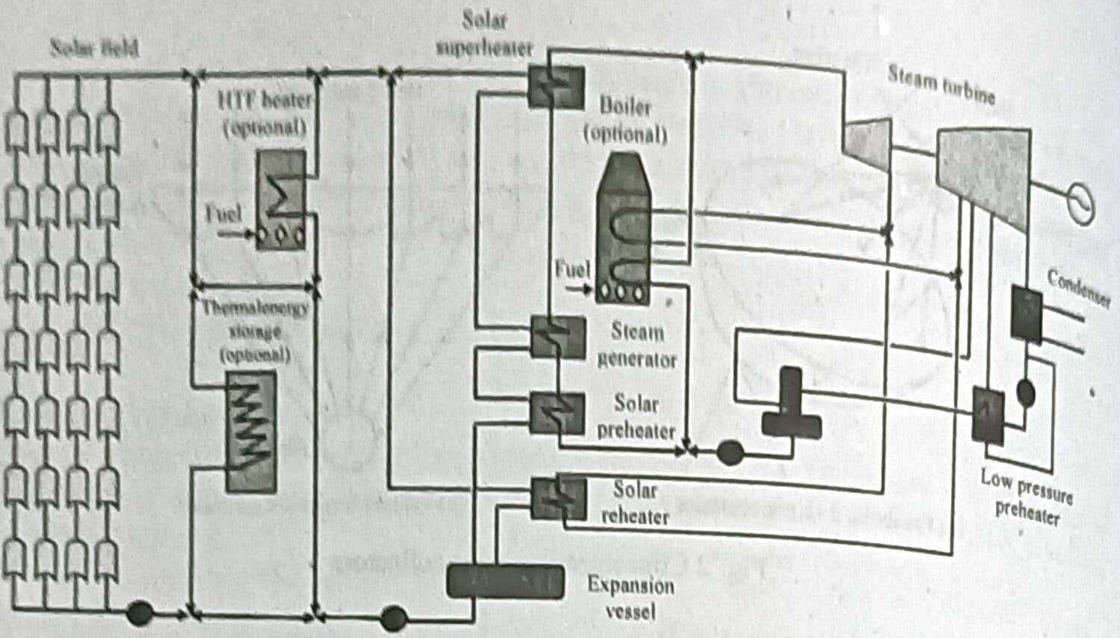
Parabolic through concentrator is a linear concentrator. The value of C may be 20 to 100. Parabolic disk concentrator is a point focus concentrator. The value of C may be 100 to 4000 for parabolic disk and heliostat field concentrator.

The mirrors and Fresnel lenses can focus only beam radiation. These concentrators are rotated through tracking mechanism to follow the motion of the sun in the sky. Temperatures as high as 1000°C can be achieved. These are mainly used in solar plants for power generation and process heat supply.

6. a) With the help of basic block diagram, explain the working of a solar photo voltaic power plant. [WBUT 2015]
b) Define [WBUT 2015]
(i) solar constant
(ii) earth sun angles
c) Derive the expression of maximum current from solar cell. [WBUT 2015, 2019]

Answer:

a) Fig. 1 shows a flow diagram of parabolic trough solar power plant. The working fluid is heated in collectors and collected in hot storage tank (2). The hot thermo-oil is used in boiler (5) to raise steam for the steam power plant. The boiler also is provided with a back-up unit (6) fired with natural gas. The cooled oil is stored in tank (3) and pumped (4) back to collector (1).



The specification of two such plants are given below:

1. Power capacity	30 MW	80 MW
2. Thermal efficiency	37.5%	37.6%
3. Aperture area	$194\times10^3\ m^2$	$464\times10^3\ m^2$
4. Collector field efficiency	43%	53%
5. Annual energy production	93 GWh	253 GWh
6. Production cost	0.15 cents/kWh	0.10 cents/kWh

A power plant of 100 MW is planned to be installed in Rajasthan.

Performance Analysis:

The heat output,

$$Q_c = nI_b A_a \eta_c \ [W]$$

where, A_a = Aperture area of a parabolic trough module [m^2]

I_b = Radiation intensity [W/m^2]

n = No. of collectors.

η_c = Collector efficiency

$$\eta_{mod} = \rho\alpha_{abs} - \frac{U_c\left(T_{abs}-T_a\right)}{CI_b}$$

where, ρ = Reflectivity of mirror

α_{abs} = Absorptivity of tubes

U_c = Overall heat loss coefficient [W/m^2 –K]

T_{abs} = Temperature of absorber [K]

T_a = Ambient temperature [K]

C = Concentration ratio

I_b = Intensity of beam radiation [W/m^2]

b) i) 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. The World Radiation Center (WRC) has adopted the value of the solar constant as 1.367 W/m^2 (1.940 cal/cm^2 min, 432 Btu/ft^2 h or 4.921 MJ/m^2 h). This has been accepted universally as a standard value of solar constant.

ii) When we want to relate the relative position of the Earth with respect to the Sun, we use spherical coordinate angles again. In case to define Earth-Sun spherical coordinate angles, do not require us to specify the complete location where a collector is, because we are mainly honing in on the gross coordinates of Earth and Sun. hence, we say that the Earth-Sun angles are independent of the observer or Collector. However, the Earth-Sun angles are dependent on the time or year and the time of the diurnal cycle (day-night). One must be able to calculate the declination (δ) and hour angles (ω) at any time and location on Earth. Also, one must find the latitude (ϕ) from a resource. The combination of declination and latitude angles, along with the hour angle, will later provide us with core information to calculate the solar altitude and solar azimuth angles.

c) The current-voltage relationship of solar cell is

$$I = I_L - I_j = I_L - I_o\left[\left(e^{\frac{eV}{kT}}\right) - 1\right]$$

For ideal cell $R_s = 0$. The open circuit voltage V_o for an ideal cell is

$$V_o = \left(\frac{kT}{e}\right)\ln\left[\frac{I_2}{I_o} + 1\right]$$

$$\therefore \quad I_L >> I_o,$$

$$V_o = \frac{kT}{e}\ln\frac{I_L}{I_o}$$

The maximum power,

$$P_{\max} = V_{mp} \times I_{mp}$$

where V_{mp} = voltage at maximum power point

I_{mp} = current at maximum power point

The maximum efficiency for the cell,

$$\eta_{\max} = \frac{V_{mp}\cdot I_{mp}}{P_{sun}} = \frac{P_{\max}}{P_{sun}} = \left[\frac{I_L E_g}{eP_{sun}}\right]\underbrace{\left[\frac{I_{mp}\cdot V_{mp}}{I_L V_o}\right]}_{\text{Fill factor}}\underbrace{\left[\frac{eV_o}{E_g}\right]}_{\text{Voltage factor}}$$

where, E_g = Forbidden energy band

$$FF = \text{Fill factor} = \frac{I_{mp} V_{mp}}{I_L V_o} = 0.8 \text{ for a properly designed cell.}$$

$$P_{max} = I_L \times V_o \times FF$$

VF = Voltage factor

$$= \frac{eV_o}{E_g} = 0.5 \text{ for a silicon cell.}$$

7. a) Describe the significance of maximum power point tracking in respect of a solar PV system. **[WBUT 2017]**

Answer:

When a solar PV system is deployed for practical applications, the I-V characteristic keeps on changing with insolation and temperature. In order to receive maximum power, the load must adjust itself accordingly to track the maximum power point. The I-V characteristics of PV system along with some common loads are shown in Fig. 1. An ideal load is one that tracks the maximum power point.

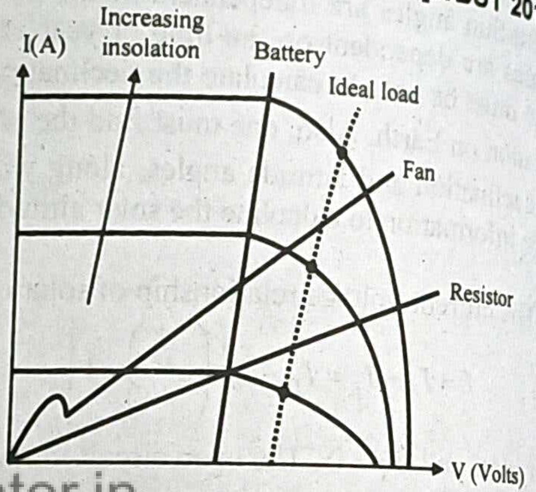


Fig: 1 Characteristic of PV and some loads

If the operating point departs significantly from the maximum power point, it may be desirable to interpose an electronic maximum power point tracker (MPPT) between PV system and load. Generally, MPPT is an adaptation of dc-dc switching voltage regulator. Coupling to the load for maximum power transfer may require either providing a higher voltage at a lower current or lower voltage for higher current. A buck-boost scheme is commonly used with voltage and current sensors tied into a feedback loop using a controller to vary the switching times. Basic elements of a buck-boost converter that may be used in an MPPT are shown in Fig. 2. The output voltage of the buck-boost converter is given by

$$V_{out} = \frac{D}{1-D} V_{in}$$

where D is the duty cycle of the MOSFET, expressed as fraction $(0 < D < 1)$. Details of operation and design of the converter may be found in any standard book of power electronics.

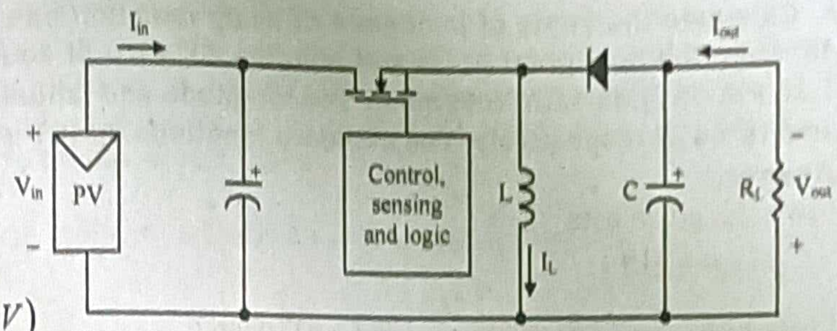


Fig: 2 Maximum point tracker using buck-boost converter

The power output of a PV system is given by

$$P = V \cdot I$$

With incremental change in current and voltage, the modified power is given by

$$P + \Delta P = (I + \Delta I) \cdot (V + \Delta V)$$

which, after ignoring small terms simplifies to

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

ΔP must be zero at peak point. Therefore, at peak point the above expression in the limit becomes

$$\frac{dV}{dI} = -\frac{V}{I}$$

It may be noted here that $\frac{dV}{dI}$ is the dynamic impedance of the source, which is required to be equal to negative of static impedance, $\frac{V}{I}$.

b) A *dc* motor having 85% efficiency is producing 900 watt power at the shaft. A PV system is used to feed the motor. Each module in the PV panel has 40 multi-crystalline silicon solar cells arranged in a 8×5 matrix. The cell size is 13cm × 13cm and cell efficiency is 12%. Solar radiation incident normally to the panel is 1 kW/m². Calculate the number of modules in the panel. [WBUT 2017]

Answer:

Motor output power $= 300$ W

Electrical power required by the motor $= \frac{900}{0.85} = 1058.8$ W

Cell area in one module $= 8 \times 5 \times 13 \times 13 \times 10^{-4} = 0.676\ \text{m}^2$

Let N is the number of modules be required.

Solar radiation incident on the panel $= 1\ \text{kW/m}^2 = 1000\ \text{W/m}^2$

Cell efficiency $= 12\% = 0.12$

Output of solar array $= 1000 \times N \times 0.676 \times 0.12 = 81.12\,N$

The output of the solar array is the input to the motor,

$$81.12N = 1058.8$$

$$N = 12.68 \simeq 13$$

Therefore, 13 modules are required in the panel.

8. Calculate the angle of incidence of beam radiation on a plane surface, tilted by 45° from the horizontal plane and pointing 30° west or south located in Mumbai at 1:30 PM (IST) on 15th November. The longitude and latitude of Mumbai are 72°49′E and 18°54′ N respectively. The standard longitude for IST is 81°44′E. [WBUT 2017]

Answer:

From the given data,

$$n = 319$$

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

$$\delta = -19.148°$$

From Eqn. $E = 9.87\sin 2B - 7.53\cos B - 1.5\sin B$ min

$$E = 14.74 \text{ min}$$

Standard Time $= 1:30$ p.m. $= 13:30$ h.

From Eqn. Solar time = Standard time $\pm 4(L_{st} - L_{loc}) + E$

Solar Time $= 13$ h 30 min $-4(81.733° - 72.816°)$ min $+ 14.74$ min $= 13$ h 9.072 min

From Eqn. $\omega = [\text{Solar Time} - 12:00]$ (in hours) $\times 12$ degrees

Hour angle, $\omega = 17.27°$

$$\gamma = 30°,\ \beta = 45°,\ \phi = +18.9°$$

Now the angle of incidence can be calculated using

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

$$\cos\theta_i = [\cos(+18.9°)\cos(45°) + \sin(+18.9°)\sin(45°)\cos(30°)]$$
$$+\sin(-19.148°)[\sin(+18.9°)\cos(45°) - \cos(+18.9°)\sin(45°)\cos(30°)]$$

$$\theta_i = \cos^{-1}(0.99686) = 4.54°$$

9. a) Describe the production process of multi-crystalline & Amorphous silicon Solar Cell.

b) Assuming that each of the single crystal silicon Solar Cell delivers an open circuit voltage of 600mv under STC, estimate the actual open circuit voltage of a non-standard module containing 18 identical interconnected cells at an ambient temperature 40°C. [WBUT 2018]

Answer:

a) ***Refer to Question 1(a) of Long Answer Type Questions.***

b) The difference of temperature that has to be tolerated by the cells in the module $= 40 - 25 = 15°$ C. The open circuit voltage of the module without temperature correction $= 18 \times 0.6$ Volts. Actual open circuit voltage at an ambient temperature of $40°\text{C} = 18 \times 0.6 = 18 \times (2.3\,\text{mV/°C} \times 15°\,\text{C}) = 18(0.6 - 0.034)$ Volts $= 18 \times 0.566$ Volts $= 10.188$ Volts.

10. a) A dc motor is fed by Solar PV System to produced 1 H.P. power at the shaft. The motor efficiency is 85%. Each module has multicrystalline silicon Solar Cells arranged in 9×4 matrix. The cell size is 125mm×125mm and the cell efficiency is 12%. Calculate the number of modules required in the PV array. Assume global radiation incident normally to the panel is 1 kW/m^2.
b) What is Earth's Albedo?
c) Describe the solar flat plate collector's function with suitable diagram.
[WBUT 2018]

Answer:
a) Motor output power = 1 hp = 746 W.
Electrical power required by the motor $= 746/0.85 = 877.64$ W
Cell area in one module $= 9\times4\times125\times125\times10^{-6} = 0.5625\,\text{m}^2$
Let N number of modules be required.
Solar radiation incident on panel $= 1\,\text{kW/m}^2 = 1000\,\text{W/m}^2$
Cell efficiency $= 0.12$
Output of solar array $= 1000\times0.5625\times N\times0.12 = 67.5\,\text{N}$
The output of solar array is the input to the motor

$$67.5\times N = 877.64$$

$$\Rightarrow \quad N = \frac{877.64}{67.5} = 13.0021 \simeq 13$$

Therefore, 13 modules are required in the panel.

b) **Albedo** is the measure of the diffuse reflection of solar radiation out of the total solar radiation received by an astronomical body (e.g. a planet like Earth). It is dimensionless and measured on a scale from 0 (corresponding to a black body that absorbs all incident radiation) to 1 (corresponding to a body that reflects all incident radiation).
Surface albedo is defined as the ratio of irradiance reflected to the irradiance received by a surface. The proportion reflected is not only determined by properties of the surface itself, but also by the spectral and angular distribution of solar radiation reaching the Earth's surface. These factors vary with atmospheric composition, geographic location and time (see position of the Sun). While bi-hemispherical reflectance is calculated for a single angle of incidence (i.e., for a given position of the Sun), albedo is the directional integration of reflectance over all solar angles in a given period. The temporal resolution may range from seconds (as obtained from flux measurements) to daily, monthly, or annual averages.

c) Flat-plate Collectors (FPC):
A typical flat-plate solar collector is shown in Fig. (1). When solar radiation passes through a transparent cover and impinges on the blackened absorber surface of high absorptivity, a large portion of this energy is absorbed by the plate and then transferred to the transport medium in the fluid tubes to be carried away for storage or use. The underside of the absorber plate and the side of casing are well insulted to reduce conduction losses. The liquid tubes can be welded to the absorbing plate. The liquid tubes are connected at both ends by large diameter header tubes.

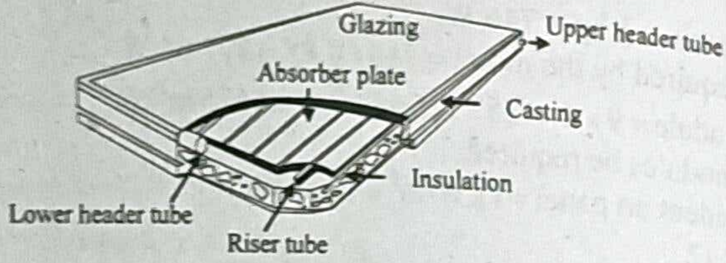


Fig: 1 Flat-plat collector detail

The transparent cover is used to reduce convection losses from the absorber plate through the restraint of the stagnant air layer between the absorber plate and the glass. It also reduces radiation losses from the collector as the glass is transparent to the short wave radiation received by the sun but it is nearly opaque to long-wave thermal radiation emitted by the absorber plate (greenhouse effect).

Flat plate collectors (FPC) are by far the most used type of collector. Flat-plate collectors are usually employed for low temperature application up to 80°C. Flat plate collectors are permanently fixed in position and require no tracking of the sun. The collectors should be oriented directly towards the equator, facing south in the northern hemisphere and north in the southern. Flat-plate collectors have been built in a wide variety of designs and from many different materials. They have been used to heat fluids such as water, water plus antifreeze additive, or air. The collector should also have a long effective life, despite the adverse effects of the sun's ultraviolet radiation, corrosion and clogging because of acidity, alkalinity or hardness of the heat transfer fluid, freezing of water, or deposition of dust or moisture on the glazing.

11. a) What is photovoltaics cell or module? **[WBUT 2019]**
b) Explain different types of photovoltaic systems using block diagram.
c) For new Delhi (28°35′N, 77°12′E), calculate the Zenith angle of the sun at 2:30 pm on 20th February, 2015. The standard IST latitude for India is 81°44′E.

Answer:

a) ***Refer to Question No. 7 of Short Answer Type Questions.***

b) Photovoltaic power systems are generally classified according to their functional and operational requirements, their component configurations, and how the equipment is connected to other power sources and electrical loads. The two principal classifications are grid-connected or utility-interactive systems and stand-alone systems.

Refer to Question No. 2(b) of Long Answer Type Questions.

c) Given, $\phi = 28°35' \text{N} = 28.58$ degrees

For 20th February, $n = 51$

$$\delta = 23.45 \times \sin\left[\frac{360}{365}(284+51)\right] \text{degrees} = -11.58 \text{ degrees}$$

$$E = 9.87\sin 2B - 7.53\cos B - 1.5\sin B \text{ min}$$

$$B = (360/364)(51-81) = -26.67$$

$$E = -14.29 \text{ min}$$

Solar time = 2:30 hrs. ± 4 × (81°44′ – 72°12′) (min) – 14.29 (min)
= 1:57.59 hrs.

$\omega = [12{:}00 - 1{:}57.59]$ (in hours) × 15 degrees = – 14.398 degrees

$$\cos\theta_z = \cos(28°35')\cos(-11.58)\cos(-14.398) + \sin(-11.58)\sin(28°35')\sin(-14.398)$$

$$= 0.7366$$

Zenith angle, $\theta_z = 42.557$ degrees

12. Write short notes on the following:

a) Local solar time **[WBUT 2013]**
b) Solar pond **[WBUT 2015]**
c) Solar water heater **[WBUT 2017]**
d) Solar Cooker **[WBUT 2018, 2019]**
e) Maximum Power Point Tracking (MPPT) **[WBUT 2018]**

Answer:

a) Local solar time:

Solar time is measured with reference to solar noon, which is the time when the sun is crossing the observer's meridian. At solar noon, the sun is at the highest position in the sky. The sun traverses each degree of longitude in 4 minutes (as the earth takes 24 hours to complete one revolution). The standard time is converted to solar time by incorporating two corrections, as follows:

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

where L_{st} and L_{loc} are the standard longitude used for measuring standard time of the country and the longitude of the observer's location respectively. The (+ve) sign is used if the standard meridian of the country lies in the western hemisphere (with reference to the prime meridian) and (–ve) if that lies in the eastern hemisphere. E is the correction arising out of the variation in the length of the solar day due to variations in the earth's rotation and orbital revolution and is called the equation of time. The solar day, which is the duration between two consecutive solar noons is not exactly of 24 hours throughout the year. E can be determined either by using the following equation or from the chart given in Fig. 1.

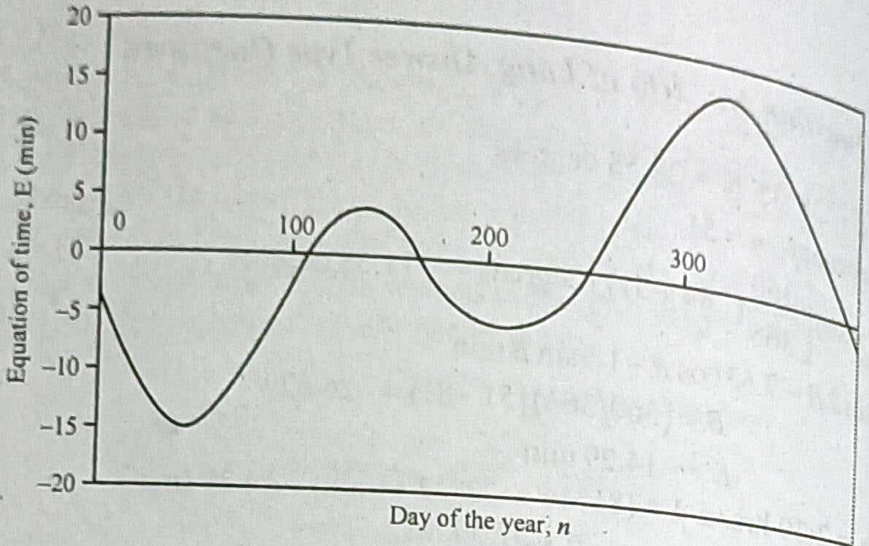


Fig: 1 The equation of time as function of day of the year

$$E = 9.87\sin 2B - 7.53\cos B - 1.5\sin B \text{ min.}$$

where $B = (360/364)(n-81)$

n = day of the year, starting from 1st January.

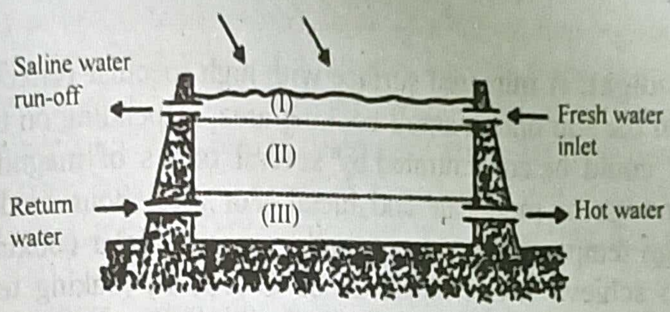
b) Solar pond:

In order to reduce the capital cost of solar thermal installations, the area of the collecting surface has to be optimized and also economical ways of collecting and storing the energy during the same period have to be proposed. When large stretches of water of small depth have been used for simultaneous collection and storage, natural convection currents prevent the rise in temperature of such a pond more than only a few degrees. Thus, an artificially designed pond in which significant temperature rises in the lower regions are possible by preventing the phenomenon of convection is called a 'Solar Pond'. The usual technique followed for preventing convection mechanism is to dissolve a particular salt in water and maintain a definite concentration gradient. Such a concept of 'salt-gradient solar ponds' are very common while concepts like gel solar pond, honey comb solar pond and equilibrium solar pond will only be touched briefly.

A schematic diagram of a solar pond is shown in Fig. 1, where there distinct layers can easily be visualized as —

I) Surface convective zone (SCZ)
II) Non-Concentration gradient zone (CGZ)
III) Lower convective zone (LCZ).

Typically, the structure is about 1 or 2 metres deep with a thick durable plastic liner laid at the bottom. Materials used for the liner are low density polyethylene (LDPE), high density polyethylene (HDPE), woven polyester yarn (XB-5), hypalon enforced with nylon mesh. Salts like magnesium chloride, sodium chloride or sodium nitrate are dissolved in water to result in a concentration varying from 20 to 30 percent at the bottom compared to almost zero at the top. Due to the upward diffusion of the salt, this concentration gradient will decay over a certain period of time. In order to maintain this gradient, fresh water is replaced through inlet at the top of the pond while saline water is run off through another inlet. At the same time, estimated quantity of concentrated brine is also added to the bottom of the pond.



(I) → Surface convective zone (SCZ)
(II) → Non-Concentration gradient zone (CGZ)
(III) → Lower convective zone (LCZ)

Fig: 1 Schematic diagram of a solar pond

For extracting the heat energy from the pond, hot water is removed continuously from the bottom and then returned back through a heat exchanger. Alternatively removal of hot water may be done through a submerged heat exchanger coil. As a result of continuous movement and mixing of the fluid at the top and bottom, the solar pond is characterized by three zones:

I) Surface convective zone (SCZ), having a small thickness around 10 to 20 cms with a low, uniform concentration and a temperature close to ambient air temperature.
II) The Non-convective zone (NCZ) is much thicker and occupies more than half the depth of the pond. It serves principally as an insulating layer for preventing heat losses in the upward direction. Thus it is also an integral part of the thermal storage.
III) Lower convective zone (LCZ), having a thickness of the same order as the NCZ, is characterized by constant concentration and temperature throughout its depth. It is thus the principal heat collection as well as thermal storage medium. Typically, the LCZ of a large solar pond operating in West Indian environment can enjoy a maximum temperature between 85° to 95°C in summer and a minimum of 50° to 60°C in winter with an annual collection efficiency ranging from 15 to 25 percent. Although the efficiency values are much low compared to flat plate collectors, the large area ponds (specially 1000 m^2 or more) have an edge over collectors with respect to lower value of cost/sq. metre.

c) Solar water heater: ***Refer to Question No. 6 of Short Answer Type Questions.***

d) Solar Cooker:

A **solar cooker** is a device which uses the energy of direct sunlight to heat, cook or pasteurize drink and other food materials. Many solar cookers currently in use are relatively inexpensive, low-tech devices, although some are as powerful or as expensive as traditional stoves, and advanced, large-scale solar cookers can cook for hundreds of people. Because they use no fuel and cost nothing to operate, many nonprofit organizations are promoting their use worldwide in order to help reduce fuel costs (especially where monetary reciprocity is low) and air pollution, and to slow down the deforestation and desertification caused by gathering firewood for cooking.

Working Principles

1) Concentrating sunlight: A mirrored surface with high specular reflectivity is used to concentrate light from the sun onto a small cooking area. Depending on the geometry of the surface, sunlight could be concentrated by several orders of magnitude producing temperatures high enough to melt salt and metal. For most household solar cooking applications, such high temperatures are not really required. Solar cooking products are typically designed to achieve temperatures of 65°C (150°F) (baking temperatures) to 400°C (750°F) (grilling/searing temperatures) on a sunny day.

2) Converting light energy to heat energy: Solar cookers concentrate sunlight onto a receiver such as a cooking pan. The interaction between the light energy and the receiver material converts light to heat and this is called conduction. This conversion is maximized by using materials that conduct and retain heat. Pots and pans used on solar cookers should be matte black in color to maximize the absorption.

3) Trapping heat energy: It is important to reduce convection by isolating the air inside the cooker from the air outside the cooker. Simply using a glass lid on your pot enhances light absorption from the top of the pan and provides a greenhouse effect that improves heat retention and minimizes convection loss. This "glazing" transmits incoming visible sunlight but is opaque to escaping infrared thermal radiation. In resource constrained settings, a high-temperature plastic bag can serve a similar function, trapping air inside and making it possible to reach temperatures on cold and windy days similar to those possible on hot days.

Advantages

- High-performance parabolic solar cookers and vacuum tube cookers can attain temperatures above 290°C (550°F). They can be used to grill meats, stir-fry vegetables, make soup, bake bread, and boil water in minutes. Vacuum tube type cookers can heat up even in the clouds and freezing cold.
- Conventional solar box cookers attain temperatures up to 165°C (325°F). They can sterilize water or prepare most foods that can be made in a conventional oven or stove, including bread, vegetables and meat over a period of hours.
- Solar cookers use no fuel. This saves cost as well as reducing environmental damage caused by fuel use. Since 2.5 billion people cook on open fires using biomass fuels, solar cookers could have large economic and environmental benefits by reducing deforestation.
- When solar cookers are used outside, they do not contribute inside heat, potentially saving fuel costs for cooling as well. Any type of cooking may evaporate grease, oil, and other material into the air, hence there may be less cleanup.

- Reduces your carbon footprint by cooking without the use of carbon based fuels or grid electricity from traditional sources.

Disadvantages

- Solar cookers are less useful in cloudy weather and near the poles (where the sun is low in the sky or below the horizon), so an alternative cooking source is still required in these conditions. Solar cooking advocates suggest three devices for an integrated cooking solution: a) a solar cooker; b) a fuel-efficient cookstove; c) an insulated storage container such as a basket filled with straw to store heated food. Very hot food may continue to cook for hours in a well-insulated container. With this three-part solution, fuel use is minimized while still providing hot meals at any hour, reliably.
- Some solar cookers, especially solar ovens, take longer to cook food than a conventional stove or oven. Using solar cookers may require food preparation start hours before the meal. However, it requires less hands-on time during the cooking, so this is often considered a reasonable trade-off.
- Cooks may need to learn special cooking techniques to fry common foods, such as fried eggs or flatbreads like chapatis and tortillas. It may not be possible to safely or completely cook some thick foods, such as large roasts, loaves of bread, or pots of soup, particularly in small panel cookers; the cook may need to divide these into smaller portions before cooking.
- Some solar cooker designs are affected by strong winds, which can slow the cooking process, cool the food due to convective losses, and disturb the reflector. It may be necessary to anchor the reflector, such as with string and weighted objects like bricks.

e) Maximum Power Point Tracking (MPPT):

MPPT or **Maximum Power Point Tracking** is algorithm that included in charge controllers used for extracting maximum available power from PV module under certain conditions. The voltage at which PV module can produce maximum power is called **maximum power point** (or peak power voltage). Maximum power varies with solar radiation, ambient temperature and **solar cell** temperature.

Typical PV module produces power with maximum power voltage of around 17 V when measured at a cell temperature of 25°C, it can drop to around 15 V on a very hot day and it can also rise to 18 V on a very cold day.

Working of MPPT: The major principle of MPPT is to extract the maximum available power from PV module by making them operate at the most efficient voltage (maximum power point). That is to say:

MPPT checks output of PV module, compares it to battery voltage then fixes what is the best power that PV module can produce to charge the battery and converts it to the best voltage to get maximum current into battery. It can also supply power to a DC load, which is connected directly to the battery.

MPPT is most effective under these conditions:

- Cold weather, cloudy or hazy days: Normally, PV module works better at cold temperatures and MPPT is utilized to extract maximum power available from them.
- When battery is deeply discharged: MPPT can extract more current and charge the battery if the state of charge in the battery is lowers.

WIND ENERGY

Multiple Choice Type Questions

1. If three blades of a propeller type wind turbine are too close to each other [WBUT 2011]
   a) the blades will break
   b) the blades will stall
   c) the succeeding blade will move due to turbulence created by the preceding blade
   d) the preceding blade will move due to turbulence created by the succeeding blade

Answer: (b)

2. Horizontal axis windmills of modern design can [WBUT 2014, 2016]
   a) always turn towards the direction of the wind T
   b) never adjust the energy output
   c) never turn towards the direction of the wind
   d) none of these

Answer: (a)

3. Most commonly used wind turbine is [WBUT 2015, 2019]
   a) simple impulse type
   b) propeller type
   c) reaction type
   d) reversible type

Answer: (b)

4. The range of wind speed suitable for power generation is [WBUT 2015]
   a) 0 to 6 m/sec
   b) 5 m/sec to 25 m/sec
   c) 25 m/sec to 50m/sec
   d) 50 m/sec to 70m/sec

Answer: (b)

5. Maximum theoretical efficiency of a wind turbine is [WBUT 2015]
   a) 80%
   b) 68%
   c) 59%
   d) none of these

Answer: (a)

6. Power available in wind is proportional to [WBUT 2016]
   a) wind speed
   b) square of the wind speed
   c) cube of the wind speed
   d) fourth power of the wind speed

Answer: (c)

7. The maximum energy conversion efficiency of a wind turbine for a given swept area is [WBUT 2017]
   a) 49.3%
   b) 51.3%
   c) 59.3%
   d) 69.3%

Answer: (c)

8. If the velocity of wind increases by 40%, power output of the wind turbine will [WBUT 2017]
   a) remain unaltered
   b) be increased by 1.4 times
   c) be increased by 2.744 times
   d) be increased by 4 times

Answer: (c)

9. The range of wind speed suitable for wind power generation is [WBUT 2018]
a) 0 to 5 m/s b) 5 to 25 m/s
c) 25 to 50 m/s d) 50 to 75 m/s

Answer: (b)

10. If the velocity of wind increases by 50%, power output of the wind turbine will be [WBUT 2018]
a) remain same b) increased by 3.375 times
c) increased by 4.25 times d) increased by 6 times

Answer: (b)

Short Answer Type Questions

1. a) How is the power output related to wind speed? [WBUT 2011]
b) What type of generators are coupled to wind turbines? [WBUT 2011, 2013]

Answer:

a) If u_o is the speed of free wind in unperturbed state, the volume of air column passing through an area *A* per unit time is given by Au_o. If ρ is the density of air, the air-mass flow rate, through area *A*, is given as, ρAu_o. Power (P_o) available in wind, is equal to kinetic energy associated with the mass of moving air, i.e.,

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

or, $$P_o = \frac{1}{2}(\rho A)u_0^3$$

Power available in wind per unit area is

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

This indicates that power available in wind is proportional to the cube of wind speed. Assuming a typical value of wind density, ρ at 15°C and at sea level to be 1.2 kg/m^3, power available in moderate wind of 10 m/s is 600 W/m^2.

b) The generators which are coupled to wind turbines
1. Squirrel cage induction generator
2. Doubly fed (wound rotor) induction generator
3. Direct drive synchronous generator

2. Draw the following:
Power vs speed characteristics of a wind turbine. [WBUT 2012]

Answer:

The power vs speed characteristics of a wind turbine have four separate regions as shown in Figure (i).

(i) Low-speed Region (Zero to Cut-in Speed): In this region, the turbine is kept in braked position till minimum wind speed (about 5m/s) is achieved, known as cut-in speed becomes available. Below this speed, the operation of the turbine is not efficient to work properly.

(ii) Maximum Power-coefficient Region: In this region, rotor speed is varied with wind speed so as to operate it at constant tip-speed ratio, corresponding to maximum power coefficient, C_{PMAX}. In this range, the nature of characteristics is close to that of maximum power available in the wind as given by $\frac{P_0}{A} = \frac{1}{2}\rho u_0^3$. The turbine is operated at maximum-power-output point using pitch control.

(iii) Constant Power Region (Constant-turbine-speed Region): During high-speed winds (speed is above 12 m/s), the rotor speed is limited to an upper permissible value based on the design limits of system components. In this region, the power coefficient is lower than C_{PMAX}. Large machines use pitch control to maintain turbine speed as constant. Such a machine is known as *pitch regulated.* Classical European machine use fixed blades (constant pitch) and the blade twist and thickness are so designed as to crudely maintain the speed as constant. Such type of machine is known as *stall regulated.* This is a simple system requiring only passive technique, as there are no moving blade surfaces or complicated hardware. However, power capture is somewhat less due to rounding of power curve.

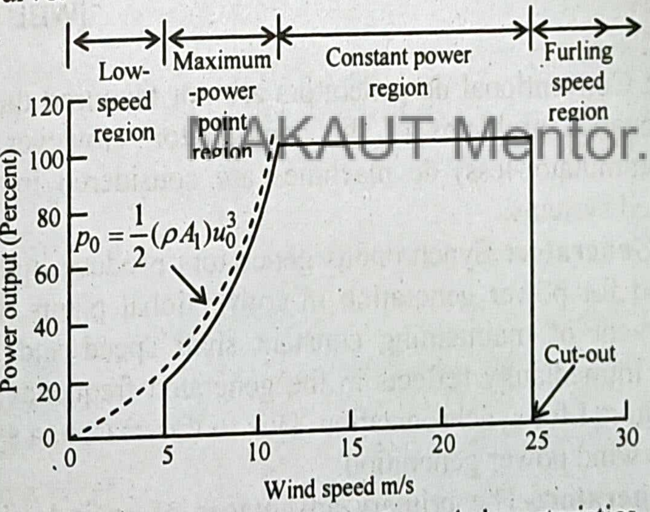


Fig: (i) Power versus wind speed characteristics

In case of fixed-blade rotor, the flow over the blade stalls. The stall performance of machine depends on the twist of the blade tip from the root and thickness of blade sections. The lift and drag coefficients change so as to flatten out the peak of the power curve. Thus, the power output of the wind turbine is limited as shown in Fig. (ii). Stall regulation can be used without much problem up to about a 25-m diameter rotor. Above this size, severe vibration problems associated with the stalled flow in high wind speeds, have been encountered. Thus, large HAWTs always have variable pitch control.

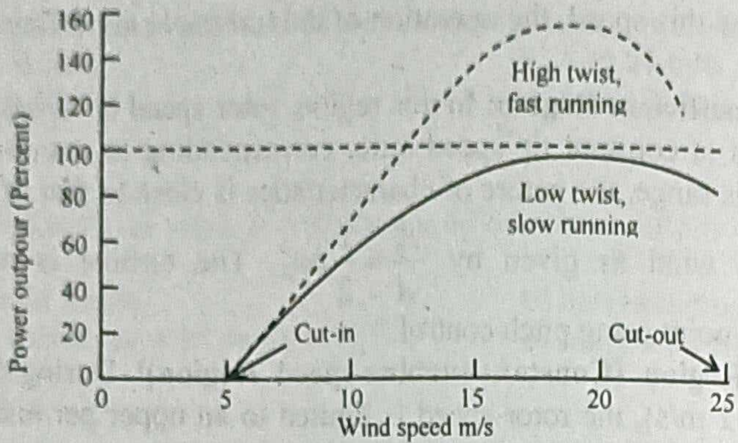


Fig: (ii) Power versus wind-speed characteristics with stall regulation

At still higher wind speeds, such as gusts, constant speed operation is maintained by employing additional means such as some kind of braking (e.g., eddy current braking).

(iv) Furling Speed Region (Cut-out Speed and Above): Beyond a certain maximum value of wind speed (around 25 m/s), the rotor is shut down and power generation is stopped to protect the blades, generator and other components of the system.

3. Explain the types of generators used with wind turbines for producing electricity. **[WBUT 2014, 2016, 2019]**

Answer:

(i) DC Generator: Conventional dc generators are not favoured due to their high cost, weight and maintenance problems of the commutator. However, permanent-magnet (brush-less and commutator-less) dc 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 very 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, a synchronous machine is not well suited to wind power generation.

(iii) Induction Generator: The primary advantages of an induction machine are the rugged, brushless construction, no need of separate dc field power and tolerance of slight variation of shaft speed (±10%) as these variations are absorbed in the slip. Compared to dc 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.

4. Explain the working of horizontal axis to blade windmill with suitable diagram. **[WBUT 2019]**

Answer:

Horizontal Axis Wind Turbine (HAWT): HAWTs have emerged as the most successful type of turbines. These are being used for commercial energy generation in many parts of the world. Their theoretical basis is well researched and sufficient field experience is available with them.

Main Components

The constructional details of the most common, three-blade rotor, horizontal axis wind turbine is shown in Fig. 1. The main parts are as follows:

Turbine Blades: Turbine blades are made of high-density wood or glass fibre and epoxy composites. They have an airfoil type of cross-section. The blades are slightly twisted from the outer up to the root to reduce the tendency to stall. In addition to centrifugal force and fatigue due to continuous vibrations. There are many extraneous forces arising from wind turbulence, gust, gravitational forces and directional changes in the wind. All these factors are to be taken care off at the designing stage. The diameter of a typical MW range, modern rotor may be of the order of 100m.

Modern wind turbines have two or three blades. Two/thee blade rotor HAWT are also known as propeller-type wind turbines owing to their similarity with propellers

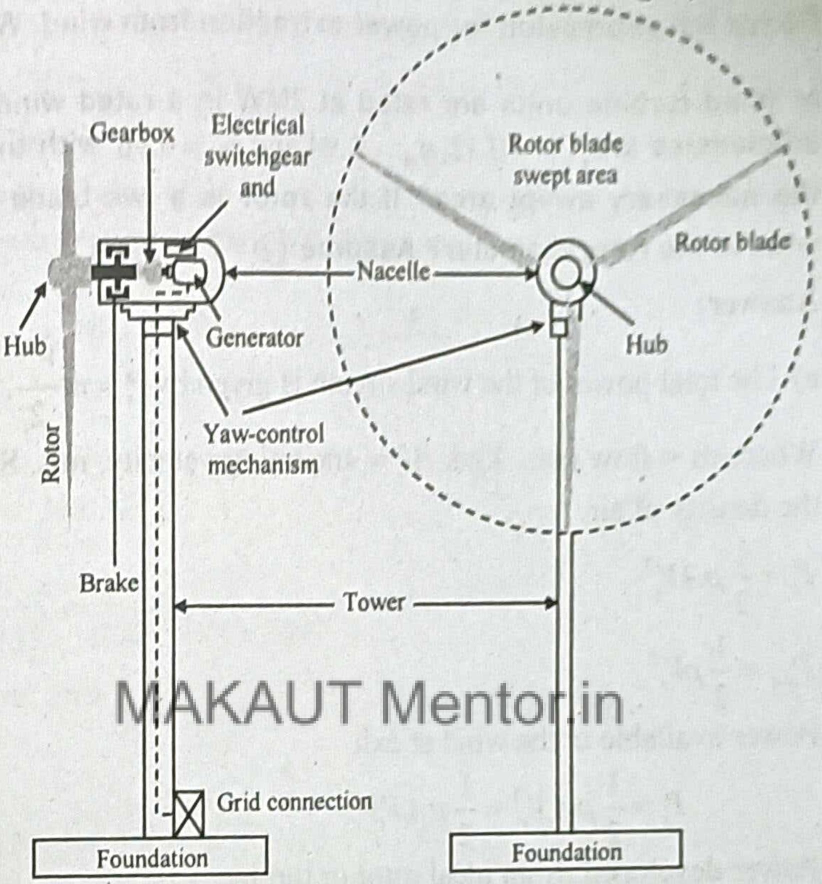


Fig: 1 Horizontal axis wind turbine

of old aeroplanes. However, the rotor rpm in case of a wind turbine is very low as compared to that for propellers.

Three blades are more common in Europe and other developing countries including India. The American practice, however, is in favour of two blades.

Hub: The central solid portion of the rotor wheel is known as hub. All blades are attached to the hub. The mechanism for pitch angle control is also provided inside the hub.

Nacelle: The term nacelle is derived from the name for housing containing the engines of an aircraft. The rotor is attached to the nacelle and mounted at the top of a tower. It contains rotor brakes, gearbox, generator and electrical switchgear and control. Brakes are used to stop the rotor when power generation is not desired. The gearbox steps up the shaft rpm to suit the generator. Protection and control functions are provided by switchgear and control block. The generated electrical power is conducted to ground terminals through a cable.

Long Answer Type Questions

1. a) Deduce the expression of maximum power that can be extracted from Wind. What is Betz Law? **[WBUT 2007]**

OR,

Derive the expression for power extraction from wind. What is Betz criterion? **[WBUT 2017]**

b) Wind turbine units are rated at 2MW in a rated wind speed of 13 m/sec. Stage efficiencies are $C_p = 0.32, \eta_{gb} = 0.94$ and $\eta_g = 0.96$ with their usual meaning. What is the necessary swept area? If the rotor is a two-blade propeller (horizontal axis), what is the rotor diameter? Assume $\left(\rho = 1.29 \text{ kg/m}^3\right)$ **[WBUT 2007, 2010]**

Answer:

a) The total power of the wind stream is given by $P_i = \dot{m}\frac{V_i^2}{2}, W$

Where m = flow rate, kg/s, V_i = incoming velocity, m/s. Since $m = \rho A V_i$, where ρ is the density of air.

$$P_i = \frac{1}{2}\rho A V_i^3$$

$$P_{i/A} = \frac{1}{2}\rho V_i^3$$

Power available in the wind at exit

$$P_e = \frac{1}{2}\rho A_e V_e^3 = \frac{1}{2}\rho A_i V_i V_e^2$$

Power developed by an ideal rotor or turbine

$$P_t = P_i - P_e = \frac{1}{2}\rho A_i V_i (V_i^2 - V_e^2)$$

A this maximum performance condition,

$$V_t = aV_i = \frac{2}{3}V_i, V_e = \frac{1}{3}v_i, A_i = \frac{2}{3}A_t, A_e = 2A_i$$

Maximum mechanical power extracted from wind

$$P_{max} = P_i - P_e = \frac{1}{2}\rho\left(A_i V_i^3 - A_e V_e^3\right) = \frac{1}{2}\rho A_i V_i^3\left(1 - \frac{A_e V_e^3}{A_i V_i^3}\right)$$

$$= \frac{1}{2}\rho A_i V_i^3\left(1 - 3/3^3\right) = \frac{8}{9}\cdot\frac{1}{2}\rho A_i V_i^3$$

Betz' Law: Betz' law states that only a maximum of 59.25% of the kinetic power in the wind can be converted to mechanical power using a wind turbine, the so called maximum power co-efficient on Betz number. This number is not higher because the wind on the back side of the rotor must have a high enough velocity to move away and allow more wind through the plane of the rotor.

The relationship between the mechanical power of the rotor blade P_R and the power of wind P in the rotor area is given by the power co-efficient c_P.

$$c_P = \frac{P_R}{P} \qquad \text{.... (1)}$$

The power co-efficient c_P can be interpreted as the efficiency between the rotor blade and the wind. The maximum power co-efficient the above mentioned Betz' number, determined by the ratio $V_2/V_1 = 1/3$. Therefore, an ideal turbine will slow down by the wind by $2/3$ of its original speed.

The question of how much of the wind energy can be transferred to the blade as mechanical energy has been answered by the Betz' law.

b) $V_\infty = 13\,\text{m/s}$ $\quad C_P = 0.32$ $\quad \eta_{gb} = 0.94$ $\quad \eta_g = 0.96$

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

$$\Rightarrow \quad 2\times10^6 = \frac{1}{2}\times0.32\times1.29\times A(13)^3$$

$$\Rightarrow \quad A = \frac{4\times10^6}{0.32\times1.29\times(13)^3} = \frac{4\times10^6}{0.32\times1.29\times2197} = 4.41\times10^3\,\text{m}^2$$

$A =$ Necessary swept area

$$\pi\cdot\frac{D^2}{4} = A$$

Solving above equation we get the value of D

$$D^2 = \frac{4.41\times10^3\times4}{\pi} = 5617.834$$

$$D = \sqrt{5617.834} = 74.95\,\text{m}$$

2. Define 'Betz Limit' and derive the expression for maximum power coefficient for wind turbine. **[WBUT 2008, 2014]**

Answer:

Betz's law is a theory about the maximum possible energy to be derived from a "hydraulic wind engine", or a wind turbine such as the Eolienne Bollee (patented in 1868), the Eclipse Windmill (developed in 1867) and the Aermotor (first appeared in 1888 to pump water for cattle and is still in production). Decades before the advent of the modern 3-blade wind turbine that generates electricity, Betz's law was developed in 1919 by the German physicist Albert Betz. According the Betz's law, no turbine can capture more than 59.3 percent of the kinetic energy in wind. The ideal or maximum theoretical efficiency n max (also called power coefficient) of a wind turbine is the ratio of maximum power obtained from the wind to the total power available in the wind. The factor 0.593 is known as Betz's coefficient (from the name of the man who first derived it). It is the maximum fraction of the power in a wind stream that can be extracted.

Power coefficient $= C_p =$ (power output from wind machine) / (power available in wind)

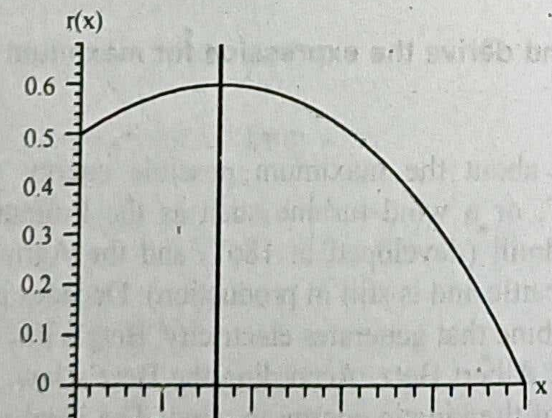
Proof: It shows the maximum possible energy — known as the Betz limit — that may be derived by means of an infinitely thin rotor from a fluid flowing at a certain speed. In order to calculate the maximum theoretical efficiency of a thin rotor (of, for example, a windmill) one imagines it to be replaced by a disc that withdraws energy from the fluid passing through it. At a certain distance behind this disc the fluid that has passed through flows with a reduced velocity.

Assumptions

1. The rotor does not possess a hub, this is an ideal rotor, with an infinite number of blades which have no drag. Any resulting drag would only lower this idealized value.
2. The flow into an out of the rotor is axial. This is a control volume analysis and to construct a solution the control volume must contain all flow going in and out, failure to account for that flow would violate the conservation equations.
3. This is incompressible flow. The density remains constant and there is no heat transfer from the rotor to the flow or vice versa.
4. The rotor is also massless. No account is taken of angular momentum imparted to either the rotor or the airflow behind the rotor, i.e., no account iş taken of any wake effect.

Betz' law and coefficient of performance

Returning to the previous expression for power based on kinetic energy:
The horizontal axis reflects the ratio v_2/v_1, the vertical axis is the "power çoefficient" C_p. By differentiating (through careful application of the chain rule) with respect to for a given fluid speed v_1 and a given area S one finds the maximum or minimum value for. The result is that reaches maximum value when.



Substituting this value results in:
The work rate obtainable from a cylinder of fluid with cross sectional area S and velocity v_1 is:
The "power coefficient" $C_p = (= P/P_{wind})$ has a maximum value of: $C_{p,max} = 16/27 = 0.593$ (or 59.3%; however, coefficients of performance are usually expressed as a decimal, not a percentage).
Rotor losses are the most significant energy losses in, for example, a windmill. It is, therefore, important to reduce these as much as possible. Modern rotors achieve values for C_p in the range of 0.4 to 0.5, which is 70 to 80% of the theoretically possible.

3. List and briefly discuss the factors that you would take into consideration in selecting a site of a land-based wind machine. [WBUT 2010, 2012]

OR,

Briefly mention the site selection criterion for installing wind turbine. [WBUT 2018]

Answer:
Land based wind machines are generally located far from population centres and require significant transmission capacity to deliver electricity to load centres. The development of high quality land based sites is being constrained by limited access to transmission and that the output of operational wind farms is increasingly being curtailed by system operators a way of reducing congestion. The size of land based turbines is restricted by the capacity limits of the existing transportation and erection equipment. The capacity limits of the existing equipment is causing the growth of land based wind turbines to level off.

The main objective in wind turbine site selection is to obtain a high incidence of a wind at a high wind speed. The factors to be taken into account in selecting site of a land based wind machine:

a) Geographical location
- access by road
- proximity to the nearest public electricity network

b) Geographical position
- altitude
- proximity to other wind machines

c) Seasonal variation of the wind
- contours of mean wind speed
- wind power/hours chart

d) Exposure
- screening of surrounding features such as hills, buildings, trees, etc.

e) Shape of ground contours
- aerofoil effect of hills to enhance the wind velocity

f) Direction of the prevailing winds
- incidence of gusting
- prevalence of wind storms

g) Necessary height of the tower
h) Costs
- installation
- repair & maintenance
- on-site guarding
- comparative costs of other power sources

4. Describe different types of Wind Turbines with neat sketches. **[WBUT 2012]**

Answer:

Wind turbines are broadly classified into two categories. When the axis of rotation is parallel to the air stream (i.e., horizontal), the turbine is said to be a Horizontal Axis Wind Turbine (HAWT) and when it is perpendicular to the air stream (i.e., vertical), it is said to be a Vertical Axis Wind Turbine (VAWT). The size of the rotor and its speed depends on rating of the turbine.

Horizontal Axis Wind Turbine (HAWT)

Refer to Question No. 4 of Short Answer Type Questions.

Yaw-Control Mechanism: The mechanism to adjust the nacelle around the vertical axis to keep it facing the wind is provided at the base of the nacelle.

Tower: The tower supports the nacelle and rotor. For medium and large sized turbines, the tower is slightly taller than the rotor diameter. In case of a small-sized turbine, the tower is much larger than the rotor diameter as the air is erratic at lower heights. Both steel and concrete towers are being used. The construction can be either tubular or lattice type.

The tower vibrations and resulting fatigue cycles under wind speed fluctuations are avoided by careful design. The required avoidance of all resonance frequencies of tower, the rotor and the nacelle from the wind-fluctuation frequencies.

Vertical Axis Wind Turbine (VAWT)

VAWTs are in the development stage and many models are undergoing field trial. The main attractions of a VAWT are

(i) it can accept wind from any direction, eliminating the need of yaw control,
(ii) the gearbox, generator, etc., are located at the ground, thus eliminating the heavy nacelle at the top of the tower, thus simplifying the design and installation of the whole structure, including the tower,
(iii) the inspection and maintenance also gets easier and
(iv) it also reduces the overall cost.

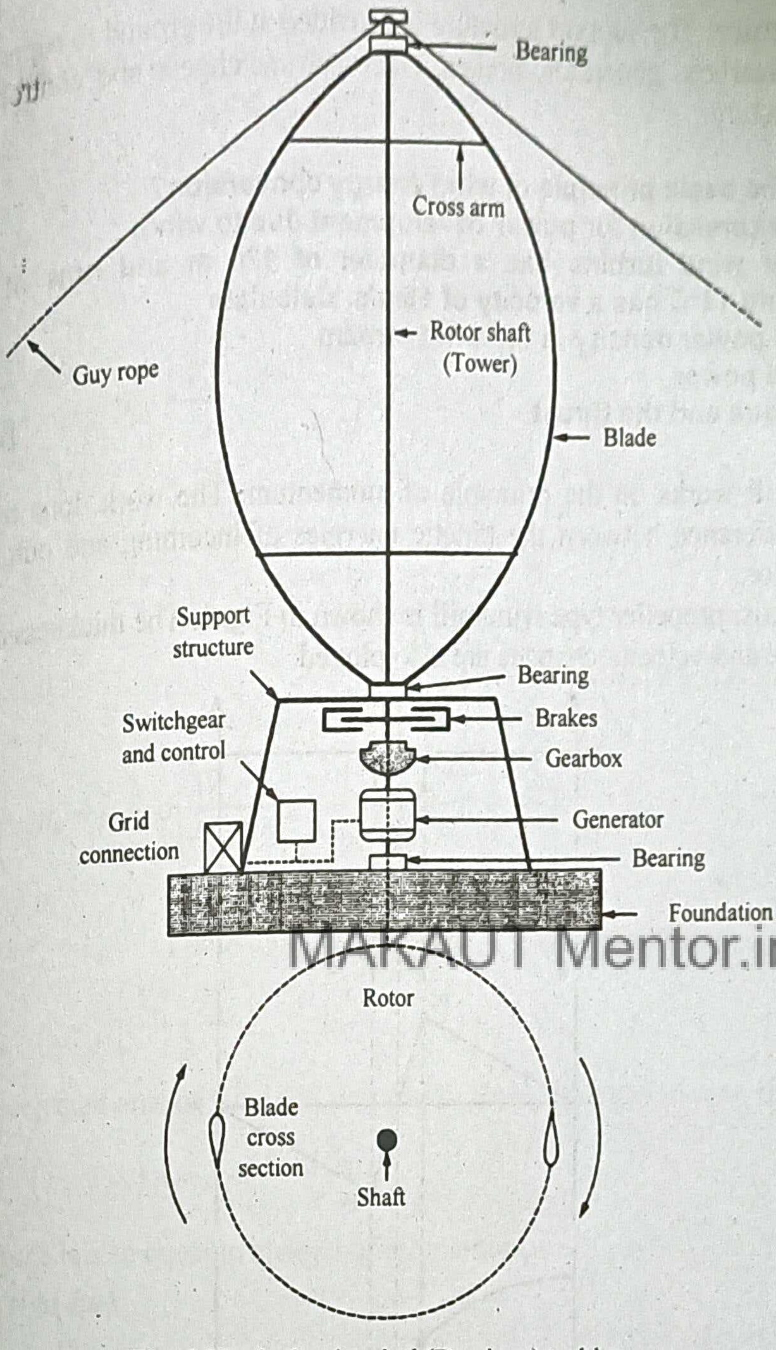


Fig: 2 Vertical axis wind (Darrieus) turbine

Tower (or Rotor Shaft): The tower is a hollow vertical rotor shaft, which rotates freely about the vertical axis between the top and bottom bearings. It is installed above a support structure. In the absence of any load at the top, a very strong tower is not required, which greatly simplifies its design. The upper part of the tower is supported by guy ropes. The height of the tower of a large turbine is around 100 m.

Blades: It has two or three thin, curved blades shaped like an eggbeater in a profile, with blades curved in a form that minimized the bending stress caused by centrifugal forces – the so called "Troposkien" profile. The blades have an airfoil cross-section with constant chord length. The pitch of the blades cannot be changed. The diameter of the rotor is slightly less than the tower height. The first large (3.8 MW), Darrieus type, Canadian machine has a rotor height as 94 m and the diameter as 65 m with a chord of 2.4 m.

Support Structure: The support structure is provided at the ground to support the weight of the rotor. Gearbox, generator, brakes, electrical switchgear and controls are housed within this structure.

5. a) What is the basic principle of wind energy conversion?
b) Derive the expression for power development due to wind.
c) A propeller wind turbine has a diameter of 120 m and runs at 1 standard atmosphere and 18°C has a velocity of 15m/s. Calculate
i) the total power density in the wind stream
ii) the total power
iii) the torque and the thrust.

[WBUT 2013]

Answer:

a) The windmill works on the principle of momentum. The work done by the turbine rotor is the difference between the kinetic energies of incoming and outgoing streams through the rotor.

A horizontal-axis, propeller type windmill is shown in Fig. 1. The thickness of wheel is a-b. The pressure and velocity changes are also plotted.

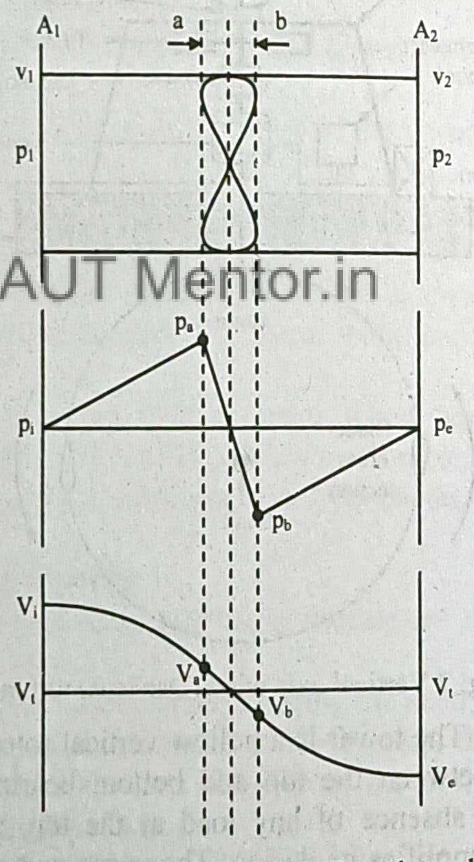


Fig: 1 Pressure and velocity profiles for air flow through a wind turbine

The exit velocity V_e is less than V_i because kinetic energy is extracted by turbine. The pressure p_e is almost equal to p_i. Applying total energy equation and taking air density $\rho =$ constant.

$$PE_1 = PE_2$$

$$p_i v + \frac{V_i^2}{2} = p_a v + \frac{V_a^2}{2}$$

$$p_i + \rho\frac{V_i}{2} = p_a + \rho\frac{V_a^2}{2}$$

where $v = \frac{1}{\rho}$

For exit area,

$$p_e v + \frac{V_e^2}{2} = p_b v + \frac{V_b^2}{2}$$

$$p_e + \rho\frac{V_2^2}{2} = p_b + \rho\frac{V_b^2}{2}$$

Now $V_i > V_a$

and $V_b > V_c$

$$p_a > p_i$$

$$p_b < p_e$$

$$\therefore \quad p_a - p_b = p_i + \rho\left(\frac{V_i^2 - V_a^2}{2}\right) - \left(p_e + \rho\frac{V_2^2 - V_b^2}{2}\right)$$

as $p_e = p_i$

$V_i = V_a = V_b$ [velocity does not change within the turbine]

$$\therefore \quad p_a - p_b = \rho\left(\frac{V_i^2 - V_e^2}{2}\right)$$

If A is the projected area of windmill perpendicular to the wind stream, the axial force,

$$F_x = (p_a - p_b)A = \rho A\left(\frac{V_i^2 - V_e^2}{2}\right)$$

The axial force is also equal to change of momentum.

$$F_x = \Delta(\dot{m}u)$$

$$\dot{m} = \rho A V_t$$

$$\therefore \quad F_x = \rho A V_t (V_i - V_e)$$

where $V_t = \left(\frac{V_i - V_e}{2}\right)$

Now steady flow work,

$$W = KE_i - KE_e = \frac{V_i^2 - V_e^2}{2}$$

The power produced is rate of work.

$$\therefore \quad P = \dot{m}\left(\frac{V_i^2 - V_e^2}{2}\right)$$

$$P = \frac{1}{2}\rho A V_i\left(V_i^2 - V_e^2\right)$$

$$P = \frac{1}{4}\rho A\left(V_i + V_e\right)\left(V_i^2 - V_e^2\right)$$

For maximum power,

$$\frac{dP}{dV_e} = 0$$

$$\therefore \quad 3V_e^2 + 2V_iV_e - V_i^2 = 0$$

$$V_{e_{opt}} = \frac{V_i}{3}$$

$$\therefore \quad P_{max} = \frac{8}{27}\rho A V_i^3$$

The maximum efficiency,

$$\eta_{max} = \frac{P_{max}}{P_{tot}} = \frac{8}{27}\times 2 = \frac{16}{27} = 0.5926 \approx 60\%$$

Therefore actual power,

$$P = \eta P_{tot} = \eta\frac{\rho AV^3}{2}$$

where η varies between 30 to 40% for real turbines.

b) ***Refer to Question No. 1(a) of Long Answer Type Questions.***

c) Assuming ideal stream line wind flow

Total wind power $P_0 = \frac{1}{2}\times\rho\times A\times u_0^3 = \frac{1}{2}\times 1.24\times 10^3\times\pi r^2\times u_0^3$

$$= \frac{1}{2}\times 1.24\times 10^3\times\pi .60^2\times 15^3 = .5\times 1240\times\pi\times 3600\times 3375$$

$$= 23653620000 = 23653.62\text{MW}$$

So Power density of wind $= \frac{1}{2}\times\rho\times u_0^2 = \frac{1}{2}\times 1.24\times 10^3\times 15^2 = .5\times 1240\times 225. = 139500$

Maximum axial thrust $_{max}(\text{force})_{max} = \frac{1}{2}\times\rho\times A\times u_0^2 = \frac{1}{2}\times 1.24\times 10^3\times\pi\times\frac{120^2}{4}\times 15^2$

$$= \frac{1}{2}\times 1.24\times 10^3\times\pi\times 60^2\times 15^2$$

$$= 620\times\pi\times 3600\times 225 = 1576908000\text{N}$$

$$= 1576.9\text{MN}$$

Actual thrust according to Bet'z criterion is equal to $0.59\times\tau_{max}$

Maximum Torque $(\tau_{max}) = C_t \times \tau_{max} = .59\times u_0 \times r\times\omega\times\tau_{max}$

$$= .59\times 15\times\frac{120}{2}\times\frac{2\pi\times 300}{60}\times 15769080000\text{N} = 1.3114\times 10^{13}\text{ N-m}$$

Power drawn from the wind by the turbine i.e., shaft power

$$= C_t \times P_0 = .59P_0 - .59\times 23653.62 = 13955.6358\text{MW}$$

ω = rotational torque of turbine

6. Wind speed is 10m/s at the standard atmospheric pressure. Calculate: (i) total power density in wind stream, (ii) total power produced by a turbine of 100 m diameter with an efficiency of 40%. Air density = 1.226 J/kg-K/m^3. [WBUT 2014]

Answer:

$V_u = 10\text{m/s}$, $\rho = 1.226$ J/Kg-K/m^3

i) Total power density in wind stream $= \frac{1}{2}\rho V_u^3$

$$= \frac{1}{2}\times 1.226\times 10^3 = 613\text{ W/m}^2$$

ii) Total power produced by a turbine of 100 m diameter is

$$P = 0.245\times\frac{\pi D^2}{4} = 0.245\times\frac{\pi\times 100^2}{4} = 1923.25\text{KW}$$

7. a) Using Betz model of wind turbine, derive the expression for power extracted from wind. What is Betz criterion?

b) A propeller type wind turbine has the following data:
Speed of free wind at a height of 10m is 12m/s, air density is 1.226 kg/m^3, α = 0.14, height of tower is 100m, diameter of rotor is 80m, wind velocity at the turbine reduces by 20%, generator efficiency is 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. [WBUT 2015]

Answer:

a) ***Refer to Question No. 1(a) of Long Answer Type Questions.***

b) From given data,

$u_H = 12$ m/s, $H = 10$ m, $z = 100$ m

$\rho = 1.226$ kg/m^3, $\alpha = 0.14$, $D = 80$ m

$A_1 = 5026.55$ m^2, $u_1 = 0.8u_0$, $\eta_{Gen} = 0.85$

From Eqn. $u_z = u_H\left(\frac{z}{H}\right)^{\alpha}$, $u_z = 16.565\text{ m/s} = u_0$ and $u_1 = 0.8\times 16.565 = 13.252$ m/s

(i) From Eqn. $\frac{P_0}{A}=\frac{1}{2}\rho u_0^3$, $P_0=14\,\text{MW}$

(ii) From Eqn. $a=\frac{(u_0-u_1)}{u_0}$, the interference factor, $a=0.2$

From Eqn. $C_p=4a(1-a)^2$, the power coefficient $C_p=0.512$

From Eqn. $P_T=C_pP_0$, power extracted by the turbine $P_T=7.168\,\text{MW}$

(iii) Electrical power generated $=0.85\times7.168=6.09\,\text{MW}$

(iv) From Eqn. $F_A=\frac{4a(1-a)(A_1)\rho u_0^2}{2}$, axial thrust on the turbine, $F_A=5.4\times10^5\,\text{N}$

(v) Maximum axial thrust occurs when $a=0.5$ and $C_F=1$

$$F_{A\max}=\left(\frac{A_1\rho u_0^2}{2}\right)=8.455\times10^5\,\text{N}.$$

8. a) Compare the advantages and disadvantages of HAWT and VAWT.
b) A propeller wind turbine has a diameter of 120 m and runs at 40 rpm. The wind at 1 standard atmosphere and 20°C has a velocity of 15 m/s. Calculate —
i) the total power density in the wind stream
ii) the maximum obtainable power density
iii) the total power at 35% efficiency
iv) the torque developed. **[WBUT 2017]**

Answer:

a) ***Refer to Question No. 10(a) of Long Answer Type Questions.***

b)

$$P=1\,\text{atm}=1.01325\times10^5\,\text{pa}$$

$$T=273+20^{-}=293^{-}$$

$$\rho=\frac{P}{RT}=\frac{(1.01325\times10^5)}{(287\times293)}=1.205\,\text{kg/m}^3$$

$$u_0=15\,\text{m/sec}$$

Radius of rotor, $R=60\,\text{m}$

Speed of rotor, $\omega=40\,\text{rpm}=\frac{(2\pi\times40)}{60}=4.1888\,\text{rad/sec}$

Tip-speed ratio, $\lambda=\frac{R\omega}{u_0}=\frac{60\times4.1888}{15}=16.7552$

i) Total power density in the wind stream,

$$\frac{P_0}{A}=\frac{1}{2}\rho u_0^3=\frac{1}{2}\times1.205\times(15)^3=2033.43\,\text{W/m}^3$$

ii) For maximum obtainable power, interference factor, $a = \frac{1}{3}$ and power coefficient,

$$C_{P\max} = \frac{16}{27} = 0.593$$

Hence, maximum obtainable power density,

$$\frac{P_T}{A} = C_P \times \frac{P_0}{A} = 1205.8 \text{ W/m}^3$$

iii) Total power at 35% efficiency is,

$$P = \eta P_{\text{tot}} = \eta \frac{A u_0^3}{2} = 6.7 \text{ MWatt}$$

iv) Torque coefficients

$$C_T = \frac{C_P}{\lambda} = \frac{0.595}{16.75} = 0.035$$

Maximum conceivable torque,

$$T_M = \frac{P_0}{u_0} R = 92 \text{ N}$$

Torque produced at the shaft,

$$T_{sh} = C_T \times T_M = 0.035 \times 92 = 3.22 \text{ N}$$

9. a) Derive the expression for power developed due to wind. **[WBUT 2019]**

b) Following data were measured for a HAWT:

Speed of wind = 20 m/s at 1 atm and 27°C

Diameter of rotor = 80 m

Speed of rotor = 40 rpm

Calculate the torque produced at the shaft for maximum output of the turbine.

c) What is the importance of site selection in wind power generation?

Answer:

a) ***Refer to Question No. 1(a) (1st Part) of Long Answer Type Questions.***

b) Given, $\mu_0 = 20$ m/s

P = 1 atm = 1.01325×10^5 Pa

$T = 273 + 27 = 300$

Radius of rotor $R = 40$ m

Speed of rotor $\omega = 40 \text{ rpm} = (2\pi) \times (40/60) = 4.188 \text{ rad/s}$

$$\rho = \frac{P}{(RT)} = \frac{1.01325 \times 10^5}{(287 \times 300)} = 1.177 \text{ kg/m}^3$$

For maximum output $a = \frac{1}{3}$, $C_{P_{\max}} = 0.593$

Tip speed ratio $\lambda = \frac{40 \times (4.188)}{20} = 8.376$

$$P_0 = \frac{1}{2}(\rho A)\mu_0^3 = 23.6665\,\text{MW}$$

$$T_m = \frac{P_o}{\mu_o}R = \frac{23.665 \times 40}{20} = 47.33N$$

$$C_{T\max} = \frac{C_{P\max}}{\lambda} = \frac{0.593}{8.378} = 0.07078$$

Torque produced at the shaft at maximum output,

$$T_{sh\max} = 47.33 \times 0.07078 = 3.35\,\text{N}$$

c) ***Refer to Question No. 3 of Long Answer Type Questions.***

10. Write short notes on the following:
a) HAWT and VAWT **[WBUT 2007, 2017]**
b) Magnus effect **[WBUT 2013]**
c) Betz criteria **[WBUT 2018]**

Answer:

a) Horizontal axis wind machines: Fig. 1 shows a schematic arrangement of a horizontal axis machine. Although the common wind turbine with a horizontal axis is simple principle, yet the design of a complete system, especially a large one that would produce electric power economically, is complex. It is paramount importance that the components like rotor, transmission, generator and tower should not only be as efficient as possible but they must also function effectively in combination.

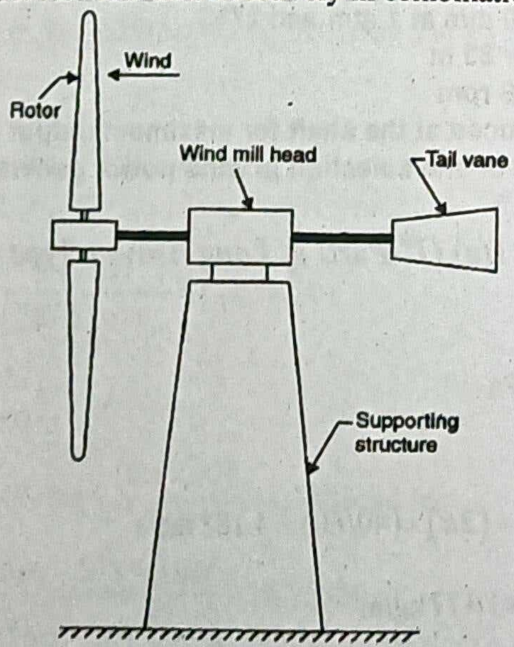


Fig: 1 Horizontal axis wind machine

Vertical axis wind machines: Fig. 2 shows vertical axis type wind machine. One of the main advantages of vertical axis rotors is that they do not have to be turned into the windstream as the wind direction changes.

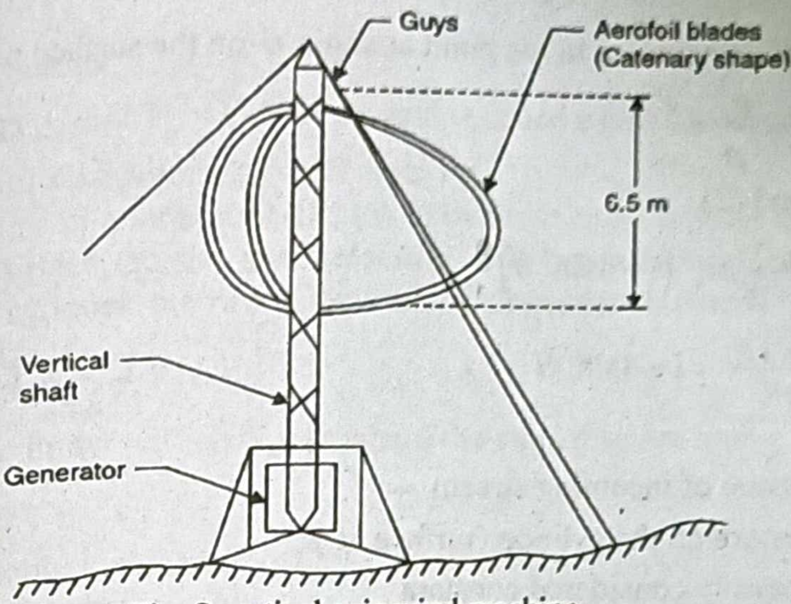


Fig: 2 vertical axis wind machine

Because their operation is independent of wind direction, vertical axis machines are called panemones.

Advantages of vertical axis wind machines:

1. The rotor is not subjected to continuous cyclic gravity loads since the blades do not turn end over end (Fatigue induced by such action is a major consideration in the design of large horizontal axis machines).
2. Since these machines would react to wind from any direction, therefore, they do not need yawing equipment to turn the rotor into the wind.
3. As heavy components (e.g., gear box, generator) can be located at ground level these machines may need less structural support.
4. The installation and maintenance are easy in this type of configuration.

b) Magnus effect: A uniform non-viscous air stream when flows past a vertical cylinder, stream lines as shown in Fig. 1 are generated. The velocity at any point on the surface of the cylinder

$$V_\theta = 2V_i \sin\theta \qquad \text{.... (1)}$$

where V_θ = air velocity on the surface of the cylinder at angle θ.

V_i = incoming uniform air velocity, far from the cylinder

θ = polar angle, measured from the stagnation point.

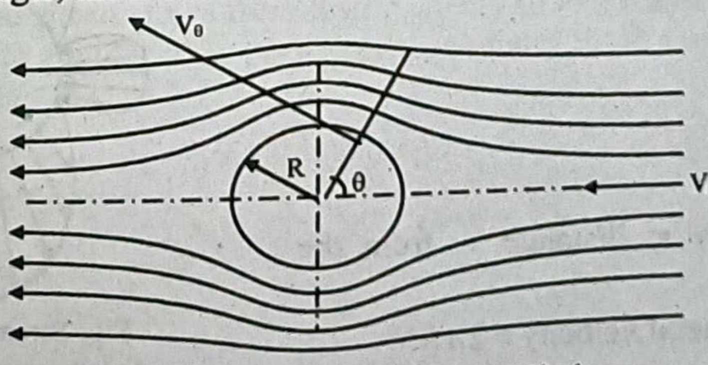


Fig: 1 Steam lines across a cylinder

Applying Bernoulli's equation to the point at angle θ on the surface of the cylinder,

$$\frac{p_i}{\rho}+\frac{V_i^2}{2}=\frac{p_\theta}{\rho}+\frac{V_\theta^2}{2} \quad \text{.... (2)}$$

From Eqns. (1) and (2),

$$p_\theta = p_i+\frac{1}{2}\rho V_i^2\left(1-4\sin^2\theta\right)$$

$$P_\theta^* = \frac{p_\theta - p_i}{\frac{\rho V_i^2}{2}} = 1-4\sin^2\theta \quad \text{.... (3)}$$

where p_i = pressure of incoming stream

p_θ = pressure on the cylinder surface at θ

ρ = air density considered constant

p_θ^* = non-dimensional pressure on cylinder surface at θ.

1. At stagnation point, $\theta = 0$

$$p_\theta - p_i = \frac{\rho V_i^2}{2}$$

$\frac{\rho V_i^2}{2}$ is the dynamic pressure of the undisturbed stream.

2. At $\theta = \pm 30°$ and $\pm 150°$

$$p_\theta = p_i$$

3. At $\theta = \pm 90°$

$$p_i = p_\theta = \frac{3\rho V_i^2}{2}.$$

Plotting these values on a cylinder, there is a symmetrical distribution of pressure and we get there is no resultant force. Therefore, there is no lift or drag on the cylinder for ideal non-viscous flow as shown in Fig.

If a cylinder is rotated about its axis in still air, a circulatory flow is produced around the cylinder where the velocity is inversely proportional to the distance from cylinder axis.

$$2\pi r V_r = 2\pi R V_p = \Gamma$$

$$\therefore \quad V_r = \frac{\Gamma}{2\pi r}$$

$$V_p = \frac{\Gamma}{2\pi R}$$

where V_r = velocity at distance r from the cylinder axis.

V_p = cylinder peripheral velocity = $2\pi RN$

r = radial distance from cylinder axis

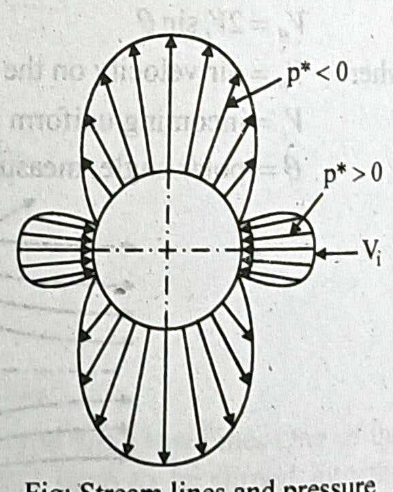


Fig: Stream lines and pressure distribution for non-viscous flow

$R =$ cylinder radius

$\Gamma =$ a constant $= 2\pi RV_p = (2\pi R)^2 N$ and is called a circulation constant.

$N =$ number of revolutions per unit time.

If a cylinder is rotating in a stream of air, the above two cases will be superimposed in such way that at cylinder top the two velocities will reinforce each other and at the bottom of horizontal cylinder, the two velocities will oppose each other.

$$V = 2V_i \sin\theta + \frac{\Gamma}{2\pi R} = V_\theta + V_p$$

The pressure on the cylinder will be higher where the velocities are low.

c) *Betz criteria:*

Betz' law states that only a maximum of 59.25% of the kinetic power in the wind can be converted to mechanical power using a wind turbine, the so called maximum power co-efficient on Betz number. This number is not higher because the wind on the back side of the rotor must have a high enough velocity to move away and allow more wind through the plane of the rotor.

The relationship between the mechanical power of the rotor blade P_R and the power of wind P in the rotor area is given by the power co-efficient c_P.

$$c_P = \frac{P_R}{P} \qquad \text{.... (1)}$$

The power co-efficient c_P can be interpreted as the efficiency between the rotor blade and the wind. The maximum power co-efficient the above mentioned Betz' number, determined by the ratio $V_2/V_1 = 1/3$. Therefore, an ideal turbine will slow down by the wind by $2/3$ of its original speed.

The question of how much of the wind energy can be transferred to the blade as mechanical energy has been answered by the Betz' law.

Betz's law applies to all Newtonian fluids, including wind. If all of the energy coming from wind movement through a turbine were extracted as useful energy, the wind speed afterward would drop to zero. If the wind stopped moving at the exit of the turbine, then no more fresh wind could get in; it would be blocked. In order to keep the wind moving through the turbine, there has to be some wind movement, however small, on the other side with some wind speed greater than zero. Betz's law shows that as air flows through a certain area, and as wind speed slows from losing energy to extraction from a turbine, the airflow must distribute to a wider area. As a result, geometry limits any turbine efficiency to a maximum of 59.3%.

BIO ENERGY

Multiple Choice Type Questions

1. Biogas is produced by a particular type of bacterial digestion. The digestion process is called. **[WBUT 2008, 2013]**

a) Normal digestion
b) Aerobic digestion
c) Anaerobic digestion
d) None of these

Answer: (c)

2. Bio-gas consists of **[WBUT 2009, 2013, 2019]**

a) only methane
b) methane and carbon dioxide
c) only ethane
d) none of these
e) all of these

Answer: (e)

3. In rural areas, the locally generated gas from cow dung used for cooking and lighting is called **[WBUT 2014]**

a) biogas
b) oxygen
c) ammonia
d) carbon dioxide

Answer: (a)

4. Bio gas consists of **[WBUT 2015]**

a) only methane
b) methane and carbon dioxide
c) only ethane
d) all of these

Answer: (d)

5. Which gas has the major share in biogas? **[WBUT 2017]**

a) N_2
b) CO_2
c) H_2
d) CH_4

Answer: (d)

6. Biogas is predominantly **[WBUT 2018]**

a) hydrogen
b) carbon monoxide
c) carbon dioxide
d) methane

Answer: (d)

Short Answer Type Questions

1. What are the main advantages and disadvantages of bio-mass energy? Explain the process of photosynthesis. **[WBUT 2008, 2013, 2014]**

Answer:

1st part:

Advantages:

1. Theoretically inexhaustible fuel source.
2. When direct combustion of plant mass is not used to generate energy (i.e. fermentation, pyrolysis, etc. are used instead), there is minimal environmental impact.

3. Alcohols and other fuels produced by biomass are efficient, viable, and relatively clean-burning.
4. Available throughout the world.

Disadvantages:

1. Biomass produces greenhouse emissions. The biggest argument against biomass is that it produces carbon dioxide and other greenhouse gases.

2. It takes more energy to plant, cultivate and harvest the crops and trees than it is worth to get a net energy gain. It also takes up more water from the earth and other fossil fuels to make the fertilizers and fuels for planting and harvesting. it also, supposedly, takes up more land for the crops and trees.

3. Biomass collection is difficult: There was a man who, in 1979, traveled from Jacksonville, Fl to Los Angeles, CA on wood he was using in his biomass gasifier attached to a Chevy Malibu. He would travel 1 mile for every pound of wood. Not the most efficient use of fuel.

4. Biomass crops not available all year: Corn, wheat, barley and the like are seasonal crops. They are not available all year. Trees are also a slow growing resource even though they are renewable. This would also tend to be a negative on the side of biomass fuels.

2^{nd} part:

Photosynthesis: Photosynthesis is the process of converting light energy to chemical energy and storing it in the bonds of sugar. This process occurs in plants and some algae (Kingdom Protista). Plants need only light energy, CO_2, and H_2O to make sugar. The process of photosynthesis takes place in the chloroplasts, specifically using chlorophyll, the green pigment involved in photosynthesis.

Process of Photosynthesis: Photosynthesis is the process of converting light energy to chemical energy and storing it in the bonds of sugar. This process occurs in plants and some algae (Kingdom Protista). Plants need only light energy, CO_2, and H_2O to make sugar. The process of photosynthesis takes place in the chloroplasts, specifically using chlorophyll, the green pigment involved in photosynthesis.

Photosynthesis takes place primarily in plant leaves, and little to none occurs in stems, etc. The parts of a typical leaf include the upper and lower epidermis, the mesophyll, the vascular bundle(s) (veins), and the stomates. The upper and lower epidermal cells do not have chloroplasts, thus photosynthesis does not occur there. They serve primarily as protection for the rest of the leaf. The stomates are holes which occur primarily in the lower epidermis and are for air exchange: they let CO2 in and O2 out. The vascular bundles or veins in a leaf are part of the plant's transportation system, moving water and nutrients around the plant as needed. The mesophyll cells have chloroplasts and this is where photosynthesis occurs.

Photosynthesis in the plants is an example of biological conversion of solar energy into sugars and starches, which are energy rich compounds. The process of photosynthesis has two main steps.

i) Conditions are sunlight, CO_2, H_2O, temperature and chlorophyll. Splitting of H_2O molecule into H_2 and O_2 under the influence of chlorophyll and sunlight. This phase of reaction is called light reaction. In this phase of reaction, light absorbed by chlorophyll causes photolysis of water. O_2 escapes and H_2 is transformed into some unknown compounds. Thus solar energy is converted into potential chemical energy.

$$CO_2 + H_2O \xrightarrow[\text{chlorophyll}]{\text{light}} (H_2CO)_6 + O_2^- \uparrow$$

$$6CO_2 + 12H_2O \longrightarrow C_6H_{12}O_6 + 6H_2O + 6O_2 \uparrow$$

ii) In the second phase, hydrogen is transferred from this unknown compound to CO_2 to form starch or sugar. Formation of starch or sugar are dark reaction.

2. Explain the principle of production of Biogas. **[WBUT 2015]**

Answer:

Most organic materials undergo a natural anaerobic digestion in the presence of moisture and absence of oxygen. 60 – 80% of carbon of biomass is converted to a gas called biogas. This contains CH_4, CO_2, N_2 and traces of H_2S. The biogas has a heating value of 18.8 to 26.4 MJ/m^3. The biogas can be upgraded to a synthetic natural gas (SNG)by removing CO_2 and H_2S. The heating value of SNG is 37 MJ/m^3. One kilogram of dry organic material produces 0.12 to 0.18m^3 of methane with energy content of 4.5 to 7 MJ/kg raw material.

A biogas plant is schematically shown in Fig 1.

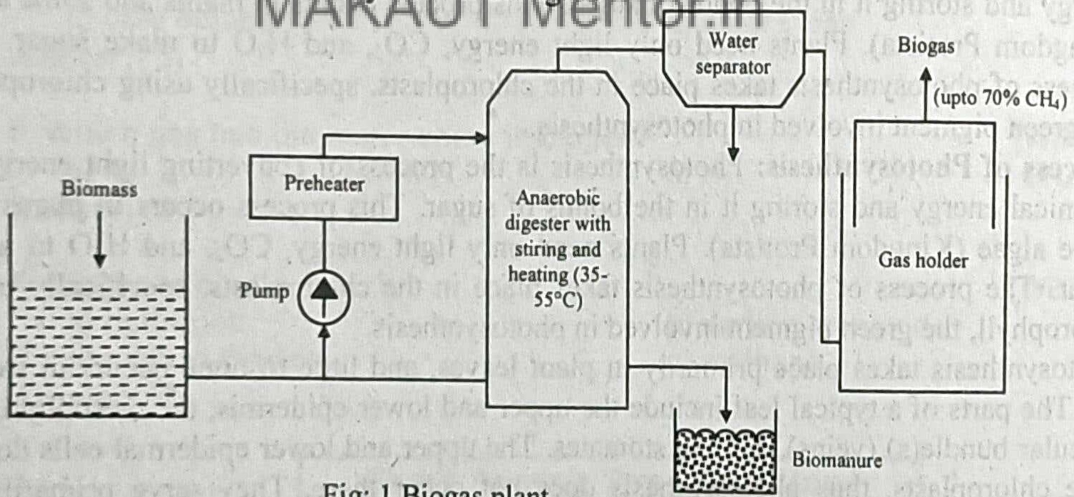


Fig: 1 Biogas plant

The various types of biomass can be vegetable waste, animal dung, silt from sewage plant of municipal and industrial effluent water, garbage and vegetable residues, waste from food processing industry. The rate of production of biogas is 0.3 to 0.7m^3 per kg of organic dried mass of animal and vegetable waste. The water vapour and sulphur can be removed from the biogas and cleaned biogas can be used to drive engine for cogeneration plant.

3. Bring out the differences between Pyrolysis and Photosynthesis. [WBUT 2017]

Answer:

Process of Photosynthesis: ***Refer to Question No. 2 of Short Answer Type Questions.***

Pyrolysis: The basic thermochemical process to convert biomass into a more valuable and / or convenient product is known as **pyrolysis.** Biomass is heated either in absence of oxygen or by partial combustion of some of the biomass in restricted air or oxygen supply. Pyrolysis can process all forms of organic materials including rubber and plastics, which cannot be handled by other methods. The products are three types of fuels — usually, a gas mixture (H_2, CO, CO_2, CH_4 and N_2), an oil-like liquid (a water-soluble phase including acetic acid, acetone, methanol and a non-aqueous phase including oil and tar) and a nearly pure carbon char. The distribution of these products depends upon the type of feedstock, the temperature and pressure during the process and its duration and the heating rate.

High temperature pyrolysis (~10000°C) maximizes the gaseous product. The process is known as gasification. Low temperature pyrolysis (up to 600°C) maximizes the char output. The process has been used for centuries for production of charcoal. The process is known as carbonisation. A liquid product is obtained through catalytic liquefaction process. Liquefaction is a relatively low temperature (250–450°C), high-pressure (270 atm) thermochemical conversion of wet biomass, usually with high hydrogen partial pressure and also a catalyst to enhance the rate of reaction and/or to improve the selectivity of the process.

4. What is biogas? [WBUT 2017]

Answer:

Biogas is a type of bio fuel that is naturally produced from the decomposition of organic waste. When organic matter, such as food scraps and animal waste, break down in an anaerobic environment (an environment absent of oxygen) they release a blend of gases, primarily methane and carbon dioxide. Because this decomposition happens in an anaerobic environment, the process of producing biogas is also known as anaerobic digestion.

Long Answer Type Questions

1. What are the advantage and disadvantages of Bio-diesel over the conventional mineral diesel oil? Explain with example. [WBUT 2010, 2012]

Answer:

Advantages:

i) Bio-diesel is a renewable source of energy.
ii) Bio-diesel is less costly.
iii) The carbon emission is less in Bio-diesel as the carbon comes from photosynthesis from air.
iv) Bio-diesel can be generated easily in India.

Disadvantages:

i) Bio-diesel is more dispersed and land-intensive then conventional mineral diesel oil.

ii) Bio-diesel is often of low energy density.

iii) Capacity of Bio-diesel is determined by availability of biomass where Capacity of conventional mineral diesel oil is fixed and based on efficiency of machineries.

2. a) Briefly discuss the method of conversion of biomass to useful energy.

[WBUT 2017]

Answer: *Refer to Question No. 2 of Short Answer Type Questions.*

b) With reference to available raw materials and other advantages, explain how biomass can be an important renewable energy source specially for rural area in India.

[WBUT 2017]

Answer:

The main advantages of biomass energy are:

i) it is a renewable source,

ii) the energy storage is an in-built feature of it,

iii) it is an indigenous source requiring little or no foreign exchange,

iv) the forestry and agricultural industries that supply feed stocks also provide substantial economic development opportunities in rural areas,

v) the pollutant emissions from combustion of biomass are usually lower than those from fossil fuels,

vi) commercial use of biomass may avoid or reduce the problems of waste disposal in other industries, particularly municipal solid waste in urban centres,

vii) use of biogas plants, apart from supplying clean gas, also leads to improved sanitation, better hygienic conditions in rural areas as the harmful decaying biomass get stabilized,

viii) the nitrogen rich bio-digested slurry and sludge from a biogas plant serves as a very good soil conditioner and improves the fertility of the soil, and

ix) varying capacity can be installed; any capacity can be operated, even at lower loads, with no seasonality involved.

3. a) What are the main advantages and disadvantages of bio-mass energy?
b) Describe briefly about the fixed dome type biogas plant with suitable diagram.
c) Calculate the volume of a fixed dome type biogas digester for the output of two cows. Also calculate the thermal power available from the biogas. Use the following data:
Retention time- 30days
Dry matter produced- 2kg/day/cow
Biogas yield-0.22 m^3/kg of dry matter
Percentage of dry matter in cow dung- 18%
Density of slurry- 1090kg/ m^3
Burner efficiency- 60%
Heat valve of biogas- 23MJ/m^3 **[WBUT 2018]**

Answer:

a) ***Refer to Question No. 1(1st part) of Short Answer Type Questions.***

b) Fixed Dome Type Biogas Plant

The fixed dome type bio gas plant consists of a closed underground digester tank made up of bricks which has a dome shaped roof also made up of bricks. This dome shape roof of the digester tank functions as gas holder and has an outlet pipe at the top to supply gas to homes.

Slurry is prepared by mixing water in cattle dung in equal proportion in mixing tank. The slurry is then sent into the digester tank with the help of inlet chamber. It should be noted that slurry is fed into the digester tank up to the point where the dome of the roof starts. Inside the digester tank, the complex carbon compounds present in the cattle dung breaks into simpler substances by the action of anaerobic microorganisms in the presence of water. This anaerobic decomposition of complex carbon compounds present in cattle dung produces bio gas and gets completed in about 60 days. The bio gas so produced starts to collect in dome shaped roof of bio gas plant and is supplied to homes through pipes. The spent slurry is replaced from time to time with fresh slurry to continue the production of bio gas.

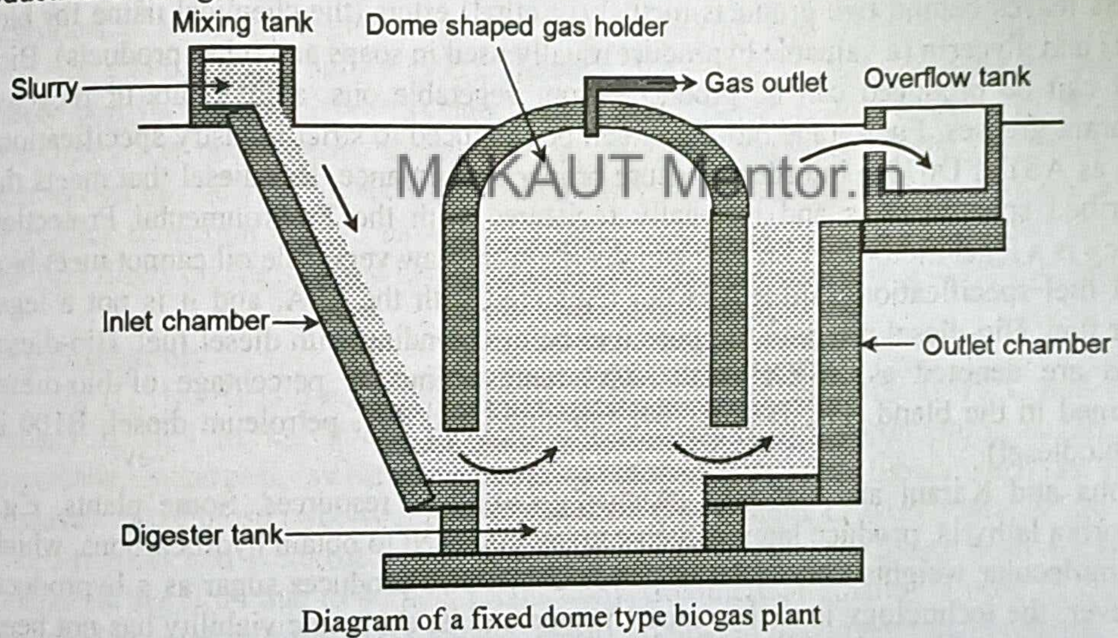


Diagram of a fixed dome type biogas plant

c) Dry matter produced by two cows = 2×2=4 kg/day
As dry matter content in cow dung is only 18%, cow dung produced = 4/0.18=22.22 kg/day.
Equal quantity of water is added to make the slurry. The amount of slurry produced per day = 22.22+22.22 = 44.44 kg/day
Slurry volume produced per day = 0.04077 m^3/day
With retention time of 30 days, total slurry in the digester =30×0.04077=1.223 m^3
As about 15% digester area is occupied by the gas, the net digester size

$$= 1.22/0.85=1.44 \text{ m}^3$$

Gas produced = $4 \times 0.22 = 0.88$ m^3/day
Thermal energy available = $0.88 \times 23 \times 0.6 = 12.144$ MJ/day
Continuous thermal power available = 140.55 W.

4. Write short notes on the following:
a) Bio-diesel **[WBUT 2008, 2009, 2012, 2017]**
b) Bio-ethanol and Bio-diesel **[WBUT 2008, 2009]**
c) Municipal Solid Waste (MSW) incineration plant **[WBUT 2018]**
d) Material for biogas **[WBUT 2019]**

Answer:

a) Some vegetable oils, edible as well as non-edible, can be used (after some chemical processing) in pure form or blended with petroleum diesel as fuel in a compression-ignition (diesel) engine. Bio-diesel is simple to use, biodegradable, non-toxic, and essentially free of sulphur and aromatics. In fact, Rudolf Diesel demonstrated an engine that could run on peanut oil. He believed that the utilization of biomass fuel was the real future of his engine. August 10 has been declared as 'International Bio-diesel Day'.

Raw vegetable oil is upgraded as bio-diesel through a chemical process called trans-esterification whereby the glycerin is separated from the animal fat or vegetable oil. The process leaves behind two products-methyl (or ethyl) esters (the chemical name for bio-diesel) and glycerin (a valuable byproduct usually used in soaps and other products). Bio-diesel can be produced can be produced from vegetable oils, animal fats or recycled restaurant greases. Fuel-grade bio-diesel can be produced to strict industry specifications (such as ASTM D6751) in order to insure proper performance. Bio-diesel that meets the prescribed specifications and is legally registered with the Environmental Protection Agency is a legal motor fuel for sale and distribution. Raw vegetable oil cannot meet bio-diesel fuel specifications, since it is not registered with the EPA, and it is not a legal motor fuel. Bio-diesel refers to the pure fuel before blending with diesel fuel. Bio-diesel blends are denoted as, 'BXX' with 'XX' representing the percentage of bio-diesel contained in the blend (i.e., B20 is 20% bio-diesel and 80% petroleum diesel, B100 is pure biodiesel).

Jatropha and Karanj are the most promising bio-diesel resources. Some plants, e.g., Euphorbia lathyris, produce latex, which can be processed to obtain hydrocarbons, which have molecular weights very close to petroleum. It also produces sugar as a byproduct. However, the technology is at the research stage and its economic viability has not been assesses yet.

The National Bio-diesel Board (USA) also has a technical definition of "bio-diesel" as a mono-alkyl ester.

Blends of bio-diesel and conventional hydrocarbon-based diesel are products most commonly distributed for use in the retail diesel fuel marketplace. Much of the world uses a system known as the "B" factor to state the amount of bio-diesel in any fuel mix:

- 100% bio-diesel is referred to as **B100**, while
- 20% bio-diesel is labeled **B20**
- 5% bio-diesel is labeled **B5**
- 2% bio-diesel is labeled **B2**

Obviously, the higher the percentage of bio-diesel, the more ecology-friendly the fuel is. It is common in the USA to see **B99.9** because a federal tax credit is awarded to the first entity, which blends petroleum diesel with pure bio-diesel. Blends of 20 percent bio-diesel with 80 percent petroleum diesel (B20) can generally be used in unmodified diesel engines. Bio-diesel can also be used in its pure form (B100), but may require certain engine modifications to avoid maintenance and performance problems. Blending B100 with petroleum diesel may be accomplished by:

- Mixing in tanks at manufacturing point prior to delivery to tanker truck.
- Splash mixing in the tanker truck (adding specific percentages of Bio-diesel and petroleum diesel).
- In-line mixing, two components arrive at tanker truck simultaneously.
- Metered pump mixing, petroleum diesel and Bio-diesel meters are set to X total volume, transfer pump pulls from two points and mix is complete on leaving pump.

Applications: Bio-diesel can be used in pure form (B100) or may be blended with petroleum diesel at any concentration in most injection pump diesel engines. New extreme high pressure (29,000 psi) common rail engines have strict factory limits of B5 or B20 depending on manufacturer. Bio-diesel has different **solvent** properties than petrodiesel, and will degrade natural **rubber gaskets** and hoses in vehicles (mostly vehicles manufactured before 1992), although these tend to wear out naturally and most likely will have already been replaced with FKM, which is non-reactive to bio-diesel. Bio-diesel has been known to break down deposits of residue in the fuel lines where petrodiesel has been used. As a result, **fuel filters** may become clogged with particulates if a quick transition to pure bio-diesel is made. Therefore, it is recommended to change the fuel filters on engines and heaters shortly after first switching to a bio-diesel blend.

b) Bio-ethanol:

Ethanol (C_2H_5OH) is a colourless liquid biofuel. Its boiling point is 78°C and energy density is 26.9 Mj/kg. It can be derived from wet biomass containing sugars (e.g., sugarcane, sugarbeet, sweet sorghum), starches (grains and tubers such as potato, cassava) or cellulose (woody matter). The main constituents of woody matter are lignin (fibrous part) and cellulose (juicy part). Ethanol is largely produced from sugar cane (maize in the USA due to surplus production). Commercial ethanol is used in specially designed IC engines with 25% mileage penalty compared to conventional vehicles. Blend of up to 22% anhydrous ethanol with gasoline, requires no engine modification and incurs no mileage penalty. It is being used by a large number of automobiles in the world.

Bio-diesel:

Refer to Question No. 3(a) of Long Answer Type Questions.

c) Municipal Solid Waste (MSW) incineration plant:

A municipal solid waste (MSW) incineration plant is a public service facility. The location should always be determined with respect to both economic and environmental issues. The environmental impact must always be assessed. Properly constructed and operated, a waste incineration plant will be comparable to medium to heavy industry in its environmental impact, potential public nuisances, transport network requirements, and other infrastructure needs.

An MSW incineration plant will generate surplus energy, which may be made available in the form of heat or power depending on the demand of the local energy market. In that respect, an MSW plant is comparable to a fossil fuel power plant. It is further comparable to a coal-fueled power plant in respect to flue gas emissions and solid residues from the combustion process and flue gas cleaning.

Therefore, a waste incineration plant should be close to an existing fossil fuel power plant for the two plants to enjoy mutual benefits from the service facilities needed–or it could be adjacent to or part of a new power plant.

Key criteria

- A controlled and well-operated landfill must be available for disposing residues.
- In relation to the air quality in the site area, frequent and prolonged inversion and smog situations are not acceptable.
- MSW incineration plants should be located in land-use zones dedicated to medium or heavy industry.
- MSW incineration plants should be located in industrial areas close to power plants.
- It should take no longer than one hour to drive a truck from the waste generation area to the plant.
- MSW incineration plants should be at least 300 to 500 meters from residential zones.
- MSW incineration plants should be located near suitable energy consumers.

– Site Feasibility Assessment
– Proximity to Waste Generation Center
– Traffic and Transport
– Air quality
– Noise
– Proximity to energy distribution networks
– Utilities
– Landfill

GEOTHERMAL ENERGY

Multiple Choice Type Questions

1. Geothermal energy field is available mainly in which of the following areas? [WBUT 2008, 2013]
   a) Hilly b) Volcanic c) Offshore d) Desert

Answer: (b)

2. A geothermal field may yield [WBUT 2009, 2013]
   a) dry steam b) wet steam c) hot air d) all of these

Answer: (d)

3. The hydrothermal resources are located at shallow to moderate depths from [WBUT 2011]
   a) 100 m to 4,500 m b) 150 m to 6,000 m
   c) 120 m to 3000 m d) 200 m to 9,000 m

Answer: (a)

4. Temperature of inner core of earth is [WBUT 2012]
   a) 1000 degree Celsius b) 4000 degree Celsius
   c) 40000 degree Celsius d) 500 degree Celsius

Answer: (b)

5. Temperature of inner core of earth is [WBUT 2015]
   a) 1000°C b) 4000°C c) 40000°C d) none of these

Answer: (b)

6. Most of potential exploitable geothermal heat is store in [WBUT 2016]
   a) water b) dry rock c) air d) steam aquifiers

Answer: (b)

7. Dolphin mechanism is a method of extracting [WBUT 2017]
   a) Solar energy b) Wind energy
   c) Ocean wave energy d) Geothermal energy

Answer: (d)

8. Temperature of inner core of earth is [WBUT 2017]
   a) 1000 degree Celsius b) 4000 degree Celsius
   c) 40000 degree Celsius d) 5000 degree Celsius

Answer: (b)

Short Answer Type Questions

1. a) What is Geo-thermal energy?
b) By what method is this energy extracted? [WBUT 2011, 2016]

Answer:

a) The earth's heat content is 10^{31} joules. This heat naturally flows to the surface by conduction at a rate of 44.2 terawatts, (TW,) and is replenished by radioactive decay at a rate of 30 TW. These power rates are more than double humanity's current energy consumption from primary sources, but most of this power is too diffuse (approximately 0.1 W/m^2 on average) to be recoverable. The Earth's crust effectively acts as a thick insulating blanket which must be pierced by fluid conduits (of magma, water or other) to release the heat underneath. This power is called by geothermal power.

b) Geothermal energy is extracted using two methods: a heat pump system or "hot dry rock" conversion. Heat pumps are large pipes that run from the top of the earth's crust into a building. In winter, the crust is hot, allowing heat to flow into the building and warm it; in summer, the crust is cold, so warm air flows from the building to the ground.
"Hot dry rock" (or HDR) extraction is slightly more complicated. Deep wells are drilled into hot rock and hot geothermal water is pulled up into tanks. The steam from the water either drives turbines itself, or the water is passed next to a liquid with a low boiling point. The second liquid then vaporizes, which drives turbines.

2. Discuss different systems used for generating power using Geothermal energy, in brief. [WBUT 2015]

Answer:

Geothermal energy reservoirs are liquid-dominated and steam dominated. Some are only hot rocks where there is no ground water. Geothermal sources are:

1. Hydrothermal systems
2. Geopressured systems
3. Petrothermal systems

Hydrothermal Systems:

Water is heated by the hot rocks. These can be vapour-dominated and liquid-dominated systems.

1. Vapour-dominated systems: In these systems, water is vaporized into steam, which reaches the earth's surface at 8 bar and 205°C in dry condition. the steam can be used to produce power by Rankine Cycle with minimum costs. However, the system is associated with corrosive and erosive materials. Such systems are very rare in the world.
2. Liquid-dominated systems: Hot water is trapped underground at a temperature of 174 to 315°C. This water is brought up either by drilling wells or pumped up. Due to pressure drop, hot water flashes into two phase mixture of low quality. The water contains high concentration of dissolved solids and power production becomes difficult due to scaling in pipes and heat exchangers. The liquid-dominated systems are much more plentiful.

Geopressured Systems:
Geopressured system is hot water or brine at about 160°C trapped underground at about 2400 to 9100m depth. The pressure is more than 1000 bar. Although it has great thermal and mechanical potential for power generation, but due to low temperatures and great depth, it may not be economical to drill for this brine. But this brine has recoverable methane and there may be economic feasibility to generate electricity involving combustion of methane as well as heat from the thermal content of water.

Petrothermal Systems:
When there is no underground water, there are hot dry rocks (HDR) at 150 to 298°C near the earth's surface. this energy is called petrothermal energy and accounts for 85% of geothermal resources. Water will have to be pumped into and back out to the surface. Fracturing methods for drilling-wells into the rocks can be by (i) high pressure water or (ii) nuclear explosions.

3. a) What is Geothermal power? **[WBUT 2017]**

Answer:
Refer to Question No. 1(1st part) of Long Answer Type Questions.

b) State various precautions to be observed during operation of geothermal plant. **[WBUT 2017]**

Answer:
The size of geothermal resources is estimated by some to be very high. The US Geological Survey defines the resource to be the entire heat content of the earth's crust above 15° C to a depth of 10km. With this definition, the USGS estimates that more than 2×10^{22} Btu of thermal energy exists within the crust. This is equivalent to 900 trillion tons of coal, enough to supply energy needs at current rates for 350,000 years. Geothermal energy is quite low grade because the temperature of the steam or hot water used is only between 150° and 250° C (at 100 psi). This compares with the steam in a conventional fossil fuel plant at 550° C and 1000 psi.
Geothermal hot spots are sparsely distributed and usually some distance from the markets needing energy. The minimum temperature of steam required for the efficient production of electricity is about 100°C. Consequently, many reservoirs of hot water can be used only for direct heating. Since thermal energy cannot be efficiently transported very far, the point of use must be close to the source.
Unfortunately, very few geothermal sources are of the dry steam type. In wet steam systems, only the part of the water that flashes to steam is used in the generation of electricity. Originally, the rest of the hot water was thrown away into a lake or steam.

Long Answer Type Questions

1. What is meant by geo-thermal energy? By what methods this energy is extracted? What are the difficulties and disadvantages of a geo-thermal generation? What are the possible sources of geo-thermal pollution? How are these avoided? **[WBUT 2008, 2013]**

Answer:

Geothermal power (from the Greek roots *geo*, meaning earth, and *thermos*, meaning heat) is power extracted from heat stored in the earth. This geothermal energy originates from the original formation of the planet, from radioactive decay of minerals, and from solar energy absorbed at the surface. It has been used for bathing since Paleolithic times and for space heating since ancient Roman times, but is now better known for generating electricity. Worldwide, about 10,715 megawatts (MW) of geothermal power is online in 24 countries. An additional 28 gigawatts of direct geothermal heating capacity is installed for district heating, space heating, spas, industrial processes, desalination and agricultural applications.

Geothermal power is cost effective, reliable, sustainable, and environmentally friendly, but has historically been limited to areas near tectonic plate boundaries. Recent technological advances have dramatically expanded the range and size of viable resources, especially for applications such as home heating, opening a potential for widespread exploitation. Geothermal wells release greenhouse gases trapped deep within the earth, but these emissions are much lower per energy unit than those of fossil fuels. As a result, geothermal power has the potential to help mitigate global warming if widely deployed in place of fossil fuels.

The Earth's geothermal resources are theoretically more than adequate to supply humanity's energy needs, but only a very small fraction may be profitably exploited. Drilling and exploration for deep resources is very expensive. Forecasts for the future of geothermal power depend on assumptions about technology, energy prices, subsidies, and interest rates.

Difficulties and Disadvantages

Geothermal power plants create some environmental problems which are peculiar to them alone. The effulent will be salty and may contain sodium and potassium compounds. Additionally, in some cases lithium, fluorine, boron and arsenic compounds may be present. Such effluents cannot be discharged into the existing water courses unless properly treated without risking severe pollution problems. Some effluents contain boron, fluorine and arsenic. All these are very harmful to plants and animal life in concentrations as low as two parts per million. Suitable waste treatment plants to prevent degradation of water quality will have to be installed to treat these new and increased sources of pollution.

Disadvantages:

1. Low overall power production efficiency (about 15% as compared to 35 to 40% for fossil fuel plants)

2. Drilling operation is noisy.
3. Large areas are needed for exploitation of geothermal energy.
4. The withdrawal of large amounts of steam or water from a hydro-thermal reservoir may result in surface subsidence or settlement.

Geothermal heat is extracted from deep within the earths surface, and this is the main disadvantage concerning finding a suitable build location,

There are some other deciding factors that may convince a constructor to build a different type of renewable energy power plant in a different location, such as a wind turbine. So, we have established the main disadvantages of building a geothermal energy plant mainly lie in the exploration stage. During exploration, researchers will do a land survey (which may take several years to complete) and then post their findings to the company that contracted the survey.

Many companies who order surveys are often disappointed, as quite often the land they were interested in cannot support a geothermal energy plant. To extract the heat we have to find certain hot spots within the earths crust, these are very common around volcanos and fault lines, but who wants to build their geothermal energy plant next to a volcano? Some areas of land may have the sufficient hot rocks to supply hot water to a power station, but what if these areas are contained in harsh areas of the world (near the poles) or high up in mountains. Some very good proven spots have been found in New Zealand, Iceland, Norway and Sweden.

Possible sources of geothermal pollution and Remedies

Fluids drawn from the deep earth carry a mixture of gases, notably carbon dioxide (CO_2), hydrogen sulfide (H_2S), methane (CH_4) and ammonia (NH_3). These pollutants contribute to global warming, acid rain, and noxious smells if released. Existing geothermal electric plants emit an average of 122 kilograms (269 lb) of CO_2 per megawatt-hour (MWh) of electricity, a small fraction of the emission intensity of conventional fossil fuel plants. Plants that experience high levels of acids and volatile chemicals are usually equipped with emission-control systems to reduce the exhaust.

In addition to dissolved gases, hot water from geothermal sources may hold in solution trace amounts of toxic chemicals such as mercury, arsenic, boron, and antimony. These chemicals precipitate as the water cools, and can cause environmental damage if released. The modern practice of injecting cooled geothermal fluids back into the Earth to stimulate production has the side benefit of reducing this environmental risk.

Direct geothermal heating systems contain pumps and compressors, which may consume energy from a polluting source. This parasitic load is normally a fraction of the heat output, so it is always less polluting than electric heating. However, if the electricity is produced by burning fossil fuels, then the net emissions of geothermal heating may be comparable to directly burning the fuel for heat. For example, a geothermal heat pump

powered by electricity from a combined cycle natural gas plant would produce about as much pollution as a natural gas condensing furnace of the same size. Therefore the environmental value of direct geothermal heating applications is highly dependent on the emissions intensity of the neighboring electric grid.
Plant construction can adversely affect land stability. Subsidence has occurred in the Wairakei field in New Zealand and in Staufen im Breisgau, Germany. Enhanced geothermal systems can trigger earthquakes as part of hydraulic fracturing. The project in Basel, Switzerland was suspended because more than 10,000 seismic events measuring up to 3.4 on the Richter Scale occurred over the first 6 days of water injection.

Geothermal has minimal land and freshwater requirements. Geothermal plants use 3.5 square kilometres (1.4 sq mi) per gigawatt of electrical production (not capacity) versus 32 and 12 square kilometres (4.6 sq mi) for coal facilities and wind farms respectively. They use 20 litres (5.3 US gal) of freshwater per MWh versus over 1,000 litres (260 US gal) per MWh for nuclear, coal, or oil.

2. a) What are the different types of geothermal resources? **[WBUT 2009, 2016]**

Answer:

Types of geothermal electric power plants

Types of plant	Geothermal fluid	Type of turbine
1. Vapour dominated geothermal power plants (Dry steam type power plant)	— Dry steam at temperature 200°C	— Steam turbine
2. Liquid dominated flashed steam type geothermal power plant	— Hot water and wet steam, at temperature > 10°C — Steam flashed from the geothermal fluid	— Steam turbine
3. Liquid dominated binary cycle plant	— Hot geothermal brine at temperature geothermal power < 150°C	— Organic fluid gas turbine
4. Liquid dominated total flow type geothermal power plant	— Hot geothermal fluid (brine)	— Special turbine driven by hot geothermal brine
5. Petrothermal (hot dry rock) Geothermal power plant	— Hot water plus steam from production well at 280°C — Cold water injected into fractured cavity in hot dry rock	— Steam turbine
6. Hybrid geothermal fossil fuel power plants	— Hot water at temperature 70°C to 150°C used for pre-heating the feed water or air	— Conventional steam thermal power plant — Conventional gas turbine plant

b) What are the major applications of geothermal energy? **[WBUT 2009, 2016]**

Answer:

1. Aquaculture, Horticulture and Thermoculture

Geothermal renewable energy can be used for aquaculture, horticulture and thermoculture. This renewable energy can be used to raise plants and marine life that needs warm waters and a tropical environment. Greenhouses can use geothermal power generation to keep plants warm and moist, with the steam and heat being provided by geothermal energy. Geothermal renewable energy is used to heat the worlds only geothermally warmed prawn farm and in the year two thousand and five this prawn farm sold twenty tons of prawns raised on the farm. Using geothermal power generation can also provide electricity to these projects as well as heat and steam.

2. Industrial and Agricultural uses

Geothermal power generation can play a big part in industrial and agricultural operations around the world. Geothermal renewable energy can play many roles in these sectors. Timber can be dried using heat from geothermal energy and paper mills like one that is located on a geothermal field in New Zealand can use this energy in almost every stage of paper processing. There are thousands of industrial and agricultural uses that geothermal energy may be perfect for and the cost of this energy is very low once the geothermal power generation facility is in place and operating.

3. Food Processing

The food processing industry is one that can benefit greatly from geothermal renewable energy. One way that this energy source can be invaluable is as steam for sterilizing food-processing facilities. The earth naturally contains high levels of heat and steam and releasing this steam can sterilize equipment and rooms without using drugs or chemicals. This will prevent any microorganisms from becoming resistant to these substances and developing more harmful strains. Geothermal energy can also help dry out plants, making powders and concentrates that are used in food processing and at times these substances can be used to add flavours or preserve food without any unnatural additives. Foods can be cooked, steamed, or prepared in other ways using geothermal energy as well.

4. Providing Heat for Residential and Commercial use

Geothermal renewable energy can be used to provide heat for all types of buildings, from homes to businesses to farms, barns and other types of buildings. Using this energy does not just provide heat; it is a complete temperature control system, which can help cool your home as well. With a geothermal heating and cooling system you will see much lower energy bills, because a furnace or air conditioner is not needed. These appliances can use a substantial amount of electricity, running up utility bills and wasting energy. Geothermal temperature control units can add heat or pull it out of your home or other type of building, keeping it comfortable all year long.

5. Electricity Generation

A geothermal power station can provide a large amount of electricity, with many benefits that using fossil fuels for electricity generation do not offer. Geothermal power generation is very clean, because it uses the heat and steam trapped in the earth to produce electricity. There are no harmful gas emissions or high carbon levels and these power generation plants do not contribute to air pollution. This energy source is renewable and does not depend on fossil fuels or foreign countries to supply energy the country needs. Geothermal energy can add stability to both the cost and the availability of electricity and heat for the entire world. Fossil fuels will run out in the near future and an alternative renewable energy plan needs to be in place to ensure that an energy crisis does not occur. Geothermal energy can help meet these needs.

c) What principles guide in the location of a geothermal power station? **[WBUT 2009, 2016]**

Answer:

Once you have build a geothermal power station, the energy is almost free. It may need a little energy to run a pump, but this can be taken from the energy being generated. But the big problem is that there are not many places where you can build a geothermal power station.

It needs hot rock of a suitable type at a depth where we can drill down to them.

Location is key for development of an efficient geothermal power station and therefore sufficient levels of electricity can only be generated in a certain areas. There are only a handful of locations across the world that are capable of producing viable and efficient level of electricity from geothermal energy sources.

Important geothermal provinces and the places where hot springs occur in India are:

i) Canbay graben province.
ii) Damodar vally graben province.
iii) Mahanadi valley graben province.
iv) Narmada Tapti graben province.
v) Andaman Nicobar geothermal province.

d) What is the prospect of geothermal energy? **[WBUT 2009, 2016]**

Answer:

Geothermal energy has prospects in the past and future life.

The Geological Survey of India and the Jadavpur University Calcutta, spearheaded respectively, heat flow, geotectonic and geochemical studies encompassing the field of research and development relating to geothermal resource evaluation.

Geotectonic basis by grouping them into geothermal provinces and by identifying the pattern and the required priorities of exploration.

Also in 1973, the first large scale and systematic field investigations in the country for the exploration and utilization of geothermal resources.

In Ladakh, Jammu and Kashmir state, where fossil fuels were non-existent and hydropower resources were difficult and costly to develop. Many national agencies such as Atomic Energy Commission, National Geophysical Research Institute and Geological Survey of India cooperated to integrate and execute geological, geophysical, geochemical and drilling activities in Puga area.

There was extended to cover two other geothermal fields at Manikaran and Kasol in the state of Himachal Pradesh and Sona in Haryana state.

3. a) Derive the expression of total energy content of hot dry rock resource.
b) i) Explain single basin, single effect tidal energy conversion scheme.
ii) A single basin type tidal power plant has a basin are of 2km^2. The tide has an average range of 13 m. Power is generated only during the ebb cycle. The turbine stops operating when the head on it falls below 3 m. Calculate the average power generated by the plant in single emptying process of the basin if the turbine generator efficiency is 0.7. Estimate the average energy generation of the plant.
[WBUT 2011, 2014, 2016]

Answer:
a) Let us consider a large mass of dry, uniform material (rock) extending from near the earth's surface to deep inside the crust, as shown in figure 1. As there is no convection and the material is uniform, the temperature, T at any point will increase linearly with depth, h. Thus

$$T = T_o + \frac{dT}{dh}h = T_o + Gh$$

where G is temperature gradient
T_o is surface temperature.

Let the minimum useful temperature, T_1 occurs at depth h_1 and increases onwards reaching T_2 at maximum depth h_2.

$$T_1 = T_o + Gh_1$$
$$T_2 = T_o + Gh_2$$
$$T_2 - T_1 = T_o + G(h_2 - h_1)$$

Average useful temperature of hot dry rock, θ_o

$$\theta_o = (T_2 - T_1)/2 = G(h_2 - h_1)/2$$

Total useful heat (energy) content of the rock to depth h_2

$$E_o = C_r\theta_o$$

where C_r is the thermal capacity of the rock between depths h_1 and h_2 and may be written as $C_r = \rho_r A c_r (h_2 - h_1)$, in terms of specific heat capacity, c_r density, ρ, area A of the rock.
Therefore, total useful energy of the rock

$$E_o = \rho_r A c_r G (h_2 - h_1)^2/2$$

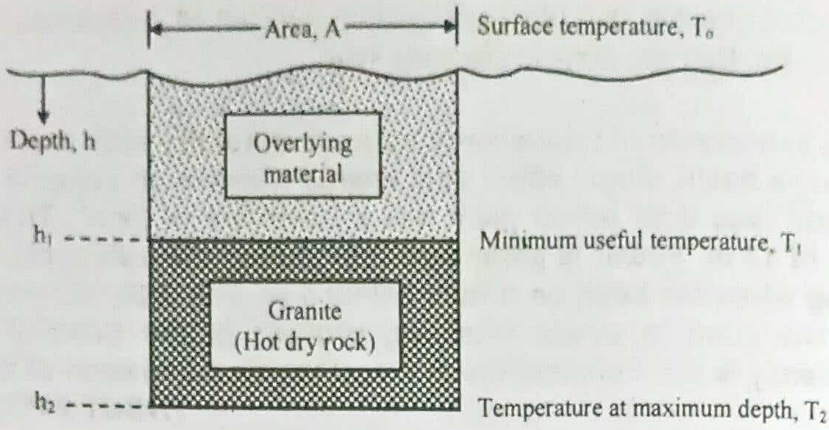
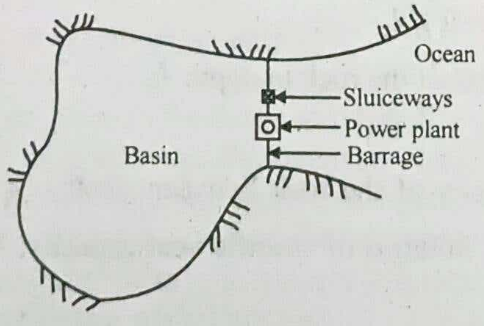


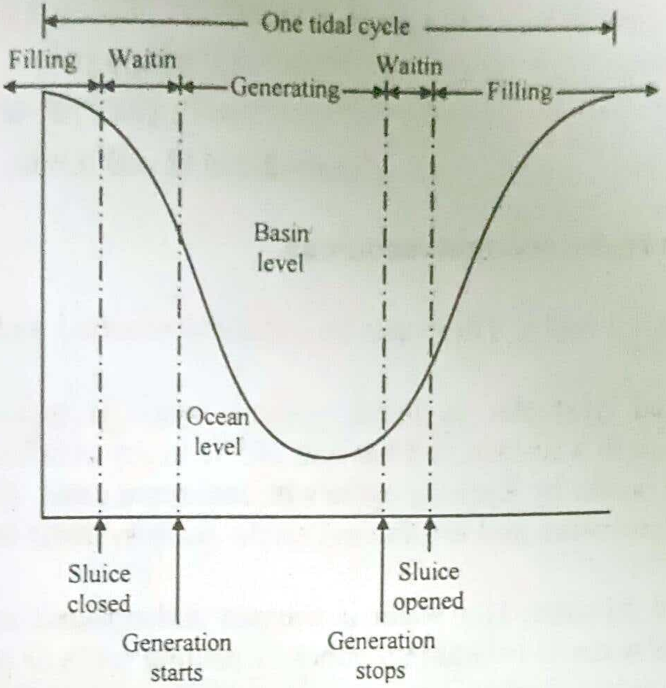
Fig: 1 Profile of hot dry rock system for calculating the heat content

b) i) The single-basin scheme has only one basin as shown in figure 1. In the single-effect scheme, power is generated either during filling or emptying the basin. Two types of operation cycles are possible. In the ebb generation cycle operation, the sluice way is opened to fill the basin during high tide. Once filled, the impounded water is held till the receding cycle creates a suitable head. Water is now allowed to flow through the turbine coupled to the generator till the rising tide reduces the head to the minimum operating point. The flow is held till the next generating cycle. The sequence of events is illustrated in figure 1. This cycle is repeated and power is generated intermittently. In the flood generation cycle operation, the sequences are altered to generate power during filling operation of the basin. However, the sloping nature of the basin shores usually makes ebb generation the more productive method.

Increased output can also be obtained by pumping during high tide to increase the basin level and therefore the generation head. The energy required for pumping must be borrowed and repaid. The pumping is done against a small head at high tide, whereas the same water is released through the turbine during low tide at a great head, producing a net energy gain.



(a) Layout of single-basin tidal energy conversion scheme



(b) Sequence of operation

Fig: 1 Single-basin, single-effect tidal energy conversion

ii) Given data:

Basin Area $A = 2\,\text{km}^2$

$R = 13\,\text{m}$

$r = 3\,\text{m}$

Turbine generator efficiency $\eta_{gen} = 0.7$

Density of seawater may be assumed as; $\rho = 1025\,\text{kg/m}^3$

Average power potential available $= 0.225 \times A\left(R^2 - r^2\right)$ Watts

$$= 0.225 \times 2 \times 10^6 \left(13^2 - 3^2\right)$$

$$= 0.225 \times 2 \times 10^6 \times 160 \quad = 72 \times 10^6\,\text{W} \quad = 72\,\text{MW}.$$

Average power generated $= 72 \times 0.7 = 50.4\,\text{MW}$.

Energy available in single emptying $= \frac{1}{2}\rho A g\left(R^2 - r^2\right)$

$$= \frac{1}{2} \times 1025 \times 2 \times 10^6 \times 9.8 \times \left(13^2 - 3^2\right)$$

$$= 1607200\,\text{MJ}.$$

One ebb cycle duration $= 12$ hr 25 min $= 12.4166$ h

Number of ebb cycles in a year $= \frac{365 \times 24}{12.4166} = 705.5071 \simeq 706$

Average annual energy generation of the plant $= 1607200 \times 706 \times 0.7 \times 10^6$ J

$$= 794278240 \times 10^6 \text{ J}$$

$$= 220632.844 \times 10^6 \text{ Wh}$$

$$= 2.20632 \times 10^8 \text{ kWh.}$$

4. Write short note on Hydro-thermal resources. **[WBUT 2013]**

Answer:

Water is heated by the hot rocks. These can be vapour dominated and liquid dominated system.

1. **Vapour Dominated Systems:** In these systems, water is vapourized into steak, which reaches the earth's surface at 8 bar and 205°C in dry condition. The steam can be used to produce power by Rankine cycle with minimum costs. However, the steam is associated with corrosive and erosive materials. Such systems are very rare in the world.
2. **Liquid-Dominated System:** Hot water is trapped underground at a temperature of 174 to 315°C. Thus water is brought up either by drilling wells or pumped up. Due to pressure drop, hot water flashes into two phase mixture of low-quality. The water contains high concentration of dissolve solids and power production becomes difficult due to scaling in pipes and heat exchangers. The liquid dominated systems are much more plentiful.

ENERGY FROM OCEAN

Multiple Choice Type Questions

1. The turbine normally employed in tidal power is [WBUT 2008, 2013, 2016]
   a) simple impulse type
   b) propeller type
   c) reaction type
   d) reversible type

Answer: (b)

2. Tidal energy utilises [WBUT 2009, 2014, 2019]
   a) kinetic energy of water
   b) potential energy of water
   c) both kinetic and potential energies of water
   d) none of these

Answer: (b)

3. Tidal power plants are built on [WBUT 2009, 2014]
   a) seashore b) cricks c) plates d) mountain range

Answer: (a)

4. Wave energy is basically harnessed in the form of [WBUT 2010, 2011, 2012, 2014, 2018]
   a) thermal energy
   b) chemical energy
   c) mechanical energy
   d) electrical energy

Answer: (c)

5. The turbine used in a tidal range plant is a [WBUT 2011]
   a) Pelton turbine
   b) Kaplan turbine with variable pitch blades
   c) Kaplan turbine with fixed pitch blades
   d) Francis turbine

Answer: (b)

6. Tidal power plants are generally built on [WBUT 2017]
   a) seashore b) plateau c) creeks d) mountain range

Answer: (a)

7. The downstream channel of outgoing water from a hydropower plant is called [WBUT 2017]
   a) head race b) tail race c) open channel d) tail channel

Answer: (d)

8. The minimum tidal range required for power generation is about [WBUT 2018]
   a) 1 m b) 5 m c) 10 m d) 20 m

Answer: (b)

9. How many basins does a single pool tidal system have? [WBUT 2019]
   a) 1 b) 2 c) 3 d) 4

Answer: (a)

Short Answer Type Questions

1. List the advantages and disadvantages of a tidal barrage scheme as a source of electrical power. **[WBUT 2007, 2009, 2014]**

Answer:

Advantages:

1. The biggest advantage of tidal power is besides being inexhaustible; it is completely independent of the precipitation (rain) and its uncertainty.
2. Tidal power generation is free from pollution, as it does not use any fuel.
3. These power plants do not demand large area of valuable land because they are on the bays (sea shore).
4. Peak power demand can be effectively met.

Disadvantages:

The following are some of the disadvantages of tidal power that should be looked upon with utmost care.

1. The fundamental drawback to all of generating tidal power is the variability in output caused by the variations in the tidal range.
2. The tide ranges is highly variable and thus the turbines have to work on a wide range of head variation.
3. Tidal range is limited to a few meters.
4. Sea water is corrosive and it was feared that the machinery may get corroded.
5. Construction in sea is found difficult.
6. Cost is not favourable compared to the other sources of energy.

2. A deep ocean wave of 2 m peak appears at a period of 8s. Find the wavelength, phase velocity. Power associated with the wave. At this power rate, find the average annual wave energy in MW h/ m. **[WBUT 2008]**

Answer:

Given: Amplitude $a = \dfrac{\text{Wave peak to peak value}}{2} = \dfrac{2}{2} = 1\,\text{m}$

Density of sea-water may be assumed as, $\rho = 1025\,\text{kg/m}^3$

Angular Frequency $(\omega) = \dfrac{2\pi}{T}$

$$= \frac{2\times\left(\frac{22}{7}\right)}{8} \quad (\because\ T = 8\,\text{sec})$$

$$= \frac{2\times 22}{7\times 8}\,\text{rad./sec.} = \frac{11}{14}\,\text{rad./sec.} = 0.7857\,\text{rad./sec.}$$

The wavelength of a travelling wave

$$\lambda = \frac{2\pi g}{\omega^2}\,\text{m} = \frac{2\times 22\times 9.81}{(0.7857)^2\times 7}\,\text{m} = 98.987\,\text{m}.$$

The phase velocity of the wave

$$v = \frac{\omega\lambda}{2\pi}\ \text{m/s.} = \frac{0.7857 \times 98.987 \times 7}{2 \times 22}\ \text{m/s.} = 12.373\ \text{m/s.}$$

Note: The phase velocity of the wave

$$v = \frac{\omega\lambda}{2\pi} = \omega \cdot \frac{\lambda}{2\pi}$$

$$= \frac{2\pi}{T} \times \frac{\lambda}{2\pi}$$

$$= \frac{\lambda}{T} \qquad \left(\because K = \frac{2\pi}{\lambda}\ \text{wave number}\right)$$

$$= \frac{\omega}{K}$$

$$= \frac{g}{\omega} \qquad \left(\because \lambda = \frac{2\pi g}{\omega^2}\ \text{or}\ \frac{\omega\lambda}{2\pi} = \frac{g}{\omega}\right)$$

$$\therefore \quad v = \frac{\omega\lambda}{2\pi} = \frac{\lambda}{T} = \frac{\omega}{K} = \frac{g}{\omega}$$

The phase velocity of the wave

$$v = \frac{g}{\omega} = \frac{9.81}{0.7857} = 12.485\ \text{m/s.}$$

Power in wave $(P) = \left(\frac{\rho g^2}{8\pi}\right) a^2 \cdot T = \frac{1025 \times 9.81^2}{8 \times \frac{22}{7}} \times (1)^2 \times 8\ \text{W/m.}$

$$= 31386.09\ \text{W/m.} = 31.39\ \text{kW/m.}$$

Average annual wave energy at the site

$$= P \times 365 \times 24\ \text{kWh/m.} = \frac{31.39 \times 365 \times 24}{1000}\ \text{MWh/m.} \equiv 275\ \text{MWh/m.}$$

3. a) What is tidal power generation system? **[WBUT 2010, 2013, 2016]**

Answer:

The power generation system which use the energy stored in tides produced by gravitational attraction of sun and moon is called by tidal power generation system. It constitutes of dam, barrage, dyke, sluice ways, bulb type power turbine generator set.

b) Discuss the advantage and limitation of tidal power generation.

[WBUT 2010, 2013, 2016]

Answer:

Advantages:

1. Tidal power is completely independent of the precipitation(rain) and its uncertainty, besides being inexhaustible.
2. Large area of valuable land is not required.

3. When a tidal power plant works in combination with thermal or hydro-electric system peak power demand can be effectively met with.
4. Tidal power generation is free from pollution.

Limitations:

1. Due to variation in tidal range the output is not uniform.
2. Since the turbines have to work on a wide range of head variation (due to variable tidal range) the plant efficiency is affected.
3. There is a fear of machinery being corroded due to corrosive sea water.
4. It is difficult to carry out construction in sea.
5. As compared to other sources of energy, the tidal power plant is costly.
6. Sedimentation and siltation of basins are the problems associated with tidal power plants.
7. The power transmission cost is high because the tidal power plants are located away from load centres.

4. What is the economics and future prospect of tidal energy? **[WBUT 2012]**

Answer:

Economics of Tidal Power: Tidal power is most cheapest form of energy which can only be generated intermittently. To convert the intermittent low-grade energy to guaranteed continuous energy to guaranteed continuous energy, additional cost must be added. Another reason is that due to the low generating heads, the cost of machinery and its supporting structure is high.

The cost economy guides that a small-scale tidal power development must be justified on its own merits, so that the unit construction cost can definitely be offset against the other consequent benefits. There are some benefits other than the power benefit, which can reduce the cost of energy to a competitive level. Major benefits that can accure from tidal power are listed below:

1. It is a renewable energy source free from weather vagaries. The cost of energy produced is quite nominal, i.e., only the operational cost.
2. Performance of the plant is free of pollution.
3. Tidal power combined with the pumped storage generation ensures continuous power supply.

Future prospect: Tidal energy is a form of hydropower 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 240-MW tidal power plant was built in 1966 in France at the mouth of the La Rance river, near St. Malo on the Brittany coast. A 20-MW tidal plant is located at Nova Scotia, Canada, and a 400-Kw capacity plant is located at Kislaya Guba, near Murmansk, Russia on the Barents Sea. Many sites have been identified in USA, Argentina, Europe, India and China for development of tidal power.

There is no functional tidal plant at present and the total potential has been estimated as 9,000 MW. Three sites have been identified for development of tidal energy.

- Gulf of Kutch: potential = 900 MW, tidal range = 5 m
- Gulf of Cambay (Khambat): Potential = 7,000 MW, tidal range = 6m
- Sundarbans: potential = 1,000 MW, tidal range = 3.9 m

5. A tidal power plant of single basin type has a basin area of 15×10^6 m². The tide has a range of 12 m. The turbine however, stops operating when the head on it falls below 2m. Calculate the energy generated in one filling process in kWh if the turbine generator efficiency is 80% (Density of sea water = 1025 k/m²). **[WBUT 2015]**

Answer:

Amplitude $R = 12$

$r = 2\,\text{m}$

Basin area $A = 15\times10^6\,\text{m}^2$

Generator efficiency $\eta = 0.8$

Density of sea water may be assumed as

$\rho = 1025\,\text{kg/m}^3$

Average power potential available

$$= 0.225\times A\left(R^2 - r^2\right)\ \text{watts}$$

$$= 0.225\times15\times10^6\left(12^2 - 2^2\right) = 0.225\times15\times10^6\times14\times10 = 472.5\,\text{MW}$$

Average power generated $= 472.5\times0.8 = 378\,\text{MW}$

Energy available in single emptying

$$= \frac{1}{2}\rho A_g\left(R^2 - r^2\right) = \frac{1}{2}\times1025\times15\times10^6\times9.8\times\left(12^2 - 2^2\right)$$

$$= \frac{1}{2}\times1025\times15\times9.8\times14\times10 = 10{,}547{,}250\,\text{MJ}$$

One ebb cycle duration = 12 h 25 min = 12.42 h

Number of ebb cycles in a year $= 365\times\frac{24}{12.42} = 705.5 \simeq 706$

Average annual energy generation $= 10{,}547{,}250\times706\times0.8\,\text{J}$

$$= 5{,}957{,}086{,}800\,\text{J}$$

$$= 5{,}957{,}086{,}800\times0.0000002778 = 1654.878\,\text{kWh.}$$

6. Briefly discuss the reasons of formation of tides with diagram. **[WBUT 2018]**

Answer:

Tides refer to the rise and fall of our oceans' surfaces. It is caused by the attractive forces of the Moon and Sun's gravitational fields as well as the centrifugal force due to the Earth's spin. As the positions of these celestial bodies change, so do the surfaces' heights. For example, when the Sun and Moon are aligned with the Earth, water levels in ocean surfaces fronting them are pulled and subsequently rise.

The Moon, although much smaller than the Sun, is much closer. Now, gravitational forces decrease rapidly as the distance between two masses widen. Thus, the Moon's gravity has a larger effect on tides than the Sun. In fact, the Sun's effect is only about half that of the Moon's.

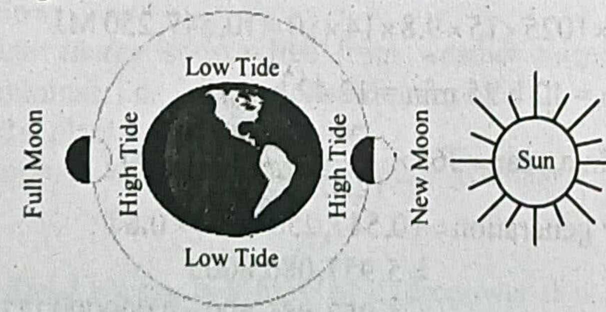
Since the total mass of the oceans does not change when this happens, part of it that was added to the high water regions must have come from somewhere. These mass-depleted regions then experience low water levels. Hence, if water on a beach near you is advancing, you can be sure that in other parts of the world, it is receding.

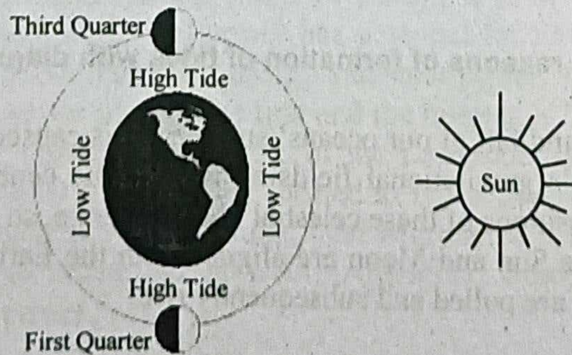
Most illustrations containing the Sun, Moon, Earth and tides depict tides to be most pronounced in regions near or at the equator. On the contrary, it is actually in these regions where the difference in high tide and low tide are not as great as those in other places in the world.

This is because the bulging of the oceans' surface follows the Moon's orbital plane. Now, this plane is not in line with the Earth's equatorial plane. Instead, it actually makes a 23-degree angle relative to it. This essentially allows the water levels at the equator to seesaw within a relatively smaller range (compared to the ranges in other places) as the orbiting moon pulls the oceans' water.

Not all tides are caused by the relative positions of these celestial bodies. Some bodies of water, like those that are relatively shallow compared to oceans, experience changing water levels because of variations in the surrounding atmospheric pressure. There are also other extreme situations wherein tides are manifested but have nothing to do with astronomical positioning.

A tidal wave or tsunami, for example, makes use of the word 'tide' and actually exhibits rise and fall of water levels (in fact, it is very noticeable). However, this phenomena is caused entirely by a displacement of a huge amount of water due to earthquakes, volcanic eruptions, underwater explosions, and others. All these causes take place on the Earth's surface and have nothing to do with the Moon or Sun.





Long Answer Type Questions

1. Write short notes on the following:
a) Wave energy **[WBUT 2009, 2012, 2015]**
b) Tidal wave energy **[WBUT 2019]**

Answer:

a) Wave energy:

Wave energy comes from the interaction between the winds and the surfaces of oceans. The energy available varies with the size and frequency of waves. It is estimated that about 10 kW of power is available for every metre width of the wave front. Wave energy when active is very concentrated, therefore, wave energy conversion into useful energy can be carried out at high power densities. A large variety of devices(e.g. hydraulic Accumulator wave machine ; high level reservoir machine; Dolphin- type wave power machine; dam-Atoll wave machine) have been developed for harvesting of energy but these are complicated and fragile in face of gigantic power of ocean storms.

Advantages of Wave energy:

1. It is relatively pollution free.
2. It is a free and renewable energy source.
3. After removal of power, the waves are in placed state.
4. Wave power devices do not require large land masses.
5. Whenever there is a large wave activity, a string of devices have to be used. The system not only produces electricity but also protects coast lines from the destructive action of large waves, minimizes erosion and help create artificial harbor.

Disadvantages of Wave energy:

1. Lack of dependability.
2. Relative scarcity of accessible sites of large wave activity.
3. The construction of conversion devices is relatively complicated.
4. The devices have to withstand enormous power of stormy seas.
5. There are unfavourable economic factors such as large capital investment and costs of repair, replacement and maintenance.

The collection of wave energy entails the following problems:

1. The variation of frequency and amplitude makes it an unsteady source.
2. Devices, installed to collect and to transfer wave energy from far off oceans, will have to with stand adverse weather conditions.
   Uptil now no major development programme for taming wave energy has been carried but successfully through any country. Small devices are available, however, and are in limited use as power supplies for buoys and navigational aids. From the engineering development point of view, wave energy development is not nearly as far long as wind and tidal energy.

b) Tidal Wave energy:

Tides are generated by the action of gravitational forces of the sun and the moon on the oceans, by the spinning of the earth around its axis and the relative positions of the earth, moon and the sun.

The tides are the periodic vertical rise and fall of ocean water. The period between consecutive high tides is 12.5 hours. The tidal rise and fall of water is accompanied by periodic horizontal to and fro motion of water called tidal currents. Tides and tidal currents are intimately related.

Tidal movement differs from wave-movement. Waves have a period of only about 6s whereas tides have a period of 12.5 h. Waves are caused by surface winds, whereas tides are caused by the gravitational forces of moon and sun on ocean water.

The amplitude of tides covers a wide range from 25 cm to 10 m. The speed of tidal currents is in the range of 1.8 km/h to 18 km/h. The tides and tidal currents possess renewable energy.

The rise and fall of the water level follows a sinusoidal curve, shown with point A indicating the high tide point and point B indicating the low tide point. The average period of time for the water level to fall from A to B and then rise from B to C is each approximately equal to 6 hours 12.5 min (Fig. 1)

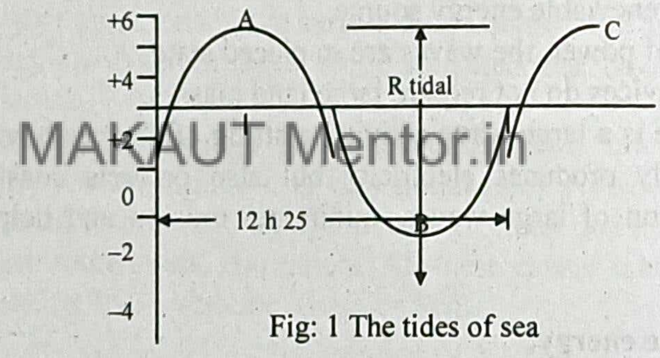


Fig: 1 The tides of sea

The difference between high and low water levels is called the range of the tide. The tidal range R is defined as:

R = water elevation at high tidewater elevation at low tide.

Because of the changing positions of the moon and sun relative to the earth, the range varies continuously. There are however, some characteristic features of this variation.

At times during full or new moon, when sun, moon and earth are approximately in a line, the gravitational forces of sun and moon are enhanced. The tidal range is then exceptionally large, the high tides are higher and low tides are lower than the average. These high tides are called spring tides. On the other hand, near the first and third quarters of the moon, when the sun and moon are at right angles with respect to the earth, neap tides occur. The tidal range is then exceptionally small; the high tides are lower and the low tides higher than the average. Hence the range is not constant. It varies during the 29.5-day lunar month and is maximum at the time of new and full moons (called the spring tides) and minimum at the time of the first and third quarter moons (called the neap tides). The spring-neap tidal cycle lasts one-half of a lunar month. A typical mean range is roughly one third of the spring range. The actual variations in range are somewhat complicated by seasonal variations caused by the ellipticity of the earth's orbit around the sun.

The variations in the periodicity and monthly and seasonal ranges must, of course, be taken into account in the design and operation of tidal power plants. The tides, however, are usually predictable and fairly accurate tide tables are usually available. Tidal ranges very from one earth location to another. They are influenced by such conditions as the profile of the local shoreline and water depth. When these are favourable, a resonance like effect causes very large tidal ranges. Ranges have to be very large to justify the huge costs of buildings dams and associated hydroelectric power plants. Such tides occur only in a few locations in the world.

The tides along most coastlines are about a metre high, but in constricted areas where they are amplified by a funnelling action, they may rise by 10 metre as or more. It is in these constricted areas that the most effective tidal power plants may be located. A dam or sluice gate is placed across an ocean bay or estuary. An incoming tide fills up the enclosed basin while passing through a row of hydraulic turbines. After the basin is filled with water, the gates are closed and the turbines are shut down. Then the turbine blades are reversed and the gates opened again to let the water surge out. Thus turbines would be rotated either way generating electric power.

MAGNETO HYDRODYNAMIC ENERGY CONVERSION

Multiple Choice Type Questions

1. MHD utilizes **[WBUT 2010, 2012, 2013, 2014, 2016]**

a) direct conversation of heat to electricity b) conversion of heat to steam
c) conversion of heat of force d) none of these

Answer: (a)

Short Answer Type Questions

1. Describe the principle of MHD generating system. What are the limitations of MHD system? **[WBUT 2017]**

Answer:

1st Part: *Refer to Question No. 1(1st Part) of Long Answer Type Questions.*

2nd Part: *Refer to Question No. 4(2nd Part) of Long Answer Type Questions.*

2. Draw schematic diagram of an MHD power generating system having heat recovery steam generator. Explain the functioning of the system. **[WBUT 2019]**

Answer:

Refer to Question No. 3(b) of Long Answer Type Questions.

Long Answer Type Questions

1. Explain the working principle of MHD energy conversion. **[WBUT 2011]**

OR,

Derive the equations for the voltage and power output of the MHD generator. **[WBUT 2015, 2019]**

Answer:

Let conducting a gas, having a conductivity of σ mho/m, moves at a speed u across the magnetic field B. The speed u and magnetic field B are held mutually perpendicular along the x-axis and y-axis respectively. The electrodes, having area A, are held at a distance, d along the z-axis, thus perpendicular to both u and B, as shown in figure 1. The magnitude of a force acting on a charged particle having charge q is given by quB. This force, as per right hand rule, will be acting in the upward direction (on a positively charged particle). The positively charged particles will be collected by the upper electrode and the negatively charged particles by the lower electrode, causing a potential difference V across them. The resulting electric field between the plates is given by:

$$E = -\frac{V}{d}.$$

Due to this field, another force qE will be acting on the charged particle in the downward direction. The net force acting on the charged particle:

$$F_{\text{net}} = qE + quB$$

or, $$F_{\text{net}} = -q\frac{V}{d} + quB$$

If no load is connected across the electrodes (i.e., open-circuit condition), no current will flow and there will be no net movement of carriers between electrodes. Therefore, no net force will be acting on the charged particles. A voltage, V_o (open circuit voltage) appears across the electrodes.

Thus,

$$F_{\text{net}} = -q\frac{V_o}{d} + quB = 0$$

$$V_o = Bud \qquad \text{.... (1)}$$

Now, if an external load R_L is connected across the terminals, current starts flowing through the load transferring power to the electrical load. As per maximum power transfer theorem, maximum output, $P_{\max}$ is obtained when the load resistance is equal to the internal resistance, R_g of the MHD generator.

$$P_{\max} = VI \qquad (\text{for } R_g = R_L)$$

$$= (IR_g)I = I^2R_g = \left(\frac{V_o}{R_L + R_g}\right)^2 R_g$$

$$P_{\max} = \frac{V_o^2}{4R_g}$$

From equation (1): $P_{\max} = \dfrac{B^2u^2d^2}{4R_g}$

Internal resistance of MHD generator is the resistance of the conducting fluid flowing between the electrodes. Thus, $R_g = \dfrac{1}{\sigma}\dfrac{d}{A}$

Therefore, $P_{\max} = \dfrac{1}{4}\sigma u^2 B^2 Ad$

The maximum power output per unit volume is given by, $\dfrac{P_{\max}}{Ad} = \dfrac{1}{4}\sigma u^2 B^2$.

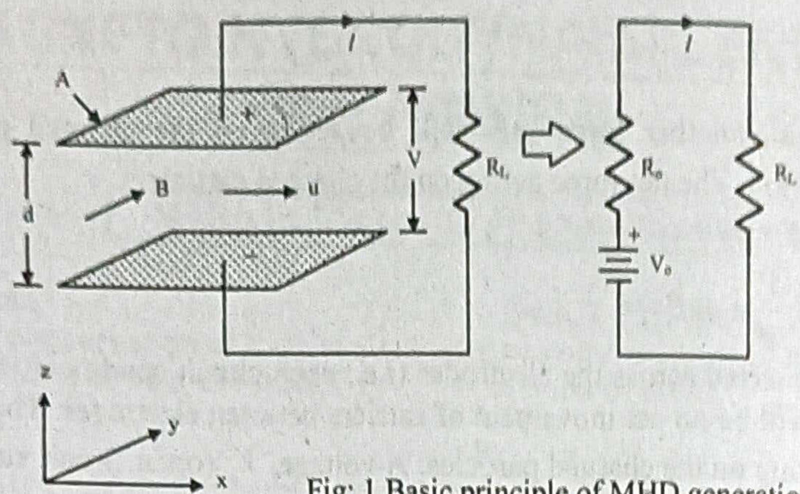


Fig: 1 Basic principle of MHD generation
and equivalent circuit

2. Calculate the open circuit voltage and maximum power output for an MHD generator having the following data:
Plate area = 0.25 m², distance between electrodes = 0.50 m, flux density = 1.8 Wb/m², average gas velocity = 1200 m/s, gaseous conductivity = 10 mho/m.

[WBUT 2014]

Answer:

Given

$A = 0.25\,\text{m}^2, d = 0.5\,\text{m}, B = 1.8\,\text{wb/m}^2, u = 1200\,\text{m/s}, \sigma = 10\,\text{mho/m}$

From equation, the open circuit voltage of the generator we get,

$$V_0 = Bud = 1.8 \times 1200 \times 0.5 = 1080\text{ V}$$

Maximum power output of the generator is given by

$$\frac{P_{max}}{Ad} = \frac{1}{4}\sigma u^2 B^2$$

or, $$P_{max} = \frac{1}{4}\sigma u^2 B^2 Ad = \frac{1}{4} \times 10 \times 1200^2 \times 1.8^2 \times 0.25 \times 0.5 = 1.458\,\text{MW}$$

3. a) What is the basic principle of MHD power generation? **[WBUT 2015]**
b) Describe the open cycle system of MHD power generation.
c) Calculate the open circuit voltage with following specifications
Plate area = 0.2 m²
Distance between plates = 0.4m
Flux density = 2 wb/m²
Average gas velocity = 1000 m/s
Conductivity of the gas = 10 mho/m.

Answer:

a) *Refer to Question No. 1 of Long Answer Type Questions.*

b) The open-cycle system is shown in Fig. 1. Hot flue gases at about 2300-2700°C, obtained from burning of coal (or other fuel) in a combustor are used as working fluid, after mixing with seed material. Aqueous potassium carbonate is generally sprayed for the purpose of seeding. To attain such a high temperature, compressed air is preheated at least up to 1100°C before supplying to the combustor. The working fluid enters the MHD channel through a nozzle and produces dc output. An inverter is used to obtain 50 Hz ac output for supply to consumers. The exhaust of an MHD channel is first used to preheat the air intake for combustor and then to raise the steam in a waste-heat steam generator. The steam so produced is used to generate additional power through a conventional turbine-generator system. The flue gases are released to the atmosphere through a chimney after seed recovery and removal of pollutants. The recovered seed material is recycled after mixing the additional quantity to make up for the loss of seed. Seed recovery is important for prevention of atmospheric pollution and for economic reasons.

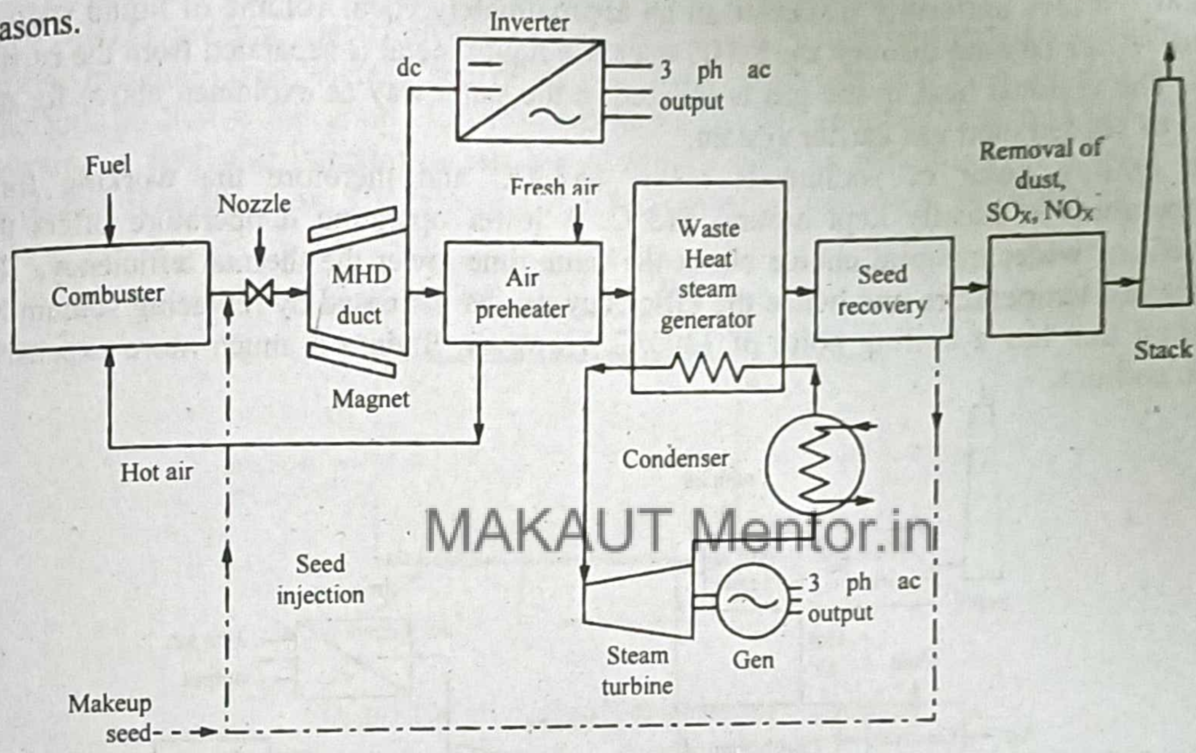


Fig: 1 Open-cycle MHD generating system

c) Given $A = 0.2\ \text{m}^2$

$d = 0.4\ \text{m}$

$B = 2\ \text{Wb/m}^2$

$u = 1000\ \text{m/s}$

$\sigma = 10\ \text{mho/m}$

The open circuit voltage of the generator we get

$V_0 = Bud = 2\times1000\times0.4 = 800\ \text{V}$ **(Ans.)**

4. a) Describe the basic principle of operation of an MHD generator. Derive expression of maximum power generation per unit volume of generator.
b) With the help of schematic diagram explain the operation of closed cycle MHD generating system. **[WBUT 2016]**

Answer:

a) ***Refer to Question No. 1 of Long Answer Type Questions.***

b) Liquid Metal-inert Gas Carrier System

In this system, instead of seeding, a liquid metal (such as Na, K or Li) is incorporated in the inert carrier gas for conductivity requirement. These metals are excellent electrical conductors in the liquid state but their vapours are poor conductors. Therefore, these are used in the working fluid in the liquid state only.

A liquid sodium-based closed loop MHD generating system with coal as input energy is shown in Fig. 13.5. The carrier gas is pressurised and heated by a passage through primary heat exchanger within the combustor. The hot gas is then incorporated into the liquid metal (usually sodium) to form the working fluid. The working fluid thus consists of gas bubbles uniformly dispersed in an approximately equal volume of liquid sodium metal. After passing through the MHD duct, the liquid metal is separated from the carrier gas. The residual heat in the gas is utilized in the same way as explained above for the case of seeded inert gas carrier system.

The boiling point of sodium is below 882.9°C and therefore the working fluid temperature is usually kept around 815°C. A lower operating temperature offers the benefit of wider material choice but at the same time lower the thermal efficiency. The operating temperature and hence the efficiency can be increased by replacing sodium by lithium that has a boiling point of 1300°C. However, lithium is much more expensive than sodium.

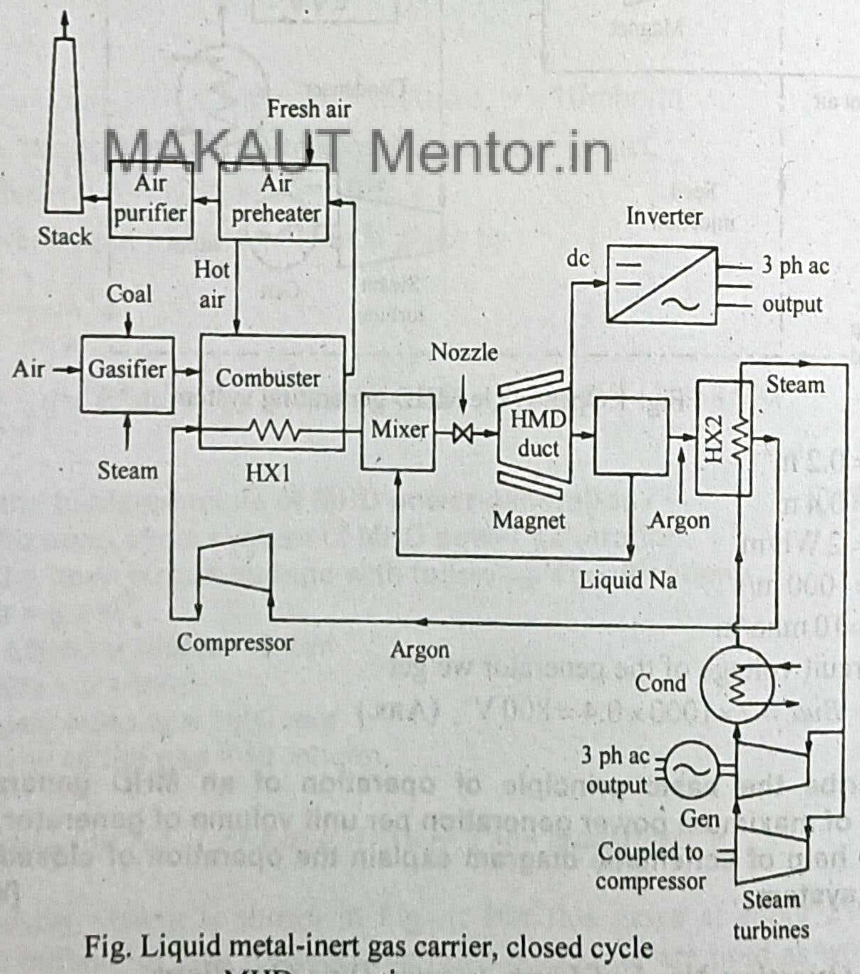


Fig. Liquid metal-inert gas carrier, closed cycle MHD generating system

5. Write short note on Magneto hydrodynamic energy conversion.
[WBUT 2009, 2012]

Answer:

In thermal generation of electric energy, the heat released by the fuel is converted to rotational mechanical energy by means of a thermocycle. The mechanical energy is then used to rotate the electric generator. Thus two stages of energy conversion are involved in which the heat to mechanical energy conversion has inherently low efficiency. Also, the rotating machine has its associated losses and maintenance problems. In MHD technology, electric energy is directly generated by the hot gases produced by the combustion of fuel without the need for mechanical moving parts.

In a MHD generator, electrically conducting gas at a very high temperature is passed in a strong magnetic field, thereby generating electricity. High temperature is needed to ionise the gas, so that it has good electrical conductivity. The conducting gas is obtained by burning a fuel and injecting a seeding materials such as potassium carbonate in the products of combustion. The principle of MHD power generation is illustrated in Fig. (a).

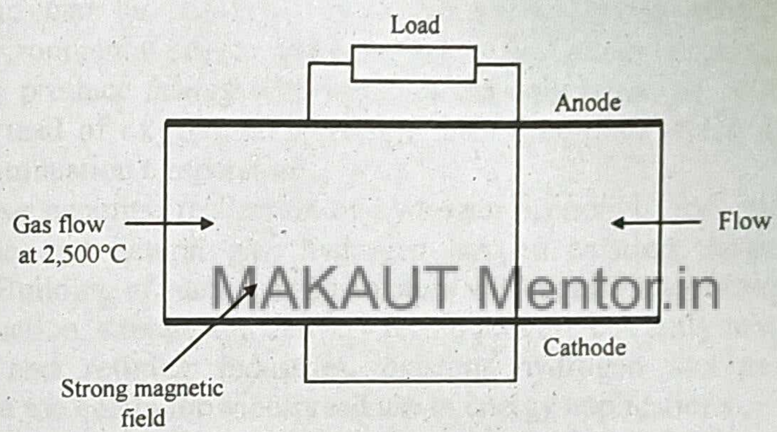


Fig: (a) The principle of MHD power generation

About 50% efficiency can be achieved if the MHD generator is operated in tandem with a conventional steam plant.

Though the technological feasibility of MHD generation has been established, its economic feasibility is yet to be demonstrated. India has started a research and development project in collaboration with the former USSR to install a pilot MHD plant based on coal and generating 2 MW power. In Russia, a 25 MW MHD plant, which uses natural gas a fuel had been in operation for some years. In fact with the development of CCGT (combined cycle gas turbine) plant, MHD development has been put on the shelf.

Drawbacks of MHD system:

1. MHD systems suffer from the reverse flow (short circuits) of electrons through the conducting fluids around the ends of the magnetic field. This loss can be reduced by i) increasing aspect ratio of the generator ii) by permitting the magnetic field poles to extend beyond the end of the electrodes and iii) by using insulated vans in the fluid ducts and at the inlet and outlet of the generator.

2. There will be high friction losses and heat transfer losses. The friction loss may be as high as 12% of input.
3. The MHD system needs very large magnets and this is a major expense.
4. The MHD system operates at very high temperature to obtain high electrical conductivity. But the electrodes must be relatively at low temperatures and hence the gas in the vicinity of the electrodes is cooler. This increases the resistivity of the gas near the electrodes and hence there will be a very large voltage drop across the gas film. By adding the seed material, the resistivity can be reduced.

HYDROGEN ENERGY

Multiple Choice Type Questions

1. The simplest method of hydrogen production is [WBUT 2018]
   a) electrolysis of water b) thermolysis of water
   c) steam reforming of methane d) biophotosynthesis

Answer: (a)

Long Answer Type Questions

1. Write short note on Hydrogen energy. [WBUT 2015]

Answer:
Hydrogen can be produced by using a variety of energy sources, such a solar, nuclear and fossil fuels and can be converted to useful energy forms efficiently and without detrimental environmental effects. When burned as fuel or converted to electricity it joins with oxygen to produce energy with water as the only emission. When air is used for combustion instead of oxygen, some NO_X is also produced, which can be reduced by lowering the combustion temperature.

Despite all these benefits, realization of hydrogen economy faces multiple challenges. Unlike gasoline and natural gas, hydrogen has no existing, large-scale supporting infrastructure. Building of such an infrastructure will require major investment. Although hydrogen production, storage and delivery techniques are currently in commercial use by the chemical and refining industries, existing hydrogen storage and conversion technologies are too costly for widespread use in energy applications.

The individual segments of the hydrogen energy system; production, delivery, storage, conversion and end use applications are closely interrelated and interdependent as shown in Fig. 1. Design and application of a hydrogen economy must carefully consider each of these segments as well as the whole system.

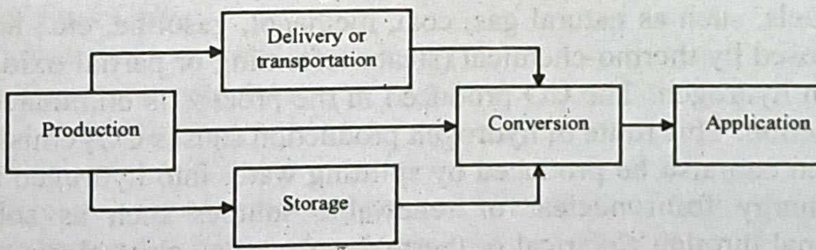


Fig: 1 Hydrogen energy system

Hydrogen can be produced in centralised facilities and distributed to an energy conversion site via pipelines or stored and shipped via rail or road. It can also be produced at decentralised locations onsite where it will be stored and/or fed directly into conversion device for stationary, mobile or portable applications.

Properties: Hydrogen is an odourless and colourless gas. It has the simplest and lightest atom with one proton and one electron and a molecular weight of 2.016.

Hydrogen has the following properties which it an attractive alternative energy source.

1. At room temperature and pressure, hydrogen is a light gas. Its density is only 1/14th of that of air and 1/9th that of natural gas.
2. At atmospheric pressure, hydrogen can be liquefied at –253°C. The liquid hydrogen has a specific gravity of 0.07 which is 1/10th that of gasoline.
3. The standard heating value of hydrogen gas is 12.1 MJ/m^3 compared with 38.3 MJ/m^3 for natural gas.
4. The heating value of liquid hydrogen is 120 MJ/kg or 8400 MJ/m^3 as compared to 44 MJ/kg or 32000 MJ/m^3 or aviation petrol. The specific energy of hydrogen liquid is superior to gasoline on mass basis but inferior on volume basis.
5. The flame speed of hydrogen when burning in air is much greater than for natural gas.
6. The ignition energy to initiate combustion is less for hydrogen than for natural gas.
7. Detonation can occur between hydrogen-air mixture between 18 and 59 percent. The internal combustion engine on hydrogen fuel can work from very rich (excess fuel) to very lean (excess air) mixture. The adjustment of air fuel ratio is less critical than for gasoline engine.
8. Mixture of hydrogen and air are combustible over a wide range of composition. The flammability limits are from 4 to 74 percent by volume of hydrogen in air at ordinary temperatures.
9. The combustion of hydrogen with oxygen from air results in release of energy and water as by-product.
10. The burning process of hydrogen is pollution free.

Production: Although hydrogen is the third-most abundant element on the earth, it does not exist in free state, except for small quantities in the upper atmosphere. It is, therefore, not a primary energy source. However, large amounts of combined hydrogen are present in compounds such as water, fossil fuels and biomass. It can therefore, be produced through two routes:

i) Fossil fuels, such as natural gas, coal, methanol, gasoline, etc., and biomass are decomposed by thermo-chemical (steam reforming or partial oxidation) methods to obtain hydrogen. The CO produced in the process is eliminated by water-gas shift reaction. This route of hydrogen production causes CO_2 emission.

ii) Hydrogen can also be produced by splitting water into hydrogen and oxygen by using energy from nuclear or renewable sources such as solar, wind, and geothermal through electrical or thermal means (i.e., electrolysis and thermolysis respectively). Water splitting is also possible through bio-photolysis process using solar radiation.

FUEL CELLS

Multiple Choice Type Questions

1. A fuel cell is basically a device for **[WBUT 2018]**
a) electrochemical energy conversion
b) thermo electric energy conversion
c) electrostatic energy conversion
d) electro mechanical energy conversion

Answer: (c)

2. Which of the following is not an example of fuel cell? **[WBUT 2019]**
a) Hydrogen-oxygen cell b) Methyl-oxygen-alcohol cell
c) Propane-oxygen cell d) Hexanone-oxygen cell

Answer: (d)

Short Answer Type Questions

1. a) What are the different types of fuel cell? **[WBUT 2010, 2016]**
b) State the advantages and limitations of fuel cell.
OR,
Explain briefly about fuel (including types, advantages and limitations).

[WBUT 2019]

Answer:
A fuel cell is an electrochemical energy conversion device that continuously converts chemical energy of a fuel directly into electrical energy. Continuous operation requires supply of fuel and oxidant and removal of water vapour, spent fuel, spent oxidant, inert residue and heat. It is known as a cell because of some similarities with a primary cell.

Different types of Fuel Cells
Fuel cells can be classified in several ways.

(a) Based on the Type of Electrolyte
(i) Phosphoric Acid Fuel cell (PAFC)
(ii) Alkaline Fuel cell (AFC)
(iii) Polymer Electrolytic Membrane Fuel cell (PEMFC) or Solid Polymer Fuel Cell (SAFC) or Proton Exchange Membrane Fuel cell (PEMFC).
(iv) Molten Carbonate Fuel Cell (MCFC)
(v) Solid Oxide Fuel Cell (SOFC)

(b) Based on the Types of the Fuel and Oxidant
(i) Hydrogen (pure) – Oxygen (pure) fuel cell
(ii) Hydrogen rich gas – air fuel cell
(iii) Hydrazine-Oxygen / hydrogen peroxide fuel cell
(iv) Ammonia – air fuel cell

(v) Synthesis gas – air fuel cell
(vi) Hydrocarbon (gas) – air fuel cell
(vii) Hydrocarbon (liquid) - air fuel cell

(c) Based on Operating Temperature
(i) Low temperature fuel cell (below 150°C)
(ii) Medium temperature fuel cell (150°C to 250°C)
(iii) High temperature fuel cell (250°C to 800°C)
(iv) Very high temperature fuel cell (800°C to 1100°C)

(d) Based on Application
(i) Fuel cell for space supplications
(ii) Fuel cell for vehicle propulsion
(iii) Fuel cell for submarines
(iv) Fuel cell for defense applications
(v) Fuel cell for commercial applications

(e) Based on the Chemical Nature of Electrolyte
(i) Acidic electrolyte type
(ii) Alkaline electrolyte type
(iii) Neutral electrolyte type.

Advantages of fuel cells:
The main advantages of a fuel cell are:
(i) it is quiet in operation as it is a static device,
(ii) it is less pollutant,
(iii) its conversion efficiency is move due to direct single-stage energy conversion,
(iv) fuel cell plant can be installed near the point of use, thus transmission and distribution losses are avoided
(v) no cooling water is needed as required in the condenser of a conventional steam plant. The heat generated can be easily removed and discharged to the atmosphere or used locally
(vi) because of modular nature, any voltage/current level can be realized and the capacity can be added later on as the demand grows,
(vii) fuel-cell plants are compact and require less space,
(viii) availability of choice from large number of possible fuels,
(ix) can be used efficiently at part load from 50% to 100%, and
(x) no charging is required.

Limitations:
1. Fuelling fuel cells is still a problem since the production, transportation
2. Distribution and storage of hydrogen is difficult.
3. Reforming hydrocarbons via reformer to produce hydrogen is technically challenging and not clearly environmentally friendly.
4. The refuelling and the starting time of fuel cell vehicles are longer and the driving range is shorter than in a "normal" car.

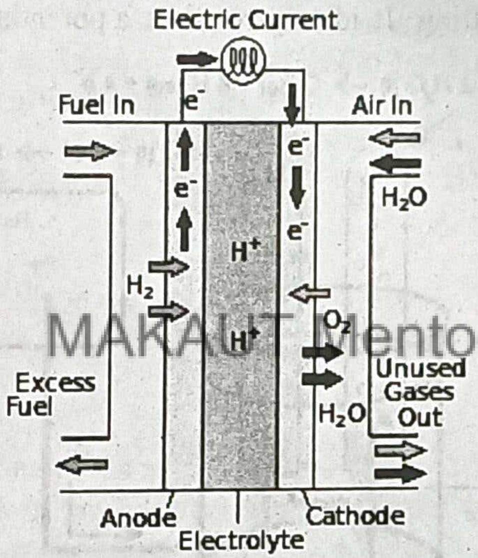
5. Fuel cells are in general slightly bigger than comparable batteries or engines. However, the size of the units is decreasing.
6. Fuel cells are currently expensive to produce, since most units are hand-made. Some fuel cells use expensive materials.
7. The technology is not yet fully developed and few products are available.

2. Describe the principle and operation of Fuel Cell with suitable diagram. **[WBUT 2018]**

Answer:

Fuel cell operation

The fuel cell is an electrochemical device, which converts chemical energy of the fuel to electricity by combining gaseous hydrogen with air in the absence of combustion. The basic principles of operation of the fuel cell is similar to that of the electrolyser in that the fuel cell is constructed with two electrodes with a conducted electrolyte between them.



For a better explanation of the fuel cell operation, we take a closer look at the **Proton Exchange Membrane (PEM)** fuel cell (shown in the figure above)

The heart of the cell is the proton conducting solid **PEM**. It is surrounded by two layers, a diffusion and a reaction layer. Under constant supply of hydrogen and oxygen the hydrogen diffuses through the anode and the diffusion layer up to the platinum catalyst, the reaction layer. The reason for the diffusion current is the tendency of hydrogen oxygen reaction.

Two main electrochemical reactions occur in the fuel cell. One at the anode (anodic reaction) and one at the cathode.

At the anode, the reaction releases hydrogen ions and electrons whose transport is crucial to energy production.

$$H_2®2H^+ + 2e^-$$

The hydrogen ion on its way to the cathode passes through the polymer membrane while the only possible way for the electrons is though an outer circuit. The hydrogen ions together with the electrons of the outer electric circuit and the oxygen which has diffused through the porous cathode reacts to water.

$$2H^+ + \frac{1}{2} O_2 + 2e^- ®H_2O$$

The water resulting from this reaction is extracted from the system by the excess air flow. The reaction is:

$$H + \frac{1}{2} O_2 ®H_2O$$

This process occurs in all types of fuel cells.

3. Briefly describe the production process of hydrogen through electrolysis of water with suitable diagram. **[WBUT 2018]**

Answer:

Electrolysis of water is the decomposition of water into oxygen and hydrogen gas due to the passage of an electric current.

This technique can be used to make hydrogen gas, a key component of hydrogen fuel, and breathable oxygen gas, or can mix the two into oxyhydrogen - also usable as fuel, though more volatile and dangerous.

It is also called water splitting. It ideally requires a potential difference of 1.23 volts to split water.

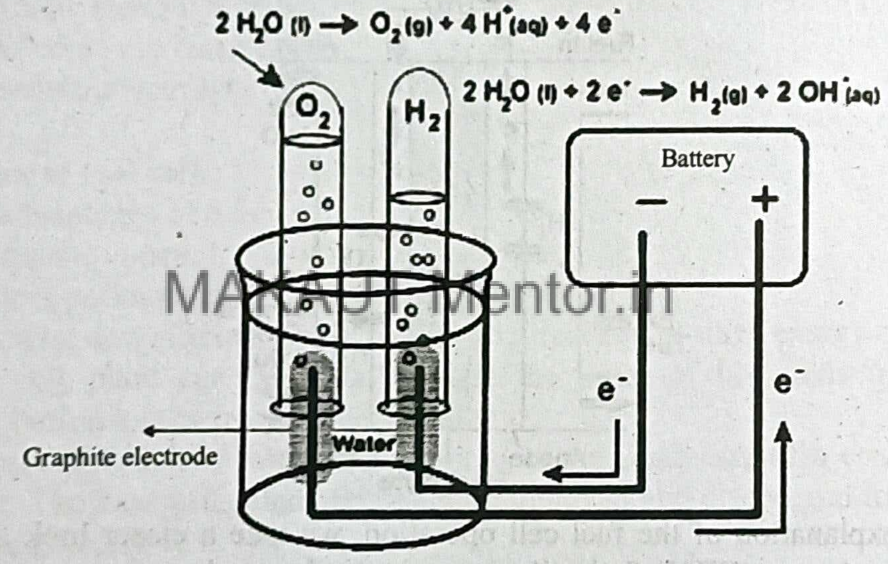


Fig: A schematic diagram represents the electrolytic production of hydrogen gas

Equations

In pure water at the negatively charged cathode, a reduction reaction takes place, with electrons (e^-) from the cathode being given to hydrogen cations to form hydrogen gas. The half reaction, balanced with acid, is:

Reduction at cathode: $2\,H^+(aq) + 2e^- \rightarrow H_2(g)$

At the positively charged anode, an oxidation reaction occurs, generating oxygen gas and giving electrons to the anode to complete the circuit:

Oxidation at anode: $2\,H_2O(l) \rightarrow O_2(g) + 4\,H^+(aq) + 4e^-$

The same half reactions can also be balanced with base as listed below. Not all half reactions must be balanced with acid or base. Many do, like the oxidation or reduction of water listed here. To add half reactions they must both be balanced with either acid or base. The acid-balanced reactions predominate in acidic (low pH) solutions, while the base-balanced reactions predominate in basic (high pH) solutions.

Cathode (reduction): $2\ H_2O(l) + 2e^- \rightarrow H_2(g) + 2\ OH^-(aq)$

Anode (oxidation): $2\ OH^-(aq) \rightarrow 1/2\ O_2(g) + H_2O(l) + 2\ e^-$

Combining either half reaction pair yields the same overall decomposition of water into oxygen and hydrogen:

Overall reaction: $2\ H_2O(l) \rightarrow 2\ H_2(g) + O_2(g)$

The number of hydrogen molecules produced is thus twice the number of oxygen molecules. Assuming equal temperature and pressure for both gases, the produced hydrogen gas has therefore twice the volume of the produced oxygen gas. The number of electrons pushed through the water is twice the number of generated hydrogen molecules and four times the number of generated oxygen molecules.

Long Answer Type Questions

1. i) What is fuel cell? **[WBUT 2009, 2012, 2014, 2016]**
ii) Discuss different types of fuel cell **[WBUT 2009, 2010, 2012, 2013, 2014, 2017]**
iii) What are the advantages of fuel cell energy?
[WBUT 2009, 2010, 2012, 2013, 2014, 2016, 2017]
iv) Discuss on alkaline fuel cell and hydrogen fuel cell. **[WBUT 2009, 2012, 2014]**

Answer:

i), ii) & iii):

Refer to Question No. 1 of Short Answer Type Questions.

iv)

Alkaline Fuel Cells (AFC)

Alkaline fuel cells (AFC) are one of the most developed technologies and have been used since the mid-1960s by NASA in the Apollo and Space Shuttle programs. The fuel cells on board these spacecraft provide electrical power for on-board systems, as well as drinking water. AFCs are among the most efficient in generating electricity at nearly 70%.

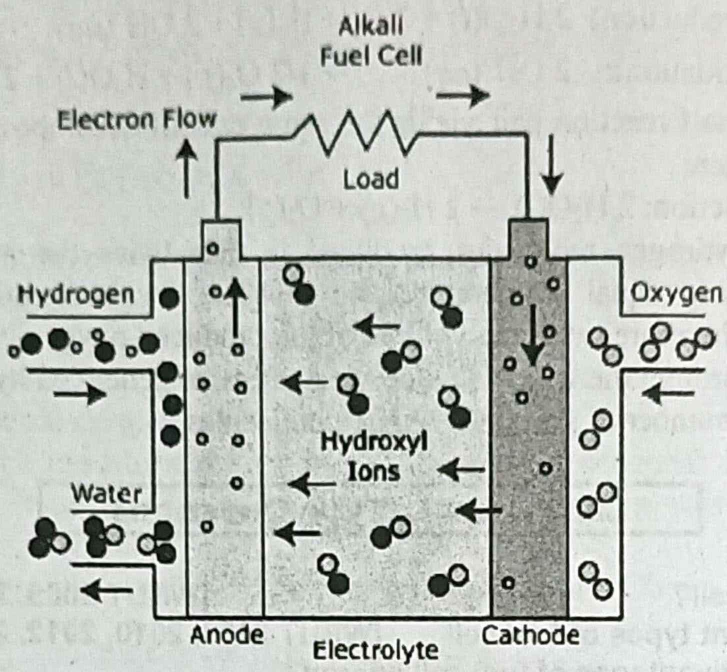


Fig: Alkaline fuel cell

Alkaline fuel cells use an electrolyte that is an aqueous (water-based) solution of potassium hydroxide (KOH) retained in a porous stabilized matrix. The concentration of KOH can be varied with the fuel cell operating temperature, which ranges from 65°C to 220°C. The charge carrier for an AFC is the hydroxyl ion (OH-) that migrates from the cathode to the anode where they react with hydrogen to produce water and electrons. Water formed at the anode migrates back to the cathode to regenerate hydroxyl ions. Therefore, the chemical reactions at the anode and cathode in an AFC are shown below. This set of reactions in the fuel cell produces electricity and by-product heat.

Anode Reaction : $2H_2 + 4OH^- \Rightarrow 4H_2O + 4e^-$

Cathode Reaction : $O_2 + 2H_2O + 4e^- \Rightarrow 4OH^-$

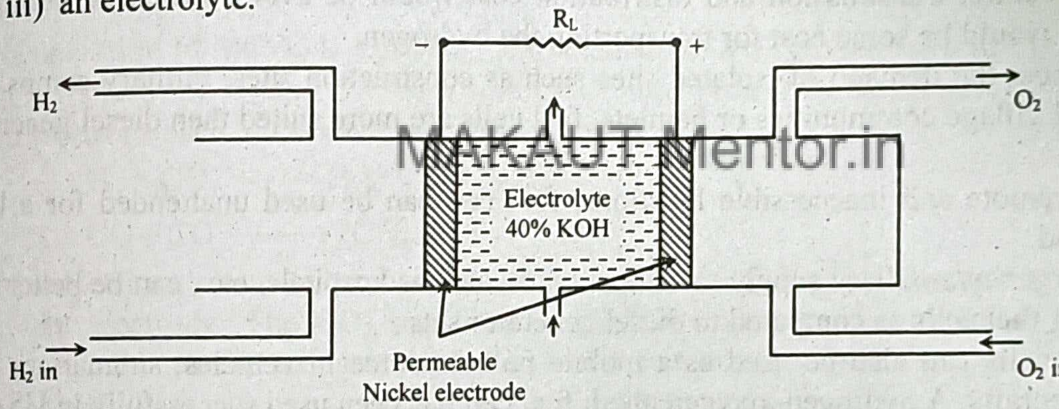
OverallNet Reaction : $2H_2 + O_2 \Rightarrow 2H_2O$

One characteristic of AFCs is that they are very sensitive to CO_2 that may be present in the fuel or air. The CO_2 reacts with the electrolyte, poisoning it rapidly, and severely degrading the fuel cell performance. Therefore, AFCs are limited to closed environments, such as space and undersea vehicles, and must be run on pure hydrogen and oxygen. Furthermore, molecules such as CO, H_2O and CH_4, which are harmless or even work as fuels to other fuel cells, are poisons to an AFC. On the positive side, AFCs are the cheapest fuel cells to manufacture. This is because the catalyst that is required on the electrodes can be any of a number of different materials that are relatively inexpensive compared to the catalysts required for other types of fuel cells.

AFCs are not being considered for automobile applications. Their sensitivity to poisoning, which requires use of pure or cleansed hydrogen and oxygen, is an insurmountable obstacle at the present time. Conversely, AFCs operate at relatively low temperatures and are among the most efficient fuel cells, characteristics that would enable a quick starting power source and high fuel efficiency, respectively.

The disadvantage of this fuel cell type is that it is easily poisoned by carbon dioxide (CO_2). In fact, even the small amount of CO_2 in the air can affect this cell's operation, making it necessary to purify both the hydrogen and oxygen used in the cell. This purification process is costly. Susceptibility to poisoning also affects the cell's lifetime (the amount of time before it must be replaced), further adding to cost.
Cost is less of a factor for remote locations, such as space or under the sea. However, to effectively compete in most mainstream commercial markets, these fuel cells will have to become more cost-effective. AFC stacks have been shown to maintain sufficiently stable operation for more than 8,000 operating hours. To be economically viable in large-scale utility applications, these fuel cells need to reach operating times exceeding 40,000 hours, something that has not yet been achieved due to material durability issues. This obstacle is possibly the most significant in commercializing this fuel cell technology.

5th Part:
Hydrogen fuel cells:
The main components of a fuel cells are:
i) a fuel electrode (anode).
ii) an oxidant or air electrode (cathode) and
iii) an electrolyte.



Hydrogen is the active material at the negative electrode and oxygen is active at the positive electrode. At the negative electrode, hydrogen gas (H_2) is converted into hydrogen ions (H^+) i.e. hydrogen with a positive electric change, plus an equivalent number of electrons (e^-). Thus,

$$H_2 \longrightarrow 2H^+ + 2e^-$$

hydrogen is diffused through the permeable nickel in which is embedded a catalyst. It enables the hydrogen molecules.
They interact with O_2 and water H_2O from the electrolyte to form negatively charged hydroxyl (OH^-) ions; thus,

$$\tfrac{1}{2}O_2 + H_2O + 2e^- \longrightarrow 2OH^-$$

$$H^+ + OH^- \longrightarrow H_2O$$

The electrolyte is typically 40% KOH solution because of its high electrical conductivity and it is less corrosive than acids.

2. a) What is a fuel cell? What are potential applications of a fuel cell?
b) Explain the principle and constructional details of a hydrogen fuel cell.
[WBUT 2011, 2015]

Answer:

a) 1st Part: ***Refer to Question No. 1(i) of Long Answer Type Questions.***

2nd Part:

Potential applications of fuel cells are listed below:

1. Fuel cells can be effectively used for load levelling. When the generation exceeds the demand, excess generated energy can be converted and stored as hydrogen by electrolysis of water. During peak load time, when the demand exceeds the generation, the stored hydrogen would be used in fuel cells to meet additional demand.
2. A central station power plant using fuel cell is also possible using gasified coal as fuel. The efficiency of such a plant would be higher due to direct energy conversion as compared to conventional thermal plants. Thus coal will be used more efficiently with reduced emissions.
3. Fuel cells are also suited for dispersed generation. By locating the fuel cells near the load centre, transmission and distribution cost would be avoided/reduced, although there would be some cost for transporting the hydrogen.
4. To meet the demand of isolated sites such as construction sites, military camps and small village communities or hamlets, fuel cells are more suited then diesel generator sets.
5. For remote and inaccessible locations, fuel cell can be used unattended for a long period.
6. Emergency/auxiliary supply to critical loads such as hospitals, etc., can be better met using fuel cells as compared to diesel generator sets.
7. Fuel cells can also be used as a mobile power source in vehicles, submarines and spacecrafts. A hydrogen–oxygen alkali fuel cell has been used successfully in USA to provide electric power in shuttle spacecrafts such as Apollo.
8. Fuel cells are also proposed as a power source for propulsion of electric vehicles.
9. Fuel cells can be used to power portable electronic devices (e.g., mobile phones and other low-power appliances, especially those used in military as substitute for primary or rechargeable batteries. Instead of waiting for several hours for recharging, a small cartridge of methanol can be replaced in the same way as an ink cartridge in a computer printer.

b) ***Refer to Question No. 1(iv) of Long Answer Type Questions.***

3. Describe in brief the operation of a Molten Carbonate Fuel Cell (MCFC).
[WBUT 2014]

OR,

Explain with a neat sketch the Molten Carbonate fuel cell. Also write down the chemical equation.
[WBUT 2019]

Answer:

In MCFC, carbonate of alkali metals (Na, K or Li) in molten (liquid) phase is used as electrolyte. This requires the cell operation at a temperature above melting points (i.e., about 600°C-700°C) of the respective carbonates. Because of high temperature of operation, a catalyst is not necessary. Porous nickel is used for electrodes and the electrolyte is held in sponge-like ceramic matrix.

A special feature of these cells is that during operation they oxidize hydrogen to water and carbon monoxide (present in fuel) to carbon dioxide. Hence gaseous mixtures of hydrogen and carbon monoxide (synthesis gas), which are relatively inexpensive to manufacture can also be used. This feature offers the prospects for use of a variety of fossil fuels including coal (gasified). These fuels are first converted (reformed) to get H_2 and CO and desulphurized to prevent poisoning of electrodes. The theoretical value of emf at no load is approximately 1 V at 700°C. However, actual voltage at load is somewhat lower (about 0.8V).

The discharges mainly consisting of steam, carbon dioxide and nitrogen from spent oxidant (air) are at a temperature exceeding 540°C. These hot gases could be used to provide industrial process heat or to generate additional power employing waste heat boilers (heat exchanger) and steam turbines. The overall efficiency of fuel would thus be increased substantially.

The operation of MCFC is explained with the help of a diagram shown in Fig. below. At the fuel electrode H_2 and CO react with CO_3^{--} ions present in the electrolyte and release two electrons each to the electrode as given below:

$$H_2 + CO_3^{--} \longrightarrow H_2O + CO_2 + 2e^-$$

$$CO + CO_3^{--} \longrightarrow 2CO_2 + 2e^-$$

These electrons circulate through external resistance, forming load current, and reach the oxidant electrode. The CO_2 produced at the fuel electrode is circulated through an external path to the oxidant electrode, where it combines with O_2 and the returning electron through the external path to produce CO_3^{--}:

$$O_2 + 2CO_2 + 4e^- \longrightarrow 2CO_3^{--}$$

The CO_3^{--} ions thus produced are responsible for transportation of charge from positive to negative electrode within the electrolyte. The overall reaction may be written as:

$$H_2 + CO + O_2 \longrightarrow H_2O + CO_2$$

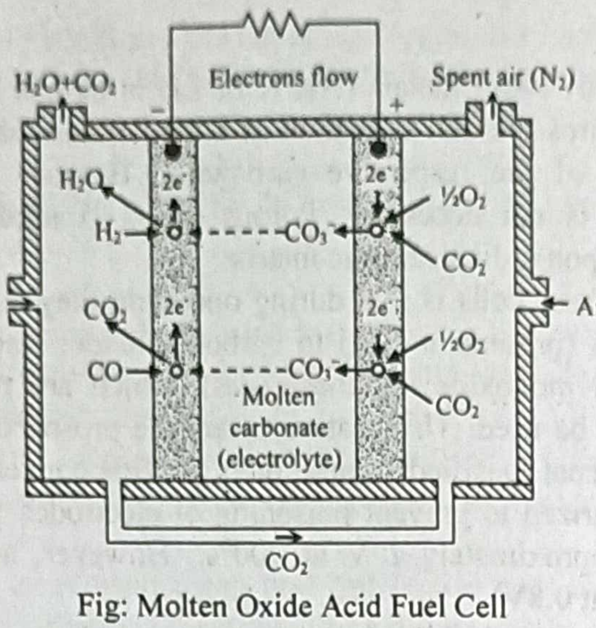


Fig: Molten Oxide Acid Fuel Cell

4. a) Explain the combustion reaction process.
b) Briefly discuss the differences in combustion and electrochemical reaction in a fuel cell.
c) List five types of fuel cells.
d) Describe a hydrogen-oxygen fuel cell with a sketch showing reaction.
[WBUT 2016]

Answer:

a) **Combustion (oxidation) zone:** In this zone, carbon from the fuel combust and forms carbon dioxide with the oxygen in the air by the reaction:

$$C + O_2 \rightarrow CO_2 + \text{Heat}$$

Because of the heat emitted during the reaction, the temperature rises unit a balance between heat supply and heat loss occurs.

b)

Combustion	Electrochemical reaction in a fuel cell
Mixing of fuel and oxidant takes place	No mixing of fuel and oxidant is allowed
Oxidation and reduction taking place simultaneously	Oxidation and reduction reaction taking place independently at anode and cathode electrodes
Heat is generated	Electricity is directly generated
No electrolyte is required	Electrolyte is required so that ions can flow from cathode to anode internally to complete the circuit for current to flow
Output is heat which is low grade energy. A turbine and a generator are required to obtain high-grade mechanical or electric energy	Output is electrical energy, which is a high-grade energy
Efficiency is limited to Carnot cycle efficiency, which is less	Efficiency is high
Combustion creates pollution	It is pollution-free conversion reaction
Cannot be controlled	Can be controlled by regulating fuel and oxidant supply

c) ***Refer to Question No. 1(ii) of Long Answer Type Questions.***

d) Fuel cells convert the chemical energy of fuel directly into electrical energy by an electrochemical process. Low voltage dc power is produced by using hydrogen or natural gas as fuel. The schematic diagram of a $H_2 - O_2$ fuel cell is shown in Fig.1.

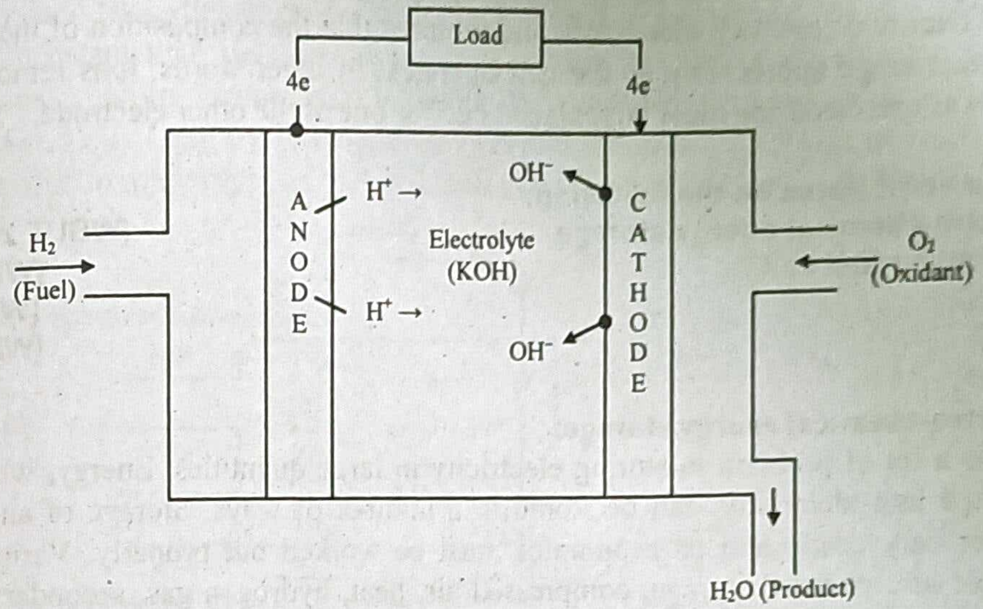


Fig: 1 Hydrogen-Oxygen Fuel Cell

The working of a fuel cell may be explained with reference to the hydrogen-oxygen fuel cell using aqueous electrolyte. It consists of two porous metal electrodes with the electrolyte between their inner faces kept stirred by recirculation. The porous electrodes as shown in Fig.1. The pressure differential between the gases and the electrolyte is sufficient to displace the liquid from the coarse pores, but not from the fine pores. In order to obtain a large area of electrode-electrolyte interface (at which electron transfer take place), the gases must either diffuse through a layer of electrolyte on the surface of the electrodes, or migrate along the surface beneath the electrolyte. Similarly the ions must diffuse through the electrolyte trapped in the fine pore layer, which is not stirred by recirculation.

The chemical reactions taking place at the two electrodes are as follows:

(i) Hydrogen electrode (anode)

$$2H_2 = 4H^+ + 4e$$

$$4H^+ + 4OH^- = 4\,H_2O + 4e$$

(ii) Oxygen electrode (cathode)

$$O_2 = 2O^-$$

$$2O^- + 2H_2O + 4e = 4OH^-$$

(iii) Ocerall cell reaction

$$2H_2 + O_2 = 2H_2O$$

The H_2 molecules break up into H^+ ions at the anode. These H^+ ions combine with OH^- ions to form water and release electrons at the anode. The electrons travel to the cathode through external circuit. At the cathode the two oxygen atoms combine with the four electrons arriving by the external circuit and two molecules of water (out of the four molecules produced at the anode) to form 4 OH^- ions. These OH^- ions migrate towards the anode and are consumed there: The electrolyte remains invariant. This invariance is a critical feature of fuel cell electrolyte and requires that the composition of the electrolyte must not change appreciably as the cell operates. In other words, ions removed by the reaction at one electrode must be replaced one for one at the other electrode.

5. Write short notes on the following:
a) Electro-chemical energy storage **[WBUT 2008, 2013]**
b) Hydrogen fuel cell **[WBUT 2010]**
c) SOFC **[WBUT 2019]**
d) AFC **[WBUT 2019]**

Answer:

a) Electro-chemical energy storage:

There is a lot of problem in storing electricity in large quantities. Energy, which can be converted into electricity, can be stored in a number of ways. Storage of any nature is however very costly and its economics must be worked out properly. Various options available are: pumped storage, compressed air, heat, hydrogen gas, secondary batteries, flywheels and super-conducting coils.

As already mentioned, gas turbines are normally used for meeting peak loads but are very expensive. A significant amount of storage capable of instantaneous use would be better way of meeting such peak loads and so far the most important way is to have a pumped storage plant as discussed earlier. Other methods are discussed below very briefly.

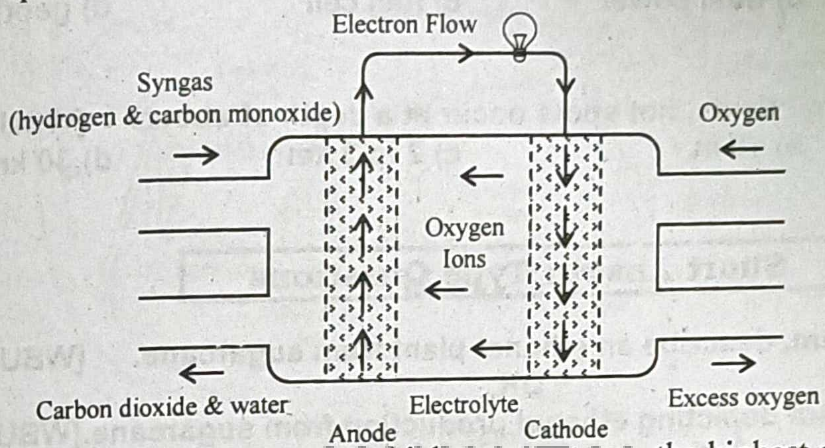
Secondary Batteries: Large-scale battery use is almost ruled out and they will be used for battery powered vehicles and local fluctuating energy sources such as wind mills or solar. The most widely used storage battery is the lead acid battery, invented by Plante in 1860. Sodium-sulphur battery (200 Wh/kg) and other combinations of materials are also being developed to get more output and storage per unit weight.

Fuel Cells: A fuel cell converts chemical energy of a fuel into electricity directly, with no intermediate combustion cycle. In the fuel cell, hydrogen is supplied to the negative electrode and oxygen (or air) to the positive. Hydrogen and oxygen are combined to give water and electricity. The porous electrodes allow hydrogen ions to pass. The main reason why fuel cells are not in wide use is their cost (> $ 2000/kW). Global electricity generating capacity from full cells will grow from just 75 MW in 2001 to 15000 MW by 2010. US, Germany and Japan may take lead for this.

Hydrogen Energy Systems: Hydrogen can be used as a medium for energy transmission and storage. Electrolysis is a well-established commercial process yielding pure hydrogen. H_2 can be converted very efficiently back to electricity by means of fuel cells. Also the use of hydrogen as fuel for aircraft and automobiles could encourage its large-scale production, storage and distribution.

b) Hydrogen fuel cell:
Refer to Question No. 1(iv) of Long Answer Type Questions.

c) SOFC: A solid oxide fuel cell (or SOFC) is an electrochemical conversion device that produces electricity directly from oxidizing a fuel. Fuel cells are characterized by their electrolyte material; the SOFC has a solid oxide or ceramic electrolyte such as zirconium oxide stabilised with yttrium oxide, instead of a liquid or membrane. Their high operating temperature means that fuels can be reformed within the fuel cell itself, eliminating the need for external reforming and allowing the units to be used with a variety of hydrocarbon fuels. They are also relatively resistant to small quantities of sulphur in the fuel, compared to other types of fuel cell, and can hence be used with coal gas.



Solid oxide fuel cells work at very high temperatures, the highest of all the fuel cell types at around 800°C to 1,000°C. They can have efficiencies of over 60% when converting fuel to electricity; if the heat they produced is also harnessed; their overall efficiency in converting fuel to energy can be over 80%.

Advantages & Disadvantages:

Advantages of this class of fuel cells include high combined heat and power efficiency, long-term stability, fuel flexibility, low emissions, and relatively low cost. The largest disadvantage is the high operating temperature which results in longer start-up times and mechanical and chemical compatibility issues.

d) AFC: ***Refer to Question No. 1(4th Part) of Long Answer Type Questions.***

MISCELLANEOUS

Multiple Choice Type Questions

1. Capacity of a micro hydel power plant is [WBUT 2012, 2015]
   a) up to 100 kW b) 101 to 1000 kW
   c) 1 to 25 MW d) 100 MW

Answer: (a)

2. Which of the following is not a renewable energy source? [WBUT 2016]
   a) hydropower b) tidal power c) fuel cell d) geothermal

Answer: (a)

3. In most hydrothermal fields, hot spots occur at a depth of about [WBUT 2018]
   a) 10 km b) 10 m c) 2 to 3 km d) 30 km

Answer: (a)

Short Answer Type Questions

1. With a block diagram, describe an ethanol plant from sugarcane. [WBUT 2008]

OR,

Draw the block diagram depicting ethanol production from sugarcane. [WBUT 2012]

Answer:

In an autonomous distillery, all the sugarcane processed is used to provide sugars for fermentation, from which ethanol is produced.

The main steps required for the ethanol production process from sugarcane in an autonomous distillery are illustrated in Fig: 1.

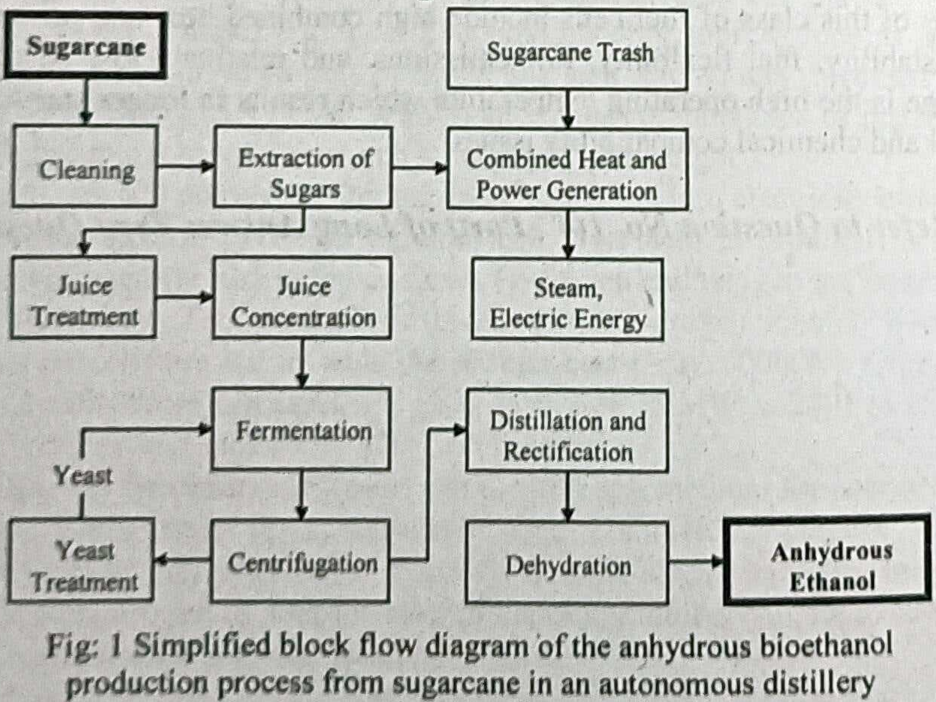


Fig: 1 Simplified block flow diagram of the anhydrous bioethanol production process from sugarcane in an autonomous distillery

2. Explain in brief the auxiliaries of a micro-hydropower plant.

[WBUT 2010, 2014, 2017]

Answer:

Auxiliaries of a micro-hydropower plant

The layout of a typical micro-hydro scheme is shown in Fig.(1) The main components of the scheme are (i) diversion weir, (ii) water-conductor system with regulating gates and spillways, (iii) desalting tank with spillway, (iv) headrace channel, (v) fore bay tank with desalting basin and spillway, (vi) penstock, (vii) powerhouse, and (viii) tailrace channel.

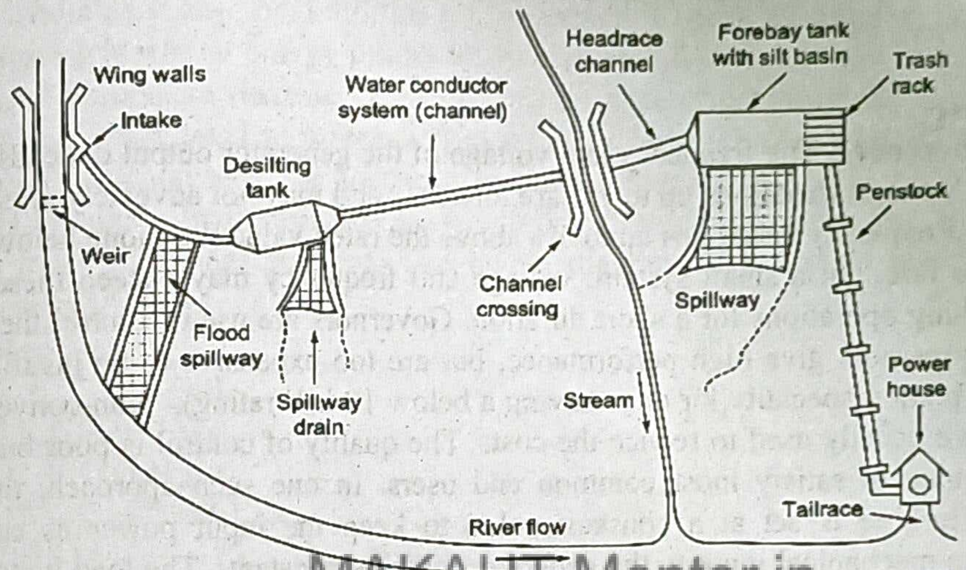


Fig: 1 Binary fluid hydrothermal system

1. Diversion Weir and Channel

A diversion weir is designed to divert and maintain constant flow in the channel for variable flow in the river through the year. If the channel overfills, damage will result. Special attention is required to save the channel during seasonal flooding. The intake structure regulates the flow. Further control or regulation is provided by spillways. The water-conductor system is a channel between weir and desilting tank and between the desilting tank to fore bay. It should be designed to ensure least loss of head due to seepage, and the flow velocity should be adequate to prevent settling of silt. The most commonly used channel section is trapezoidal. The channel follows the contour of the hillside so as to preserve the elevation of the diverted water.

2. Desilting Tank

A desilting tank is usually provided in the initial reaches of water to trap the suspended silt load and pebbles, so as to minimize erosion damages to the turbine runner. Abrasive effects become more pronounced with increasing head. The size of the silt particles to be trapped for medium head turbines is 0.2 to 0.5 mm and that for high heads to 01 to 0.2 mm. The depth of a silt tank may be 1.5 to 4 m, and the horizontal flow velocity should not exceed 0.4 to 0.6 m/s. The deposits of silt tank are periodically flushed out to make room for further deposition.

3. Forebay, Penstock and Tailrace
A forebay is a temporary storage of water (pondage), to be finally utilized for energy generation. The storage size ranges from 2 minutes to 6 hours depending on the economic justifiability. Trash racks are also provided to prevent entry of trash, debris and ice. The flow velocity through a trash rack is kept at (1.6 to 0.9 m/s, so that there is no significant head loss. A penstock is a water conduit joining a forebay and turbine. A hell-mouth entry is provided to reduce the head loss and to ensure smooth entry of water. A tailrace is a simple water channel to transport discharge from the turbine back to the river with maximum flow of 1 m/s.

4. Powerhouse
(a) Speed Governor: The frequency and voltage of the generator output depends on the shaft speed. Voltage variations up to 7% are tolerable and may not adversely affect most of the loads. Frequency variations up to 5% above the rated value (but none below it) are considered as fare. In a small system, voltage and frequency may exceed these limits during switching operations for a short duration. Governors are use to control the speed. Traditional governors give high performance, but are too expensive to be justified in a micro-hydro plant (especially for ones having a below 10 kW rating). Non-conventional approaches are usually used to reduce the cost. The quality of control is poor but it can still be adequate to satisfy most common end users. In one such approach, the flow through the turbine is set at a constant value to keep the input power as constant. Therefore, the mechanical input to the generator remains constant. The load imposed on the generator is also kept fairly constant. This requires a ballast (stabilizing) load across the generator to be increased or decreased accordingly as the user load varies. The generated energy that is not used productively is wasted in the ballast load also known as dump load). An electronic load controller (ELC) is employed to perform this function. Thus, the electronic load controller ensures that the generator always supplies a constant electrical load. In this way, both the mechanical input and electrical output remains constant and therefore, the speed remains constant. In this approach, the part of the generated energy that is consumed in the ballast load is wasted. For run-of-the-river schemes, this is irrelevant as there is no provision for storage of unused water for later productive use.

(b) Turbine: A suitable turbine is used to get mechanical power at the shaft from flowing stream of water.

(c) Generator: A generator coupled with turbines gives electrical output from mechanical input.

Long Answer Type Questions

1. a) Explain and deduce the effect of combination of a pumped storage facility with a total barrage scheme. What assumption is to be made to again maximum benefit from the pump storage addition? **[WBUT 2010]**

Answer:

1st Part:

Pumped storage is the most successful, economical and widely used storage technology presently available to electrical utilities for load leveling (peak shaving). It could also be used for storing electrical energy produced from solar and wind energy. Electrical power in excess of immediate demand is used to pump water from a supply (lake, river or reservoir) at a lower level to a reservoir at a higher level. During peak demand period when the demand exceeds the normal generating capacity, water is allowed to flow backwards through a hydraulic turbine, which drives an electric generator and produces power to meet additional demand. The layout diagram of a typical pumped storage system is shown below.

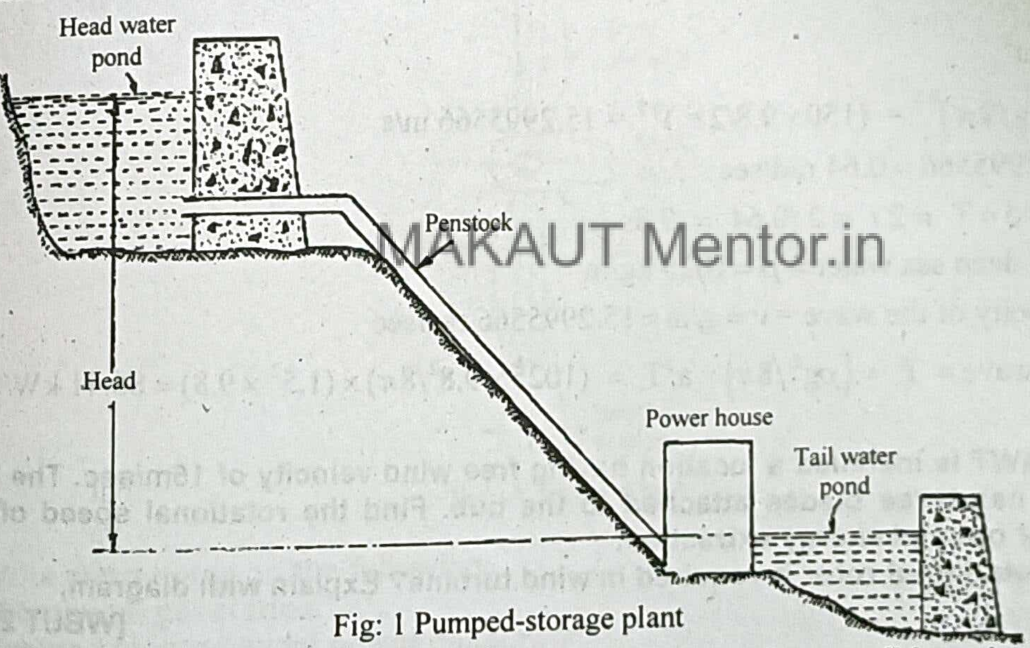


Fig: 1 Pumped-storage plant

In most pumped storage plants, the turbine generator system is reversible and can serve to pump water as well. In the pumping mode, the generator works as motor and draws electrical power from the electrical network. The turbine then operates as a pump driven by the motor. Start up of the turbine-generator or reversal from motor-pump to turbine-generator requires only a few minutes. The overall energy recovery efficiency of pumped storage, that is the recovered electrical energy as an electrical energy used to pump water, is about 70 percent.

There are relatively few suitable sites where there is water supply at a lower level and a reservoir can be constructed at a higher level. However, the use of natural or excavated underground caverns as lower reservoirs, no being developed, should greatly increase the number of possible sites.

2nd Part:
A pumped storage scheme utilizes the surplus energy available from base load stations (thermal & nuclear plants) during off-peak hours for pumping the water from a lower reservoir to the upper reservoir and the same is released during peak hours for generation by running the units in generating mode. The capacity of upper/lower reservoirs, availability of surplus off-peak energy, intended operating pattern of the pumped storage scheme determines its installed capacity. The procedure for optimization of the installed capacity and deciding the number of units is same as applied for run-of-river schemes/ storage based schemes.

b) What is the extractable power from a deep-sea wave of wavelength 150m and height 1.5m if $g = 9.8 m/s^2$? [WBUT 2010]

Answer:
Height = amplitude a = 1.5 m
Wavelength = λ = 150 m
$g = 9.8 m/s^2$
$\lambda = 2\pi g/\omega^2$
$g/\omega = (\lambda g/2\pi)^{0.5} = (150 \times 9.8/2\pi)^{0.5} = 15.2995566$ m/s
$\omega = g/15.2995566 = 0.64$ rad/sec
Time period = T = 2 / = 2 /0.64 = 9.8s

Density of deep sea water = ρ = 1025 kg/m^2
phase velocity of the wave = $v = g/\omega = 15.2995566$ rad/sec
Power in wave = $P = (\rho g^2/8\pi) \times a^2 T = (1025 \times 9.8^2/8\pi) \times (1.5^2 \times 9.8) = 86.41$ kW/m

2. a) A HAWT is installed a location having free wind velocity of 15m/sec. The 80m dia rotor has three blades attached to the hub. Find the rotational speed of the turbine for optimal energy extraction.
b) Why teetering of rotor is required in wind turbine? Explain with diagram. [WBUT 2018]

Answer:
a) Rotor diameter = 80 m, R = 40 m
$u_0 = 15 m/s, n = 3$
Tip-speed ratio for optimum output,

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

From Eq. 7.21, tip-speed ratio is given by $\lambda_0 = \frac{R\omega}{u_0}$

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

$$\omega = 1.57$$

If N is rotor speed in rpm, $\omega = 2\pi N/60$

N = 15 rpm

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

b) As wind speed rises with height, the axial force on blade when it attains the upper position is significantly higher as compared to that when it is at a lower position. For one- and two-blade rotors, this causes cyclic (sinusoidal) load on a rigid hub leading to fatigue. This is greatly relieved by providing a teeter hinge (a pivot within the hub) that allows a sew-saw motion to take place out of the plane of rotation (i.e., vertical plane). The rotor leans backwords to accommodate the extra force as shown in figure. This also reduces blade loads near the root by approximately 40%. The use of a third blade has approximately the same effect as a teeter hinge on the hub moments since the polar symmetry of the rotor averages out the applied sinusoidal loads. Therefore, teetering is not required when the number of blades is three or more.

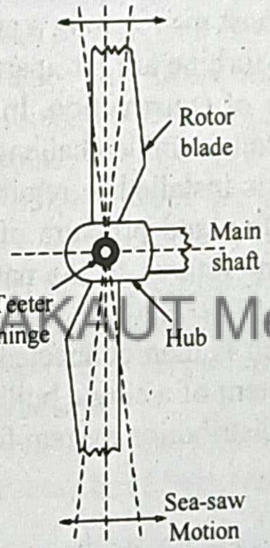


Fig: A teetered hub

3. Write short notes on the following: **[WBUT 2009, 2012]**
a) Microhydel generation **[WBUT 2017]**
b) Pumped storage hydel power generation

Answer:

a) Microhydel generation:

Micro hydro is a term used for hydroelectric power installations that typically produce up to 100 kW of power. These installations can provide power to an isolated home or small community, or are sometimes connected to electric power networks. There are many of these installations around the world, particularly in developing nations as they can provide an economical source of energy without purchase of fuel.

Micro hydro systems complement photovoltaic solar energy systems because in many areas, water flow, and thus available hydro power, is highest in the winter when solar energy is at a minimum.

Micro hydro is frequently accomplished with a Pelton wheel for high head, low flow water supply. The installation is often just a small dammed pool, at the top of a waterfall, with several hundred feet of pipe leading to a small generator housing.

Construction and characteristics

Construction details of a microhydro plant are site-specific, but the common elements of all hydroelectric plants are present. A supply of water is needed – this can be a mountain stream, or a river. Usually microhydro installations do not have a dam and reservoir, relying on a minimal flow of water to be available year-round. Sometimes an existing mill-pond or other artificial reservoir is available and can be adapted for power production. An intake structure is required to screen out floating debris and fish, using a screen or array of bars to keep out large objects. In temperate climates this structure must resist ice as well. The intake may have a gate to allow the system to be dewatered for inspection and maintenance.

Water withdrawn from the source must move along a power canal or a pipe (penstock) to the turbine. If the water source and turbine are far apart, the construction of the penstock may be the largest part of the costs of construction. In mountainous areas, access to the route of the penstock may provide considerable challenges.

At the turbine, a controlling valve is installed to regulate the flow and the speed of the turbine. The turbine converts the flow and pressure of the water to mechanical energy; the water emerging from the turbine returns to the natural watercourse along a tailrace channel.

The turbine turns a generator, which is then connected to electrical loads; this might be directly connected to the power system of a single building in very small installations, or may be connected to a community distribution system for several homes or buildings.

Regulation and operation

Typically, an automatic controller operates the turbine inlet valve to maintain constant speed (and frequency) when the load changes on the generator. In a system connected to a grid with multiple sources, the turbine control ensures that power always flows out from the generator to the system. The frequency of the alternating current generated needs to match the local standard utility frequency. In some systems, if the useful load on the generator is not high enough, a load bank may be automatically connected to the generator to dissipate energy not required by the load; while this wastes energy, it may be required if its not possible to stop the water flow through the turbine.

An induction generator always operates at the grid frequency irrespective of its rotation speed; all that is necessary is to ensure that it is driven by the turbine faster than the synchronous speed so that it generates power rather than consuming it. Other types of generator require a speed control systems for frequency matching.

With the availability of modern power electronics it is often easier to operate the generator at an arbitrary frequency and feed its output through an inverter, which produces output at grid frequency. Power electronics now allow the use of permanent magnet alternators that produce wild AC to be stabilised. This approach allows low speed low head water turbines to be competitive; they can run at the best speed for extraction of energy and the power frequency is controlled by the electronics instead of the generator. Very small installations, a few kilowatts or smaller, may generate direct current and charge batteries for peak use times.

Turbine types

Several different types of water turbines can be used in micro hydro installations, selection depending on the head of water, the volume of flow, and such factors as availability of local maintenance and transport of equipment to the site. For mountainous regions where a waterfall of 50 meters or more may be available, a Pelton wheel can be used. For low head installations, Francis or propeller-type turbines are used. Very low head installations of only a few meters may use propeller-type turbines in a pit. The very smallest micro hydro installations may successfully use industrial centrifugal pumps, run in reverse as prime movers; while the efficiency may not be as high as a purpose-built runner, the relatively low cost makes the projects economically feasible.

In low-head installations, maintenance and mechanism costs often become important. A low-head system moves larger amounts of water, and is more likely to encounter surface debris. For this reason a Banki turbine, a pressurized self-cleaning crossflow waterwheel, is often preferred for low-head microhydropower systems. Though less efficient, its simpler structure is less expensive than other low-head turbines of the same capacity. Since the water flows in, then out of it, it cleans itself and is less prone to jam with debris. Two low-head schemes in England, Settle Hydro and Torrs Hydro use a reverse Archimedes' screw, which is another debris-tolerant design. Other options include Gorlov, Francis and propeller turbines.

Another alternative is a large diameter, slow turning, permanent magnet, sloped open flow Kaplan turbine. A number of these have been installed at Trousy VLH, France.

Advantages of Microhydel generation

1. Microhydel plants can be tailored to the needs of the end use market within the limits of water resources available.
2. It serves to enhance economic development and living standards, especially in remote areas with limited or no electricity at all.
3. For microhydel plants, the civil engineering work does not need elaborate construction plans. No expensive powerhouses or highly optimized electromechanical equipments are required.
4. It has a short gestation period.
5. Microhydel plant requires few operating personnel, with some of the machinery capable of being operated entirely by remote control.
6. There is no need of long transmission lines because the output is consumed near the source.
7. High performing electrical equipment (alternators, control circuits, battery storage, regulators etc.) can be easily found in the market.

Disadvantages:

(i) The majority of microhydel plants are located in remote places and are not connected with the grid. Therefore, transmission of surplus power to other places is not possible. Therefore, during low-demand periods, they continue to operate at a low load factor that leads to the loss power generation which in turn results in poor revenue collection.

(ii) In the absence of adequate hydrological and geological data, there are always uncertainties about their potential as resource. Also, once commissioned, there is no surety of selling the electricity at a rate that is comparable to the outcome of the investment. Due to these reasons private developers avoid to have a stake in small hydro projects.

(iii) The rotation of turbines can kill fishes, especially young fishes, swimming downstream.

(iv) Spilling of water over spillways can result in super saturation of water with gases from the air. The gas bubbles, absorbed into fish tissue, may cause damage and ultimately kill the fish.

(v) Most hydroelectric facilities require construction of dams. Dams present a migratory barrier that can effect the free movement of fish species and their reproduction cycle. However, the effects upon stream ecology are minor compared to those caused by large hydroelectric facilities.

b) Pumped storage hydel power generation:

Refer to Question No. 1(a) of Long Answer Type Questions.

QUESTION 2015

Group – A
(Multiple Choice Type Questions)

1. Answer any ten questions:

i) Global warming is mainly caused due to
a) emission of heat from engine
✓b) emission of CO_2 due to burning of fossil fuels
c) use of nuclear energy
d) air pollution

ii) A typical open circuit voltage of a solar cell is
✓a) 0.45 V DC
b) 3 V DC
c) 1.5 V DC
d) 0.05 V DC

iii) Bio gas consists of
a) only methane
b) methane and carbon dioxide
c) only ethane
✓d) all of these

iv) The range of wind speed suitable for power generation is
a) 0 to 6 m/sec
✓b) 5 m/sec to 25 m/sec
c) 25 m/sec to 50m/sec
d) 50 m/sec to 70m/sec

v) Maximum theoretical efficiency of a wind turbine is
✓a) 80%
b) 68%
c) 59%
d) none of these

vi) Temperature of inner core of earth is
a) 1000°C
✓b) 4000°C
c) 40000°C
d) none of these

vii) Capacity of a micro hydel power plant is
✓a) up to 100 kW
b) 101 to 1000 kW
c) 1 to 25 mW
d) none of these

viii) Which material has the highest solar cell efficiency?
✓a) Amorphous Silicon
b) Poly Crystalline Silicon
c) Thin Filmed Silicon
d) Single Crystalline Silicon

ix) Most commonly used wind turbine is
a) simple impulse type
✓b) propeller type
c) reaction type
d) reversible type

x) A solar thermal water pump
a) use solar thermal energy to evaporate water
b) uses solar thermal energy to circulate hot water
✓c) uses electric powered pump to circulate water heated by solar energy
d) uses solar thermal energy for production of power to drive the pump

xi) The energy radiated by sun on a bright sunny day is about
a) 200 W/m^2
b) 500 W/m^2
✓c) 1 kW/m^2
d) 2.5 kW/m^2

Group – B
(Short Answer Type Questions)

2. Discuss different renewable sources of energy with reference to Indian context.
See Topic: INTRODUCTION TO ENERGY SOURCES, Short Answer Type Question No. 1.

3. Discuss different systems used for generating power using Geothermal energy, in brief.
See Topic: GEOTHERMAL ENERGY, Short Answer Type Question No. 2.

4. Explain the principle of production of Biogas.
See Topic: BIO ENERGY, Short Answer Type Question No. 4.

5. A tidal power plant of single basin type has a basin area of 15×10^6 m^2. The tide has a range of 12 m. The turbine however, stops operating when the head on it falls below 2m. Calculate the energy generated in one filling process in kWh if the turbine generator efficiency is 80% (Density of sea water = 1025 k/m^2).
See Topic: ENERGY FROM OCEAN, Short Answer Type Question No. 5.

6. Derive the equations for the voltage and power output of the MHD generator.
See Topic: MAGNETO HYDRODYNAMIC ENERGY CONVERSION, Long Answer type Question No. 1.

Group – C
(Long Answer Type Questions)

7. a) With the help of basic block diagram, explain the working of a solar photo voltaic power plant.
b) Define
   (i) solar constant
   (ii) earth sun angles

c) Derive the expression of maximum current from solar cell.
See Topic: SOLAR ENERGY, Long Answer Type Question No. 6.

8. a) Using Betz model of wind turbine, derive the expression for power extracted from wind. What is Betz criterion?
b) A propeller type wind turbine has the following data:
Speed of free wind at a height of 10m is 12m/s, air density is 1.226 kg/m^3, $\alpha = 0.14$, height of tower is 100m, diameter of rotor is 80m, wind velocity at the turbine reduces by 20%, generator efficiency is 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.
See Topic: WIND ENERGY, Long Answer Type Question No. 7.

9. a) What is the basic principle of MHD power generation?
b) Describe the open cycle system of MHD power generation.
c) Calculate the open circuit voltage with following specifications
   Plate area = 0.2 m^2
   Distance between plates = 0.4m

Flux density = 2 wb/m^2
Average gas velocity = 1000 m/s
Conductivity of the gas = 10 mho/m.

See Topic: MAGNETOHYDRODYNAMIC ENERGY CONVERSION, Long Answer Type Question No. 3.

10. a) What is a fuel cell?
b) What are the potential applications of a fuel cell?
c) Explain the working principle and constructional details of a hydrogen fuel cell.

See Topic: FUEL CELLS, Long Answer Type Question No. 2.

11. Write short notes on any *three* of the following:
a) Hydrogen energy
b) Kyoto protocol
c) Solar pond
d) Wave energy.

a) See Topic: HYDROGEN ENERGY, Long Answer Type Question No. 1.
b) See Topic: INTRODUCTION TO ENERGY SOURCES, Long Answer Type Question No. 3(c).
c) See Topic: SOLAR ENERGY, Long Answer Type Question No. 12(b).
d) See Topic: ENERGY FROM OCEAN, Long Answer Type Question No. 1(a).

QUESTION 2016

Group – A

(Multiple Choice Type Questions)

1. Choose the correct alternatives for any *ten* of the following:

i) Power available in wind is proportional to
a) wind speed
b) square of the wind speed
✓c) cube of the wind speed
d) fourth power of the wind speed

ii) The output f a solar cell is of the order of
✓a) 0.5 W
b) 1.0 W
c) 5.0 W
d) 10.0

iii) Most of potential exploitable geothermal heat is store in
a) water
✓b) dry rock
c) air
d) steam aquifiers

iv) For a polar PV cell dark current is because of
a) minority carriers
b) majority carriers
✓c) both (a) and (b)
d) none of these

v) Harmful nuclear radiation includes
a) alpha particles
b) beta particles
c) gamma particles
✓d) all of these

vi) Fill factor indicates the
a) solar radiation
b) energy of solar cell
✓c) quality of solar cell
d) none of these

vii) Which of the following is not a renewable energy source?
✓a) hydropower b) tidal power c) fuel cell d) geothermal

viii) The Greenhouse gas is
✓a) carbon dioxide b) methane c) nitrous oxide d) all of these

ix) MHD utilizes
✓a) direct conversion of heat to electricity
b) conversion of heat to stream
c) conversion of heat to force
d) none of these

x) Photo-voltaic cell is basically a/an
✓a) *p-n* junction
b) photo transistor
c) amorphous *p-n* junction
d) none of these

xi) Horizontal axis windmills of modern design can
✓a) always turn towards the direction of the wind
b) never adjust the energy output
c) never turn toward the direction of the wind
d) none of these

xii) The turbine normally employed in tidal power is
a) simple impulse type
✓b) propeller type
c) reaction type
d) reversible type

Group – B
(Short Answer Type Questions)

2. Explain the type of generators used with the wind turbines for producing electricity.
See Topic: WIND ENERGY, Short Answer Type Question No. 3.

3. a) What is tidal power generation system?
b) Discuss the advantage and limitation of tidal power generation.
See Topic: ENERGY FROM OCEAN, Short Answer Type Question No. 3(a) & (b).

4. a) What are the different types of fuel cell?
b) State the advantages and limitations of fuel cell.
See Topic: FUEL CELLS, Short Answer Type Question No. 1(a) & (b).

5. Discuss solar water heating system with antifreeze with a neat sketch.
See Topic: SOLAR ENERGY, Short Answer Type Question No. 6.

6. a) What is geothermal energy?
b) By what method is this energy extracted?
See Topic: GEOTHERMAL ENERGY, Short Answer Type Question No. 1(a) & (b).

Group – C
(Long Answer Type Questions)

7. a) What is *PV* cell? What is 'fill factor' of a PV cell?
b) Draw the equivalent circuit of a practical solar cell and describe its *I-V* characteristics. Also give a brief idea about the effect of variation of insolation and temperature.
c) Describe a single crystalline solar cell with constructional details.

a) See Topic: SOLAR ENERGY, Short Answer Type Question No. 7.
b) See Topic: SOLAR ENERGY, Long Answer Type Question No. 1(a).
c) See Topic: SOLAR ENERGY, Short Answer Type Question No. 1(a).

8. a) Explain single basin, single effect tidal energy conversion scheme.
b) A single basin type tidal power plant has a basin area of 2 km^2. The tide has an average of 13 m. Power is generated only during the ebb cycle. The turbine stops operating when the head on it falls below 3 cm. Calculate the average power generated by the plant in single emptying process of the basin if the turbine generator efficiency is 0.7.
c) Discuss the advantage and limitation of tidal power generation.
a) & b) See Topic: GEOTHERMAL ENERGY, Long Answer Type Question No. 3(b) (i) & (ii).
c) See Topic: ENERGY FROM OCEAN, Short Answer Type Question No. 3(b).

9. a) Describe the basic principle of operation of an MHD generator. Derive expression of maximum power generation per unit volume of generator.
b) With the help of schematic diagram explain the operation of closed cycle MHD generating system.
See Topic: MAGNETOHYDRODYNAMIC ENERGY CONVERSION, Long Answer Type Question No. 4.

10. a) Explain the combustion reaction process.
b) Briefly discuss the differences in combustion and electrochemical reaction in a fuel cell.
c) List five types of fuel cells.
d) Describe a hydrogen-oxygen fuel cell with a sketch showing reaction.
See Topic: FUEL CELLS, Long Answer Type Question No. 4.

11. a) What are the different types of geothermal resources?
b) What are the major applications of geothermal energy?
c) What principles guide in the location of a geothermal power station?
d) What is the prospect of geothermal energy?
See Topic: GEOTHERMAL ENERGY, Long Answer Type Question No. 2.

QUESTION 2017

Group – A
(Multiple Choice Type Questions)

1. Choose the correct alternatives for any *ten* of the following:

i) At maximum power point of the solar cell
a) product of voltage and current is maximum
✓b) both voltage and current are maximum
c) current is maximum
d) voltage is maximum

ii) Tidal power plants are generally built on
✓a) seashore b) plateau c) creeks d) mountain range

iii) The downstream channel of outgoing water from a hydropower plant is called
a) head race b) tail race c) open channel ✓d) tail channel

iv) Which material has the highest solar cell efficiency?
✓a) Amorphous silicon
b) Thin-filmed silicon
c) Poly crystalline silicon
d) Single crystalline silicon

v) Dolphin mechanism is a method of extracting
a) Solar energy
b) Wind energy
c) Ocean wave energy
✓d) Geothermal energy

vi) The greenhouse gas is
✓a) carbon dioxide
b) methane
c) nitrous oxide
d) all of these

vii) Temperature of inner core of earth is
a) 1000 degree Celsius
✓b) 4000 degree Celsius
c) 40000 degree Celsius
d) 5000 degree Celsius

viii) Output of solar cell depends on
a) ultraviolet radiation
b) heat component of solar radiation
✓c) intensity of solar radiation
d) infrared radiation

ix) The maximum energy conversion efficiency of a wind turbine for a given swept area is
a) 49.3%
b) 51.3%
✓c) 59.3%
d) 69.3%

x) If the velocity of wind increases by 40%, power output of the wind turbine will
a) remain unaltered
b) be increased by 1.4 times
✓c) be increased by 2.744 times
d) be increased by 4 times

xi) Which gas has the major share in biogas?
a) N_2
b) CO_2
c) H_2
✓d) CH_4

xii) Which process is responsible for production of energy in the Sun?
a) Nuclear fission
✓b) Nuclear fusion
c) Exothermal reaction
d) All of these

Group – B
(Short Answer Type Questions)

2. Describe the principle of MHD generating system. What are the limitations of MHD system?
See Topic: MAGNETO HYDRODYNAMIC ENERGY CONVERSION, Short Answer Type Question No. 1.

3. Explain in brief the auxiliaries of a micro-hydropower plant.
See Topic: MISCELLANEOUS, Short Answer Type Question No. 2.

4. Classify different types of fuel cells. Explain the advantages or fuel cell as a source of energy.
See Topic: FUEL CELL, Long Answer Type Question No. 1(ii) & (iii).

5. Bring out the differences between Pyrolysis and Photosynthesis.
See Topic: BIO ENERGY, Short Answer Type Question No. 3.

6. a) What is Geothermal power?
b) State various precautions to be observed during operation of geothermal plant.
See Topic: GEOTHERMAL ENERGY, Short Answer Type Question No. 3.

Group – C
(Long Answer Type Questions)

7. a) Derive the expression for power extraction from wind. What is Betz criterion?
b) Compare the advantages and disadvantages of HAWT and VAWT.
c) A propeller wind turbine has a diameter of 120 m and runs at 40 rpm. The wind at 1 standard atmosphere and 20°C has a velocity of 15 m/s. Calculate —
   i) the total power density in the wind stream
   ii) the maximum obtainable power density
   iii) the total power at 35% efficiency
   iv) the torque developed.

a) See Topic: WIND ENERGY, Long Answer Type Question No. 1(a).
b) & c) See Topic: WIND ENERGY, Long Answer Type Question No. 8.

8. a) What is biogas?
b) Briefly discuss the method of conversion of biomass to useful energy.
c) With reference to available raw materials and other advantages, explain how biomass can be an important renewable energy source specially for rural area in India.
a) See Topic: BIO ENERGY, Short Answer Type Question No. 4.
b) & c) See Topic: BIO ENERGY, Long Answer Type Question No. 2.

9. a) What is PV cell? What is fill factor of a PV cell?
b) Describe the significance of maximum power point tracking in respect of a solar PV system.
c) A *dc* motor having 85% efficiency is producing 900 watt power at the shaft. A PV system is used to feed the motor. Each module in the PV panel has 40 multi-crystalline silicon solar cells arranged in a 8×5 matrix. The cell size is 13cm × 13cm and cell efficiency is 12%. Solar radiation incident normally to the panel is 1 kW/m^2. Calculate the number of modules in the panel.
a) See Topic: SOLAR ENERGY, Short Answer Type Question No. 7.
b) & c) See Topic: SOLAR ENERGY, Long Answer Type Question No. 7.

10. a) Calculate the angle of incidence of beam radiation on a plane surface, tilted by 45° from the horizontal plane and pointing 30° west or south located in Mumbai at 1:30 PM (IST) on 15th November. The longitude and latitude of Mumbai are 72°49′E and 18°54′ N respectively. The standard longitude for IST is 81°44′E.
b) What is greenhouse effect? Write down the consequences of global warming.
a) See Topic: SOLAR ENERGY, Long Answer Type Question No. 8.
b) See Topic: INTRODUCTION TO ENERGY SOURCES, Long Answer Type Question No. 2.

11. Write short notes on any *three* of the following:
   a) Biodiesel
   b) Pumped storage hydel power generation
   c) Solar water heater
   d) Kyoto protocol.

a) See Topic: BIO ENERGY, Long Answer Type Question No. 4(a).
b) See Topic: MISCELLANEOUS, Long Answer Type Question No. 3(b).
c) See Topic: SOLAR ENERGY, Long Answer Type Question No. 12(c).
d) See Topic: INTRODUCTION TO ENERGY SOURCES, Long Answer Type Question No. 3(b).

QUESTION 2018

Group – A
(Multiple Choice Type Questions)

1. Choose the correct alternatives for each of the following:

i) Solar PV cell is basically
- a) a voltage source, controlled by flux radiation
- ✓b) a current source, controlled by flux radiation
- c) an uncontrolled voltage source
- d) an uncontrolled current source

ii) The temperature in the crust increases with depth at a rate of about
a) 300°C/km b) 10°C/km ✓c) 1°C/km d) 30°C/km

iii) The minimum tidal range required for power generation is about
a) 1 m ✓b) 5 m c) 10 m d) 20 m

iv) The range of wind speed suitable for wind power generation is
a) 0 to 5 m/s ✓b) 5 to 25 m/s c) 25 to 50 m/s d) 50 to 75 m/s

v) Which of the following is not renewable energy source?
a) Geo Thermal power b) Tidal power
c) Hydral ✓d) Fuel Cell

vi) In most hydrothermal fields, hot spots occur at a depth of about
✓a) 10 km b) 10 m c) 2 to 3 km d) 30 km

vii) Biogas is predominantly
a) hydrogen b) carbon monoxide c) carbon dioxide ✓d) methane

viii) Wave energy is basically harnessed in the form of
✓a) Mechanical energy b) Thermal energy
c) Electrical energy d) Chemical energy

ix) If the velocity of wind increases by 50%, power output of the wind turbine will be
a) remain same ✓b) increased by 3.375 times
c) increased by 4.25 times d) increased by 6 times

x) A fuel cell is basically a device for
a) electrochemical energy conversion b) thermo electric energy conversion
✓c) electrostatic energy conversion d) electro mechanical energy conversion

xi) The simplest method of hydrogen production is
✓a) electrolysis of water b) thermolysis of water
c) steam reforming of methane d) biophotosynthesis

xii) The payback period of an ordinary passive solar water heater is
a) 20-60 years b) 1 year c) 2-6 years ✓d) 6-10 years

Group – B
(Short Answer Type Questions)

2. Briefly discuss the reasons of formation of tides with diagram.
See Topic: ENERGY FROM OCEAN, Short Answer Type Question No. 6.

3. Briefly mention the site selection criterion for installing wind turbine.
See Topic: WIND ENERGY, Long Answer Type Question No. 3.

4. Discuss the advantages and disadvantages in generation of power by solar P.V. Cell.
See Topic: SOLAR ENERGY, Short Answer Type Question No. 8.

5. Describe the principle and operation of Fuel Cell with suitable diagram.
See Topic: FUEL CELLS, Short Answer Type Question No. 2.

6. Briefly describe the production process of hydrogen through electrolysis of water with suitable diagram.
See Topic: FUEL CELLS, Short Answer Type Question No. 3.

Group – C
(Long Answer Type Questions)

7. a) A HAWT is installed a location having free wind velocity of 15m/sec. The 80m dia rotor has three blades attached to the hub. Find the rotational speed of the turbine for optimal energy extraction.
b) Why teetering of rotor is required in wind turbine? Explain with diagram.
See Topic: MISCELLANEOUS, Long Answer Type Question No. 2.

8. a) Describe the production process of multi-crystalline & Amorphous silicon Solar Cell.
b) Assuming that each of the single crystal silicon Solar Cell delivers an open circuit voltage of 600mv under STC, estimate the actual open circuit voltage of a non-standard module containing 18 identical interconnected cells at an ambient temperature 40°C.
See Topic: SOLAR ENERGY, Long Answer Type Question No. 9.

9. a) A dc motor is fed by Solar PV System to produced 1 H.P. power at the shaft. The motor efficiency is 85%. Each module has multicrystalline silicon Solar Cells arranged in 9×4 matrix. The cell size is 125mm×125mm and the cell efficiency is 12%. Calculate the number of modules required in the PV array. Assume global radiation incident normally to the panel is 1 kW/m^2.
b) What is Earth's Albedo?
c) Describe the solar flat plate collector's function with suitable diagram.
See Topic: SOLAR ENERGY, Long Answer Type Question No. 10.

10. a) What are the main advantages and disadvantages of bio-mass energy?
b) Describe briefly about the fixed dome type biogas plant with suitable diagram.
c) Calculate the volume of a fixed dome type biogas digester for the output of two cows. Also calculate the thermal power available from the biogas. Use the following data:
Retention time- 30days
Dry matter produced- 2kg/day/cow

Biogas yield-0.22 m^3/kg of dry matter
Percentage of dry matter in cow dung- 18%
Density of slurry- 1090kg/ m^3
Burner efficiency- 60%
Heat valve of biogas- 23MJ/m^3
See Topic: BIO ENERGY, Long Answer Type Question No. 3.

11. Write short notes on any of three of the following:
    i) Green house effect
    ii) Solar Cooker
    iii) Maximum Power Point Tracker (MPPT)
    iv) Betz criteria
    v) Municipal Solid Waste (MSW) incineration plant

i) See Topic: INTRODUCTION TO ENERGY SOURCES, Long Answer Type Question No. 3(d).
ii) See Topic: SOLAR ENERGY, Long Answer Type Question No. 12(d).
iii) See Topic: SOLAR ENERGY, Long Answer Type Question No. 12(e).
iv) See Topic: WIND ENERGY, Long Answer Type Question No. 10(c).
v) See Topic: BIO ENERGY, Long Answer Type Question No. 4(c).

QUESTION 2019

Group – A
(Multiple Choice Type Questions)

1. Choose the correct alternative for any *ten* of the following:

i) PV cell is basically a/an
✓a) p-n junction   b) phototransistor
c) amorphous p-n junction   d) none of these

ii) In a solar panel, the metal used is
a) Gold   ✓b) Copper   c) Silver   d) Nickel

iii) A typical open circuit voltage of a solar cell is
✓a) 0.45 V DC   b) 3 V DC   c) 1.5 V DC   d) 0.05 V DC

iv) Most commonly used wind turbine is
a) Simple impulse type   ✓b) Propeller type
c) Reaction type   d) Reversible type

v) Which energy accounts for largest share in the renewable energy basket of India?
a) Wind   b) Nuclear   ✓c) Hydel   d) Solar

vi) How many basins does a single pool tidal system have?
✓a) 1   b) 2   c) 3   d) 4

vii) The ratio of the beam radiation flux falling on a tilted surface to that falling on a horizontal surface is called the
a) Radiation shape factor   ✓b) Tilt factor
c) Slope   d) None of these

viii) Which of the following is not an example of fuel cell?
a) Hydrogen-oxygen cell
b) Methyl-oxygen-alcohol cell
c) Propane-oxygen cell
✓d) Hexanone-oxygen cell

ix) An illuminated solar cell is
a) Constant voltage device
✓b) Constant current device
c) Constant power output device
d) None of these

x) Bio-gas consists of
a) only methane
b) methane and carbon dioxide
c) only ethane
✓d) all of these
e) none of these

xi) The angle made in the horizontal plane between the horizontal line due south and the projection of the normal to the surface on the horizontal plane is
✓a) Hour angle
b) Declination angle
c) Surface Azimuth angle
d) Solar altitude angle

xii) Tidal energy utilizes
a) Kinetic energy of water
✓b) Potential energy of water
c) Both Kinetic and Potential energies of water
d) None of these

Group – B
(Short Answer Type Questions)

2. Explain the types of generators used with wind turbines for producing electricity.
See Topic: WIND ENERGY, Short Answer Type Question No. 3.

3. Explain briefly about fuel (including types, advantages and limitations).
See Topic: FUEL CELLS, Short Answer Type Question No. 1.

4. Define latitude, declination, hour angles with proper diagram. Calculate the declination angle (δ) for March 31 in a leap year.
See Topic: SOLAR ENERGY, Short Answer Type Question No. 9.

5. What is solar cooling and where is it used?
See Topic: SOLAR ENERGY, Short Answer Type Question No. 10.

6. Explain the working of horizontal axis to blade windmill with suitable diagram.
See Topic: WIND ENERGY, Short Answer Type Question No. 4.

Group – C
(Long Answer Type Questions)

7. a) Derive the expression for power developed due to wind.
b) Following data were measured for a HAWT:
Speed of wind = 20 m/s at 1 atm and 27°C
Diameter of rotor = 80 m
Speed of rotor = 40 rpm
Calculate the torque produced at the shaft for maximum output of the turbine.
c) What is the importance of site selection in wind power generation?

See Topic: WIND ENERGY, Long Answer Type Question No. 9.

8. a) Explain beam and diffuse radiation.
b) Derive the expression of maximum current for solar cell.
c) Draw and explain the equivalent circuit diagram and I-V characteristics of a solar cell.
a) See Topic: SOLAR ENERGY, Long Answer Type Question No. 4(a).
b) See Topic: SOLAR ENERGY, Long Answer Type Question No. 6(c).
c) See Topic: SOLAR ENERGY, Long Answer Type Question No. 1(a).

9. a) What is photovoltaics cell or module?
b) Explain different types of photovoltaic systems using block diagram.
c) For new Delhi (28°35′N, 77°12′E), calculate the Zenith angle of the sun at 2:30 pm on 20th February, 2015. The standard IST latitude for India is 81°44′E.
See Topic: SOLAR ENERGY, Long Answer Type Question No. 11.

10. a) Draw schematic diagram of an MHD power generating system having heat recovery steam generator. Explain the functioning of the system.
b) Derive the equations for the voltage and power output of MHD generator.
c) Explain with a neat sketch the Molten Carbonate fuel cell. Also write down the chemical equation.
a) See Topic: MAGNETO HYDRODYNAMIC ENERGY CONVERSION, Short Answer Type Question No. 2.
b) See Topic: MAGNETO HYDRODYNAMIC ENERGY CONVERSION, Long Answer Type Question No. 1.
c) See Topic: FUEL CELLS, Long Answer Type Question No. 3.

11. Write short notes on any three of the following:
    a) SOFC
    b) Solar cooker
    c) AFC
    d) Material for biogas
    e) Tidal wave energy

a) See Topic: FUEL CELLS, Long Answer Type Question No. 5(c).
b) See Topic: SOLAR ENERGY, Long Answer Type Question No. 12(d).
c) See Topic: FUEL CELLS, Long Answer Type Question No. 5(d).
d) See Topic: BIO ENERGY, Long Answer Type Question No. 4(d).
e) See Topic: ENERGY FROM OCEAN, Long Answer Type Question No. 1(b).