PHY (N)-121

B. Sc. II Semester

RENEWABLE ENERGY

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1.1 INTRODUCTION

All the processes occur in nature involve energy. The all activities in this world ether done by any living being or by nature is caused due to flow or transformation of energy As we know the mass is also equivalent to energy and can be given by Einstein famous mass energy equivalence relation ($E=mc^2$) thus we say that all the matter in this universe is nothing but energy. Even all living beings include human are a nothing but a form of energy. As energy is flowing from one to another, the human is also moving on the Earth. We can also say that the universe is made of energy in space-time. Therefore energy is an important aspect of our life and knowledge energy is essential. As we know most of the scientific terms are taken from Greek language, similarly term energy is also derived from Greekword 'en-ergon', which means 'in-work' or 'work content'. The energy is nothing but the capacity or power of doing work. The work output depends on the energy input.

In physics, energy as the ability to do work, it is the quantitative property that is transferred to a body or to a physical system, recognizable in the performance of work. The energy may be different form as heat, mechanical energy, kinetic energy, electrical, chemical, gravitational, and light. According to law of conservation of energy, the energy cannot be created or destroyed but converted from one form to another. In modern society people know haw the energy can convert from one form to another for different purposes. For example, the food you eat contains chemical energy, and your body stores this energy until you use it as kinetic energy during work or play. The stored chemical energy in coal or natural gas and the kinetic energy of water flowing in rivers can be converted to electrical energy, which can be converted to light and heat.People use energy for a variety of things, such as to walk and bicycle, to move cars along roads and boats through water, to cook food on stoves, to make ice in freezers, to light our homes and offices, to manufacture products, and to send astronauts into space. The unit of measurement for energy in the International System of Units (SI) is the joule (J).

In present unit, we are focused on the energy requirement for human society, especially commercial energy. Human civilization requires energy for different functions, which it gets from energy resources such as fossil fuels, nuclear fuel, or renewable energy. The Earth's climate and ecosystems processes are driven by the energy the planet receives from the Sun (although a small amount is also contributed by geothermal energy). Thus we study different resource of energy.

1.2 OBJECTIVE

After reading this unit, we will be able to understand:

1. Basic idea energy
2. Classification of energy, Primary and Secondary Energy, Commercial, Non Commercial
3. Renewable, Non-Renewable Energy, Conventional and Non-conventional energy etc.

4 Primary Energy Reserves, Primary Energy production
5. Primary Energy Consumption
6. Primary energy production
7. World electricity generation
8. Total energy supply (TES)
9. Indian Energy Scenario, Energy Supply, Energy Consumption
10. Energy Needs of Growing Economy, Energy Pricing in India

1.3 Classification of energy:

Energy can be classified into several types based on the following criteria:

- Primary and Secondary energy
- Commercial and Noncommercial energy
- Renewable and Non-Renewable energy
- Conventional and Non-conventional energy

1.3.1 Primary and secondary Energy

Primary energy sources are those that are either found orstored in nature. Common primary energy sources are coal,oil, natural gas, and biomass(such as wood). Other primary energy sources available include nuclear energy from radioactive substances, thermalenergy stored in earth's interior, and potential energy due to earth's gravity. The major primary and secondary energy sources are shown in Figure 1.1. The primary energy can be convert to secondary for the industrial or commercial activity. For example coal can be convert into electricity for commercial use.

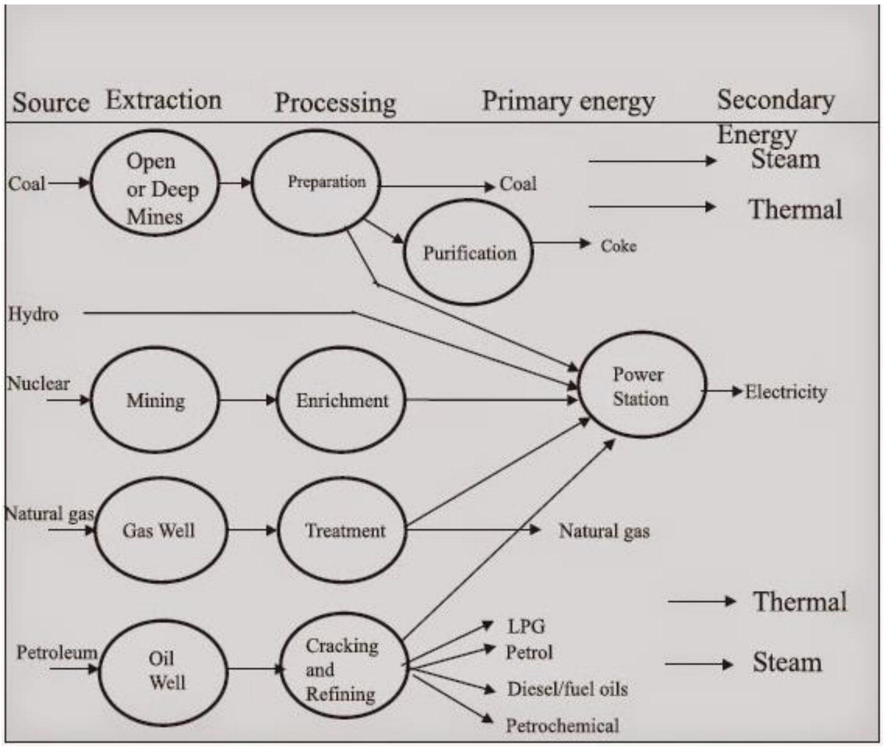


Figure 1.1: Primary and Secondary Energy.

1.3.2 Commercial Energy and Non Commercial Energy

Commercial Energy

The energy sources that are available in the market for a definite price are known as commercial energy. By far the most important forms of commercial energy are electricity, coal and refined petroleum products. Commercial energy forms the basis of industrial, agricultural, transport and commercial development in the modern world. In the industrialized countries, commercialized fuels are predominant source not only for economic production, but also for many household tasks of general population. Examples: Electricity, lignite, coal, oil, natural gas etc.

Non-Commercial Energy

The energy sources that are not available in the commercial market for a price are classified as non-commercial energy. Non-commercial energy sources include fuels such as firewood, cattledung and agricultural wastes, which are traditionally gathered, and not bought at a price used especially in rural households. These are also called traditional fuels. Non-commercial energy is often ignored in energy accounting.

Example: Firewood, agro waste in rural areas; solar energy for water heating, electricity generation, for drying grain, fish and fruits; animal power for transport, threshing, lifting water for irrigation, crushing sugarcane; wind energy for lifting water and electricity generation.

1.3.3 Renewable and Non-Renewable Energy

Renewable energy is energy obtained from sources that are essentially inexhaustible. Examples of renewable resources include wind power, solar power, geothermal energy, tidal power and hydroelectric power (Figure 1.2). The most important feature of renewable energy is that itcan be harnessed without the release of harmful pollutants.

Non-renewable energy is the conventional fossil fuels such as coal, oil and gas, which are likely to deplete with time.

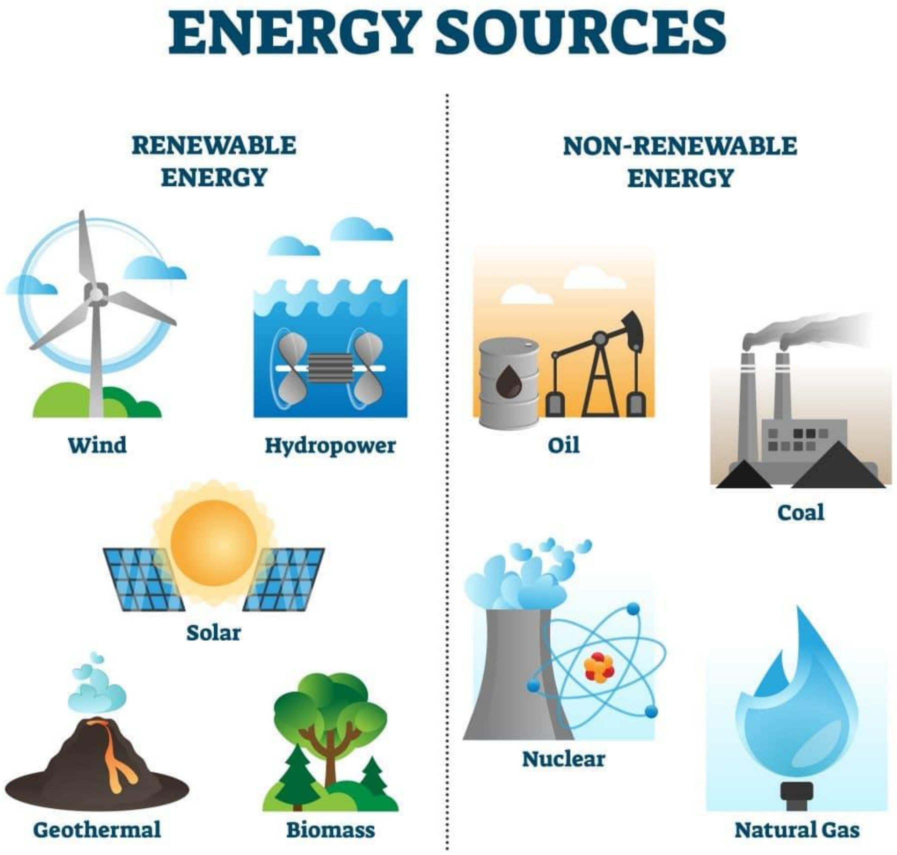
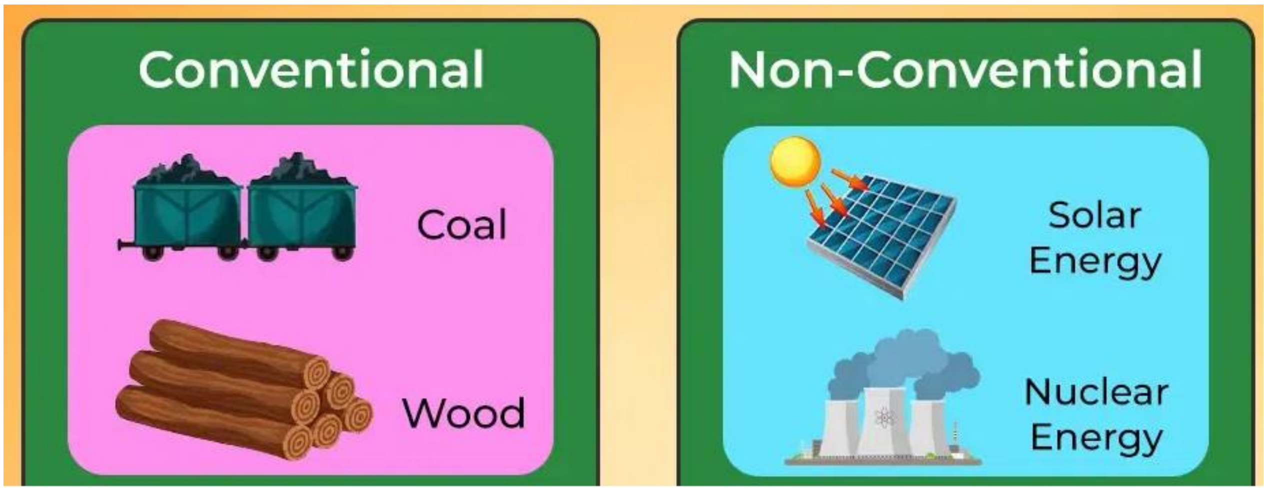


Figure 1.2 Renewable energy and Non- Renewable energy

1.3.4 Conventional and Non-conventional energy resources:

Conventional energy resources which are being traditionally used for many decades and were in common use around oil crisis of 1973 are called conventional energy resources, e.g., fossil fuel, nuclear and hydro resources. On the other hand Non-conventional energy resources which are considered for large – scale use after oil crisis of1973,are called non-conventional energy sources, e.g., solar, wind, biomass, etc.



1.4 Global Primary Energy Reserves

1.4.1 Coal

The proven global coal reserve was estimated to be 9,84,453 million tonnes by end of 2003. The USA had the largest share of the global reserve (25.4%) followed by Russia (15.9%), China (11.6%). India was 4th in the list with 8.6%.

1.4.2 Oil

The global proven oil reserve was estimated to be 1147 billion barrels by the end of 2003. Saudi Arabia had the largest share of the reserve with almost 23%.
(One barrel of oil is approximately 160 litres)

1.4.3 Gas

The global proven gas reserve was estimated to be 176 trillion cubic meters by the end of 2003. The Russian Federation had the largest share of there serve with almost 27%. World oil and gas reserves are estimated at just 45 years and 65years respectively. Coal is likely to last a little over 200 years.

Figure 1.3 Coal, Crude Oil, Petroleum and Gas (Primary Energy)

1.5 Primary Energy production:

This is the worldwide production of energy, extracted or captured directly from natural sources. In energy statistics, primary energy (PE) refers to the first stage where energy enters the supply chain before any further conversion or transformation process. Primary energy assessment by IEA follows certain rules to ease measurement of different kinds of energy. Water and air flow energy that drives hydro and wind turbines, and sunlight that powers solar panels, are not taken as PE, which is set at the electric energy produced. But fossil and nuclear energy are set at the reaction heat, which is about three times the electric energy. This measurement difference can lead to underestimating the economic contribution of renewable energy. The table 1.1 lists worldwide PE and the countries producing most (76%) of that in 2021, using Ener data. The amounts are rounded and given in million tonnes of oil equivalent per year.

Renewable is Biomass plus Heat plus renewable percentage of Electricity production (hydro, wind, solar). Nuclear is nonrenewable percentage of Electricity production. The above-mentioned underestimation of hydro, wind and solar energy, compared to nuclear and fossil energy, applies also to Enerdata.

Table 1.1: Largest Primary Energy producers as of 2021 (in million tonnes of oil equivalent per year)

Contrary	**Total (MToe)**	**Coal**	**Oil & Gas**	**Renewable**	**Nuclear**
China	2,950	71%	13%	10%	6%
United States	2,210	13%	69%	8%	10%
Russia	1,516	16%	78%	2%	4%
Saudi Arabia	610	0	100%	0	0
Iran	354	0	99%	0	1%
United Arab Emirates	218	0	99%	0	1%
India	615	50%	11%	33%	6%
Canada	536	5%	81%	10%	4%
Indonesia	451	69%	17%	14%	0
Australia	423	64%	33%	3%	0
Brazil	325	1%	55%	42%	2%
Nigeria	249	0	47%	53%	0
Algeria	150	0	100%	0	0
South Africa	151	91%	1%	8%	0
Norway	214	0	93%	7%	0
France	128	0	1%	34%	65%
Germany	102	27%	3%	47%	23%
World	**14800**	**27%**	**53%**	**13%**	**7%**

The invention of the solar cell in 1954 started electricity generation by solar panels, connected to a power inverter. Mass production of panels around the year 2000 made this economic.

1.5.1 Global Primary Energy Consumption

The global primary energy consumption at the end of 2003 was equivalent to 9741 million tonnes of oil equivalent (Mtoe). The Figure 1.3 shows in what proportions the sources men- tioned above contributed to this global figure.

1 Mtoe = 11.63 TWh (3.23 mega joules), where 1 TWh = 10^9 kWh.

The primary energy consumption for few of the developed and developing countries are shown in Table 1.1. It may be seen that India's absolute primary energy consumption is only 1/29th of the world, 1/7th of USA, 1/1.6th time of Japan but 1.1, 1.3, 1.5 times that of Canada, France and U.K respectively.

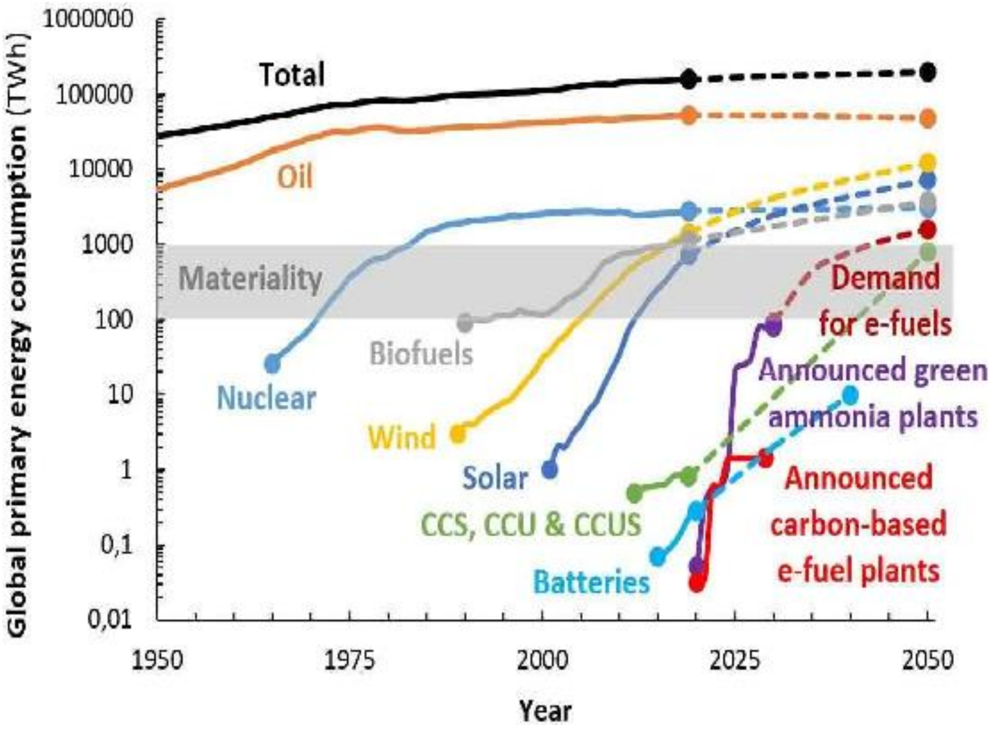


Figure1.4: Global Primary Energy Consumption

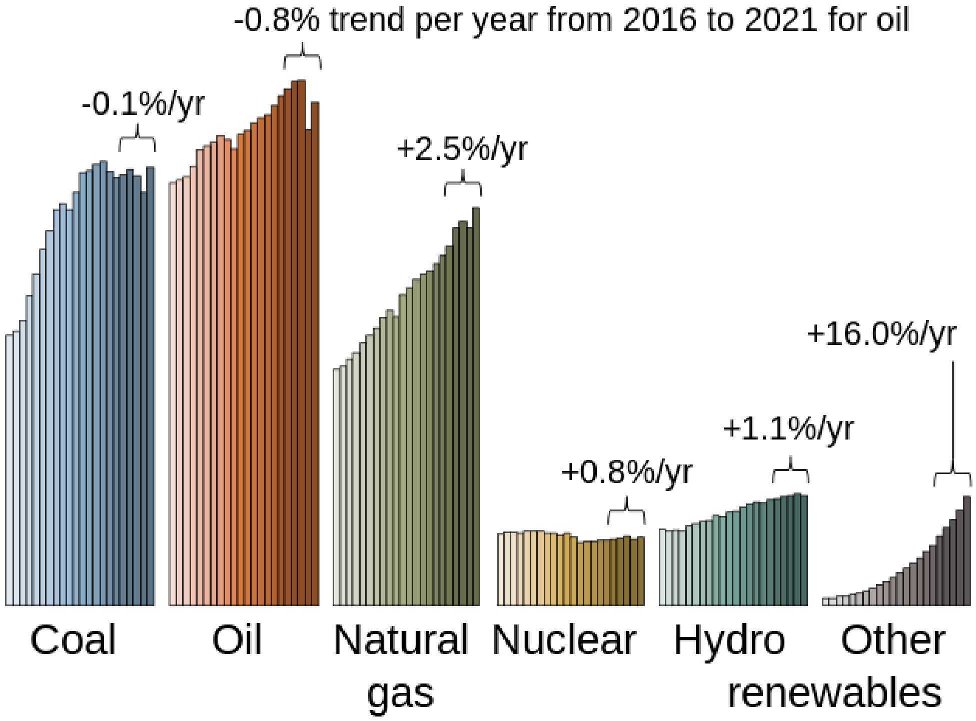


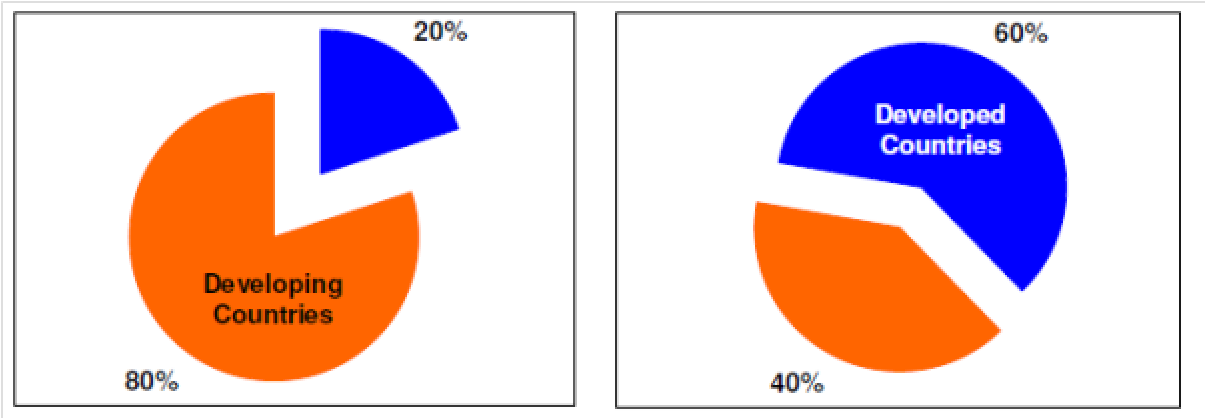
Figure1.5 Change in trend on Global Primary Energy Consumption

TABLE 1.2: Primary energy consumption by fuel, 2003 (in mtoe)

Country	Oil	aturalGas	Coal	NuclearEnergy	Hydroelectric	Total
USA	914.3	566.8	573.9	181.9	60.9	2297.8
Canada	96.4	78.7	31.0	16.8	68.6	291.4
France	94.2	39.4	12.4	99.8	14.8	260.6
Russian Federation	124.7	365.2	111.3	34.0	35.6	670.8
United Kingdom	76.8	85.7	39.1	20.1	1.3	223.2
China	275.2	29.5	799.7	9.8	64.0	1178.3
India	113.3	27.1	185.3	4.1	15.6	345.3
Japan	248.7	68.9	112.2	52.2	22.8	504.8
Malaysia	23.9	25.6	3.2	-	1.7	54.4
Pakistan	17.0	19.0	2.7	0.4	5.6	44.8
Singapore	34.1	4.8	-	-	-	38.9
TOTALWORLD	3636.6	2331.9	2578.4	598.8	595.4	9741.1

1.5.2 Energy Distribution Between Developed and Developing Countries

Although 80 percent of the world's population lies in the developing countries (a four- fold population increase in the past 25 years),their energy consumption amounts to only 40 percent of the world total energy consumption. The high standards of living in the developed countries are attributable to high- energy consumption levels. Also, the rapid population growth in the developing coun- tries has kept the per capita energy consumption low compared with that of highly industrialized developed countries. The world average energy consumption per person is equivalent to 2.2 tonnes of coal. In industrialized countries, people use four to five times more than the world average, and nine times more than the average for the developing countries. An American uses 32 times more commercial energy than an Indian.



World Population **Enrgy consuption**

Figure1.6: Energy Distribution between Developed and Developing Countries

1.5.3 Primary energy production

According to Statistical Review of World Energy2021, World total primary energy production in 2020 is given below.

TABLE 1.3: World total primary energy production

S. No.	Resource	primary energy production
1	Oil	31.2%
2	Coal	27.2%
3	Natural Gas	24.7%
4	Hydro (renewables)	6.9%
5	Nuclear	4.3%
6	Others (renewables)	5.7%

1.5.4 World electricity generation

In year 2021 world electricity generation by different sources.

TABLE 1.4: World electricity generation by different sources

S. No.	Resource	electricity generation
1	Coal	36%
2	Natural Gas	23%
3	Hydro (renewables)	15%
4	Nuclear	10%
5	Wind	7%
6	Solar (renewables)	4%
7	Other	5%

1.5.5 Total energy supply (TES)

Total energy supply (TES) indicates the sum of production and imports subtracting exports and storage changes. For the whole world TES nearly equals primary energy PE because imports and exports cancel out, but for countries TES and PE differ in quantity, and also in quality as secondary energy is involved, e.g., import of an oil refinery product. TES is all energy required to supply energy for end users. 25% of worldwide primary production is used for conversion and transport, and 6% for non-energy products like lubricants, asphalt and petrochemicals. In 2019 TES was 606 EJ and final consumption was 418 EJ, 69% of TES. Most of the energy lost by conversion occurs in thermal electricity plants and the energy industry own use.

TABLE 1.5: Total energy supply

S. No.	**Year**	**TES (Total energy supply)** million tonnes of oil equivalent
1	1990	8,700
2	2000	9,900
3	2010	12,600
4	2019	14,400
5	2020	13,800
6	2021	14,500

1.6 Indian Energy Scenario:

Coal dominates the energy mix in India, contributing to 55% of the total primary energy production. Over the years, there has been a marked increase in the share of natural gas in primary energy production from 10% in 1994 to 13% in 1999. There has been a decline in the share of oil in primary energy production from 20% to 17% during the same period

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1.6.1 Energy Supply:

Coal Supply

India has huge coal reserves, at least 84,396 million tons of proven recoverable reserves (at the end of 2003). This amounts to almost 8.6% of the world reserves and it may last for about 230 years at the current Reserve to Production (R/P) ratio. In contrast, the world's proven coal reserves are expected to last only for 192 years at the current R/P ratio.

Reserves/Production (R/P) ratio- If the reserves remaining at the end of the year are divided by the production in that year, the result is the length of time that the remaining reserves would last if production were to continue at that level.

India is the fourth largest producer of coal and lignite in the world. Coal production is concentrated in these states (Andhra Pradesh, Uttar Pradesh, Bihar, Madhya Pradesh, Maharashtra, Orissa, Jharkhand, and West Bengal).

Oil Supply

Oil accounts for about 36 % of India's total energy consumption. India today is one of the top ten oil-guzzling nations in the world and will soon overtake Korea as the third largest consumer of oil in Asia after China and Japan. The country's annual crudeoil production is peaked at about 32 million tonne as against the currentpeak demand of about 110 million tonne. In the current scenario, India's oil consumption by end of 2007 is expected to reach 136 million tonne(MT), of which domestic production will be only 34 MT. India will have to pay an oil billof roughly $50 billion, assuming a weighted average price of $50 per barrel of crude. In 2003- 04, against total export of $64 billion, oil imports accounted for $21 billion. India imports 70%of its crude needs mainly from gulf nations. The majority of India's roughly 5.4 billion barrels in oil reserves are located in the Bombay High, upper Assam, Cambay, Krishna-Godavari. In terms of sector wise petroleum product consumption, transport accounts for 42% followed by domestic and industry with 24% and 24% respectively. India spent more than Rs.1,10,000 crore on oil imports at the end of 2004.

Natural Gas Supply

Natural gas accounts for about 8.9 per cent of energy consumption in the country. The current demand for natural gas is about 96 million cubic metres per day (mcmd) as against availability of 67 mcmd. By 2007, the demand is expected to be around 200 mcmd. Natural gas reserves are estimated at 660 billion cubic meters.

Electrical Energy Supply

The all India installed capacity of electric power generating stations under utilities was 1,12,581 MW as on 31st May 2004, consisting of 28,860 MW- hydro, 77,931 MW - thermal and 2,720 MW- nuclear and 1,869 MW- wind (Ministry of Power). The gross generation of power in the year 2002-2003 stood at 531 billion units (kWh).

Nuclear Power Supply:

Nuclear Power contributes to about 2.4 per cent of electricity generated in India. India has ten nuclear power reactors at five nuclear power stations producing electricity. More nuclear reactors have also been approved for construction.

Hydro Power Supply:

India is endowed with a vast and viable hydro potential for power generation of which only 15% has been harnessed so far. The share of hydropower in the country's total generated units has steadily decreased and it presently stands at 25% as on 31st May 2004. It is assessed that exploitable potential at 60% load factor is 84,000 MW.

1.6.2 Final Energy Consumption

Final energy consumption is the actual energy demand at the user end. This is the difference between primary energy consumption and the losses that takes place in transport, transmission & distribution and refinement. The actual final energy consumption (past and projected) is given in Table 1.6.

DEMAND FOR COMMERCIAL ENERGY FOR FINALCONSUMPTION (BAU SCENARIO)

Source	**Units**	**1994-95**	**2001-02**	**2006-07**	**2011-12**
Electricity	Billion Units	289.36	480.08	712.67	1067.88
Coal	Million Tonnes	76.67	109.01	134.99	173.47
Lignite	Million Tonnes	4.85	11.69	16.02	19.70
Natural Gas	Million Cubic Meters	9880	15730	18291	20853
Oil Products	Million Tonnes	63.55	99.89	139.95	196.47

Source: Planning Commission *BAU:_Business As Usual*

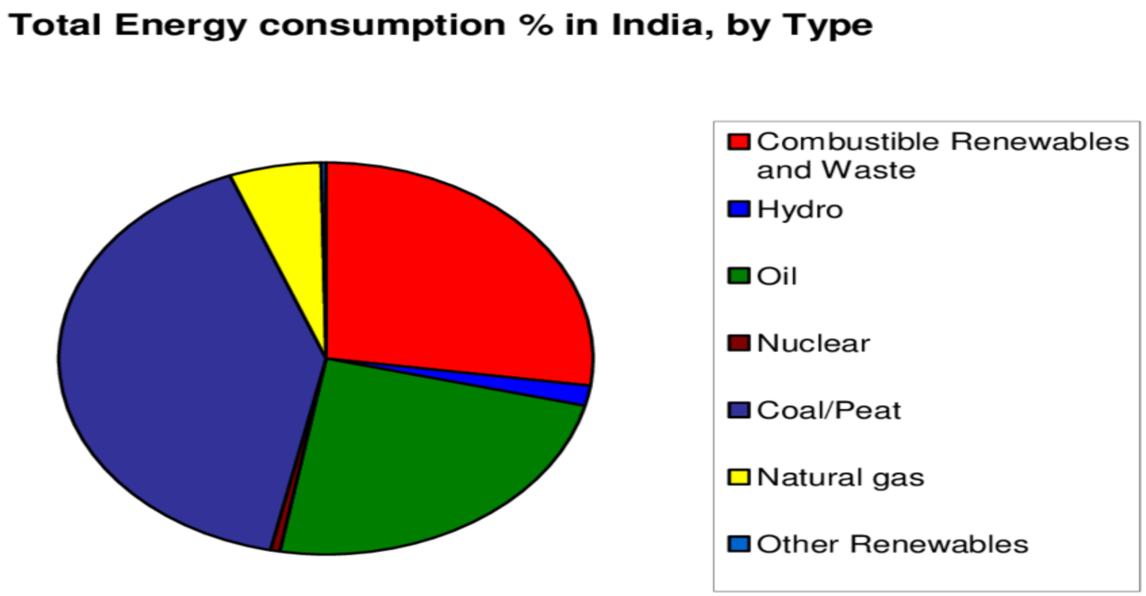

Figure 1.7: Energy Consumption in India

1.6.3 Sector Wise Energy Consumption in India

The major commercial energy consuming sectors in thecountry are classified as shown in the Figure 1.5. As seen from the figure, industry remains the biggest consumer of commercial energy and its share in the overall consumption is 49%. (Reference year: 1999/2000)

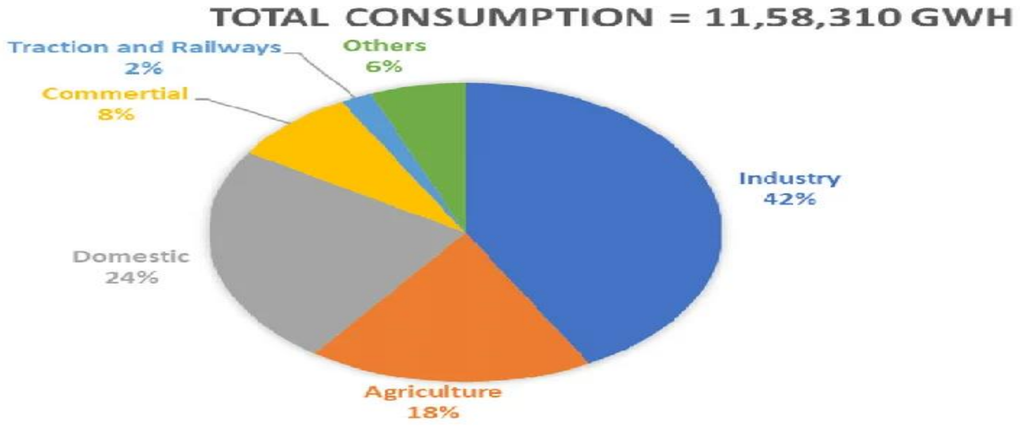

Figure 1.8: Sector Wise Energy Consumption in India

1.6.4 Energy Needs of growing Economy

Economic growth is desirable for developing countries, and energy is essential for economic growth. However, the relationship between economic growth and increased energy demand is not always a straightforward linear one. For example, under present conditions, 6% increase in India's Gross Domestic Product (GDP) would impose an increased demand of 9 % on its energy sector.

In this context, the ratio of energy demand to GDP is a useful indicator. A high ratio reflectsenergy dependence and a strong influence of energy on GDP growth. The developed countries,by focusing on energy efficiency and lower energy-intensive routes, maintain their energy to GDP ratios at values of less than 1. The ratios for developing countries are much higher.

1.6.5 India's Energy Needs

India is likely to account for 25% of global energy demand growth over the next two decades. India is also focused on Biofuels Alliance. The global biofuel market likely go up from 92 bn dollars at present to 200 bn dollars very shortly. The 10 percent ethnaol blending has led to considerable savings on the import and it will increase with 20 percent blending. India’s energy consumption is 3 times of the global average. India’s Energy demand is shown in figure 1.

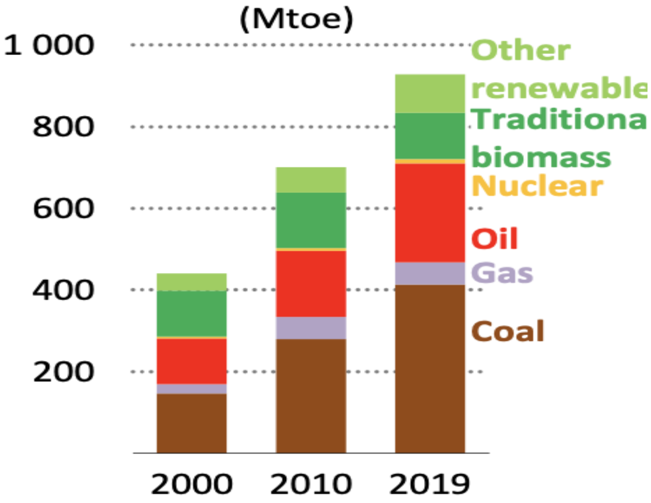

Figure 1.9: India’s Energy demand

1.6.6 Per Capita Energy Consumption

The per capita energy consumption (see Figure 1.7) is too low for India as compared to developed countries. It is just 4% of USA and 20% of the world average. The per capita consumption is likely to grow in India with growth in economy thus increasing the energy demand.

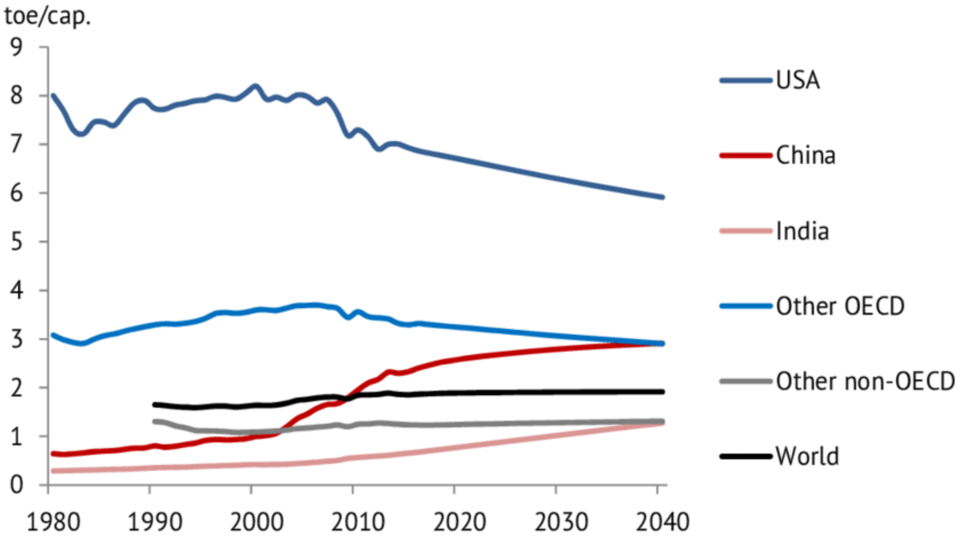

Figure1.10 Per-Capita Energy Consumption

1.6.6.1 Energy Intensity

Energy intensity is energy consumption per unit of GDP. Energy intensity indicates the development stage of the country. India's energy intensity is 3.7 times of Japan, 1.55 times of USA, 1.47 times of Asia and 1.5 times of World average.

1.6.7 Long Term Energy Scenario for India:

Coal

Coal is the predominant energy source for power production in India, generating approximately 70% of total domestic electricity. Energy demand in India is expected to increase over the next 10-15 years; although new oil and gas plants are planned, coal is expected to remain the dominant fuel for power generation. Despite significant increases in total installed capacity during the last decade, the gap between electricity supply and demand continues to increase. The resulting shortfall has had a negative impact on industrial output and economic growth.However, to meet expected future demand, indigenous coal production will have to be greatly expanded. Production currently stands at around 290 Million tonnes per year, but coal demand is expected to more than double by 2010. Indian coal is typically of poor quality and as such requires to be beneficiated to improve the quality; Coal imports will also need to increase dramatically to satisfy industrial and power generation requirements.

Oil

India's demand for petroleum products is likely to rise from 97.7 million tonnes in 2001-02 to around 139.95 million tonnes in 2006-07, according to projections of the Tenth Five-Year Plan. The plan document puts compound annual growth rate (CAGR) at 3.6 % during the plan period. Domestic crude oil production is likely to rise marginally from 32.03 million tonnes in 2001-02 to 33.97 million tonnes by the end of the 10th plan period (2006-07). India's self-sufficiency in oil has consistently declined from 60% in the 50s to 30% currently. Same is expected to go down to 8% by 2020. As shown inthe figure 1.8, around 92% of India's total oil demand by 2020 has to be met by imports.

Natural Gas

India's natural gas production is likely to rise from 86.56 million cmpd in 2002-03 to 103.08 million cmpd in 2006-07. It is mainly based on the strength of a more than doubling of production by private operators to 38.25 mm cmpd.

Electricity:

India currently has a peak demand shortage of around 14% and an energy deficit of 8.4%. Keeping this in view and to maintain a GDP (gross domestic product) growth of 8% to 10%, the Government of India has very prudently set a target of 215,804 MW power generation capacity by March 2012 from the level of 100,010 MW as on March 2001, that is a capacity addition of 115,794 MW in the next 11 years (Table 1.3). In the area of nuclear power the objective is to achieve 20,000 MW of nuclear generation capacity by the year 2020.

INDIA'S PERSPECTIVE PLAN FOR POWER FOR ZERO DEFICIT POWER BY 2011/12 (SOURCE TENTH AND ELEVENTH FIVE-YEARPLAN PROJECTIONS)

	Thermal (Coal) (MW)	**Gas / LNG / Diesel (MW)**	**Nuclear (MW)**	**Hydro (MW)**	**Total(MW)**
Installed capacity as on March 2001	61,157	Gas: 10,153 Diesel: 864	2720	25,116	100,010
Additional capacity(2001-2012)	53,333	20,408	9380	32,673	115,794
Total capacity as on March 2012	114,490 (53.0%)	31,425 (14.6%)	12,100 (5.6%)	57,789 (26.8%)	215,804

1.6.8 Energy Pricing in India:

Price of energy does not reflect true cost to society. The basic assumption underlying efficiency of market place does not hold in our economy, since energy prices are undervalued and energy wastages are not taken seriously. Pricing practices in India like many other developing countries are influenced by political, social and economic compulsions at the state and central level. More often than not, this has been the foundation for energy sector policies in India. The Indianenergy sector offers many examples of cross subsidies e.g., diesel, LPG and kerosene being subsidised by petrol, petroleum products for industrial usage and industrial, and commercial consumers of electricity subsidising the agricultural and domestic consumers.

Coal:

Grade wise basic price of coal at the pithead excluding statutory levies for run-of-mine (ROM) coal are fixed by Coal India Ltd from time to time. The pithead price of coal in India compares favourably with price of imported coal. In spite of this, industries still import coal due its higher calorific value and low ash content.

Oil:

As part of the energy sector reforms, the government has attempted to bring prices for many ofthe petroleum products (naphtha, furnace oil, LSHS, LDO and bitumen) in line with international prices. The most important achievement has been the linking of diesel prices to international prices and a reduction in subsidy. However, LPG and kerosene, consumed mainly by domestic sectors, continue to be heavily subsidised. Subsidies and cross-subsidies have resulted in serious distortions in prices, as they do not reflect economic costs in many cases.

Natural Gas:

The government has been the sole authority for fixing the price of natural gas in the country. Ithas also been taking decisions on the allocation of gas to various competing consumers. The gasprices varies from Rs 5 to Rs.15 per cubic metre.

Electricity:

Electricity tariffs in India are structured in a relatively simple manner. While high tension consumers are charged based on both demand (kVA) and energy (kWh), the low-tension (LT) consumer pays only for the energy consumed (kWh) as per tariff system in most of the electricity boards. The price per kWh varies significantly across States as well as customer segments with-in a State. Tariffs in India have been modified to consider the time of usage and voltage level of supply. In addition to the base tariffs, some State Electricity Boards have additional recovery from customers in form of fuel surcharges, electricity duties and taxes. For example, for anindustrial consumer the demand charges may vary from Rs. 150 to Rs. 300 per kVA, whereas the energy charges may vary anywhere between Rs. 2 to Rs. 5 per kWh. As for the tariff adjustment mechanism, even when some States have regulatory commissions for tariff review, the decisions to effect changes are still political and there is no automatic adjustment mechanism, which can ensure recovery of costs for the electricity boards.

1.7 Energy Sector Reforms:

Since the initiation of economic reforms in India in 1991, there has been a growing acceptanceof the need for deepening these reforms in several sectors of the economy, which were essentially in the hands of the government for several decades. It is now been realized that if sub- stance has to be provided to macroeconomic policy reform, then it must be based on reforms that concern the functioning of several critical sectors of the economy, among which the infra- structure sectors in general and the energy sector in particular, are paramount.

Coal:

The government has recognized the need for new coal policy initiatives and for rationalization of the legal and regulatory framework that would govern the future development of this indus- try. One of the key reforms is that the government has allowed importing of coal to meet our requirements. Private sector has been allowed to extract coal for captive use only. Further reforms are contemplated for which the Coal Mines Nationalization Act needs to be amended for which the Bill is awaiting approval of the Parliament.

The ultimate objective of some of the ongoing measures and others under consideration is to see that a competitive environment is created for the functioning of various entities in this industry.

This would not only bring about gains in efficiency but also effect cost reduction, which would consequently ensure supply of coal on a larger scale at lower prices. Competitionwould also have the desirable effect of bringing in new technology, for which there is an urgentand overdue need since the coal industry has suffered a prolonged period of stagnation in technological innovation.

Oil and Natural Gas:

Since 1993, private investors have been allowed to import and market liquefied petroleum gas (LPG) and kerosene freely; private investment is also been allowed in lubricants, which are not subject to price controls. Prices for naphtha and some other fuels have been liberalized. In 1997the government introduced the New Exploration Licensing Policy (NELP) in an effort to pro- mote investment in the exploration and production of domestic oil and gas. In addition, the refining sector has been opened to private and foreign investors in order to reduce imports of refined products and to encourage investment in downstream pipelines. Attractive terms are being offered to investors for the construction of liquefied natural gas (LNG) import facilities.

Electricity:

Following the enactment of the Electricity Regulatory Commission Legislation, the Central Electricity Regulatory Commission (CERC) was set up, with the main objective of regulating the Central power generation utilities. State level regulatory bodies have also been set up to settariffs and promote competition. Private investments in power generation were also allowed. The State SEBs were asked to switch over to separate Generation, Transmission and Distribution corporations. There are plans to link all SEB grids and form a unified national power grid.

1.8 Electricity Act 2003:

The government has enacted Electricity Act, 2003 which seeks to bring about a qualitative transformation of the electricity sector. The Act seeks to create liberal framework of development for the power sector by distancing Government from regulation. It replaces the three existing legislations, namely, Indian Electricity Act, 1910, the Electricity (Supply) Act, 1948 and the Electricity Regulatory Commissions Act, 1998. The objectives of the Act are "to consolidate the laws relating to generation, transmission, distribution, trading and use of electricity and generally for taking measures conducive to development of electricity industry, promoting competition therein, protecting interest of consumers and supply of electricity to all areas, ratio- nalization of electricity tariff, ensuring transparent policies regarding subsidies, promotion of efficient and environmentally benign policies, constitution of Central Electricity Authority, Regulatory Commissions and establishment of Appellate Tribunal and for matters connected therewith or incidental thereto."

1.9 Summary

1. The energy is nothing but the capacity or power of doing work. The work output depends on the energy input. The energy may be different form as heat, mechanical energy, kinetic energy, electrical, chemical, gravitational, and light.

2. Primary energy sources are those that are either found orstored in nature. Common primary energy sources are coal,oil, natural gas, and biomass(such as wood). The primary energy can be

convert to secondary for the industrial or commercial activity. For example coal can be convert into electricity for commercial use.

3. The energy sources that are available in the market for a definite price are known as commercial energy. Commercial energy forms the basis of industrial, agricultural, transport and commercial development in the modern world. Examples: Electricity, lignite, coal, oil, natural gas etc. The energy sources that are not available in the commercial market for a price are classified asnon-commercial energy. Non-commercial energy sources include fuels such as firewood, cattledung and agricultural wastes.

4. Renewable energy is energy obtained from sources that are essentially inexhaustible. Examples of renewable resources include wind power, solar power, geothermal energy, tidal power and hydroelectric. Non-renewable energy is the conventional fossil fuels such as coal, oil and gas, which are likely to deplete with time.

5. Conventional energy resources which are being traditionally used for many decades and were in common use around oil crisis of 1973 e.g., fossil fuel, nuclear and hydro resources. On the other hand Non-conventional energy resources which are considered for large – scale use after oil crisis of1973,are called non-conventional energy sources, e.g., solar, wind, biomass, etc.

6. In energy statistics, primary energy (PE) refers to the first stage where energy enters the supply chain before any further conversion or transformation process.

7. India's absolute primary energy consumption is only 1/29th of the world, 1/7th of USA, 1/1.6th time of Japan but 1.1, 1.3, 1.5 times that of Canada, France and U.K respectively.

8. The unit Million tonnes of oil equivalent (Mtoe) is define as
1 Mtoe = 11.63 TWh (3.23 mega joules), where 1 TWh = 10^9 kWh.

9. The high standards of living in the developed countries are attributable to high- energy consumption levels.

10. Total energy supply (TES) indicates the sum of production and imports subtracting exports and storage changes. For the whole world TES nearly equals primary energy PE because imports and exports cancel out, but for countries TES and PE differ in quantity, and also in quality as secondary energy is involved, e.g., import of an oil refinery product.

11. Coal dominates the energy mix in India, contributing to 55% of the total primary energy production. Oil accounts for about 36 % of India's total energy consumption. Natural gas accounts for about 8.9 per cent of energy consumption in the country.

12. The all India installed capacity of electric power generating stations under utilities was 1,12,581 MW as on 31st May 2004, consisting of 28,860 MW- hydro, 77,931 MW - thermal and 2,720 MW- nuclear and 1,869 MW- wind (Ministry of Power). The gross generation of power in the year

2002-2003 stood at 531 billion units (kWh).

1.10 Glossary

Energy: energy is also derived from Greekword ‘en-ergon’, which means ‘in-work’ or ‘work content’. The energy is nothing but the capacity or power of doing work.

Commercial Energy: Energy sources that are available in the market for a definite price.

Renewable: sources that are essentially inexhaustible

Coal: A sedimentary deposit composed predominantly of carbon that is readily combustible

Crude oil: Crude oil means a mixture of hydrocarbons that exists in liquid phase in natural underground reservoirs and remains liquid at atmospheric pressure after passing through surface separating facilities.

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1.12 SUGGESTED READING

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1.13 Terminal Questions

1.13.1 Objective types

1. The energy sources that are either found or stored in nature are

a) Secondary Energy Sources b) <u>Primary Energy Sources</u>
c) both (a) and (b) d) none of the above

2. Which of the following is commercial energy source?
a) <u>Electricity</u> b) Coal c) Oil d) All the above

3. Inexhaustible energy sources are known as

a) commercial Energy b) renewable Energy
c) primary energy d) secondary energy

4. Which country has the largest share of the global coal reserves?
a) Russia b) China c) USAd) India

5. World oil reserves are estimated to last over
a) 45 years b) 60 years c) 200 years d) 75 years

6. Which fuel dominates the energy mix in Indian energy scenario?–
a) Oil b) Natural gas c) Coal d) Nuclear

7. Indian per capita energy consumption is _ of the world average.
a) 4% b) 20% c) 1% d) 10%

8. Energy consumption per unit of GDP is called as:
a) Energy Ratio b) Energy intensity c) Per capita consumption d) None

9. Name the Act, which is proposed to bring the qualitative transformation of the electricity sector:

a) Regulatory Commission Act 1998 b) Indian Electricity Act 1910
c) Supply Act 1948 d) Electricity Act 2003

1.13.2. Short type questions:

1. Classify the types of the energy available on the earth?
2. Briefly mention about primary sources of energy?
3. What is renewable energy and list at least three renewable energy sources?
4 Name the five states in India, where coal production is concentrated.
5. What is Energy intensity and what it indicates?
6. What is main objective of Electricity Act, 2003?

1.13.2. Long type questions:

1. List the strategies for better energy security of the nation?

2. List the strategies for better energy security of the nation?
3. How do an Industry, nation and globe would benefit from energy efficiency programs?
4. Briefly describe the economic reforms in Coal, oil and natural gas and electricity sectors.

5. How energy pricing is done in India?

UNIT 2 SOLAR RADIATION AND THERMAL COLLECTORS

Structure

2.1 INTRODUCTION

In this unit we are making an attempt to understand about the sun, solar radiation, and solar energy. We can start from sun which is the ultimate source of energy and history and existence of sun. It is assumed by scientific community that about 13.7 billion year ago Big Bang took place and these galaxies and stars are come into existence. Human still do not know about the entire size of our universe but is believed that the observable size of universe is about 90 billion light years (1 light year = 9.46×10^{15} m).In the universes, there are billions of galaxies. The sun is the part of a galaxy known as Milky Way among the approximately 100 billion stars. Sun has a solar system with planets and satellites. The age of sun is estimated approximately 4.6billion years. Earth is also made from the sun about 4.5 billion years back. Earth is third planet in the solar system. Sun provides the energy to our planet Earth and responsible for the existence of life. It is the ultimate source of all the energy sources. The energy emission in the sun is due to continuous nuclear fusion reactions on it. The centre or core of the star plays the platform for fusion process. After the energy production, it is emitted away from the sun by means of electromagnetic radiation.

The Sun is the largest object in our solar system. The radius of the sun is 6.9×10^{8}m while the radius of the earth is 6.4×10^{6}m. The radius of sun is approximately 109 times that of the earth. The mass of sun is 2×10^{30} kg which is around 333,000 times the mass of Earth (5.97×10^{24} kg). The mean distance between sun and earth is 1.5×10^{11} m which is called one Astronomical unit (AU) . Due to this large distance the sun subtends a small angle of 2 minutes (1 degree = 60 minute) on the earth. Thus it assumes that earth receives almost a parallel beam of light or electromagnetic radiation on its surface.

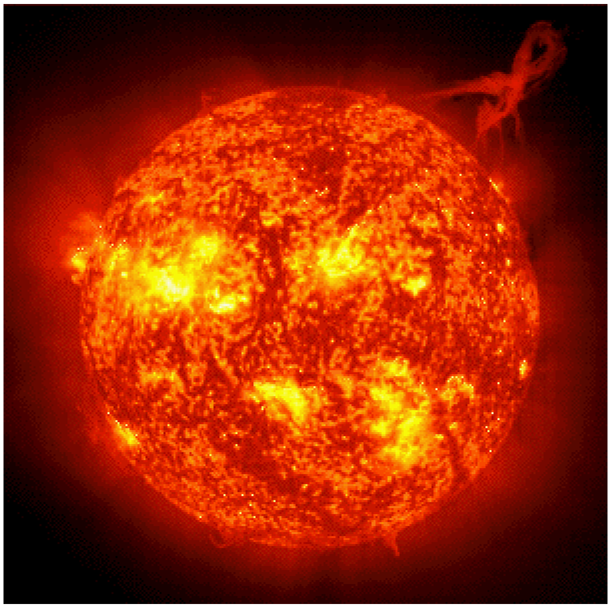

Figure 2.1: The Sun as seen from space

2.2 OBJECTIVE

After reading this unit we will able to understand:

1. Solar radiation
2. Irradiance and irradiation
3 Extraterrestrial radiation
4 Spectral distribution of Extraterrestrial radiation
5 Terrestrial solar radiation
6 Insolation, Beam radiation, Diffused radiation,
7 Air mass (m)
8 Solar radiation geometry
9 Solar radiation measurements
10 Solar Thermal Collectors

2.3 Solar radiation:

The earth received solar energy from the sun. Due to motion of earth and climate conditions the amount of energy varies at different points on the earth at different time. The rate at which solar energy reaches at the top of earth atmosphere is called solar constant I_{SC}. This is the rate of solar energy received in unit area, in unit time perpendicular to rays of sun. This is basically energy flux at the top of atmosphere. Since the distance between sun and earth changes throughout the year therefore the amount of energy received is changed accordingly. Thus we take the solar constant at the average distance between sun and earth i.e. 1AU. The standard value of solar constant in different units is given as

I_{SC} = 1353 W/m^2(watts per square meter (kW/m^2)

I_{SC} = 116.5 Cal/(cm^2 – hour) or Langley's

The distance between sun and earth varies throughout the year hence the extra terrestrial radiation varies throughout the year. The earth revolves around the sun in an elliptical orbit as shown in figure 2.2. The earth is closest to the sun on 21 March and 23 September. The earth is farthest from the sun on 21 June and 22 December. The intensity of solar radiation outside the earth's atmosphere reduces with distance and it is dependent on the distance between the earth and the sun. In fact, the intensity of solar radiation reaching outside the earth's atmospheric varies with the square of the distance between centers of the earth and the sun. This is the reason why earth receives 7 % more radiation on 21 March and 23 September as compared to 21 June and 22 December. The mean distance of the earth from the sun is 1.495 × 1011 m. The extraterrestrial radiation on any day of the year can be calculated by given formula

$$I'_{SC} = I_{SC}[1 + 0.033\cos(360n/365)] \qquad (1)$$

Where n is the day of the year.

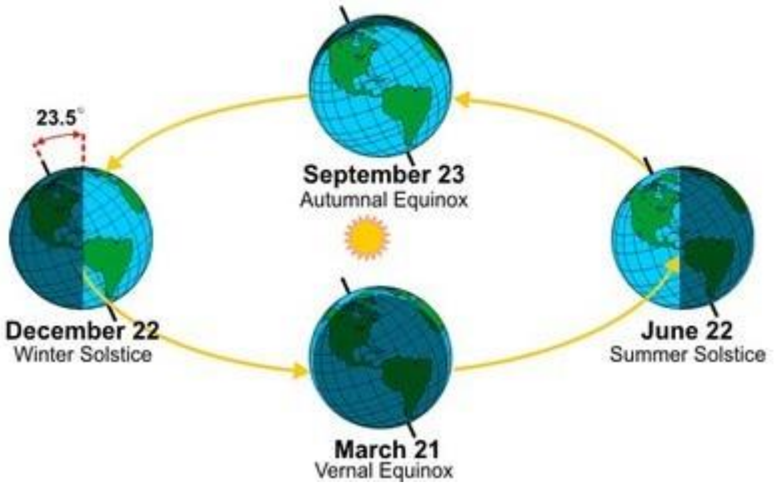

Figure 2.2: Orbital motion of earth around the Sun

The earth axis is tilted about 23.5° with respect to earth's orbit around the sun as shown in figure 2.3 owing to this tilting of earth's axis, the northern hemisphere of the earth points towards the sun in the month of June and it point away from the sun in the month of December. However, earth's axis remains perpendicular to the imaginary line drawn from the earth to sun during the month of September and March. The sun- earth's distance varies during earth's rotation around the sun, there by varying the solar energy reaching its surface during revolution, which bring about seasonal changes. The northern hemisphere has summer in the month of September and March, both the hemisphere are at the same distance from the sun and receive equal sunshine. During the summer, the sun is higher in the sky, while the sun is lower in the sky during winter for the northern hemisphere.

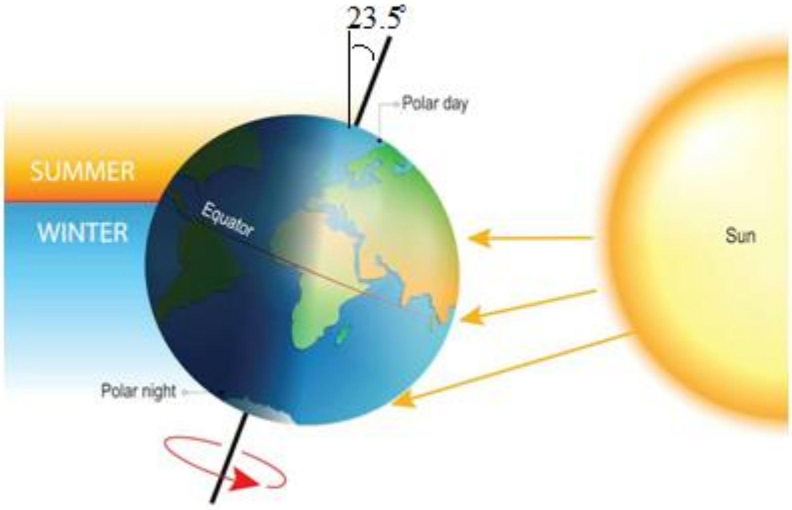

Figure 2.3: Orbital motion of earth around the Sun

2.3.1 Irradiance and irradiation

Solar radiation is generally measured in Irradiance which is defined as the rate at which radiant energy is incident on a unit surface area in per unit time. It is the measure of power density of sun light falling per unit area and time. Irradiance is the power of solar radiation per unit area, and measured in watt per square meter (W/m^2). If the energy received in the form of heat then it can be measured in joules and watt or joules per second is unit of power. Irradiation is the process by which an object is exposed to radiation.

2.3.2 Extraterrestrial radiation

Solar radiation incident on the outer atmosphere of the earth is called extraterrestrial radiation. The extraterrestrial radiation varies based on the change in sun- earth's distance arising from earth's elliptical orbit of rotation. The extraterrestrial radiation is not affected by changes in atmospheric condition.

2.3.3 Spectral distribution of Extraterrestrial radiation:

The spectral distribution of extra terrestrial solar radiation give the idea abuts the different wavelengths available in the solar radiation with radiation energy flux. This is nothing but a curve between wavelength and radiation flux. Figure 2.2 shows the spectral distribution of solar radiation. The figure shows that the spectral radiation first increase sharply and becomes maximum nearly at wavelength 480 nm and then decrease gradually as shown in figure. We know that the optical region is nearly 350 to 780 nm and it can be observed that the maximum part of radiation is the optical part of electromagnetic radiation. 99% of solar radiation is obtained in the wavelength range of 200 to 4000 nm. The solar energy radiation arrive in earth is consists of 8% ultraviolet light (which have wavelength less than 350 nm), 46 % visible light (350 to 780 nm) and 46% of infrared (which have wavelength more than 780 nm).

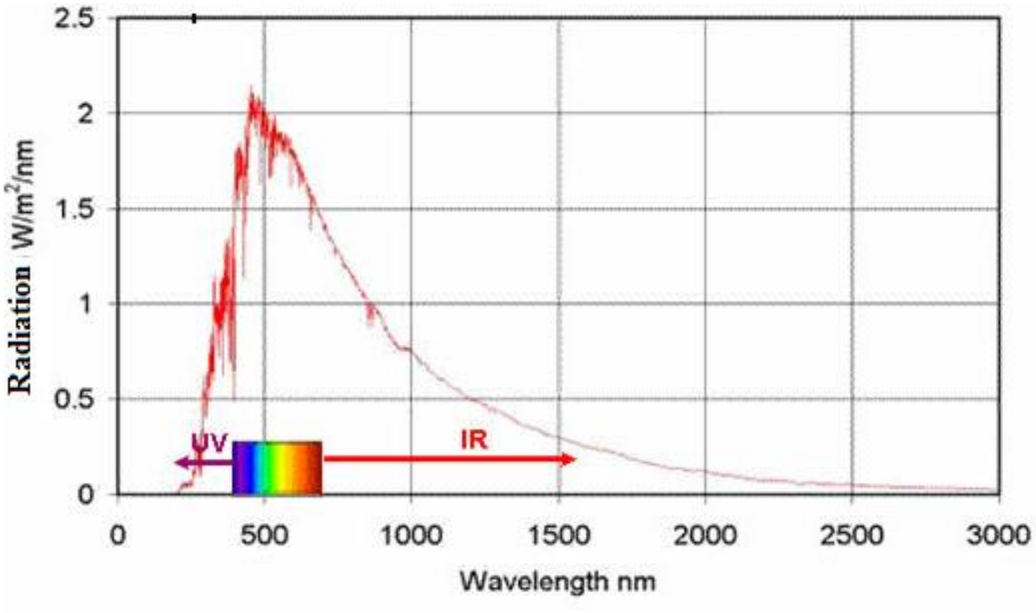

Figure 2.4: Spectral distribution of Extraterrestrial radiation

2.4 Terrestrial solar radiation (Solar radiation on earth surface):

When the solar radiation reaches in the earth surface, it passes through atmosphere. In earth atmosphere the absorption, scattering, diffraction takes place because of ozone layer, water molecules different gases as CO_2, O_2, NO_2 CH_2 N_2 and other matter etc. Therefore, solar radiation or intensity of radiation is depleted during its passage through the atmosphere. The solar radiation that reaches earth's surface after passing through earth's atmosphere is called terrestrial radiation.

Types of solar radiation

2.4.1 Insolation: Insolation is the downward solar energy flux at the ground surface in the shortwave region of electromagnetic spectrum. The solar radiation reaches earth's surface in two ways from extraterrestrial region.

2.4.2 Beam radiation - a part of sun's radiation travels through earth's atmosphere and its reaches directly, which is called direct or beam radiation. The solar radiation along with the line joining the receiving point and the sun is called beam radiation. This radiation has any unique direction

2.4.3 Diffuse radiation -the remaining major part of the solar radiation is scattered, reflected back into the space or absorbed by earth's atmosphere. A part of this radiation may reach earth's surface. This radiation reaching earth's surface by the mechanism of scattering and reflecting, that is, radiation, is called diffuse or sky radiation. The solar radiation which is scattered by the particles in earth's atmosphere and this radiation dose not have any unique direction. The diffuse radiation takes pace uniformly in the all direction and its intensity does not change with the orientation of the surface.

2.4.4 Total or global radiation at any location on earth's surface= beam radiation + diffuse radiation.

However, direct or beam radiation depends on the orientation of the surface. The beam radiation depends on the angle of incident on the surface and its intensity is maximum when the solar radiation is falling normal to the surface. The solar radiation propagating normal to its direction is specified by I*n*.

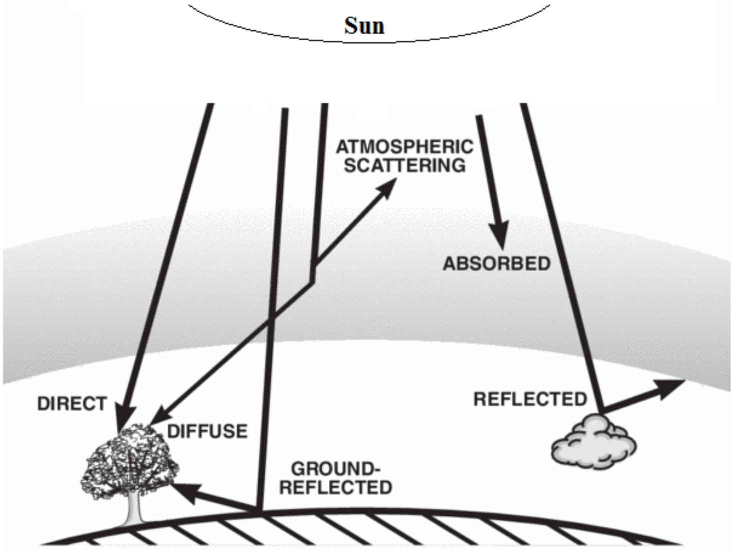

Figure 2.5: Direct, Diffused, Reflected and Total Radiation

2.4.5 Air mass (m)

The radiation reaching earth surfaces also depend on atmospheric condition and depletion. It used to assess the distance that travel in the atmosphere before reaching at a particular point on earth's surface. Air mass is the ratio of the path through the atmosphere to the vertical path length when the sun is directly overhead i.e. sun is at the zenith. The air mass is unity when the sun is vertically is in the sky (directly overhead or inclination angle 90^0). Just above the earth's atmosphere, the air mass (m) becomes 0 corresponding to extra terrestrial radiation. If the angle between the sun ray and a line perpendicular to horizontal plane (called zenith angle θ_Z) is 60^0 , then air mass (m) = 2.

2.5 Solar radiation geometry:

The radiation reaching on the earth can be analyzed with the help of following parameters which are different angles as given below:

1. **Angle of incident= $\boldsymbol{\theta}$**
2. **Latitude of location= $\boldsymbol{\phi}$**
3. **Longitude of location = $\boldsymbol{\lambda}$**
4. **Declination = $\boldsymbol{\delta}$**
5. **Hour Angle= $\boldsymbol{\omega}$**
6. **Slope = $\boldsymbol{\beta}$**
7. **Altitude angle = $\boldsymbol{\alpha}$**
8. **Zenith angle= $\boldsymbol{\theta_Z}$**
9. **Solar azimuth angle = $\boldsymbol{\gamma_s}$**
10. **Surface azimuth angle = $\boldsymbol{\gamma}$**

2.5.1. Angle of incident ($\boldsymbol{\theta}$):

As usual practice, angle of incident is the angle between incident radiation beam (or ray) $I_{bn}$and a line perpendicular to the plane of surface. It is generally denoted byθ.

2.5.2Latitude or angle of latitude ($\boldsymbol{\phi}$):

For determining latitude of any location, fist we consider the center of earth as origin O, at the center of equatorial plane which is perpendicular to the axis of rotation. The angle made by the radial line joining the specified location to the centre of earth with the projection of this line on the equatorial plane as shown in figure 2.6a and 2.6b. Therefore, the latitude equator is 0 and 90˚ at poles. On a globe of the earth, lines of latitude are circles of different size. The largest one is the circle at equator (circle at equator with centre at earth' centre) whose latitude is taken as zero. The circles at the poles have latitude of 90˚north and 90˚south (or 90˚) where these circles shrink to a point.

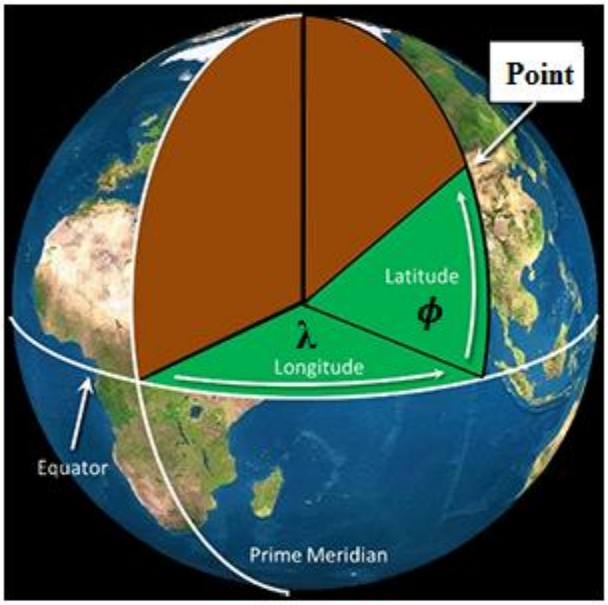

Figure 2.6 a: Latitude and Longitude of any point location

2. 5.3. Longitude of location (λ)

These are the imaginary lines from North Pole to South Pole as shown in figure 2.6b. The reference point or line is taken prime meridian which is the meridian passing through the royal astronomical observatory at Greenwich, UK had been chosen as zero longitude. The meridian passing through this location is called prime meridian. Like any circle, if center of the earth is center point, it has 360 degrees or division around the equatorial plane. Every meridian has to cross the equator. We measure longitude as 180 east and 180 west from prime meridian. Hence prime meridian or longitude is considered zero longitude and there are 180 longitude lines or degrees at cast (+ 180°) of Greenwich. The longitude lines have wide separation at the equator about 111 km as the total length of equator is 3960 km (111x360) which is nothing but circumference of earth at equator.

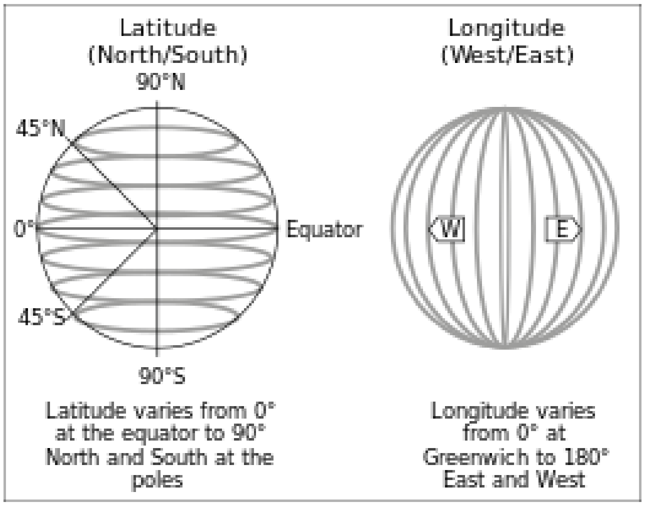

Figure 2.6 b: Variation in Latitude and Longitude on earth

2.5.4 Declination ($\boldsymbol{\delta}$)

It is the angle made by the line joining the centers of sun and earth with its projection on equatorial plane. It arises due to tilt of earth of its rotational axis as shown in figure 2.7. The angle of declination varies when earth revolves around the sun. It has maximum value of 23.5° when earth achieves a position in its orbit corresponding to 21 June and it has minimum value of 23.45° when earth is in orbital position corresponding to 22 December. The Declination is zero on two equinox days on 22 March and 22 September. The angle of declination can be given by relation called (Cooper's equation)

$$\boldsymbol{\delta = 23.45\, sin\, [(360/365)(284 + n)]} \qquad (\mathbf{2})$$

where n is the day of year for example for 8 June, n= 31+28+31+30+31+8 = 159

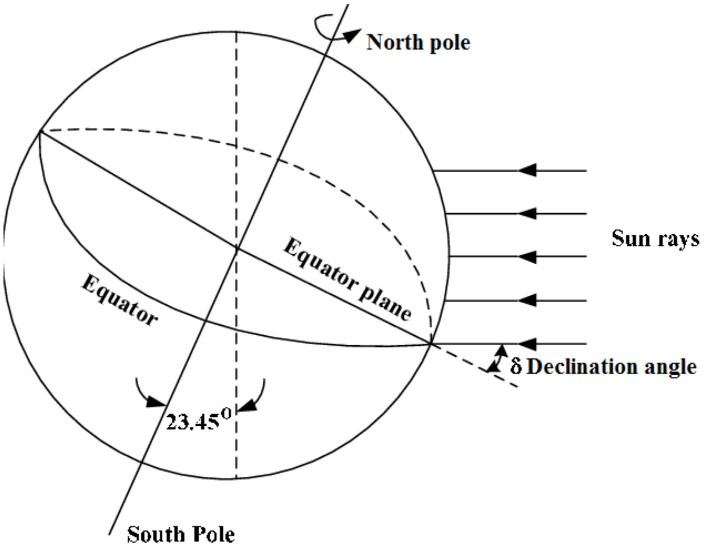

Figure 2.7: Declination angle (δ)

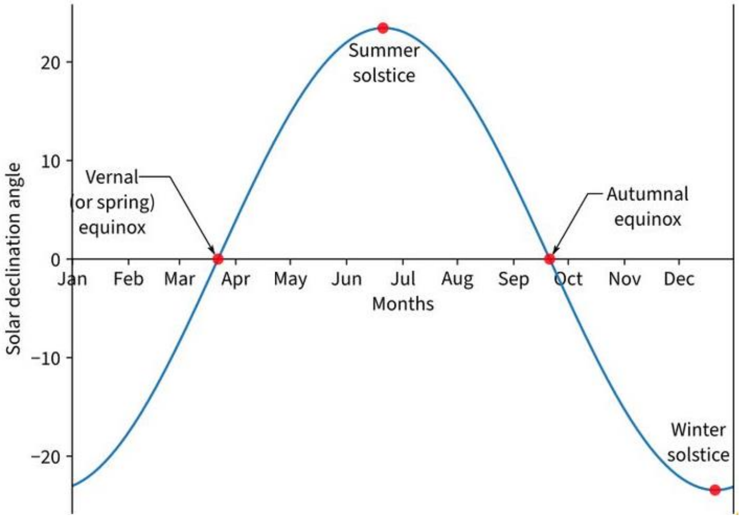

Figure 2.8: Variation in solar Declination (δ)

2.5.5. Hour Angle (ω)

The hour angle at any instant is the angle through which the earth must turn to bring the meridian at a point directly in line with sun's rays as shown in figure 2.9. It is an angular measure of time and 1 hour is equivalent to 15 degree. It also varies from +180˚to - 180˚ corresponding to longitude. It is measured from noon base local solar time (LST) or local apparent time (LAT). It is positive at morning and negative at evening as shown in figure 2.10.

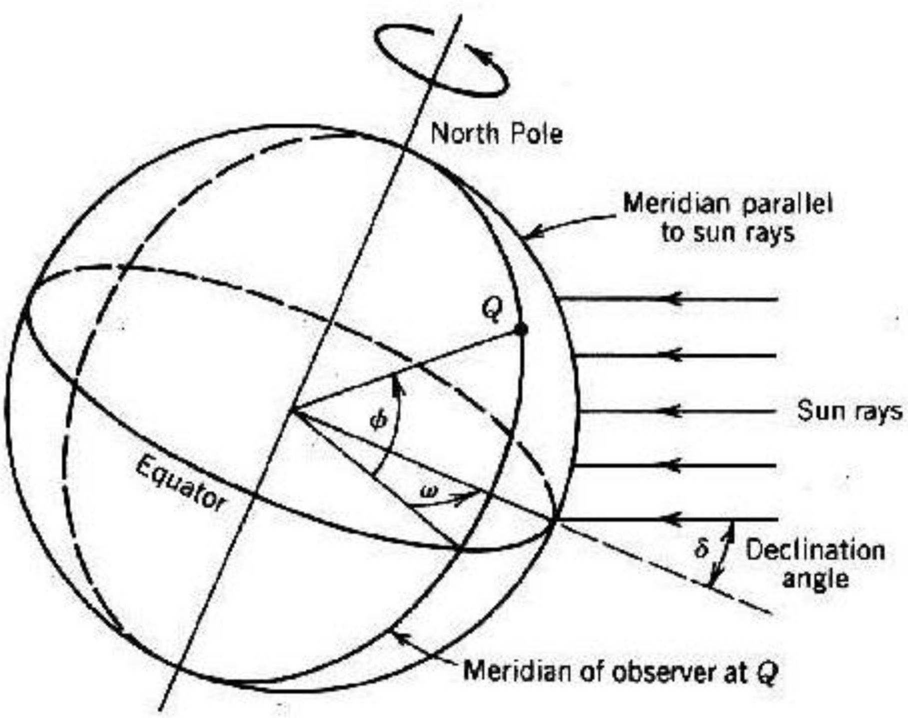

Figure 2.9: Hour Angle (ω)

2.5.6 Slope or tilt(β)

Slope β is the angle made by plane surface with the horizon. It is positive if the slop is toward the south and negative if the slop is towardsthe north as shown in figure 2.10.

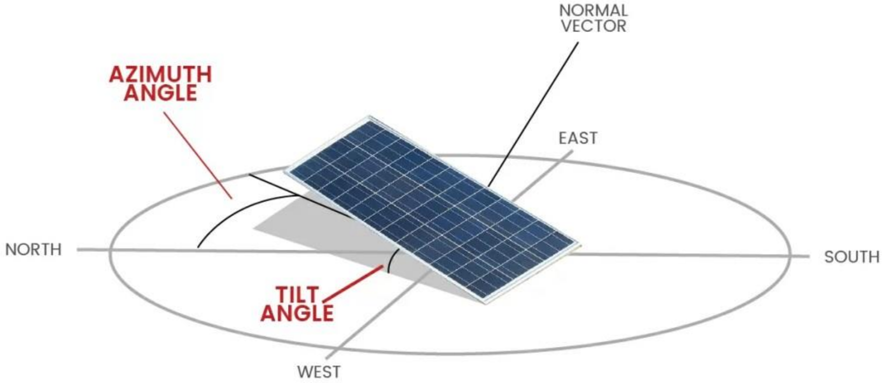

Figure 2.10: Slope (β)

2.5.7 Altitude angle (α)

Altitude angle is the vertical angle between direction of sun ray and projection of sun ray on the horizontal plane. Altitude angle (α)is shown in figure 2.11and in figure 2.12.

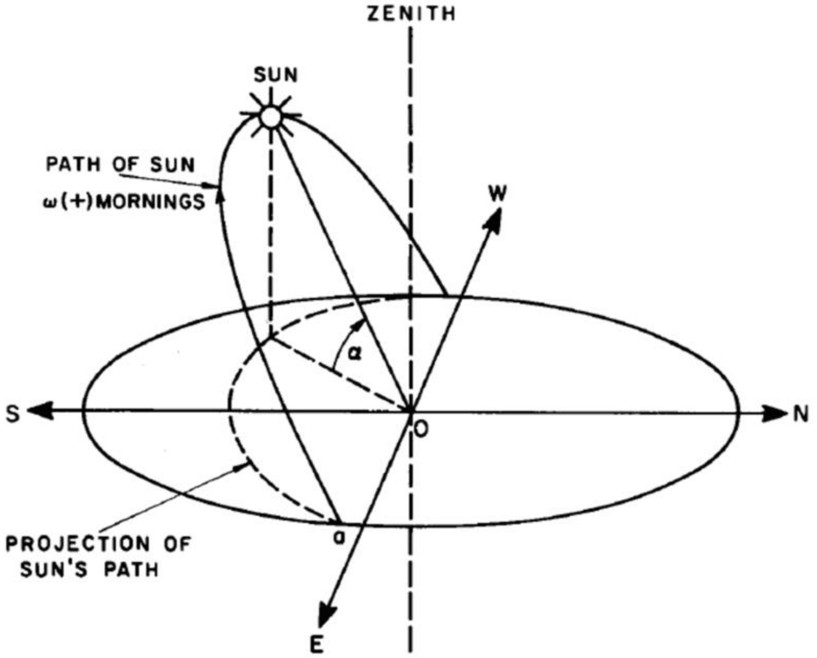

Figure 2.11: Altitude Angle(α)

2.5.8 Zenith angle (θ_Z)

Zenith angle (θ_Z) is a vertical angle between the sun's ray and a line perpendicular to horizontal plane at any point i.e. zenith line as shown in figure 5.12. Zenith line always passes through center of the earth. It is clear from the figure the relation between the zenith angle and altitude angle is

$$\theta_Z + \boldsymbol{\alpha} = 90^0 \qquad (3)$$

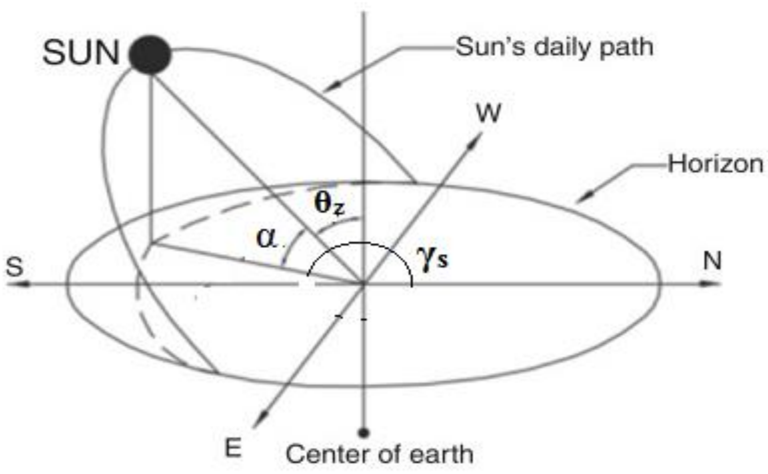

Figure 2.12: Altitude Angle(α), Zenith angle (θ_Z) and solar azimuth angle (γ_s)

2.5.9 Solar azimuth angle (γ_s)

Solar azimuth angle (γ_s) is the angle on the horizontal plane measured from the extreme north to the horizontal projection of sun's ray as shown in figure 2.12 and 2.13.The value of the azimuth angle is taken positive when it is measure from towards west.

2.5.10 Surface azimuth angle (γ)

Surface azimuth angle (γ) is the angle on the horizontal plane between line due south and the projection of the normal to the surface on horizontal plane as shown in figure 2.13. The value of the azimuth angle vary from – 180 to + 180. The angle is taken positive when the normal is east of south and negative if normal is west of south.

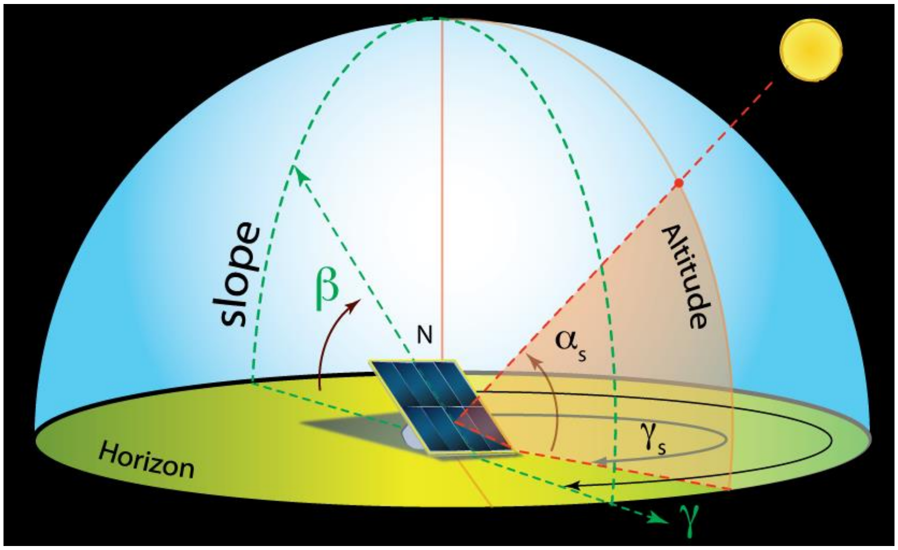

Figure 2.13: Slope or tilt(β), Surface azimuth angle $(\gamma)$and solar azimuth angle (γ_s)

2.5.11 Relation between different angles:

The zenith angleθ_Z can be given as (in terms of , ω, δ)

$$\cos\theta_Z = \cos\phi\ \cos\omega\ \cos\delta + \sin\phi\ \sin\delta \qquad (4)$$

Solar azimuth angle (γ_s) can be given as

$$\cos\ \gamma_s = \sec\alpha\ (\cos\phi\ \sin\delta - \cos\delta\sin\phi\cos\omega) \qquad (5)$$

$$\sin\gamma_s = \sec\alpha\ \cos\delta\ \sin\omega \qquad (6)$$

The incident angle θ can be given as

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

(7)

For horizontal surface on the earth the tilt angle $\beta = 0$ and the angle of incident θ becomes zenith angle θ_Z. Thus the equation (7) becomes

$$\cos\boldsymbol{\theta_Z} = \sin\boldsymbol{\phi}\ \sin\boldsymbol{\delta} + \cos\boldsymbol{\phi}\ \cos\boldsymbol{\delta}\ \cos\boldsymbol{\omega} \qquad (8)$$

$$\cos\boldsymbol{\theta_Z} = \sin\boldsymbol{\alpha} \qquad \text{as } \boldsymbol{\theta_Z} = 90 - \boldsymbol{\alpha}$$

For vertical surface facing due south the tilt angle $\beta = 0$ and the surface azimuth angle $\boldsymbol{\gamma}$ becomes 0. Thus the equation (7) becomes

$$\cos\boldsymbol{\theta_Z} = \sin\boldsymbol{\phi}\ \cos\ \boldsymbol{\delta}\, cos\ \boldsymbol{\omega} - \cos\boldsymbol{\phi}\ \sin\boldsymbol{\delta} \qquad (9)$$

2.5.12 Sunrise or sunset hour angles (ω_S) and length of day:

The hour angle at the time of sunset or sunrise on a horizontal plane is called sunrise or sunset hour angle ω_S. At the time of sunset or sunrise the zenith angle $\theta_Z = 90^0$ and the equation (8) becomes

$$0 = \sin\boldsymbol{\phi}\ \sin\boldsymbol{\delta} + \cos\boldsymbol{\phi}\ \cos\boldsymbol{\delta}\ \cos\boldsymbol{\omega}$$

$$\cos\boldsymbol{\omega_S} = -\tan\boldsymbol{\phi}\ \tan\boldsymbol{\delta} \qquad (10)$$

$$\boldsymbol{\omega_S} = cos^{-1}(-\tan\boldsymbol{\phi}\ \tan\boldsymbol{\delta})$$

The value of ω_S may be positive and negative corresponding to sunrise and sunset respectively. The angle between sunrise and sunset is the **solar day length**. It is given by

Solar day length = $-2\boldsymbol{\omega_S} = 2\ cos^{-1}(-\tan\boldsymbol{\phi}\ \tan\boldsymbol{\delta})$

Since the time length is 1 hour corresponding to 15^0, the **duration of sunshine hour ($\boldsymbol{t_d}$)** or **daylight hours** is given by

$$\boldsymbol{t_d} = \textbf{Angle between sunrise and sunset / 15 hour}$$

$$\boldsymbol{t_d} = \frac{2}{15}\ cos^{-1}(-\tan\boldsymbol{\phi}\ \tan\boldsymbol{\delta}) \qquad (11)$$

For tilted surface, the sunrise or sunset hour angle ω_S can be obtained by using equation (7). During the period of 21 March and 22 September, there is a certain value of tilt angle $\boldsymbol{\beta}$ therefore the sunrise or sunset hour angle ω_S will be lesser than the value obtained by equation (10).

Similarly for **surface facing exactly south, the $\boldsymbol{\gamma} = 0$**, the main equation 2.7 becomes

$$\cos\boldsymbol{\theta} = \sin\boldsymbol{\phi}\,(\sin\boldsymbol{\delta}\ \ cos\boldsymbol{\beta} + \cos\boldsymbol{\delta}\ sin\ \boldsymbol{\omega}\ sin\ \boldsymbol{\beta})$$

$$+ \cos\boldsymbol{\phi}\ (\cos\boldsymbol{\delta}\cos\boldsymbol{\omega}\ \cos\boldsymbol{\beta} - \sin\boldsymbol{\delta}\sin\boldsymbol{\beta})$$

$$\text{or} \qquad \cos\boldsymbol{\theta} = \sin\boldsymbol{\delta}\ \sin(\boldsymbol{\phi} - \boldsymbol{\beta}) - \cos\boldsymbol{\omega}\ \cos\boldsymbol{\beta}\ cos\,(\boldsymbol{\phi} - \boldsymbol{\beta}) \qquad (12)$$

At the time of sunset or sunrise the zenith angle $\theta = \theta_Z = 90^0$ and on putting the value on the equation (12) we get the **hour angle for tilted surface** as

$$\boldsymbol{\omega_{ST} = 2\, cos^{-1}\, [-\tan(\phi - \beta)\ \tan\delta]} \qquad (\mathbf{13})$$

Corresponding day length can be given as

$$\boldsymbol{t_d = \frac{2}{15}\, cos^{-1}\, [-\tan(\phi - \beta)\ \tan\delta]} \qquad (\mathbf{14})$$

2.5.13 Local Solar time (LST) or local apparent time (LAT):

The time estimated by equation 7 with the help of other equations (8-14) is called Local Solar time (LST) or local apparent time (LAT).

LST may or may not be same as the local clock time. LST gives the idea about actual solar position at a particular point on earth. The local clock time at any place is set in such a way that at 12.00 noon, the sun becomes exactly on the overhead (i.e. zenith angle is 0) at that point. Different countries select a particular longitude for setting standard local time. For example Indian standard time is set corresponding to 82.5 east longitude (meridian). If the locations are different from selected longitude, then local solar time (LST) will be different than local clock time. For example in India, in northeast religion the local solar time is advanced them the local clock time (Indian standard time). This occurs due to change in longitude.

To calculate the LST time from the standard time observed on clock two corrections are to be made. The first correction appears due to difference between longitude of location and the longitude (meridian) on which standard time is set. This correction is of 4 minutes for every degree difference in the longitude. The second correction is called equation of time correction, this correction arises due to the fact that the Earth orbit and rate of rotation are not constant throughout the year, and it varies slightly. The equation of time correction is based on experimental results as plotted in figure 2.14. Thus the LST can be given as

$$\boldsymbol{LST = standard\ time \pm 4(standard\ time\ longitude - longitude\ of\ location) + equation\ of\ time\ correction}$$

In first correction, negative sign is used in eastern hemisphere and positive sign is used in western hemisphere.

Example

Calculator Local Solar time (LST) corresponding to 14.30 IST on July 19th 1998 at Pithoragarh (29.5° N, 80.5° E). The equation of time corresponding to 19th July 1997 is 6 minutes and Indian standard time (IST) or local clock time is based on the latitude 82.5 degree east. Also calculate declination.

Solution: Local Solar time (LST) or local apparent time (LAT) can be given as

$$LST = \text{standard time} - (\text{standard time longitude} - \text{longitude of location}) + \text{equation of time correction}$$

$$LST = 14.30 - 4(82^0.5' - 80^0.5') - 6\text{ min}$$

$$LST = 14.16\ \ hours$$

Declination can be calculated with the help of Cooper's equation that is

$$\boldsymbol{\delta = 23.45\, sin\, [(360/365)(284+n)]} \qquad (2)$$

where n is the day of year for example for 19 July, n= 31+28+31+30+31+30+19 = 200

$$\boldsymbol{\delta = 23.45\, sin\, [(360/365)(284+197)]}$$

$$\boldsymbol{\delta} = -8.5^0$$

2.6 Solar radiation measurements

The following instruments are used to measure duration and quantifying solar radiation.

1. Pyranometer: Measures the total or Global radiation i.e. the summation of direct and diffuse radiation
2. Pyrheliometer or Tube Solarimeter: Measures direct solar beam i.e. radiation falling on a plane surface at normal (perpendicular) incidence angle.
3. Sunshine Recorder: It measures the duration of Bright Sunshine (BSS) Hours in any given day.

2.6.1 Pyranometer:

A **pyranometer** is a type of actinometer used for measuring solar irradiance on a planar surface and it is designed to measure the solar radiation flux density (W/m^2) from the hemisphere above within a wavelength range 0.3 µm to 3 µm. A typical pyranometer does not require any power to operate. However, recent technical development includes use of electronics in pyranometers, which do require (low) external power.

Figure 2.14: **pyranometer**

Figure 2.15: Pyrheliometer or Tube Solarimeter

2.6.2. Pyrheliometer or Tube Solarimeter:

Pyrheliometers measure 'direct solar radiation' E: the amount of solar energy per unit area per unit time incident on a plane normal to the position of the sun in the sky, coming directly from the sun itself. This is also called 'direct normal irradiance', often abbreviated to DNI. A pyrheliometer needs to be mounted on a solar tracker: a device that points the instrument at the sun throughout the day.

2.6.3. Sunshine Recorder:

A sunshine recorder is a device that records the amount of sunshine at a given location or region at any time. The results provide information about the weather and climate as well as the temperature of a geographical area. This information is useful in meteorology, science, agriculture and other fields. It has also been called a heliograph. There are two basic types of sunshine recorders. One type uses the sun itself as a time-scale for the sunshine readings. The other type uses some form of clock for the time scale. Older recorders required a human observer to interpret the results; recorded results might differ among observers. Modern sunshine recorders use electronics and computers for precise data that do not depend on a human interpreter. Newer recorders can also measure the global and diffuse radiation.

Figure 2.16: sunshine recorder

2.7 Average daily global solar radiation:

The average daily solar radiation at any place is an important parameter to assess the solar radiation power. It varies different places on the earth. The best approves to estimate the solar radiation at any place is to measure the solar radiation over a period of time at that place and on the basis of data, we can estimate the solar radiation. If this is not possible, data from the nearby locations having similar latitude, climate conditions and geographical condition can be used to estimate the solar radiation. Sometime empirical relation can be used to calculate the average daily global solar radiation at any location. The first attempt to estimate the solar radiation was made by Angstrom in 1924. He suggested that monthly average daily global radiation can be given in the terms of sunshine hours as given below.

$$\frac{H}{H_0'} = a' + b'\left(\frac{S}{S_{max}}\right)$$

where H is monthly average of daily global radiation on horizontal surface at a location.

H_0'= monthly average of daily global radiation on horizontal surface at a location on a clear sky

$S =$ monthly average of sunshine hours per day at a location

$S_{max} =$ monthly average of the maximum sunshine hours per day at a location (day length t_d)

$a', b' =$ arbitrary constants

It is very difficult to decide clear sky thus sometime the factor H_0' is replaced by H_0 which is monthly average of daily extraterrestrial radiation which falls on horizontal surface at that location. Thus above relation becomes

$$\frac{\boldsymbol{H}}{\boldsymbol{H_0}} = \boldsymbol{a} + \boldsymbol{b}\left(\frac{\boldsymbol{S}}{\boldsymbol{S_{max}}}\right)$$

The values of constant a and b of some cities are given in given table.

Location	a	b	Location	a	b
Ahmadabad	0.28	0.48	Bangalore	0.18	0.64
Baroda	0.28	0.48	Bhopal	0.27	0.50
New Delhi	0.25	0.57	Roorkee	0.25	0.57
Calcutta	0.28	0.42	Jodhpur	0.33	0.48
Chennai	0.30	0.44	Pune	0.30	0.51
Hamburg	0.22	0.57	Texas USA	0.54	0.20

The empirical relation for calculating H_0 is given as

$$\boldsymbol{H_0} = \frac{\boldsymbol{24}}{\boldsymbol{\pi}}\boldsymbol{I_{Sc}}\left[\boldsymbol{1} + \boldsymbol{0.033}\,\boldsymbol{cos}\left(\frac{\boldsymbol{360n}}{\boldsymbol{365}}\right)\right] \times [\boldsymbol{cos\,\phi\,cos\,\delta\,sin\,\omega_s} + \boldsymbol{\omega_s\,sin\,\phi\,\,sin\,\delta}]$$

Here the symbols have their usual meaning. In this imperial relation, declination $\boldsymbol{\delta}$, sunrise hour angle $\boldsymbol{\omega_S}$ and day length $\boldsymbol{t_d}$ (as previously defined) can be given as

$$\boldsymbol{\delta} = \boldsymbol{23.45\,sin}\,[(\boldsymbol{360/365})(\boldsymbol{284} + \boldsymbol{n})]$$

$$\boldsymbol{\omega_S} = \boldsymbol{cos}^{-\boldsymbol{1}}\,(-\,\mathbf{tan}\,\boldsymbol{\phi}\,\,\mathbf{tan}\,\boldsymbol{\delta})$$

$$\boldsymbol{S_{max}} = \boldsymbol{t_d} = \frac{\boldsymbol{1}}{\boldsymbol{15}}2\boldsymbol{\omega_S} = \frac{\boldsymbol{2}}{\boldsymbol{15}}\boldsymbol{cos}^{-\boldsymbol{1}}[-\,\mathbf{tan}\,\boldsymbol{\phi}\,\,\mathbf{tan}\,\boldsymbol{\delta}]$$

Example: Calculate the average value of solar radiation on a horizontal surface on the Delhi (28^0 $35'$ N, 77^0 $12'$ E) on June 19. The constant *a* and *b* are as 0.25 and 0.57 respectively. The average sunshine hours per day are 7.5 hours.

Solution:

The declination $\boldsymbol{\delta}$ (as previously defined) can be given as

$$\boldsymbol{\delta = 23.45\, sin\, [(360/365)(284+n)]}$$

On June 19, n=31+28+31+30+31+19 = 170, putting this value in above eq.

$$\boldsymbol{\delta = 23.45\, sin\, [(360/365)(284+170)]}$$

$$\boldsymbol{\delta = 23.43^0}$$

Sunrise hour angle $\boldsymbol{\omega_S}$ (as previously defined) can be given as

$$\boldsymbol{\omega_S = \; cos^{-1}\,(-\tan\phi\; \tan\delta)}$$

Here $\boldsymbol{\phi = 28.35^0}$, putting these value in above eq.

$$\boldsymbol{\omega_S = \; cos^{-1}\,(-\tan 28.35\; \tan 23.43) = 76.5^0 = 1.33\, radian}$$

$$\boldsymbol{Solar\ constant\ I_{Sc} = 1.353\frac{kJ}{m^2-s} = 1.353\times 3600\frac{kJ}{m^2-hour}}$$

H_0 is given as

$$\boldsymbol{H_0 = \frac{24}{\pi} I_{Sc}\left[1+0.033\, cos\,\left(\frac{360n}{365}\right)\right]\times[cos\,\phi\, cos\,\delta\, sin\,\omega_s + \omega_s\, sin\,\phi\;\, sin\,\delta]}$$

$$\boldsymbol{H_0 = \frac{24}{\pi} 1.353\times 3600\left[1+0.033\, cos\,\left(\frac{360\times 170}{365}\right)\right]}$$
$$\boldsymbol{\times[cos\,35\, cos\,23.4\, sin\,76.5 + 1.33\, sin\,35\;\, sin\,23.4]}$$

$$\boldsymbol{H_0 = 37229.04\times[1.016]\times[.678 + .30] = 10144.17}$$

$$\boldsymbol{H_0 = 36689.92\,\frac{kJ}{m^2-day}}$$

day length $\boldsymbol{t_d}$ (as previously defined) can be given as

$$\boldsymbol{S_{max} = t_d \; = \frac{2}{15} cos^{-1}[-\tan\phi\; \tan\delta]}$$

$$\boldsymbol{S_{max} = t_d \; = \frac{2}{15} cos^{-1}[-\tan 28.35\; \tan 23.4]}$$

$\boldsymbol{S_{max} = t_d}$ **= 13.69 h**

Here sunshine hours per day is S =7.5 hours

Thus

$$\frac{H}{H_0} = a + b\left(\frac{S}{S_{max}}\right)$$

$$\frac{H}{36689.92} = 0.25 + 0.57\left(\frac{7.5}{13.69}\right)$$

$$H = 20629.69\frac{kJ}{m^2 - day}$$

2.8 Solar Thermal Collectors:

A thermal collector is a device which collects solar radiation energy. Solar radiation is energy in the form of electromagnetic radiation from the infrared (long) to the ultraviolet (short) wavelengths. Solar collectors are two types. One is flat plate collector or non-concentrating. In the non-concentrating type, the collector area (i.e., the area that intercepts the solar radiation) is the same as the absorber area (i.e., the area absorbing the radiation). In these types the whole solar panel absorbs light. Non concentrating solar thermal collectors are generally used for low and medium temperature requirements. Solar water heating is the perfect example of a non - concentrating type of solar thermal application. This type of collector are simple in design and there is no moving part so needs less maintenance. The collectors collect both direct and diffused solar radiation energy. With the help flat plate collectors the temperature of the working fluid can be raised up to 40 to 100^0 C. Working fluid is the fluid (water or other aqueous solution) which is used for transfer of heat energy from solar collector to storage device or turbine.

Other type of collector is concentrating collectors which have a larger interceptor than absorber. Mirrors or lenses are used to concentrate solar radiation on a small absorber area. For example, a large convex lance can be used to focus or concentrate solar radiation in a small absorber area. With the help concentrating collectors the temperature of the working fluid can be raised up to 100 to 400^0 C.

2.8.1 Flat Plate Solar Thermal Collectors:

2.8.1.1 Flat Plate Collectors -consist of a thin metal box with insulated sides and back, a glass or plastic cover (the glazing) and a dark colour absorber. The glazing allows most of the solar energy into the box whilst preventing the escape of much of the heat gained. The absorber plate is in the box painted with a selective dark colour coating, designed to maximize the amount of solar energy absorbed as heat. Running through the absorber plate are many fine tubes, through which water is pumped. As the water travels through these tubes, it absorbs the heat. This heated water is then gathered in a larger collector pipe to be transported into the hot water system.

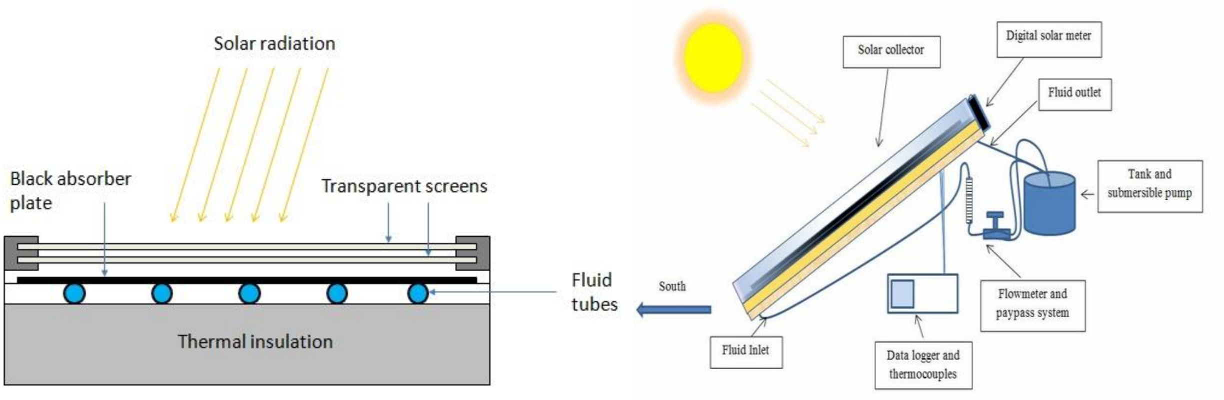

Figure 2.17: Flat Plate Collectors and its working

2.8.1.2 Evacuated Tube Collector:

Evacuated tube collectors are more modern and more efficient in design. These can heat water to much higher temperatures and require less area. However, they are also correspondingly more expensive. Instead of an absorber plate, water is pumped though absorber tubes (metal tubes with a selective solar radiation absorbing coating), gaining heat before going into the collector pipe. Each absorber tube is housed inside a glass tube from which the air has been evacuated forming a vacuum. The glass tube allows solar radiation through to the absorber tube where it can be turned into heat. The vacuum eliminates convective as well as conductive heat loss and virtually all heat absorbed is transferred to the water.

Figure 2.18 Evacuated Tube Collector

2.8.2 Concentrating Solar collectors

These systems utilize solar radiation to generate heat – as hot water, air or steam that can be readily deployed for meeting numerous applications in different sectors such as industrial process heating, power generation on a large scale and space heating/cooling. These applications make use of solar energy collectors as heat exchangers that transform solar radiation energy to internal energy of the transport medium (or heat transfer fluid, usually air, water, or oil).The solar energy thus collected is carried from the circulating fluid either directly to the hot water or space conditioning equipment or to a thermal energy storage tank from which can it be drawn for use at night and/or cloudy days. Unlike the non - concentrating solar thermal systems, concentrating solar thermal systems use mirrors and lenses to reach higher temperature mainly for various industrial processes. Under the concentrating type - there are imaging and non - imaging technologies. Imaging technologies have a smaller range of acceptance angle compared to that of non - imaging technologies. For example, imaging concentration gives about 1/3 of the theoretical maximum for the design acceptance angle, that is, for the same overall tolerances for the system. Non - imaging optics, which have a larger acceptance angle range, can be used to approach the theoretical maximum.

Imaging technologies, which make use of mirrors and lenses, are divided in to two types each based on the focus and receiver type. Line Focus collectors track the sun along a single axis and focus the irradiance on a linear receiver. Point focus collectors track the sun along two axes and focus the irradiance at a single point receiver which allows for higher temperatures. Fixed receivers are stationary devices that remain independent of the plant's focusing device which eases the transport of collected heat. Mobile receivers move together with the focusing device which enables more energy to be collected. The different types of solar thermal technologies are depicted in the figure below.

The Concentrating Solar collectors are classified in following categories.

A. Point Focus Technology (examples are Fixed focus automatically tracked elliptical dish (Scheffler dish) etc.)
B. Line Focus Technology (example are parabolic troughs collectors (PTC), Linear Fresnel Reflector (LFR) etc.)
C. Non-Focussing Technology (examples is Compound Parabolic Collectors(CPC))

In focusing type collector, the solar radiation is focused onto the absorber with the help of lens. However in non-focusing type collector, the solar radiation is reflected to the absorber with the help of mirrors. For basic understanding, the Linear Fresnel Reflector (LFR) is shown in figure 2.19 and discussed below.

2.8.3 Linear Fresnel reflector (LFR):

A compact linear Fresnel reflector (CLFR) – also referred to as a concentrating linear Fresnel reflector – is a specific type of linear Fresnel reflector (LFR) technology. They are named for their similarity to a Fresnel lens, in which many small, thin lens fragments are combined to simulate a much thicker simple lens. These mirrors are capable of concentrating the sun's energy to approximately 30 times its normal intensity. Linear Fresnel reflectors use long, thin segments of mirrors to focus sunlight onto a fixed absorber located at a common focal point of the reflectors. This concentrated energy is transferred through the absorber into some thermal fluid (this is typically oil capable of maintaining liquid state at very high temperatures). The fluid then goes through a heat exchanger to power a steam generator. As opposed to traditional LFR's, the CLFR utilizes multiple absorbers within the vicinity of the mirrors.

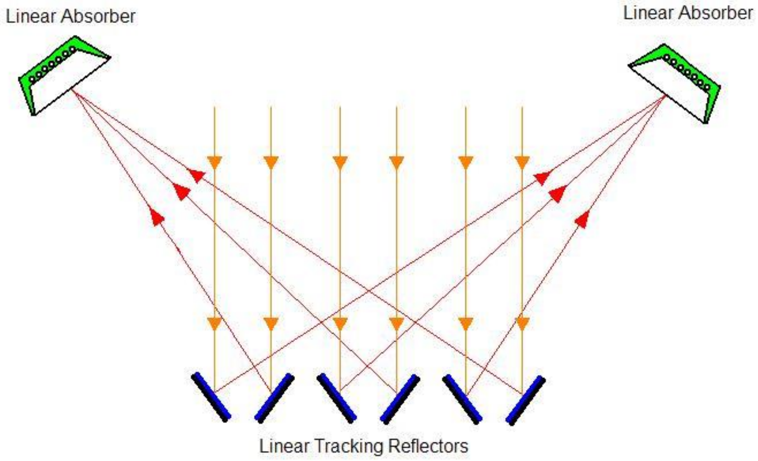

Figure 2.19 Linear Fresnel reflector

Design: The reflectors are located at the base of the system and converge the sun's rays into the absorber. A key component that makes all LFR's more advantageous than traditional parabolic trough mirror systems is the use of "Fresnel reflectors". These reflectors make use of the Fresnel lens effect, which allows for a concentrating mirror with a large aperture and short focal length while simultaneously reducing the volume of material required for the reflector. This greatly reduces the system's cost since sagged-glass parabolic reflectors are typically very expensive. However, in recent years thin-film nanotechnology has significantly reduced the cost of parabolic mirrors.

A major challenge that must be addressed in any solar concentrating technology is the changing angle of the incident rays (the rays of sunlight striking the mirrors) as the sun progresses throughout the day. The reflectors of a CLFR are typically aligned in a north-south orientation and turn about a single axis using a computer controlled solar tracker system. This allows the system to maintain the proper angle of incidence between the sun's rays and the mirrors, thereby optimizing energy transfer.

Absorber: The absorber is located at the focal line of the mirrors. It runs parallel to and above the reflector segments to transport radiation into some working thermal fluid. The basic design of the absorber for the CLFR system is an inverted air cavity with a glass cover enclosing insulated steam tubes, shown in Fig.2. This design has been demonstrated to be simple and cost effective with good optical and thermal performance.

Applications: In March 2009, the German company Novatec Biosol constructed a Fresnel solar power plant known as PE 1. The solar thermal power plant uses a standard linear Fresnel optical design (not CLFR) and has an electrical capacity of 1.4 MW. PE 1 comprises a solar boiler with mirror surface of approximately 18,000 m^2 (1.8 ha; 4.4 acres). The steam is generated by concentrating sunlight directly onto a linear receiver, which is 7.40 metres above the ground. An absorber tube is positioned in the focal line of the mirror field where water is heated into 270 °C (543 K; 518 °F) saturated steam. This steam in turn powers a generator. The commercial success of the PE 1 led Novatec Solar to design a 30 MW solar power plant known as PE 2. PE 2 has been in commercial operation since 2012.

2.8.4 Fresnel Reflector Based Dish (ARUN Dish)

ARUN dish is a Fresnel paraboloid solar concentrator with a point focus. Fresnel Reflector Based Dish (ARUN Dish) is made from panels of flat mirrors mounted on a frame such that the incident sunlight is reflected on to a cavity receiver which is specially designed to reduce heat losses. The receiver which is insulated on the outside is held in a fixed position in relation to the reflectors by means of a suitable structure. The entire array of panels with the receiver move to track the sun. The cavity receivers allow energy to be intercepted by a small aperture or opening which results in low losses. The inside of the cavity may be specially coated to increase its absorption of the sunlight that falls on it. There are certain mechanisms to prevent or reduce convective heat losses from the receiver. Usually Fresnel Dishes are large and could have an aperture area of 100 m2 or 160 m2. Schematic diagram is shown in figure 2.

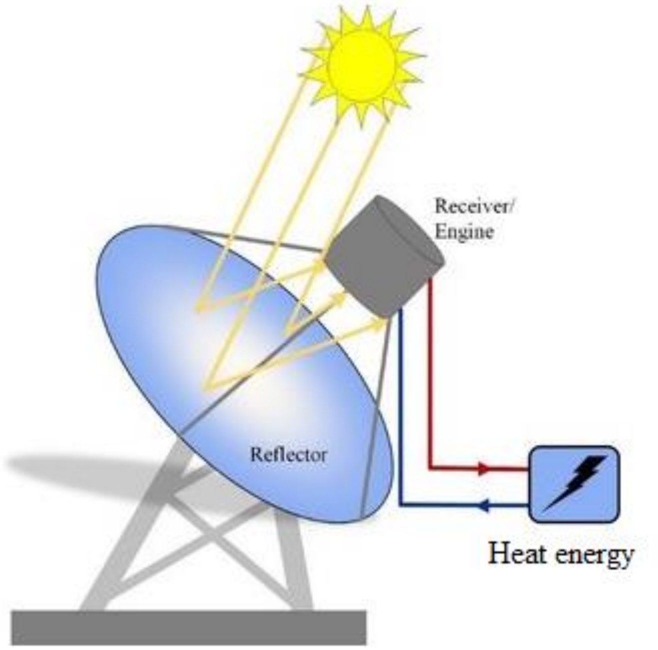

Figure 2.20: Schematic diagram ARUN dish

It can handle various heat transfer fluids including steam, hot oil, hot water or even hot air at temperatures up to 350°C and pressures up to 25 bar. The low area required for installation makes it ideal for industries with space constraints. ARUN is currently being used for various industrial process heating applications like steam generation for process heating in various industries including laundry, food processing, auto, dairy, pharma, chemical, hospitality, amongst others. It has also been installed for comfort cooling, industrial canteen cooking, sterilization, milk pasteurization, effluent evaporation, etc.

For example, Mother Dairy, Patparganj, New Delhi has installed 1520 sq. m of Paraboloid Dish (Dual axis) for generating upto 1 Lakh Ltrs. of hot water per day at upto 85°C for cleaning application. CST system generates hot water at required temperature and stores it in insulated tanks, so as to utilize it anytime as per process requirement. This is one of the largest solar thermal projects for industrial process heating application with total solar field collector area of 1520 m2. Solar Thermal System since its inception in last two months itself has helped save more than 60,000 kg of CO2 which has been another huge advantage for environment.

Figure2.21 : 1520 sq. m of Paraboloid Dish at Mother Dairy, New Delhi

2.9 Summary

1. Sun provides the energy to our planet Earth and responsible for the existence of life. The radius of the sun is 6.9×10^8m while the radius of the earth is 6.4×10^6m. The mass of sun is 2×10^{30} kg which is around 333,000 times the mass of Earth (5.97×10^{24} kg). The mean distance between sun and earth is 1.5×10^{11} m which is called one Astronomical unit (AU)
2. The earth received solar energy from the sun. Due to motion of earth and climate conditions the amount of energy varies at different points on the earth at different time. The rate at which solar energy reaches at the top of earth atmosphere is called solar constant I_{SC}.
   I_{SC} = 1353 W/m^2(watts per square meter (kW/m^2
3. Solar radiation incident on the outer atmosphere of the earth is called extraterrestrial radiation. The extraterrestrial radiation on any day of the year can be calculated by given formula

$$I'_{SC} = I_{SC}\left[1 + 0.033\cos\left(\frac{360n}{365}\right)\right]$$

4. . The solar radiation that reaches earth’s surface after passing through earth’s atmosphere is called terrestrial radiation.
5. Total or global radiation at any location on earth’s surface= beam radiation + diffuse radiation.
6. Air mass is the ratio of the path through the atmosphere to the vertical path length when the sun is directly overhead i.e. sun is at the zenith. The air mass is unity when the sun is vertically is in the sky (directly overhead or inclination angle 90^0).
7. Declination ($\boldsymbol{\delta}$) is the angle made by the line joining the centers of sun and earth with its projection on equatorial plane. It arises due to tilt of earth of its rotational axis.
$$\boldsymbol{\delta = 23.45\, sin}\, [(\mathbf{360/365})(\mathbf{284}+\boldsymbol{n})]$$
8. The hour angle at any instant is the angle through which the earth must turn to bring the meridian at a point directly in line with sun’s rays. It is an angular measure of time and 1 hour is equivalent to 15 degree. It also varies from +180˚to - 180˚ corresponding to longitude.
9. Altitude angle is the vertical angle between direction of sun ray and projection of sun ray on the horizontal plane.
10. Zenith angle (θ_Z) is a vertical angle between the sun’s ray and a line perpendicular to horizontal plane at any point i.e. zenith line. Zenith line always passes through center of the earth. It is clear from the figure the relation between the zenith angle and altitude angle is
$$\theta_Z + \boldsymbol{\alpha} = 90^0$$
11. Solar azimuth angle (γ_s) is the angle on the horizontal plane measured from the extreme north to the horizontal projection of sun’s ray.
12. Surface azimuth angle (γ) is the angle on the horizontal plane between line due south and the projection of the normal to the surface on horizontal plane.
13. The hour angle at the time of sunset or sunrise on a horizontal plane is called sunrise or sunset hour angle ω_S.
$$\boldsymbol{\omega_S = \, cos^{-1}}\,(-\tan\boldsymbol{\phi}\, \tan\boldsymbol{\delta})$$
14. The angle between sunrise and sunset is the **solar day length**. It is given by
Solar day length = $-2\boldsymbol{\omega_S} = \mathbf{2}\, \boldsymbol{cos^{-1}}\,(-\tan\boldsymbol{\phi}\, \tan\boldsymbol{\delta})$
15. The duration of **sunshine hour ($\boldsymbol{t_d}$)** or **daylight hours** is
$$\boldsymbol{t_d} = \frac{\mathbf{2}}{\mathbf{15}}\, \boldsymbol{cos^{-1}}\,(-\tan\boldsymbol{\phi}\, \tan\boldsymbol{\delta})$$
16. The equation of time correction is based on experimental results the LST can be given as
$$\boldsymbol{LST = \, standard\ time \pm 4(standard\ time\ longitude - longitude\ of\ location) + equation\ of\ time\ correction}$$
17. The monthly average daily global radiation can be given in the terms of sunshine hours as given below.

$$\boldsymbol{\frac{H}{H_0} = a + b\left(\frac{S}{S_{max}}\right)}$$

The values of constant a and b are different for different cities or locations.

18. The empirical relation for calculating H_0 is given as

$$\boldsymbol{H_0 = \frac{24}{\pi} I_{Sc}\left[1 + 0.033\, cos\,\left(\frac{360n}{365}\right)\right]} \times [\boldsymbol{cos\,\phi\, cos\,\delta\, sin\,\omega_s + \omega_s\, sin\,\phi\ \ sin\,\delta}]$$

Here the symbols have their usual meaning. In this imperial relation, declination $\boldsymbol{\delta}$, sunrise hour angle $\boldsymbol{\omega_S}$ and day length $\boldsymbol{t_d}$ (as previously defined).

19. A thermal collector is a device which collects solar radiation energy.

2.10 Glossary

Solar constant: The rate at which solar energy reaches at the top of earth atmosphere.

Global radiation: Total radiation at any location on earth's surface (beam radiation + diffuse radiation)

Declination: the angle made by the line joining the centers of sun and earth with its projection on equatorial plane.

Hour angle: The angle through which the earth must turn to bring the meridian at a point directly in line with sun's rays.

Altitude angle: The vertical angle between direction of sun ray and projection of sun ray on the horizontal plane.
Zenith angle: vertical angle between the sun's ray and a line perpendicular to horizontal plane at any point i.e. zenith line.

LST: Local Solar time
LAT: local apparent time

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2.12 SUGGESTED READING

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2. Solar Energy, S P Sukhatme and J K Nayak, *McGraw Hill Education (India) Private Limited* (2018)

2.13 Terminal Questions

Short answer type Questions

1. What do you mean by solar radiation and solar constant?

2. Explain extraterrestrial radiation and give the formula for calculating the extraterrestrial radiation on any day of the year.
3. Explain spectral distribution of extra-terrestrial solar radiation and give the idea abuts the different wavelengths available in the solar radiation.
4. Define air mass.
5. Define Local Solar time (LST) or local apparent time (LAT).
6. What do you mean by Solar Thermal Collectors?
7. Classify different types of collectors.
8. Explain the working of compact linear Fresnel reflector (CLFR).

Long answer type Questions

1. What is terrestrial radiation? Give different types of solar radiation that reaches earth's surface after passing through earth's atmosphere.

2. Define following terms for solar geometry.
(a) Declination = $\boldsymbol{\delta}$
(b) Hour Angle= $\boldsymbol{\omega}$
(c) Tilt or Slope = $\boldsymbol{\beta}$
(d) Altitude angle = $\boldsymbol{\alpha}$
(e) Zenith angle= $\boldsymbol{\theta_Z}$

3. Explain the hour angle and obtain Sunrise or sunset hour angles (ω_S). Define the expression for length of day.

4. Define following terms for solar geometry.
(a) Hour Angle= $\boldsymbol{\omega}$

(b) Altitude angle $= \boldsymbol{\alpha}$
(c) Zenith angle$= \boldsymbol{\theta_Z}$
(d) Solar azimuth angle $= \boldsymbol{\gamma_s}$

5. With the help of diagram explain the working of different types of Flat plate Solar Thermal Collectors.
6. What are Concentrating Solar collectors?

Numerical answer type Questions

1. Calculate the day length on April 1and November 1 for a south facing surface tilted at an angle of 40 degree at Delhi (28^0 35′ N, 77^0 12′).

2. Calculate the sunset hour angle and day length at a location of on February 8 at location at Delhi (28^0 35′ N, 77^0 12′).

UNIT 3 SOLAR PHOTOVOLTAIC DEVICES

Structure

3.1 INTRODUCTION

There are two distinct technologies used in the direct exploitation of solar energy captured by solar panels, one is thermal solar energy, which generates calories, and another is solar photovoltaic energy, which produces electricity.

In our pursuit of a greener, more sustainable future, solar photovoltaic (PV) technology is a shining example of sustainable energy generation. Fundamentally, photovoltaic technology uses the inexhaustible energy of the Sun to turn that energy directly into electricity, a process that embodies the marvels of modern science and engineering. Since it provides a dependable and increasingly affordable response to the urgent problems of climate change and energy security, this ground-breaking method of producing electricity has quickly developed into a key component of renewable energy systems throughout the world.

PV devices, which are the core of solar photovoltaic systems, are available in a variety of configurations, from modern thin-film technologies to conventional silicon-based solar panels. Each type of device has its own distinctive set of characteristics, efficiencies and applications. These devices show remarkable versatility in satisfying the increasing need for clean electricity worldwide, from large solar farms to residential rooftops. Solar PV has the potential to completely transform our energy landscape and bring in a future powered by the sun's infinite energy with further research, development, and widespread acceptance.

3.2 OBJECTIVES

After studying this unit, you should be able to-

- Understand about Photovoltaic technology
- Explain Solar cell technology in detail
- Explain characteristics of PV system and its equivalent circuit
- Explain components, sizing and economics of PV system
- Understand peak power operation
- Explain stand alone and grid connected systems
- Explain solar constant, solar radiation spectrum and classification of solar cell

- Understand first generation single crystalline and poly crystalline and its application

3.3 PHOTO VOLTAIC TECHNOLOGY- PRESENT STATUS

In 2023, three-quarters of the global increase in renewable capacity came from solar photovoltaics alone. Over the next five years, there will be a continued increase in the capacity added to renewable power sources, with solar PV and wind power accounting for a record 96% of this growth. This is because, in most countries, their generation costs are lower than those of both fossil and non-fossil alternatives, and policies continue to promote them.

In comparison to 2022, solar PV and wind additions are expected to more than double by 2028, consistently overtaking records to reach almost 710 GW. In 2022, there was a 26% (270 TWh) increase in photovoltaic energy output, reaching around 1400 TWh. It has been demonstrated the highest absolute growth rate among all the renewable technologies in 2022. This generation growth rate between 2023 and 2030 matches the level projected in the Net Zero Emissions by 2050 scenario. Due to PV's continued economic attractiveness, the supply chain's quick expansion, and the increasing legislative support it is receiving, especially in China, the US, the EU, and India, capacity growth is expected to pick up even more pace in the coming years. The Net Zero Scenario requires yearly capacity additions that are almost three times higher than those realized between 2022 and 2030 to sustain generating growth. To get there, there needs to be persistent political ambition and efforts from both the public and private sectors, especially in integrating the frame and resolving political, regulatory, and funding-related challenges.

3.4 SOLAR CELL TECHNOLOGY

A solar cell, also referred to as a photovoltaic cell (PV), is an electrical device that directly converts light energy into electrical power by means of photovoltaic effect. It has to do with a photoelectric cell, which changes its electrical properties in reaction to sun radiation. A common component of photovoltaic modules' electrical systems is independent solar equipment. Another slang word for these individual solar cell devices is "solaires". The maximum open-circuit voltage that a simple solar cell with a single silicon junction can generate is between 0.5 and 0.6 volts. We will now discuss the central idea of photovoltaics (PV): the conversion of light into electrical energy. The word "photovoltaic" comes from the Greek words "photos," which means "light," and "Volta," which is the name of the Italian physician who discovered electricity in 1800s. However, French physicist Antoine Becquerel was the first to notice the conversion of energy through the variation in conductivity of a material under the effect of light.

Therefore, it follows that in order to facilitate this energy conversion, the photovoltaic material needs to possess particular optical and electrical properties. Three inter-related and simultaneous physical phenomena are involved in this process:

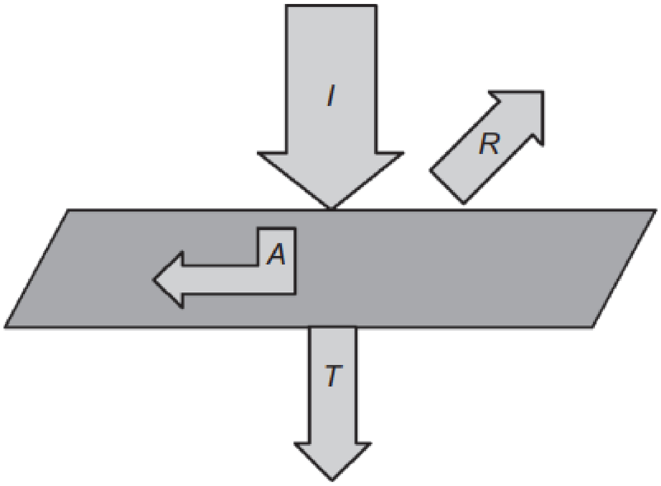
- Light absorption into the material
- Photon energy conversion into electrical charges
- Collection of current.

3.4.1 Absorption of light

We already know that light is made up of small particles called photons, each carrying energy dependent on its wavelength (or colour). These photons have the ability to enter certain materials and even go through them. Objects that are transparent for our eyes allow visible light to pass through them.

Three different kinds of optical events are seen when light impacts a substance.

- **Reflection:** light escaping from the surface of an object
- **Transmission:** the passage of light through a material
- **Absorption:** The process of light entering an object's interior and staying there while transforming its energy into a different form is known as absorption.



I (incident flux) = R (reflected) + A (absorbed) + T (transmitted)

Fig. 3.1 Reflection, transmission and absorption

Further information

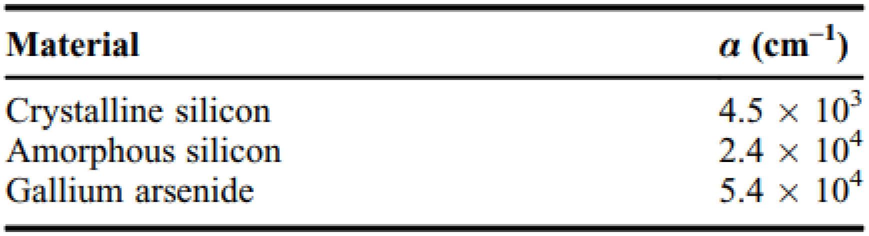
When a material absorbs light, energy is subject to a law of exponential reduction, because the part remaining to be absorbed reduces as it penetrates into the material. If E_{inc} is incident energy, the energy remaining at depth d is described thus:

$$E = E_{\text{inc}} e^{-\alpha d}$$

Thus, energy absorbed in thickness d is equal to

$$E_{\text{abs}} = E_{\text{inc}} - E_{\text{inc}} e^{-\alpha d} = E_{\text{inc}}(1 - e^{-\alpha d})$$

The *coefficient of absorption* α depends on the material and the wavelength of the incident energy. It is expressed as cm^{-1}, with the thickness d in cm.



Material	α (cm^{-1})
Crystalline silicon	4.5×10^3
Amorphous silicon	2.4×10^4
Gallium arsenide	5.4×10^4

Table 3.1 Optical absorption of some photovoltaic materials (thickness 0.59 mm)

Solar cell technology, also known as photovoltaics (PV), is the cornerstone of solar energy generation. At its essence, a solar cell is a semiconductor device that converts sunlight directly into electricity through the photovoltaic effect. Let us discuss some key aspects of solar cell technology.

Photovoltaic Effect: The photovoltaic effect is the phenomenon where certain materials generate an electric current when exposed to sunlight. This effect occurs due to the interaction between photons (particles of light) and electrons within the semiconductor material of the solar cell.

Semiconductor Materials: Solar cells are primarily made of semiconductor materials, most commonly crystalline silicon. Silicon solar cells dominate the market due to their efficiency, reliability, and abundance. Other semiconductor materials used in solar cells include thin-film materials like cadmium telluride (CdTe), copper indium gallium selenide (CIGS), and amorphous silicon.

Cell Structure: Once the silicon wafers usually p type have been formed, they must undergo the following stages in solar cell manufacture:

- Cleaning of the surface with caustic soda to repair damage caused during the sawing process, and etching to create a rough texture to increase their light gathering capacity.
- Treatment with phosphorus to create the PV junction, by forming an n+ layer on the surface and n at the junction.
- Doping of the base with aluminium (silk-screening and firing), which creates a diffusion p+ layer and a surface that improves the collection of charges.
- Deposition of an anti-reflective layer on the face.
- Deposition of a metallisation grill on the face (- electrode).
- Deposition of a solderable metal on the back (+ electrode).
- The testing and grading of all the cells manufactured.

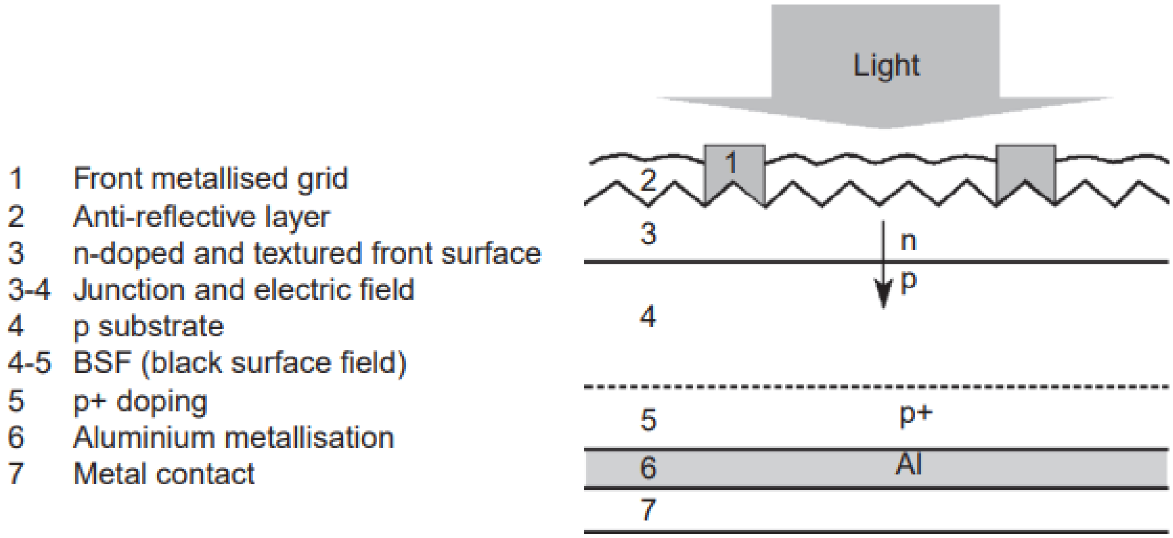


Fig. 3.2: Cross section of a monocrystalline silicon cell

Operation: When sunlight strikes the solar cell, photons with sufficient energy create electron-hole pairs in the absorption layer. The built-in electric field at the p-n junction separates these charge carriers, causing electrons to flow towards the front contact and holes towards the back contact, creating an electric current. This current can then be harnessed for various applications.

Efficiency: Solar cell efficiency refers to the percentage of sunlight converted into electricity. Efficiency varies depending on factors such as the semiconductor material used, cell design, and environmental conditions. Current commercial silicon-based solar cells typically have efficiencies ranging from 15% to 22%, while advanced technologies may achieve higher efficiencies.

Applications: Solar cells find widespread applications in both grid-connected and off-grid systems, including residential and commercial rooftops, solar farms, portable chargers, spacecraft, and more. They offer a reliable and sustainable source of electricity, reducing dependence on fossil fuels and mitigating greenhouse gas emissions. Continued research and development in solar cell technology aim to improve efficiency, reduce manufacturing costs, and expand applications, further solidifying solar energy's role as a vital component of the global energy mix.

3.4.1.1 From cell to module

The PV module is a collection of cells assembled to generate a usableelectric current when it is exposed to light. A single cell does not generate enough voltage, around 0.6 V for crystalline technology. Almost always, several cells have to be mounted in series to generate a useful voltage.

So modules of different powers are produced according to the surface area to be used (typically from 1 to 300 W_p/module), capable of generating direct current when they are exposed to the light. These modules constitute the energy producing part of a PV generator.

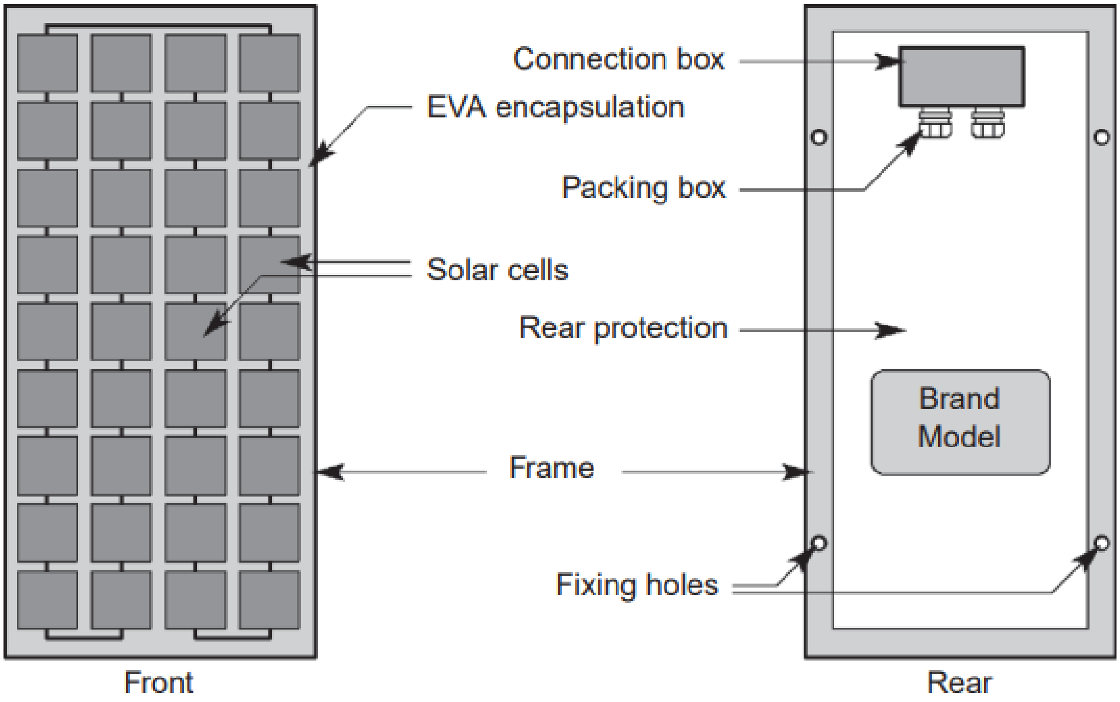


Fig. 3.3 Structure of a crystalline silicon PV module

3.5 EQUIVALENT CIRCUIT OF PHOTOVOLTAIC CELL

The equivalent circuit of a photovoltaic (PV) cell or module is a simplified electrical model that represents the behaviour and performance of the PV device under various operating conditions. It provides a convenient framework for analyzing and understanding the electrical characteristics of the PV system. Here's a detailed explanation of the components and parameters in the equivalent circuit:

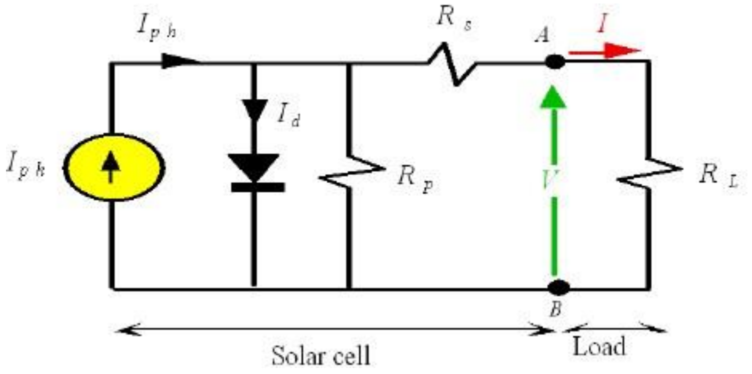


Fig. 3.4 Equivalent circuit of Solar cell or PV cell

Current Source (Iph): The photovoltaic effect generates a current (Iph) when photons from sunlight are absorbed by the semiconductor material of the PV cell. This current source represents the internal current generated by the incident light and is typically proportional to the intensity of sunlight.

Diode (D): The semiconductor material of the PV cell behaves like a diode, allowing current to flow in one direction while blocking it in the reverse direction. The diode represents the built-in potential barrier at the p-n junction of the cell. It is characterized by its saturation current (Is) and ideality factor (n), which determine its forward and reverse characteristics.

Series Resistance (Rs): Series resistance accounts for the internal resistance of the PV cell and interconnections within the module. It includes resistance from materials such as the metal contacts, busbars, and semiconductor material itself. Series resistance reduces the effective voltage output of the PV device under load and can vary with temperature and operating conditions.

Parallel Resistance (Rp): Parallel resistance is often included in the equivalent circuit to represent the high impedance path between the PV cell and ground. It accounts for the leakage current that bypasses the load resistance, particularly under open-circuit conditions. Parallel resistance is typically very high compared to series resistance and shunt resistance.

Load Resistance (RL): Load resistance represents the external electrical load connected to the PV device, such as a battery, inverter, or electrical grid. It determines the operating point of the PV system on the current-voltage (I-V) characteristic curve and affects the power output and efficiency of the system. Maximum power transfer occurs when the load resistance matches the internal resistance of the PV device.

The equivalent circuit of a PV cell or module is often represented using the single-diode model, which combines the aforementioned components into a concise and practical model for analysis and simulation. By accurately characterizing and understanding the behavior of the equivalent circuit, engineers and researchers can optimize the design, performance, and integration of PV systems for various applications and operating conditions.

3.6 CHARACTERISTICS OF PV SYSTEM

Photovoltaic (PV) characteristics encompass a range of properties and behaviours that define the performance and functionality of solar cells and PV systems. Understanding these characteristics is important for optimizing the design, operation, and integration of PV technology. Here's a detailed explanation of key photovoltaic characteristics:

Efficiency: Efficiency is a measure of how effectively a solar cell converts sunlight into electricity. It is typically expressed as a percentage and represents the ratio of electrical power output to the solar power input. Higher efficiency indicates a greater conversion of sunlight into usable electrical energy. Improving efficiency is a primary focus of PV research and development efforts.

I-V Curve (Current-Voltage Curve): The I-V curve illustrates the relationship between the current (I) and voltage (V) generated by a solar cell under varying levels of sunlight intensity (irradiance) and temperature. It helps characterize the electrical behavior of the cell and is essential for system design, performance analysis, and maximum power point tracking (MPPT) algorithms in PV inverters.

Maximum Power Point (MPP): The maximum power point is the operating point on the I-V curve where the solar cell or PV system generates the highest electrical power output. It varies with changes in sunlight intensity and temperature. MPPT techniques are employed to track and maintain operation at the MPP, optimizing energy harvest and system efficiency.

Fill Factor (FF): The fill factor is a measure of how effectively a solar cell utilizes its maximum power-producing capacity. It is calculated as the ratio of the maximum power output of the cell to the product of its open-circuit voltage and short-circuits current. A higher fill factor indicates better utilization of the cell's power-producing capability.

Temperature Coefficient: The temperature coefficient describes how a solar cell's electrical parameters, such as voltage, current, and power output, change with fluctuations in temperature. It is expressed as a percentage per degree Celsius (°C) change in temperature. Temperature coefficients help predict and compensate for performance variations due to temperature changes, ensuring reliable operation in different environmental conditions.

Spectral Response: The spectral response characterizes a solar cell's sensitivity to different wavelengths of sunlight across the solar spectrum. It indicates the cell's efficiency in converting photons of varying energies into electrical current. Understanding spectral response is crucial for optimizing cell materials and designs to maximize energy conversion efficiency under different light conditions.

Degradation and Aging: Solar cells and PV modules undergo gradual degradation and aging over time due to factors such as exposure to sunlight, temperature variations, humidity, and environmental stressors. Understanding degradation mechanisms and assessing long-term performance degradation is essential for predicting system lifespan, reliability, and maintenance requirements.

Shading Effects: Shading can significantly impact PV system performance by reducing sunlight exposure to individual cells or modules. Even partial shading of a small area can disproportionately decrease overall system output due to the series connection of cells within modules. Techniques such as bypass diodes and optimized array layouts are employed to minimize shading effects and maximize energy harvest.

By comprehensively analyzing and optimizing these photovoltaic characteristics, engineers and researchers can enhance the performance, reliability, and cost-effectiveness of solar cells and PV systems, further advancing the adoption of solar energy as a clean and sustainable power source.

3.6 ARRAY DESIGN

Designing a solar cell array involves arranging individual solar cells or modules into a larger system to achieve the desired power output, efficiency, and functionality. Several factors must be considered in array design to optimize performance and meet specific project requirements. To ensure an installed power of several hundred watts, kilowatts or even mega-watts, PV modules must be assembled in a PV array of varying area. Series and parallel assembly respond to known laws of electricity: when the modules are mounted in series, voltage increases and the current remains constant, and when they are mounted in parallel, the reverse is true, the current increases and the voltage remains constant. The current of the different panels therefore must be identical in a series array, and the same with voltage in a parallel array. The first rule to be remembered is that

- mount in series only those panels having the same operating current (and they need not have the same voltage)
- mount in parallel only those panels having the same operating voltage (but they need not have the same current).

In reality, as panels are not all absolutely identical, they can be paired in voltage or in current as required. This consists of connecting panels whose values are the closest. Even when paired, panels may not always output the same power on the ground, simply because they do not all receive the same solar radiation. A shadow falling on one part of the array can cause the output of the whole array to drop significantly for a time. The simplest way of avoiding any problem of this kind is to place anti-return diodes of adequate power at the output of each series of panels.

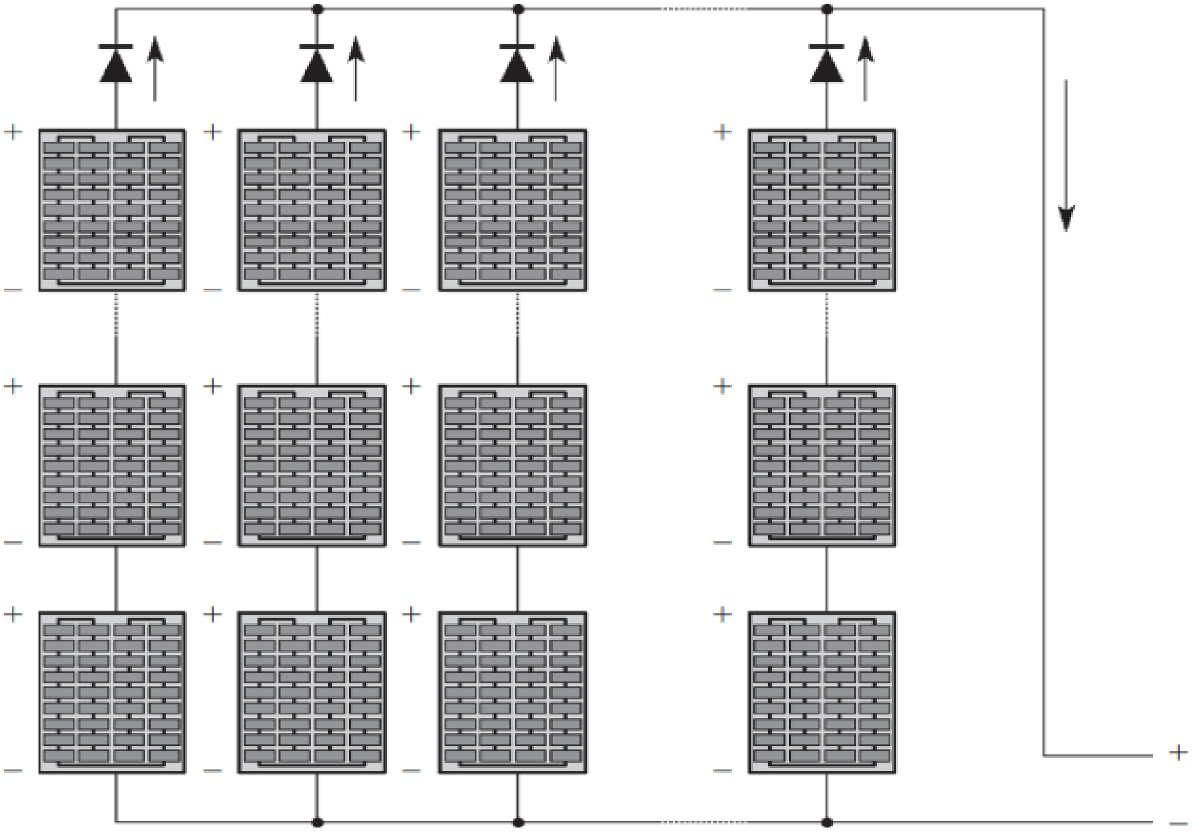


Fig.3.5 Array of panels mounted in parallel series

Some important steps of designing a Solar array are given in detail:

Cell or Module Selection: The first step in array design is selecting the appropriate type and configuration of solar cells or modules based on factors such as efficiency, cost, available space, and environmental conditions. Common types include mono-crystalline, polycrystalline, and thin-film solar modules, each with its own advantages and limitations.

Orientation and Tilt Angle: The orientation and tilt angle of the solar array significantly affect its energy production throughout the day and across seasons. In the northern hemisphere, optimal orientation is typically south-facing to maximize sunlight exposure. The tilt angle is often set equal to the latitude of the installation site for maximum annual energy yield, although adjustments may be made for specific applications or objectives.

Array Configuration: Solar cell arrays can be configured in various layouts, including fixed-tilt, tracking, and seasonal adjustment systems. Fixed-tilt arrays remain stationary and are cost-effective for most installations. Tracking systems continuously adjust the tilt and orientation of the array to track the sun's path throughout the day, maximizing energy capture. Seasonal adjustment systems allow for manual or automated tilt angle adjustments to optimize energy production during different seasons.

Shading Analysis: Shading from obstructions such as buildings, trees, or neighbouring structures can significantly impact the performance of a solar array by reducing sunlight exposure to individual cells or modules. Conducting a shading analysis helps identify potential shading issues and optimize the array layout to minimize shading losses. Techniques such as tilt angle optimization, string sizing, and module-level power electronics (MLPE) can mitigate shading effects and improve overall system performance.

String Configuration: Solar cells or modules are typically connected in series or parallel strings to form an array. Series connections increase the voltage output, while parallel connections increase the current output. The choice of string configuration depends on the system voltage requirements, shading conditions, and balance of system (BOS) considerations. String sizing and configuration must be carefully optimized to ensure proper voltage matching, current balance, and overall system reliability.

Electrical Design: The electrical design of a solar cell array includes sizing conductors, fuses, and circuit breakers, as well as selecting inverters, charge controllers, and other balance of system (BOS) components. Proper electrical design ensures efficient power transmission, protection against overcurrent and overvoltage conditions, and compliance with relevant electrical codes and standards.

Interconnection and Mounting: Solar cells or modules are interconnected using cables, connectors, and junction boxes to form a complete array. Mounting systems, such as roof mounts, ground mounts, or tracking systems, provide structural support and secure attachment of the array to the installation surface. Proper interconnection and mounting are essential for system safety, reliability, and longevity.

Monitoring and Maintenance: Once the solar array is installed, ongoing monitoring and maintenance are necessary to ensure optimal performance and longevity. Monitoring systems track energy production, system efficiency, and fault detection, allowing for timely maintenance and troubleshooting. Regular inspection, cleaning, and maintenance of the array components help prevent degradation, maximize energy yield, and extend the lifespan of the system.

By carefully considering these aspects of solar cell array design, engineers and project planners can optimize the performance, efficiency, and reliability of solar energy systems for various applications and environments. Effective array design plays a crucial role in harnessing the abundant energy of the sun and advancing the transition to clean, renewable energy sources.

3.8 BUILDING INTEGRATED PV SYSTEM AND ITS COMPONENT

Building Integrated Photovoltaics (BIPV) systems seamlessly integrate solar energy generation components into the architecture of buildings, serving both aesthetic and functional purposes. BIPV systems not only generate renewable electricity but also provide added value by acting as building elements such as roofs, facades, windows, or shading structures.

The detailed explanation of the components and characteristics of a Building Integrated PV system:

Solar Modules: BIPV systems utilize solar modules or panels that are specifically designed to blend with the architectural elements of the building. These modules can vary in size, shape, color, and transparency to suit different applications and design requirements. Common types of BIPV modules include solar roof tiles, solar glass panels, solar facades, and solar awnings.

Mounting and Integration Systems: Mounting and integration systems are used to securely attach BIPV modules to the building structure while maintaining the integrity of the building envelope. These systems are designed to withstand wind, snow, seismic loads, and other environmental conditions. They ensure proper alignment, spacing, and support of the modules while allowing for thermal expansion and contraction.

Electrical Components: BIPV systems include electrical components such as inverters, cables, connectors, junction boxes, and electrical enclosures. Inverters are used to convert the direct current (DC) generated by the solar modules into alternating current (AC) suitable for use in the building's electrical system. Cables, connectors, and junction boxes facilitate the connection and distribution of electrical power within the BIPV system.

Energy Storage (Optional): Some BIPV systems may include energy storage systems such as batteries or other storage devices to store excess energy generated during periods of high sunlight for use during periods of low sunlight or high electricity demand. Energy storage enhances the self-consumption of solar energy and provides backup power in the event of grid outages.

Building Integration Features: BIPV systems are designed to seamlessly integrate with the architectural features of the building, enhancing its aesthetic appeal and functionality. Solar modules can be integrated into roofs, facades, windows, skylights, canopies, balconies, and other building elements without compromising their structural integrity or visual appearance. BIPV systems can also provide additional benefits such as shading, daylighting, glare control, and thermal insulation.

Control and Monitoring Systems: Control and monitoring systems are used to monitor the performance, operation, and maintenance of BIPV systems. These systems collect data on energy production, system efficiency, weather conditions, and equipment status to optimize performance, diagnose faults, and schedule maintenance tasks. Advanced monitoring systems may include remote monitoring, data logging, analytics, and reporting capabilities.

Grid Connection and Net Metering: BIPV systems are typically connected to the electrical grid, allowing excess energy generated by the solar modules to be exported to the grid for credit or compensation. Net metering policies enable building owners to offset their electricity consumption with solar energy production, effectively reducing their utility bills and carbon footprint.

Regulatory and Permitting Requirements: BIPV systems must comply with local building codes, zoning regulations, and permitting requirements. Building permits may be required for the installation of BIPV systems, especially for structural modifications or electrical work. In addition, BIPV systems may be eligible for incentives, rebates, tax credits, or other financial incentives to promote their adoption and deployment.

Building Integrated Photovoltaics offer a versatile and sustainable solution for incorporating solar energy generation into buildings, transforming them into active contributors to the renewable energy transition. By integrating solar modules seamlessly into the built environment, BIPV systems not only generate clean energy but also enhance the architectural design, functionality, and value of buildings.

3.9 SIZING AND ECONOMICS

Sizing and economics are critical aspects of designing a photovoltaic (PV) system, ensuring that it meets energy requirements efficiently while remaining economically viable. Let's delve into each aspect in detail:

3.9.1 Sizing of Photovoltaic System

Load Analysis: Begin by analyzing the energy needs of the intended application or system. Determine the total electrical load, including both AC and DC loads, as well as any peak power requirements.

Solar Resource Assessment: Assess the solar resource available at the installation site. Factors such as solar irradiance, shading, orientation, and tilt angle influence the energy production potential of the PV system.

System Design: Based on the load analysis and solar resource assessment, determine the size and configuration of the PV system. Consider factors such as:

- **Peak power demand:** Size the system to meet peak power demand, accounting for variations throughout the day and year.
- **Energy storage:** Include battery storage capacity if the system requires energy storage for off-grid or backup power applications.
- **Grid connection:** Determine whether the system will be grid-connected or off-grid, considering grid interconnection requirements and regulations.
- **System losses:** Account for losses due to factors such as shading, soiling, temperature, and inverter efficiency.
- **Safety and reliability:** Design the system with safety features and redundancy to ensure reliable operation.

PV Array Sizing: Calculate the size of the PV array required to meet the energy demand of the load. Consider factors such as:

- **Capacity factor:** Estimate the average daily or annual energy output of the PV array based on the solar resource and system configuration.
- **Derating factors:** Apply derating factors to account for losses due to temperature, shading, soiling, and other factors.
- **Oversizing:** Consider oversizing the PV array to account for variations in solar irradiance, system degradation over time, and future load growth.
- **Balance of System (BOS):** Determine the sizing and specifications of balance of system components, including inverters, charge controllers, wiring, mounting structures, and electrical protection devices.
- **System Layout and Configuration:** Design the layout and configuration of the PV system, including the placement of PV modules, orientation, tilt angle, and wiring connections.

3.9.2: Economics of Photovoltaic System

Cost Analysis: Conduct a comprehensive cost analysis to estimate the capital cost of the PV system, including:

- Equipment costs: PV modules, inverters, mounting structures, balance of system components, and energy storage (if applicable).
- Installation costs: Labour, permitting, engineering, and other installation expenses.
- Operations and maintenance (O&M) costs: Estimate ongoing costs for system monitoring, maintenance, and repairs.
- Financing costs: Consider financing options, interest rates, and financial incentives such as tax credits, rebates, and grants.
- Financial Metrics: Calculate financial metrics to evaluate the economic viability of the PV system, including:
- Payback period: The time required for the cumulative savings from the PV system to equal the initial investment cost.
- Return on investment (ROI): The percentage return on the initial investment over the system's lifetime.
- Net present value (NPV): The present value of future cash flows generated by the PV system, adjusted for the time value of money.

- Internal rate of return (IRR): The discount rate that makes the NPV of the PV system's cash flows equal to zero.
- Financial Incentives: Explore available financial incentives, such as: tax credits,

3.10 PEAK POWER OPERATION

Peak power operation in the context of photovoltaic (PV) systems refers to the operation of the system at its maximum power output under specific conditions. Understanding peak power operation is crucial for optimizing the performance and efficiency of PV systems.

Peak power, also known as maximum power, refers to the maximum electrical power output that a PV system can produce under standard test conditions (STC). It is typically measured in watts (W) or kilowatts (kW) and represents the maximum energy that the system can deliver to the load or grid at a given moment. The peak power point (MPP) is the operating point on the current-voltage (I-V) characteristic curve of a PV system where it generates maximum electrical power. At the MPP, the product of the voltage and current is maximized, resulting in optimal power output. Several factors influence the peak power operation of a PV system:

Solar Irradiance: Peak power output increases with higher solar irradiance levels, as more sunlight is available to generate electricity. However, the relationship between irradiance and power output is not linear, and there may be diminishing returns at very high irradiance levels.

Temperature: PV modules experience a decrease in efficiency as temperature increases. Higher temperatures lead to higher module operating voltages but lower efficiency, affecting the overall power output of the system. Cooling measures such as ventilation or active cooling systems can help mitigate temperature effects and improve performance.

Shading: Shading from obstructions such as buildings, trees, or nearby structures can reduce the amount of sunlight reaching the PV modules, impacting their power output. Even partial shading of a small area can disproportionately decrease overall system output due to series connections within modules.

Angle of Incidence: The angle of incidence of sunlight on the PV modules affects the amount of light absorbed and converted into electricity. Adjusting the tilt angle or using tracking systems to optimize the angle of incidence can improve power output, especially in locations with varying sun angles throughout the day.

To ensure that a PV system operates at its peak power point under changing environmental conditions, maximum power point tracking (MPPT) algorithms are employed in PV inverters. MPPT continuously adjusts the operating voltage and current of the PV system to maintain operation at the MPP, maximizing energy harvest and system efficiency.

Designing the PV system with appropriate sizing, orientation, and tilt angle to maximize solar exposure. Implementing shading analysis to minimize shading losses and optimize array layout. Using high-efficiency PV modules and inverters to maximize power output under various operating conditions. Regular maintenance and monitoring of the PV system to ensure optimal performance and identify any issues affecting peak power operation.

In summary, peak power operation is essential for maximizing the energy output and efficiency of PV systems. By understanding the factors influencing peak power and employing effective optimization strategies, stakeholders can harness the full potential of solar energy and achieve maximum performance from their PV installations.

3.11 STAND ALONE AND GRID CONNECTED SYSTEMS

Stand-alone and grid-connected PV systems represent two distinct approaches to harnessing solar energy for electricity generation, each suited to different applications and requirements. Let's explore each in detail along with examples:

3.10.1 Stand-Alone PV Systems

Stand-alone PV systems, also known as off-grid systems, operate independently of the utility grid and are designed to meet the energy needs of a specific application or location without access to grid electricity. These systems typically incorporate batteries for energy storage to provide power when sunlight is unavailable. Key components and characteristics of stand-alone PV systems is given .

PV Modules: Photovoltaic modules are used to convert sunlight into electricity. They are typically installed on rooftops, ground-mounted structures, or other suitable locations to maximize solar exposure.

Charge Controller: A charge controller regulates the charging and discharging of batteries to prevent overcharging and deep discharge, extending battery life and ensuring system reliability.

Battery Bank: Energy storage is provided by a battery bank, which stores excess energy generated by the PV modules during periods of sunlight for use when solar generation is insufficient.

Inverter: An inverter converts the DC (direct current) electricity generated by the PV modules and stored in the batteries into AC (alternating current) electricity for use by AC-powered devices.

Examples of stand-alone PV systems include:

- Remote Off-Grid Homes: Homes located in remote or rural areas where grid electricity is unavailable or prohibitively expensive may use stand-alone PV systems to meet their energy needs independently.
- Off-Grid Cabins and Campsites: Cabins, campsites, and recreational vehicles (RVs) that are not connected to the grid may utilize stand-alone PV systems to power lighting, appliances, and other electrical devices.
- Telecommunications Towers: Stand-alone PV systems are commonly used to power remote telecommunications towers and equipment, providing reliable communication services in off-grid locations.

3.10.2 Grid-Connected PV Systems

Grid-connected PV systems, also known as grid-tied systems, are connected to the utility grid and operate in parallel with it. These systems feed excess energy generated by the PV modules into the grid, offsetting electricity consumption from the grid and potentially earning revenue through net metering or feed-in tariffs. Key components and characteristics of grid-connected PV systems are given:

PV Modules: Photovoltaic modules are installed on rooftops, ground-mounted structures, or other suitable locations to generate electricity from sunlight.

Inverter: An inverter converts the DC electricity generated by the PV modules into AC electricity synchronized with the grid's voltage and frequency.

Metering Equipment: Metering equipment, such as bi-directional utility meters, monitors the flow of electricity between the grid and the PV system, enabling accurate measurement of energy production and consumption.

Grid Connection: Grid-connected PV systems are connected to the utility grid through electrical wiring and grid interconnection equipment, allowing for the exchange of electricity with the grid.

Examples of grid-connected PV systems include:

- Residential Rooftop Solar: Homeowners install grid-connected PV systems on their rooftops to generate clean electricity for on-site consumption and potentially earn credits for excess energy fed back into the grid through net metering programs.
- Commercial and Industrial Buildings: Businesses and industries install grid-connected PV systems on their rooftops or land to reduce electricity costs, lower carbon emissions, and demonstrate corporate sustainability initiatives.
- Utility-Scale Solar Farms: Large-scale PV installations, often spanning several acres or hectares, generate electricity for distribution to the grid, providing clean, renewable energy to meet the needs of communities and regions.

Stand-alone and grid-connected PV systems offer distinct advantages and are suitable for different applications and contexts. Stand-alone systems provide energy independence in off-grid locations, while grid-connected systems enable integration with the utility grid for enhanced reliability, flexibility, and economic benefits. The choice between the two depends on factors such as location, energy requirements, cost considerations, and regulatory policies.

3.12 SOLAR CONSTANT AND SOLAR RADIATION SPECTRUM

The Solar Constant is a fundamental concept in the realm of solar energy and astrophysics, essential for understanding the potential and dynamics of solar radiation reaching the Earth's surface. For students delving into the realms of renewable energy or astrophysics, comprehending this concept is paramount. Let's explore what the Solar Constant entails and its implications for harnessing solar energy.

The Solar Constant refers to the amount of solar radiation received per unit area at a certain distance from the Sun. It represents the average solar irradiance measured at the Earth's distance from the Sun, approximately 1 astronomical unit (AU), or about 149.6 million kilometers. Expressed in watts per square meter (W/m^2), the Solar Constant represents the power per unit area received from the Sun in the form of electromagnetic radiation, including visible light, infrared, and ultraviolet radiation.

Solar radiation is the primary source of energy driving Earth's climate, weather systems, and supporting life through photosynthesis. It originates from the Sun's nuclear fusion reactions, where hydrogen nuclei fuse to form helium, releasing vast amounts of energy in the process. This energy radiates outward in all directions, eventually reaching the Earth. However, due to the vast distance between the Earth and the Sun and the Earth's orbit's elliptical nature, the amount of solar radiation received varies slightly throughout the year. The Solar Constant provides an average value of this radiation flux, enabling scientists to study and model Earth's climate and energy balance. It serves as a baseline for estimating the solar energy potential of a particular location. By knowing the Solar Constant and accounting for factors such as atmospheric conditions, geographical location, and solar panel efficiency, engineers and researchers can accurately predict how much solar energy can be harvested at a given location. The Solar Constant also influences the design and efficiency of solar energy systems. Solar panels and collectors are optimized to capture and convert solar radiation into usable energy. By maximizing exposure to sunlight and enhancing conversion efficiency, solar energy systems can harness more energy from the Sun, contributing to sustainable energy solutions.

While the Solar Constant provides a useful average, it's essential to recognize that solar radiation isn't constant throughout the day or year. Factors such as cloud cover, atmospheric absorption, and the Earth's tilt and rotation affect the amount of solar radiation reaching the surface. Additionally, geographical factors such as latitude, altitude, and local weather patterns further influence solar energy potential. For instance, regions closer to the equator generally receive more intense sunlight throughout the year compared to polar regions.

In conclusion, the Solar Constant serves as a fundamental concept in understanding solar radiation and its implications for solar energy harnessing. As we continue to advance renewable energy technologies, the knowledge of the Solar Constant will remain vital for optimizing solar energy systems and realizing a cleaner, more sustainable energy future.

3.12.1 Solar Radiation Spectrum

The Solar Constant, representing the average solar irradiance received at Earth's distance from the Sun, encompasses a broad spectrum of electromagnetic radiation. This solar spectrum spans various wavelengths, from short-wavelength ultraviolet (UV) radiation to long-wavelength infrared (IR) radiation, with visible light occupying a middle ground. Understanding the solar spectrum's range is crucial for comprehending how different wavelengths interact with Earth's atmosphere and surface, influencing climate, weather, and solar energy conversion processes. Ultraviolet radiation, with wavelengths shorter than visible light, is known for its energy-rich nature. While the Earth's atmosphere partially absorbs UV radiation, particularly the most harmful UV-C wavelengths, a significant portion reaches the surface. UV radiation plays a vital role in processes like vitamin D synthesis in organisms and the formation of the ozone layer. However, excessive exposure to UV radiation can also pose health risks, including skin damage and increased risk of skin cancer.

Visible light, occupying a significant portion of the solar spectrum, is essential for supporting life on Earth and driving photosynthesis in plants. It encompasses wavelengths ranging from approximately 400 to 700 nanometers, with shorter wavelengths appearing violet and longer wavelengths appearing red. Visible light penetrates Earth's atmosphere relatively unhindered, providing the energy necessary for biological processes and serving as the primary source of illumination.

Infrared radiation, with wavelengths longer than visible light, constitutes a substantial portion of the solar spectrum. While some short-wavelength infrared radiation is absorbed by Earth's atmosphere, longer-wavelength infrared radiation, often referred to as thermal infrared, plays a crucial role in heating Earth's surface and maintaining its temperature. This process, known as the greenhouse effect, is essential for sustaining Earth's habitable conditions. However, human activities have contributed to an increase in greenhouse gas concentrations, leading to enhanced infrared absorption and potentially contributing to global warming and climate change.

Understanding the solar spectrum's range enables scientists and engineers to develop solar energy technologies capable of efficiently capturing and converting different wavelengths of solar radiation. While traditional silicon-based photovoltaic cells primarily convert visible light into electricity, emerging technologies such as thin-film solar cells and concentrated solar power systems aim to harness a broader range of the solar spectrum, including infrared and even ultraviolet radiation. By maximizing the utilization of available solar energy resources, these technologies offer promising avenues for expanding renewable energy deployment and reducing reliance on fossil fuels.

3.12 CLASSIFICATION OF SOLAR CELL

As discussed above solar cells, also known as photovoltaic (PV) cells, are devices that convert sunlight directly into electricity through the photovoltaic effect. Over the years, several types of solar cells have been developed, each with its unique materials, structures, and characteristics. Understanding the classification of solar cells is crucial for assessing their suitability for different applications and advancing solar energy technology. Let's explore the main types of solar cells:

- **Monocrystalline Silicon Solar Cells:** Monocrystalline silicon solar cells are among the most mature and widely used solar cell technologies. They are made from single-crystal silicon ingots, resulting in high purity and efficiency. Monocrystalline cells typically have a uniform dark color and are easily recognizable by their rounded edges.
  - **Characteristics:**
  - High efficiency: Monocrystalline silicon cells typically exhibit high conversion efficiencies, often exceeding 20%.
  - Space-efficient: Due to their high efficiency, monocrystalline cells require less space to generate a given amount of electricity, making them suitable for rooftop installations and space-constrained environments.
  - Long lifespan: Mono-crystalline silicon cells are known for their durability and long lifespan, with warranties often exceeding 25 years.
  - Higher cost: The manufacturing process for mono-crystalline silicon cells involves elaborate procedures, resulting in higher production costs compared to other types of solar cells.
- **Polycrystalline Silicon Solar Cells:** Polycrystalline silicon solar cells are fabricated from silicon ingots composed of multiple crystal structures. Unlike mono-crystalline cells, polycrystalline cells have a distinctive textured appearance, characterized by a mosaic of different shades of blue.
  - **Characteristics:**
  - Lower cost: Polycrystalline silicon cells are typically less expensive to manufacture than monocrystalline cells due to simpler production processes and lower material requirements.
  - Slightly lower efficiency: While polycrystalline cells generally exhibit lower conversion efficiencies compared to monocrystalline cells, advancements in technology have narrowed the efficiency gap in recent years.
  - Greater temperature sensitivity: Polycrystalline cells may experience slightly higher efficiency losses at elevated temperatures compared to monocrystalline cells.

  - Wider availability: Polycrystalline silicon cells are widely available and commonly used in residential and commercial solar installations due to their cost-effectiveness.
- **Thin-Film Solar Cells:** Thin-film solar cells are fabricated using thin layers of semiconductor materials deposited onto substrates such as glass, metal, or plastic. Unlike crystalline silicon cells, thin-film cells do not require single-crystal ingots, allowing for more flexible and cost-effective manufacturing processes.
- **Types of Thin-Film Solar Cells:**
  - Amorphous Silicon (a-Si): Amorphous silicon thin-film cells are composed of non-crystalline silicon deposited in thin layers. They are known for their flexibility and suitability for applications requiring lightweight and flexible solar panels.
  - Cadmium Telluride (CdTe): Cadmium telluride thin-film cells consist of cadmium telluride deposited onto a substrate. CdTe cells offer competitive efficiency and are commonly used in utility-scale solar installations.
  - Copper Indium Gallium Selenide (CIGS): CIGS thin-film cells are composed of copper, indium, gallium, and selenium deposited in thin layers. They offer high efficiency potential and are known for their lightweight and flexibility.
  - ➢ **Characteristics:**
  - Lightweight and flexible: Thin-film solar cells are inherently thin and flexible, making them suitable for applications where weight and form factor are critical, such as building-integrated photovoltaics (BIPV) and portable electronics.
  - Lower efficiency: Thin-film cells generally exhibit lower conversion efficiencies compared to crystalline silicon cells. However, ongoing research and development efforts aim to improve thin-film efficiency and performance.
  - Cost-effectiveness: Thin-film solar cells offer potential cost savings due to their simpler manufacturing processes and lower material requirements. As a result, they are increasingly being adopted in large-scale solar projects and emerging markets.

Solar cells come in various types, each with its unique materials, characteristics, and applications. From the high efficiency of monocrystalline silicon cells to the flexibility of thin-film and organic solar cells, the diversity of solar cell technologies reflects ongoing efforts to optimize performance, reduce costs, and expand the reach of solar energy across diverse applications and markets. As research and development continue to drive innovation in solar technology, the future holds promise for even more efficient, cost-effective, and sustainable solar energy solutions.

3.13 FIRST GENERATION SINGLE CRYSTALLINE AND POLY CRYSTALLINE CELLS

First-generation solar cells, encompassing both single-crystalline (monocrystalline) and polycrystalline silicon technologies, represent the earliest and most widely deployed types of photovoltaic devices. These solar cells have played a significant role in the growth of the solar energy industry and continue to dominate a large portion of the market due to their proven reliability and efficiency.

Single-Crystalline Silicon Solar Cells: Single-crystalline silicon solar cells, often referred to as monocrystalline cells, are fabricated from high-purity silicon ingots grown in a controlled environment to form a single crystal structure. This process results in a uniform, continuous crystal lattice with minimal defects, maximizing electron mobility and overall efficiency.

Characteristics:

High Efficiency: Single-crystalline silicon solar cells are known for their high efficiency, typically ranging from 18% to over 25%. This efficiency is a result of the material's excellent electrical properties and the absence of grain boundaries, which can impede electron flow in polycrystalline materials.

Space Efficiency: Due to their high efficiency, monocrystalline silicon cells require less space to generate a given amount of electricity compared to other solar cell types. This makes them ideal for applications with limited space, such as rooftop installations.

Longevity: Single-crystalline silicon cells are renowned for their longevity and durability. With proper maintenance, these solar cells can have a lifespan of 25 years or more, making them a reliable investment for long-term energy generation.

Higher Cost: The manufacturing process for single-crystalline silicon cells involves complex procedures and high-purity silicon, resulting in higher production costs compared to other solar cell technologies. However, the superior efficiency and longevity often justify the initial investment.

Polycrystalline Silicon Solar Cells: Polycrystalline silicon solar cells, also known as multicrystalline cells, are fabricated from silicon ingots containing multiple crystal structures. These ingots are melted and cast into blocks, resulting in a material with grain boundaries between adjacent crystals.

Characteristics:

Lower Cost: Polycrystalline silicon cells are generally less expensive to manufacture than their single-crystalline counterparts. The production process involves simpler procedures and lower purity silicon, leading to cost savings.

Slightly Lower Efficiency: While polycrystalline cells typically exhibit slightly lower conversion efficiencies compared to monocrystalline cells, advancements in technology have narrowed this efficiency gap in recent years. Modern polycrystalline cells can achieve efficiencies ranging from 15% to 20%.

Blue Appearance: Polycrystalline silicon cells have a distinctive blue appearance due to light scattering caused by the grain boundaries between crystal structures. This visual characteristic is often used to differentiate them from monocrystalline cells.

Wide Availability: Polycrystalline silicon cells are widely available and commonly used in residential and commercial solar installations due to their cost-effectiveness. They offer a balance between efficiency, reliability, and affordability, making them a popular choice for various applications.

First-generation single-crystalline and polycrystalline silicon solar cells have been instrumental in driving the growth of the solar energy industry and expanding access to clean and renewable electricity. While single-crystalline cells boast higher efficiency and longevity, polycrystalline cells offer a cost-effective alternative with competitive performance. Both technologies continue to evolve, with ongoing research and development efforts aimed at improving efficiency, reducing costs, and expanding the range of applications for solar energy. As the world transitions towards a more sustainable energy future, first-generation silicon solar cells will remain a cornerstone of the global renewable energy infrastructure.

3.14 APPLICATION OF PV CELL OR MODULE

Photovoltaic (PV) cells and modules have a wide range of applications across various sectors, contributing to the transition towards clean and sustainable energy sources. From residential rooftops to large-scale utility installations, PV technology is transforming the way we generate electricity, reduce carbon emissions, and mitigate the impacts of climate change. Let's explore some of the key applications of PV cells and modules:

- **Residential Solar Power Systems:** One of the most common applications of PV cells is in residential solar power systems. Homeowners install rooftop solar panels to generate electricity for their households, reducing reliance on grid-supplied electricity and lowering utility bills. Residential solar systems typically consist of PV modules mounted on rooftops or ground-mounted arrays, connected to inverters that convert DC electricity generated by the panels into AC electricity usable in homes. These systems can provide clean and renewable energy for powering appliances, lighting, heating, and cooling systems, contributing to energy independence and sustainability.
- **Commercial and Industrial Solar Installations:** PV technology is also widely used in commercial and industrial settings to meet energy needs and reduce operating costs. Businesses, factories, warehouses, and other commercial facilities install solar panels on rooftops, parking structures, or vacant land to offset electricity consumption from the grid. Commercial and industrial solar installations can range from small-scale systems providing onsite power to large-scale projects supplying electricity to entire facilities or feeding excess energy back into the grid through net metering arrangements.
- **Utility-Scale Solar Power Plants:** Utility-scale solar power plants represent large-scale deployments of PV technology for centralized electricity generation. These solar farms consist of vast arrays of PV modules installed on open land or in desert regions, where sunlight is abundant. Utility-scale solar projects can generate hundreds of megawatts (MW) or even gigawatts (GW) of electricity, supplying power to thousands or millions of homes and businesses. These projects play a crucial role in diversifying the energy mix, reducing carbon emissions, and meeting renewable energy targets set by governments and utilities.
- **Off-Grid and Remote Power Systems:** PV technology is also utilized in off-grid and remote power systems to provide electricity in areas without access to the utility grid or in locations where grid connection is impractical or cost-prohibitive. Off-grid solar systems typically incorporate PV modules, batteries for energy storage, and power electronics to regulate and distribute electricity to off-grid homes, cabins, telecommunications towers, remote villages, and agricultural operations. These systems offer a reliable and sustainable

energy solution for powering essential services and improving quality of life in remote and underserved communities.

- **Portable and Mobile Solar Solutions:** PV cells and modules are integrated into portable and mobile solar solutions, providing renewable energy for various applications on the go. Portable solar chargers, backpacks, and foldable panels allow outdoor enthusiasts, campers, hikers, and adventurers to harness solar energy to charge electronic devices such as smartphones, laptops, GPS devices, and cameras while off the grid. Mobile solar trailers, generators, and power stations equipped with PV modules offer temporary or emergency power for events, construction sites, disaster relief efforts, and military operations, reducing reliance on fossil fuel generators and diesel-powered generators.
- **Building-Integrated Photovoltaics (BIPV):** Building-integrated photovoltaics (BIPV) integrate PV technology directly into building materials and architectural elements, seamlessly blending solar power generation with building design and aesthetics. BIPV solutions include solar roof tiles, solar shingles, solar facades, and solar windows that replace conventional building materials while generating electricity from sunlight. BIPV systems offer dual functionality by providing building envelope protection and renewable energy generation, making them an attractive option for sustainable construction and green building projects.

The application of PV cells and modules spans a diverse range of sectors and scenarios, from residential rooftops to utility-scale solar farms and beyond. As the world transitions towards a more sustainable and renewable energy future, PV technology will continue to play a vital role in meeting energy demands, reducing greenhouse gas emissions, and mitigating the impacts of climate change. By harnessing the power of the sun, PV cells and modules offer clean, reliable, and cost-effective solutions for powering our homes, businesses, communities, and beyond.

3.15 SUMMARY

Solar photovoltaic (PV) cells are integral components of solar energy systems, converting sunlight directly into electricity through the photovoltaic effect. In the context of economics, a comprehensive cost analysis is essential for estimating the capital cost of PV systems, considering equipment costs, installation expenses, operations and maintenance costs, and financing options. Financial metrics such as payback period, return on investment (ROI), net present value (NPV), and internal rate of return (IRR) help evaluate the economic viability of PV systems. Moreover, financial incentives like tax credits, rebates, and renewable energy certificates can further enhance the economics of PV projects. Cost reduction strategies such as bulk purchasing, competitive bidding, and leveraging technology advancements are crucial for improving the economics of PV systems.

Understanding peak power operation is vital for optimizing the performance and efficiency of PV systems. Factors affecting peak power operation include solar irradiance, temperature, shading, and angle of incidence. Maximum power point tracking (MPPT) algorithms ensure that PV systems operate at their peak power point under changing environmental conditions. Designing PV systems with appropriate sizing, orientation, and tilt angle, implementing shading analysis, using high-efficiency PV modules and inverters, and regular maintenance and monitoring are practical considerations for maximizing peak power operation.

Stand-alone and grid-connected PV systems represent two distinct approaches to harnessing solar energy. Stand-alone systems operate independently of the utility grid and incorporate batteries for energy storage, making them suitable for off-grid locations. Grid-connected systems are connected to the utility grid, allowing for the exchange of electricity and potentially earning revenue through net metering or feed-in tariffs. Each system type has its advantages and applications, depending on factors such as location, energy requirements, cost considerations, and regulatory policies.

The solar constant represents the average solar irradiance received at Earth's distance from the Sun and serves as a baseline for estimating solar energy potential. The solar radiation spectrum encompasses various wavelengths of electromagnetic radiation, including ultraviolet, visible light, and infrared, influencing climate, weather, and solar energy conversion processes. Understanding the solar spectrum enables the development of solar energy technologies capable of efficiently capturing and converting different wavelengths of solar radiation.

Solar cells are classified into several types, including monocrystalline silicon, polycrystalline silicon, thin-film, and organic solar cells, each with unique materials, characteristics, and applications. First-generation single-crystalline and polycrystalline silicon solar cells represent the earliest and most widely deployed PV technologies, offering high efficiency, longevity, and cost-effectiveness. These solar cells find applications in residential, commercial, industrial, utility-scale, off-grid, portable, and building-integrated photovoltaic systems, contributing to the transition towards clean and sustainable energy sources. As the world embraces solar energy solutions, understanding the economics, peak power operation, system types, solar radiation, cell classifications, and applications of PV technology is essential for undergraduate students studying solar photovoltaic cells.

3.17 GLOSSARY

Photovoltaic (PV) Cells: Semiconductor devices that convert sunlight directly into electricity through the photovoltaic effect.

Economics of Photovoltaic System: The financial analysis of PV systems, including cost analysis, financial metrics, incentives, and cost reduction strategies.

Peak Power Operation: Operating a PV system at its maximum power output under specific conditions to optimize performance and efficiency.

Stand-alone PV Systems: Off-grid PV systems that operate independently of the utility grid, typically incorporating batteries for energy storage.

Grid-connected PV Systems: PV systems connected to the utility grid, allowing for the exchange of electricity and potentially earning revenue through net metering or feed-in tariffs.

Solar Constant: The average solar irradiance received at Earth's distance from the Sun, representing the baseline for estimating solar energy potential.

Solar Radiation Spectrum: The range of wavelengths of electromagnetic radiation emitted by the Sun, including ultraviolet, visible light, and infrared radiation.

Monocrystalline Silicon Solar Cells: Solar cells fabricated from single-crystal silicon ingots, known for high efficiency and longevity.

Polycrystalline Silicon Solar Cells: Solar cells fabricated from silicon ingots containing multiple crystal structures, offering cost-effectiveness and competitive performance

Organic Solar Cells: Solar cells utilizing organic semiconductor materials, known for flexibility and potential low-cost manufacturing processes.

Solar Irradiance: The power per unit area received from the Sun, typically measured in watts per square meter (W/m^2), influencing the peak power output of PV systems.

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3.19 SUGGESTED READINGS

Solar Photovoltaic Systems: Installation, Operation, and Maintenance" by Geoff Stapleton and Susan Neill.

"Solar Energy: Technologies and Project Delivery for Buildings" by Andy Walker.

"Photovoltaic Systems Engineering" by Roger Messenger and Jerry Ventre.

"Renewable Energy Finance: Powering the Future" by Charles W. Donovan.

"Solar Electricity Handbook: A Simple, Practical Guide to Solar Energy - Designing and Installing Photovoltaic Solar Electric Systems" by Michael Boxwell.

3.19 TERMINAL QUESTIONS

1. What are the key components involved in the cost analysis of a photovoltaic (PV) system, and why is it important to conduct such an analysis?

2. Explain the concept of peak power operation in PV systems and discuss the factors that influence it.

3. Compare and contrast stand-alone (off-grid) PV systems with grid-connected PV systems, highlighting their respective applications and advantages.

4. What is the Solar Constant, and why is it significant in the context of solar energy harnessing?

3. Describe the solar radiation spectrum and its implications for solar energy conversion processes.

6. What are the main types of solar cells, and how do they differ in terms of materials, efficiency, and applications?

7. Discuss the characteristics and applications of first-generation single-crystalline and polycrystalline silicon solar cells.

8. Explain the various applications of PV cells and modules across residential, commercial, industrial, and off-grid settings, providing examples for each.

9. What are some cost reduction strategies that can be implemented to improve the economics of PV systems?

10. How do maximum power point tracking (MPPT) algorithms contribute to optimizing the performance of PV systems under changing environmental condition?

UNIT-4: WIND ENERGY

4.1 INTRODUCTION

Wind energy is a renewable and sustainable source of power that harnesses the kinetic energy of moving air to generate electricity. It has been used for centuries, initially in the form of windmills for tasks like grinding grain and pumping water. However, in recent decades, wind energy has undergone a remarkable transformation, evolving into a modern, clean, and efficient means of producing electricity on a large scale. Wind energy has been utilized for centuries, from traditional windmills used for grinding grains and pumping water to the cutting-edge wind turbines of today, which are capable of producing significant amounts of electricity. This introductory source of power has become a critical player in the effort to reduce greenhouse gas emissions, combat climate change, and secure a reliable source of clean energy for the future.

In the present unit, we will explore the fundamental principles of wind energy, its environmental benefits, economic considerations, and its role in the global energy landscape, setting the stage for a deeper understanding of this renewable energy source.

4.2 OBJECTIVE

1. Describe the fundamental principles of wind energy and how wind turbines work.
2. Explain the environmental benefits and challenges associated with wind energy.
3. Components of wind energy conversion system.
4. Understand the sub-components of wind turbine in detail.
5. Define the different types of wind turbines.
6. Analyze the economic aspects of wind energy projects, including job creation and cost-effectiveness.
7. Evaluate the global significance of wind energy in addressing climate change and energy security.

4.3 INTRODUCTION TO WIND POWER

Wind power constitutes a form of indirect solar energy technology, deriving from the movement of air generated by the pressure gradient resulting from solar radiation. Approximately two percent of the solar radiation reaching the Earth's surface transforms into kinetic energy, a potential source that, if harnessed, could fulfil energy demands. Wind's kinetic energy can be directly utilized, converted into mechanical energy, or employed for electricity generation. Beyond historical applications like grinding grains and water pumping using windmills, contemporary wind turbines are widely recognized for electricity production.

Several factors influence the distribution of wind energy in a given area. The topography, cloud cover, and solar angle all play crucial roles in wind generation. Features like mountain ranges guide air currents, while hills, trees, and structures obstruct and alter airflow directions. Additionally, the frictional impact of the surface determines wind speed; hence, coastal areas often experience higher wind speeds due to reduced friction over smooth surfaces, such as the sea. Understanding these factors is pivotal for optimizing the harnessing of wind energy in various regions.

4.4 HISTORY AND EVOLUTION OF WIND ENERGY

The history and evolution of wind energy can be traced back thousands of years, with humans harnessing the power of the wind for various purposes. Here's an overview of the key milestones in the history of wind energy:

1. Early Windmills (200 BCE - 9th Century): The earliest recorded use of wind power dates back to ancient civilizations in Persia and China, where simple windmills were used to pump water and grind grain. These early devices consisted of vertical-axis wind turbines.

2. Medieval Europe (7th - 12th Century): Windmills became more prevalent in Europe during the middle Ages, particularly in the Netherlands. These windmills were used for various tasks, including drainage of low-lying land and milling grain.

3. Industrial Revolution (18th - 19th Century): The Industrial Revolution saw advancements in windmill technology, with the introduction of more efficient designs. Sail-type blades were replaced by more rigid wooden blades, and horizontal-axis windmills became common.

4. Pumping Water (Late 19th - Early 20th Century): In the late 19th and early 20th centuries, windmills were widely used in the United States and other parts of the world to pump water for irrigation and livestock. These windmills, often located on farms, featured tall towers and large rotor diameters.

5. Electricity Generation (Late 19th Century - Early 20th Century): The late 19th century saw the development of wind turbines for electricity generation. Pioneers such as Charles F. Brush and Poul la Cour built experimental wind turbines to generate electricity, laying the foundation for the use of wind power in the electrical grid.

6. Decline and Resurgence (Mid-20th Century): With the rise of fossil fuels, particularly after World War II, interest in wind energy waned. However, the energy crisis of the 1970s renewed interest in renewable energy sources, leading to government initiatives and research projects to develop modern wind turbines.

7. Modern Wind Turbines (1980s - Present): The 1980s marked the beginning of the modern era of wind energy. Technological advancements, including the use of composite materials, improved aerodynamics, and the development of variable-speed generators, contributed to more efficient and cost-effective wind turbines. Wind farms, consisting of multiple turbines, became common, especially in regions with favorable wind conditions.

8. Offshore Wind Farms (21st Century): In the 21st century, there has been a significant expansion of offshore wind farms, taking advantage of strong and consistent wind resources over oceans. Offshore wind has become a major contributor to global wind energy capacity.

9. Technological Advancements (Present): Ongoing research and development continue to enhance the efficiency and cost-effectiveness of wind energy. Advances in materials, aerodynamics, and grid integration technologies contribute to the further growth and integration of wind power into the global energy mix.

4.5 STATUS OF WIND ENERGY IN INDIA

India currently holds the position of having the fourth-largest installed capacity in wind power globally, following China, the United States, and Germany. The cumulative installed capacity of wind power in India stands at approximately 32 GW, with a widespread distribution across the Southern, Western, and Northern regions of the country. The states of Andhra Pradesh, Gujarat, Karnataka, Madhya Pradesh, Maharashtra, Rajasthan, Tamil Nadu, and Telangana exhibit substantial potential for wind energy. Among these, Tamil Nadu boasts the highest installed capacity at around 7.5 GW, attributed to favorable climatic conditions for wind power development. Maharashtra follows with the second-highest capacity of about 5 GW, and Gujarat holds the third position with an installed capacity of approximately 4 GW. Noteworthy is the presence of India's largest windmill farm in Kanyakumari, generating an impressive 380 MW of electricity.

Table 1: Installed wind capacity in different states of India.

State	Total Capacity (MW)
Tamil Nadu	8,197
Gujarat	5,613
Maharashtra	4,784
Karnataka	4,509
Rajasthan	4,298
Andhra Pradesh	3,963
Madhya Pradesh	2,520
Telangana	101
Kerala	53
Others	4
Total	**34,043**

Tamil Nadu has emerged as a frontrunner in wind power within India, boasting a significant 29% share of the country's total wind power capacity. Notably, the Muppandal wind farm in Tamil Nadu stands as India's largest wind power plant, with a total capacity of 1500 MW. With a cumulative installed capacity of 7633 MW, Tamil Nadu has solidified its leadership in the Indian wind energy landscape. Maharashtra follows closely as a key player in the wind power sector, ranking second to Tamil Nadu. The state has witnessed a surge in wind power projects, with 50 developers currently registered with the Maharashtra Energy Development Agency for project development. Major industry players like Suzlon, Vestas, Gamesa, Regen, and Leitner Shriram actively contribute to the wind power initiatives in Maharashtra (Ministry of New and Renewable Energy, 2017).

The Government of Gujarat has strategically prioritized renewable energy, resulting in a substantial increase in wind power capacity in recent years. ONGC Ltd. has notably established a 51MW wind energy farm in Bhuj, Gujarat. Embracing an innovative approach, the Government of Madhya Pradesh has approved a 15 MW project for Madhya Pradesh Windfarms Ltd. (MPWL) in Nagda Hills near Dewas, following guidance from Consolidated Energy Consultants Ltd. (CECL) in Bhopal. Kerala has made strides in wind power with a 55 MW production, tracing its roots back to the establishment of the state's first wind farm in Kanjikode, Palakkad district, in 1997. Presently, Kerala's installed capacity stands at 2.0 MW. Odisha holds substantial wind power potential, estimated at 1700 MW. Additionally, certain regions in Jammu & Kashmir, specifically Kargil and Ladakh, possess untapped wind energy potential awaiting harnessing (Ministry of New and Renewable Energy, 2017).

4.6 USES OF WIND ENERGY

Wind energy finds diverse applications, as outlined below:

1. **Wind Power Generation:** Wind energy is employed for the generation of wind power. This involves utilizing a wind turbine to capture the kinetic energy of the wind. As the wind sets the turbine blades in motion, a generator is activated, generating electricity.
2. **Transportation:** Another application of wind energy is in the realm of transportation. Throughout history, civilizations have utilized wind energy for transportation, primarily in the form of sailing. In contemporary times, both small and large ships have harnessed the power of the wind for propulsion. Notably, modern shipping companies are increasingly adopting wind energy for transportation efficiency. Certain vessels, such as fishing trawlers and cargo ships, have integrated large kites to assist in reducing fuel consumption during long journeys, achieving up to a 30% reduction under favorable conditions. This shift is particularly appealing to companies aiming to cut fuel costs and minimize their environmental impact.
3. **Agricultural Practices:** Wind energy has a historical association with food production, particularly through the utilization of windmills. Predating the industrial revolution, windmills were prevalent in milling grain, a crucial step in producing staple foods like bread.
4. **Water Pumping:** Wind pumps, akin to traditional windmills but adapted for different purposes, play a role in pumping water. Historically employed for land drainage, these structures have been replaced with the advent of electric motors.

4.7 BENEFITS OF WIND ENERGY

1. **It is renewable & sustainable:** Wind energy is both renewable and sustainable. The wind will never run out, unlike reserves of fossil fuels (such as coal, oil, and gas.) This makes it a good choice of energy for a sustainable power supply. We should look utilized wind energy for sustainable development.
2. **It is environmentally friendly**: Wind energy is also one of the most environmentally friendly energy sources available in present time. The simple reason is that wind turbines don’t create pollution during electricity generation. Most non-renewable energy sources need to be burnt. This process releases certain harmful gases such as CO_2, CH_4 into the

ambient environment. These gases are known to contribute to climate change and global warming. On the other hand, wind turbines produce no greenhouse gases.

3. **It can reduce fossil fuel consumption:** Wind energy reduces the need to burn fossil fuel alternatives such as coal, oil, and gas. This can help to conserve dwindling supplies of the natural resources on earth. As a consequence, they will last longer and help to support future generations.
4. **It is Free:** If we compare wind energy with other non-renewable energy sources we will find that the wind energy is completely free. Everyone can make use of the wind and it will never run out. This makes wind power a feasible alternative for generating cheap electricity.
5. **It has a small footprint:** Wind turbines have a comparatively small land footprint. Although they can tower high above the ground, the impact on the land at the base is minimal. Wind turbines are often constructed in fields, on hills or out at sea. At these locations, they pose hardly any inconvenience to the surrounding land. Farmers may also use their fields, livestock can still graze the hills and fishermen can still able to fishing.
6. **It may be used in remote locations:** Wind turbines can play an important role in helping to bring power to remote areas. This may help to benefit everything from small off-grid villages to remote research facilities. It might be impractical or too expensive to hook such remote areas up to traditional electricity supplies. In these cases, wind turbines could have the solution. Wind turbines may be used to generate power in such areas.
7. **It is cheaper:** The first wind turbine of world started generating electricity in 1888. Since, wind energy have become more efficient and have come down in price. Therefore, wind power is becoming much more reachable. Government subsidies are also helpful to minimize the prizes of the wind technologies. Many nations of the world now provide incentives for the construction of wind turbines.
8. **Low maintenance:** The wind turbines require low maintenance charges. New wind turbines can last a long time prior to it requiring any maintenance. Although, older turbines can come up against reliability issues, technological advancements are helping to improve overall reliability
9. **Low running costs:** As you know wind energy is free, running costs are also generally low. The only ongoing cost of wind energy is for the maintenance of wind turbines, but in above point it also explicitly cleared that maintenance of wind turbines required minimum costs.

10. **High Potential:** Wind energy has huge potential, as it is both renewable and sustainable and is present in a wide variety of locations. Although wind turbines aren’t cost-effective at every areas the technology is not limited to just a handful of locations. This is an issue that can affect other renewable energy technologies for example geothermal power plants.

4.8 LIMITATIONS OF WIND ENERGY

Wind energy comes with certain drawbacks, including:

1. **Variability in wind:** One significant disadvantage of wind energy is the inconsistency in wind patterns. This poses challenges for developers of wind farms, who invest considerable time and resources in assessing the suitability of a particular location for wind power generation.
2. **Expensive installation:** However, the costs of installation of wind turbines are reducing over time. But, wind turbines are still expensive. At the starting of the installation, an engineer should take out a site survey. This may involve having to erect a sample turbine to measure wind speeds over a period of time. If deemed sufficient, a wind turbine then needs to be manufactured, transported and erected on top of a pre-built foundation. All of these processes can rise the expenditure during installation.
3. **Threat to wildlife:** Wind turbines pose a threat to wildlife. These turbines are especially harmful to birds and bats. However, scientists now believe that turbines create less of a threat to wildlife than other anthropogenic structures
4. **Create noise pollution:** It is one of the most common disadvantages of wind turbines. You can frequently hear a single wind turbine from hundreds of meters away. Combine multiple wind turbines with the right wind direction and the audible effects can be much greater. Noise pollution from wind turbines has ruined the lives of many communities.
5. **Create visual pollution:** Another common disadvantage of wind turbines is the visual pollution. Although many people actually like the look of wind turbines, others don’t**.**

4.9 ENERGY AVAILABLE IN THE WIND

The power in the wind is computed by the concept of kinetics. The wind mill works on the principle of converting kinetic energy of the wind into mechanical energy.

Power = Energy/unit time

Energy available = Kinetic energy of the wind

Kinetic energy of any particle = ½ mV^2 ………………(1)

Amount of air passing in unit time through an area A, with velocity V = A. V

Its mass is equal to its volume multiple by its density ρ of air,

$m = \rho A.V$……………..(2)

where m is the mass of transversing the area A swept by the rotating blades of a wind mill type generator

Substituting this value of mass (2) in kinetic energy equation (1),

Kinetic energy $=1/2\ \rho\ A.V.V^2$………………(3)

$=1/2\ \rho\ A.V^3$ watts………………(4)

The wind power available is proportional to air density. It is 1.225 kg/m3 at sea level. The variation in air density over the year is 10-15 per cent due to changes in pressure and temperature.

The power is also proportional to intercept area. So an aeroturbine with large swept area has higher power than that with smaller area.

Since the area is normally circular of diameter D in horizontal axis aeroturbines,

$A = \frac{\pi D^2}{4}$ sq.m …………………. (5)

Substitute (5) in (4), it becomes

Available wind power = ½ $\rho \frac{\pi D^2}{4}.V^3$ watts …………..(6)

$=1/8\rho.\pi D^2 V^3$………………… (7)

4.10 WIND ENERGY CONVERSION SYSTEM

Air circulation is a result of the uneven heating of the Earth's surface by the sun. Warm areas cause air to expand, rising as cooler, denser air flows in from neighboring regions. The kinetic energy in wind is a product of its movement.

Wind energy is captured by a wind turbine mounted on a tower. Wind speed is directly related to height, with a tower height of 30 meters or more being advantageous, as it allows access to faster and less turbulent wind. At a height of 10 meters, wind speed is 20-25 percent higher than at the surface, and at 60 meters, it can be 30-60 percent higher due to reduced drag from the Earth's surface. To be economically viable, the average wind speeds in a specific location must exceed 6–8 meters per second (m/s) for a small wind turbine.

Wind energy conversion systems are commonly known as WECS, aerogenerators, wind turbine generators, or simply wind turbines. Several factors impact the output of a wind energy converter, including wind speed, the cross-sectional area of the wind swept by the rotor, and the overall efficiency of the rotor, transmission system, and generator or pump. The available maximum wind energy is directly proportional to the cube of the wind speed. Therefore, even a slight increase in wind speed can result in a significant boost in wind power.

4.11 LIFT AND DRAG

The basis for wind energy conversion is Lift and Drag. The extraction of power from the wind depends on creating certain forces and applying them to rotate a mechanism. There are two primary mechanisms for producing forces from the wind

- Lift and

- Drag

Lift forces act perpendicular to the direction of airflow, while drag forces act in the direction of flow. These forces result from altering the velocity of the air stream over the lifting surface, with increased air speed causing a drop in pressure and decreased speed leading to a pressure increase. The resulting pressure difference across the lifting surface generates a force that moves from the high-pressure side to the low-pressure side, forming what is known as an airfoil.

An effective airfoil boasts a high lift/drag ratio, with lift increasing as the angle between the airfoil and the air-stream becomes less acute until the airflow angle on the low-pressure side becomes excessive. Turbulences can lead to a decrease in lift and a substantial increase in drag force, known as stalling. For optimal wind turbine performance, a balance is sought with high lift and minimal drag force.

Besides the airfoil, two other methods for generating lift include the Magnus effect and Thwaits slot. The Magnus effect is induced by spinning a cylinder in an airstream, altering air speed on either side of the moving cylinder. Thwaits slot involves blowing air through narrow slots in a cylinder, causing rotational airflow that generates lift.

4.12 PRINCIPLE OF POWER GENERATION FROM WIND

Wind turbine is used to extract useful energy from wind. The energy can be extracted by partially decelerating and expanding the airstream (reduction of pressure) using wind turbine. The rotor of the wind turbine captures wind from the entire area covered by the rotor. This area can be envisioned as an airstream tube, following the Betz model of expanding air.

In this model, the airstream tube undergoes continuous expansion. The mass flow rate of air remains constant, in accordance with the law of continuity, requiring a decrease in wind speed as the air expands. The upstream section of the airstream tube has an area denoted as A_0, while it passes through the rotor blade (aerofoil) with an area of A_1, and finally, it has an area of A_2 downstream.

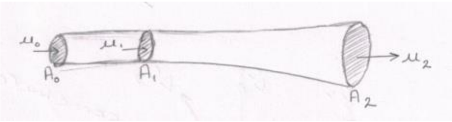

Figure 1: Airstream tube.

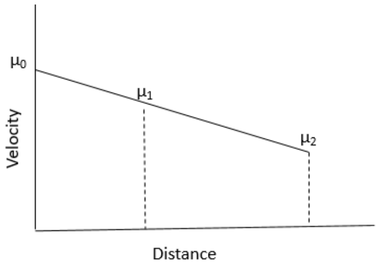

Figure 2: Airstream on aerofoil.

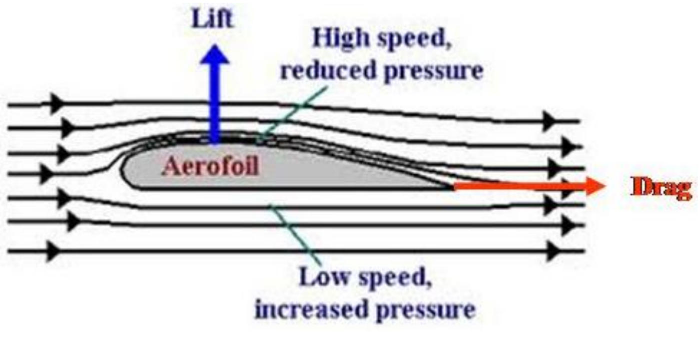

Figure 3: Variation of wind velocity.

Consider that μ_o and μ_2 are wind velocities at upstream and downstream. The velocity reduction from μ_o to μ_2 means that there is reduction in momentum of wind as it passes through wind turbine, resulting in a force being exerted on the blade of rotor, given by following equation:

Force , $F = m \times \mu_o - m \times \mu_2 = m (\mu_o - \mu_2)$ …………… (8)

where ‘m’ is mass flow per unit time through stream tube.

The force described above is applied consistently as the airflow travels across the rotor blade at a velocity of μ_1. Consequently, the power extracted is equivalent to the work performed by the airstream in displacing over a distance of μ_1 against the force F. This can be expressed as:

Power of turbine, $P_T = F \times \mu_1$………….. (9)

Substituting Equation 8 in 9,

$P_T = m (\mu_o - \mu_2) \times \mu_1$…………….. (10)

The power extracted by the wind turbine from the wind is equal to the change or loss of kinetic energy of the wind.

$\Delta KE = P_w = 1/2\ m (\mu_o^2 - \mu_2^2)$ ……………………… (11)

The energy extracted equal to energy lost by wind

$P_T = P_w$

$m (\mu_o - \mu_2) \times \mu_1 = 1/2\ m (\mu_o^2 - \mu_2^2)$ …………….(12)

$\mu_1 = (\mu_o + \mu_2)/2$……………. (13)

where μ_1 is the average of μ_o and μ_2

Substituting Equation 13 in 10,

$PT = m (\mu_o - \mu_2) \times (\mu_o + \mu_2)/2$

$= 1/2\ m (\mu_o^2 - \mu_2^2)$ …………… (14)

The mass flow (m) is the product of area, velocity and density,

$m = A_1 \times \mu_1 \times \rho$

$= A_1 \times (\mu_o + \mu_2)/2 \times \rho$…………… (15)

Substituting Equation 14 and 15,

$P_T = \frac{1}{4} A_1 \times \rho \times (\mu_o^2 - \mu_2^2) \times (\mu_o + \mu_2)$……….(16)

If an interference factor ‘α’ is there, then

$\mu_1 = (1- \alpha) \times \mu_0$
$\alpha = 1 - \mu_1/\mu_o = 1- (\mu_o + \mu_2)/2 \times / \mu_o = (\mu_o - \mu_2)/2 \times \mu_o$

$\mu_2 = (1- 2\alpha) \times \mu_0$

Then turbine power is

$P_T = \frac{1}{4} A_1 \times \rho \times (2 \times \alpha \times \mu_0) \times [\mu_0 + (1-2\alpha) \mu_0]^2$

$= 4 \times \alpha \times (1- \alpha)^2 [1/2\ \rho \times A_1 \times \mu_0^3]$ …………(17)

And Wind power is given by

$P_W = 1/2\ \rho \times A_1 \times \mu_0^3$………………………(18) substituting $‘m’ = A_1 \times (\mu_o + \mu_2)/2 \times \rho$

From Eqn 16 and 17, we have

$P_T = 4 \times \alpha \times (1- \alpha)^2 \times P_W$

$= C_p \times P_W$

where C_p is the power coefficient and is given by

$C_p = 4\ \alpha\ (1- \alpha)^2$

The power coefficient, C_p, serves as a measure indicating the proportion or percentage of wind power effectively harvested by a wind turbine. The theoretical or maximum efficiency, η_{max}, of a wind turbine, expressed as the power coefficient, represents the ratio of the maximum power derived from the wind to the total power present in the wind. This ratio signifies the relationship between the actual power output and the theoretical power potential.

Power co-efficient, C_p = Power output from wind machine / Power available in wind

$= P_{actual} / P_{theoretical}$

When $\alpha = 0$, then $\mu_1 = \mu_0$, $\mu_2 = \mu_0$ and no power generation takes place

When $\alpha = 1/3$, then $\mu_1 = 2/3\mu_0$, $\mu_2 = 1/3\mu_0$ and maximum power generation takes place

When $\alpha = 1/2$, then $\mu_1 = 1/2\mu_0$, $\mu_2 = 0$ and only turbulence occurs at downstream

When $\alpha = 1$, then μ_1 and it results in stalling of turbine

4.13 THEORETICAL MAXIMUM WIND POWER

Air density is directly related to both air temperature and air pressure, and these factors fluctuate with altitude above sea level. The conversion of wind power into the mechanical energy of a wind turbine is not entirely efficient, with losses occurring due to friction that diminish the actual wind power harnessed. The theoretical upper limit for extracting energy from the wind was computed by Betz in 1926.

The power output from wind turbine is given as follows

$P_T = \frac{1}{4} A_1 \times \rho \times (\mu_o^2 - \mu_2^2) \times (\mu_o + \mu_2)$

The power output depends on outlet velocity μ_2, Hence for the maximum output $dP_T/d\mu_2 = 0$
And so $\mu_2 = - \mu_1$, which is impossible $\mu_2 = \mu_1/3$

Substituting $\mu_2 = \mu_1/3$ in Equation 16, then

$P_T = 8/27\ \rho \times A \times \mu_0^3 = 16/27\ [1/2 \times \rho \times A \times \mu_0^3]$

$= 16/27 \times P_w$

$= 59.3\% \times P_W$

According to Betz theory, a wind turbine can only utilize 59% of wind power even if no losses occur, hence the power is increased by a factor of 0.59. Unavoidable swirl losses lower the turbine's efficiency to 42%, resulting in a value of 0.42.

4.14 BASIC COMPONENTS OF WIND ENERGY CONVERSION SYSTEM

The conversion of wind energy into mechanical or electrical power to fulfill diverse energy needs is achieved through a wind energy conversion system (WECS). The pivotal element of the WECS is the wind turbine, which was previously referred to as a windmill. The presence of a wind turbine system is crucial for capturing the available wind energy at any given location.

The main components of a wind energy conversion system for electricity (Figure 4) are

1. Aeroturbine
2. Gearing
3. Coupling

4. Electrical generator
5. Controller

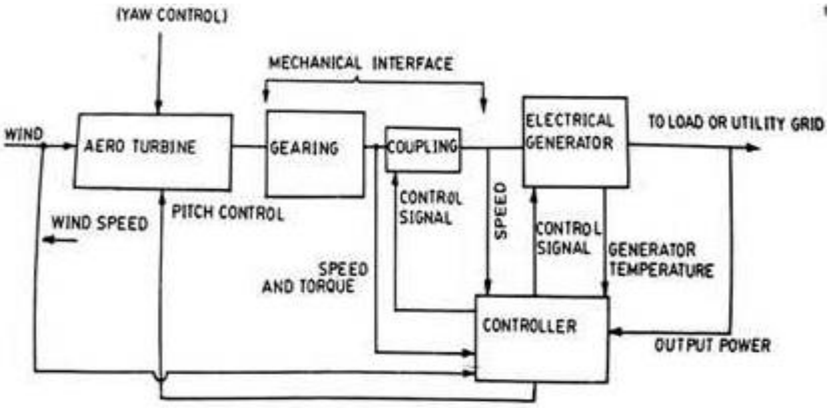

Figure 4: Basic Components of Wind Energy Conversion System. (Adapted from Rai, 1988)

The wind turbine transforms the energy from the wind into rotary mechanical energy, facilitated by pitch control and yaw control for optimal functioning. The mechanical interface consists of a step-up gear and coupling, enabling the transmission of rotary mechanical energy to an electric generator. The power output is then connected to either the load or the power grid.

Yaw control is employed in wind turbines located in areas where wind direction changes. A motor gradually rotates the turbine around the vertical axis to orient the blades into the wind. The controller plays a crucial role in monitoring various parameters such as wind speed, wind direction, shaft speed, and torques at different points, power generated, and generator temperature. It also senses control signals to compare the electrical output with the wind energy input, providing protection against adverse conditions such as strong winds, electrical faults, and other extremes.

4.15 WIND TURBINE

A wind turbine is a system that converts the kinetic energy available in the wind into mechanical or electrical energy.

Parts of a wind turbine system:

1. Foundation
2. Tower
3. Nacelle

4. Hub
5. Rotor
6. Drive -train
7. Gearbox
8. Generator
9. Electronics & Controls
10. Yaw
11. Pitch
12. Braking
13. Cooling

Generally, the components of a wind turbine system can be categorized as follows:

Rotor: There are two types of rotors, namely the Horizontal Axis Rotor and the Vertical Axis Rotor. Vertical axis machines are capable of operating in all wind directions and do not require yaw adjustments.

- The wind turbine head or turbine assembly comprises the rotor, rotor bearings housing, and various control mechanisms. It includes safety features such as the ability to adjust the pitch of the blades and a tail vane to align the rotor with the wind direction.
- Structural Support

The detailed diagram in Figure 5 illustrates the various components of a wind turbine.

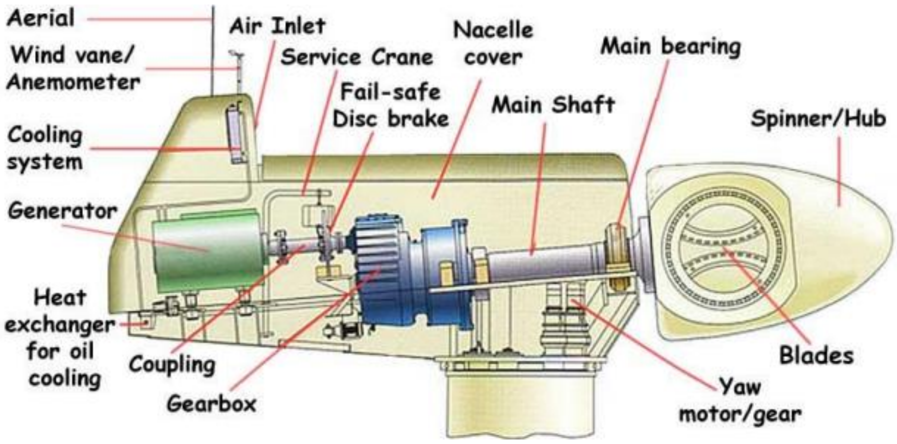

Figure 5: Diagram of different parts of wind turbine.

- The transmission and control system regulate the rotation speed of large wind turbine generators, especially when operating at or below their rated capacity. This is achieved by adjusting the pitch of the rotor blades. Transmission options encompass mechanical systems employing fixed ratio gears, as well as belts and chains either individually or in combinations. Hydraulic systems involving fluid pumps and motors are also a viable option. For equipment mounted at the top, fixed ratio gears are recommended.

4.15.1 Rotor: This is the element of the wind turbine responsible for rotation, facilitating the conversion of kinetic energy into mechanical energy. It is composed of blades and hubs.

4.15.2 Hub: The rotor hub serves to link the rotor blades to the rotor shaft. Its role is critical in regulating the power generation of the wind turbine.

4.15.3 Blades: These are rotating components of the system, operating on the principles of lift and drag (aerodynamic principles). They transform kinetic energy initially into mechanical energy and then transmit it through the shaft to the generator for further conversion into electrical energy.

Wind turbines typically feature either two or three blades. When wind flows over the blades, they experience lift, causing rotation. Two-bladed turbines have a lighter hub, resulting in a lighter overall structure. On the other hand, three-bladed turbines are aerodynamically efficient and produce less noise.

The length of the blades is a crucial factor in estimating the wind power generation potential of a turbine, and the torque increases with a greater number of blades.

Blades are commonly constructed from composites such as fiberglass, glass-reinforced plastics (GRP), or carbon fiber-reinforced plastics (CFRP). Wooden materials and epoxy laminates are also used in blade manufacturing.

Solidity is a defined parameter representing the ratio of the projected area of the rotor blades on the rotor plane to the swept area of the rotor. High-solidity rotors utilize force for rotation and turn at slower speeds, while low-solidity rotors with slender aerofoils use lift force for rotation and spin faster.

Chord: The chord refers to the width of the blade, measured from one edge to the other.

4.15.4 Drive train: The drive train comprises a low-speed shaft, gearbox, and a high-speed shaft, along with supporting bearings, couplings, brakes, and the rotating components of the generator.

4.15.5 Nacelle: The nacelle is the enclosed section of the wind turbine system positioned at the top of the tower. It accommodates the gearbox, low-speed shaft, high-speed shaft, generator, controller, and brake. The nacelle plays a crucial role in safeguarding wind turbine components from diverse weather conditions and contributes to minimizing noise generated by the turbine's rotation.

4.15.6 Low-speed shaft: This shaft transfers torque from the rotor to the drive train and is a rotating component located on the rotor side of the turbine. The connection to this low-speed shaft enhances the rotations per minute, and it also provides support for the weight of the rotor.

4.15.7 Gearbox: The gearbox is responsible for increasing the speed as required by the electric generator. Gears connect the low-speed shaft to the high-speed shaft, raising the rotational speed necessary for electricity generation. The increase in rotational speeds typically ranges from 30-60 rpm to 1000-1800 rpm, and this component is known for its high cost. Some types of gearboxes include Planetary Gear Boxes and Parallel Shaft Gearboxes.

4.15.8 High-speed shaft: The speed and torque generated by the gearbox are transmitted to drive the generator through the high-speed shaft. This component is situated on the generator side of the turbine.

4.15.9 Brake: This part is meant to stop the running of wind turbines during extreme weather conditions.

The various types of brakes are

- Mechanical brake (Disc brake, clutch brake),
- Aerodynamic brake (Tip brake and spoilers)

4.15.10 Generator: The conversion of rotational energy to electrical energy is carried out by generator.

In general the wind driven electric generator produces 50-cycle AC electricity. The types of generators are

- Synchronous generator (Electrically excited, permanent magnet),
- Asynchronous generator (SQIG -Squirrel cage induction generators, Slip ring)

4.15.11 Controller: The turbine system's controller manages the quality of the electric current sent to the grid. It initiates the turbine at the cut-in wind speed (typically 3 m/s) and ceases operation at the cut-out wind speed (generally 25 m/s), following design specifications. The controller monitors and regulates various parameters, including voltage, current, frequency, temperature within the nacelle, wind direction, wind speed, yawing direction, shaft speed, generator overheating, hydraulic pressure level, proper valve function, vibration level, power cable twisting, emergency brake circuit, overheating of small electric motors for yawing, hydraulic pumps, and brake caliper adjustment, among others.

4.15.12 Anemometer: An anemometer is a device designed to measure wind speed. It provides input to the controller for power regulation and braking beyond the cut-out and survival wind speeds. Typically, the anemometer is installed at the top of the wind turbine.

4.15.13 Pitch: The control of electricity production is managed through pitch adjustments under varying wind intensities. The blades are either turned or pitched out of the wind to regulate rotor speed and prevent rotation in winds that are excessively high or too low for efficient electricity generation.

4.15.14 Tower: This helps to use the wind energy at sufficient heights above ground. This helps to absorb and securely discharge static and dynamic stress exerted on the rotor, the power train and the nacelle into the ground. The major types of towers used in wind turbine are

- Lattice tower,
- Tubular tower,
- Guyed tower,
- Hybrid Tower

Table 2: Concise overview of different tower types in terms of their characteristics related to area of contact, loading, and load distribution.

Tower Type	Area of Contact	Loading	Load Distribution
Tubular Steel Tower	More	More	Even
Tubular Concrete Tower	More	More	Even
Lattice Tower	Less	Less	Uneven
Three-Legged Tower	Less	Less	Uneven
Guy Wired Tower	Less	Less	Even
Hybrid Tower	A combination of tubular and lattice	Varies	Varies

Tubular towers have gained popularity in contemporary wind turbines due to their reduced airflow interference, minimized downstream turbulence creation, and enhanced aesthetic appeal. While tubular steel towers are more expensive, lattice towers, three-legged towers, and guy-wired towers are favored for their ease of transportation and fabrication, with guy-wired towers being particularly suitable for smaller wind turbines.

Typically, the tower height is 1 to 1.5 times the rotor diameter, and the standard height is around 20 meters. The selection of a tower is significantly influenced by site characteristics. Tower stiffness is a crucial factor in wind turbine systems, addressing the potential for coupled vibrations between the rotor and the tower.

Tower shadow, which is the wake formed by airflow around a tower, has notable effects on turbine dynamics, power fluctuations, and noise generation, particularly for downwind wind turbines. It's essential to consider these factors when determining the appropriate tower for a wind turbine system.

4.15.15 Foundation: The selection of the foundation type for a wind turbine is based on the soil conditions and water table location at the designated site.

- Onshore Foundation Types: Slab Foundation (preferred for robust topsoil conditions),
- Pile Foundation (preferred when the topsoil is softer).
- Offshore Foundation Types: Monopile, Gravity Base, Tripod.

4.15.16 Wind Vane: The wind vane is an instrument used to measure wind direction. It supplies information to the controller to ensure proper orientation (yawing) of the turbine in alignment with the wind direction.

4.15.17 Yaw Drive: The yaw drive is responsible for maintaining the alignment of the turbine with the wind. It accomplishes this by turning the nacelle, along with the rotor, according to the wind direction. This is achieved through a rotary actuator that engages with a gear ring beneath the nacelle. There are two main types of yaw drive systems: active yaw and free yaw. The active yaw drive utilizes yaw motors and is controlled by an automatic yaw control system, equipped with a wind direction sensor mounted on the nacelle when not in the yawing position. This system is commonly employed in upwind wind turbines. On the other hand, free yaw systems are capable of self-aligning with the wind and are commonly used in downwind wind turbine systems.

4.15.18 Yaw Motor: The yaw motor provides the power necessary to drive the yaw drive.

4.16 WIND TURBINE CLASSIFICATION

There are different types of turbine technology

- **Based on axis orientation:**
    - ✓ Horizontal
    - ✓ Vertical
- **Based on Number of Blades**
    - ✓ One
    - ✓ Two
    - ✓ Three
    - ✓ Three
    - ✓ Multi-bladed
- **Based on Location**
    - ✓ On-shore
    - ✓ Off-shore
- **Based on Power control**
    - ✓ Stall

    - ✓ Variable Pitch
    - ✓ Controllable Aerodynamic
- **Based on Surfaces / Yaw Control Yaw Orientation**
    - ✓ Driven Yaw
    - ✓ Free Yaw
    - ✓ Fixed Yaw
- **Based on Rotor Position**
    - ✓ Upwind
    - ✓ Downwind
- **Based on Transmission**
    - ✓ with gear
    - ✓ without gear
- **Based on Type of Hub**
    - ✓ Rigid
    - ✓ Teetered
    - ✓ Hinged blades
    - ✓ Gimbaled
- **Based on Generator Speed**
    - ✓ Constant
    - ✓ Variable

- **The common classification is based on axis type.**
    - ✓ Horizontal axis Wind turbine (HAWT)
    - ✓ Vertical axis Wind turbine (VAWT)

4.16.1 Horizontal axis Wind turbine (HAWT)

The prevalent wind turbine variety is the Horizontal Axis Wind Turbine (HAWT), where the rotation axis is parallel to the ground. In HAWT, the blade rotation axis aligns with the direction of the wind flow. Common examples of horizontal axis wind mills include the aero-turbine mill with 35% efficiency and farm mills with 15% efficiency. The primary components of HAWT are:

- The rotor, comprising blades responsible for converting wind energy into rotational energy, constitutes 20% of the overall wind turbine cost.
- The generator component, which includes the electrical generator, control systems, and gearbox, plays a crucial role in transforming low-speed rotational energy into the high-speed rotational energy required for electricity generation. This component accounts for 34% of the total wind turbine cost.
- Structural support includes tower and yaw mechanism and it costs 15% of the turbine cost.

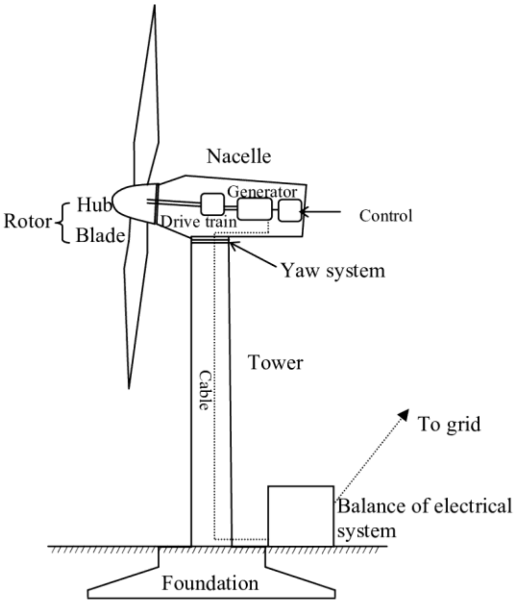

Figure 6: Main components of Horizontal axis wind turbine system

The HAWT works on principles of aerodynamic lift of wind turbines (Figure 7).

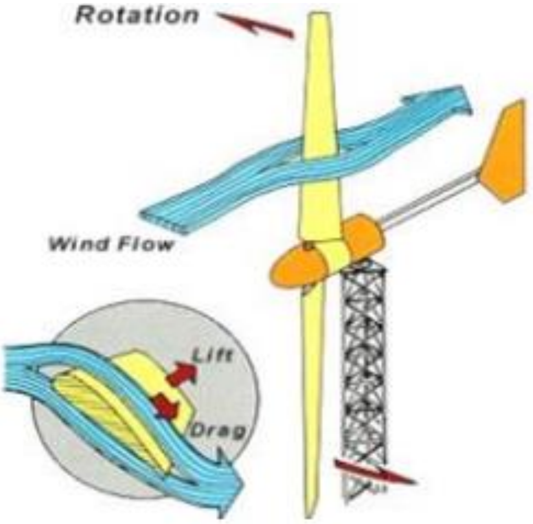

Figure 7: Principle of working of HAWT.

Classification of HAWT are based on

Rotor orientation

- Upwind of the tower
- Downwind of the tower

Hub design

- Rigid
- Teetering

Rotor control

- Pitch
- Stall

Based on number of blades

- Two blades
- Three blades

Based on how they are aligned with the wind

- Free yaw
- Active yaw

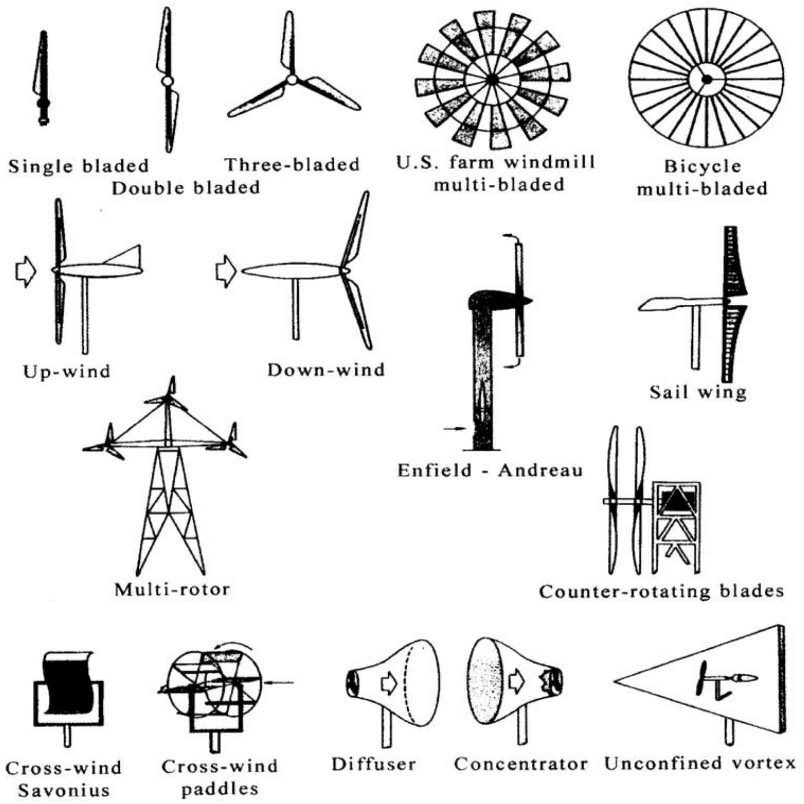

Figure. 8: Various concepts for horizontal axis turbines (Eldridge, 1980).

Examples of HAWT are

Fig. 9: Single blade, two blade, three blade and multi blade HAWT.

Advantages of Horizontal Axis Wind Turbines (HAWT):

- **Enhanced Stability:** HAWTs offer increased stability due to the placement of blades to the side of the turbine's center of gravity, resulting in a more balanced and stable structure.

- **Improved Efficiency:** The efficiency of HAWTs is higher as they can maximize the collection of wind energy by adjusting the angle of attack, optimizing the turbine's performance in varying wind conditions.

- **Storm Resilience**: HAWTs exhibit resilience during storms as the rotor blades have the capability to pitch, allowing for adjustments that help in minimizing potential damage during adverse weather conditions.

- **Access to Strong Winds:** The tall tower design of HAWTs facilitates access to stronger and more consistent wind resources, enabling efficient energy generation in areas with strong and reliable wind currents.

- **Versatility in Placement:** HAWTs are suitable for deployment in areas with wind shear and on uneven terrains, making them adaptable for both onshore and offshore locations.

Disadvantages of Horizontal Axis Wind Turbines (HAWT):

- **Ground-Level Operation Challenges:** HAWTs face difficulties when operating near the ground, limiting their applicability in certain environments where ground-level operation is essential.

- **Transportation Challenges:** The transportation of heavy and tall towers, as well as long blades, poses challenges, leading to logistical difficulties and increased costs during the installation process.

- **Special Installation Procedures:** HAWTs require specific and sometimes complex installation procedures, adding to the overall complexity of deploying these turbines.

- **Navigation Issues Offshore:** Offshore deployment of HAWTs can create navigation problems, particularly in shipping lanes and areas with high maritime traffic, which may necessitate careful consideration of turbine placement to mitigate such concerns.

4.16.2 Vertical Axis Wind Turbine (VAWT):

Vertical Axis Wind Turbines (VAWT) are less common than Horizontal Axis Wind Turbines (HAWT) mainly because their axis is parallel to the ground, which prevents them from capitalizing on the higher wind speeds found at elevated positions. Despite their lower prevalence, there are several basic designs of VAWTs, including:

- ✓ Darrieus Wind Turbine (Figure 10): This type features curved blades and boasts an efficiency of 35%.
- ✓ Giromill Wind Turbine (Figure 11): Characterized by straight blades, the Giromill design also achieves an efficiency of 35%.
- ✓ Savonius Wind Turbine (Figure 12): The Savonius design utilizes scoops to capture the wind, achieving an efficiency of 30%.

The figure 10 of Darrieus wind turbine explains how the VAWT works.

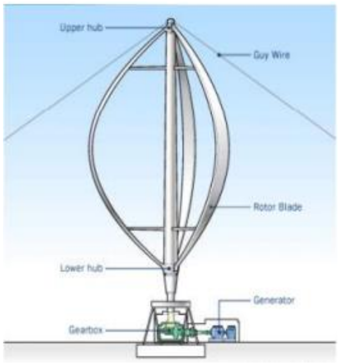

Figure 10: Darrieus wind turbine

(b) Giromill Wind turbine

Figure 11 (a): Helical Giromill Wind Turbine.

Figure 12: Savonius wind turbine

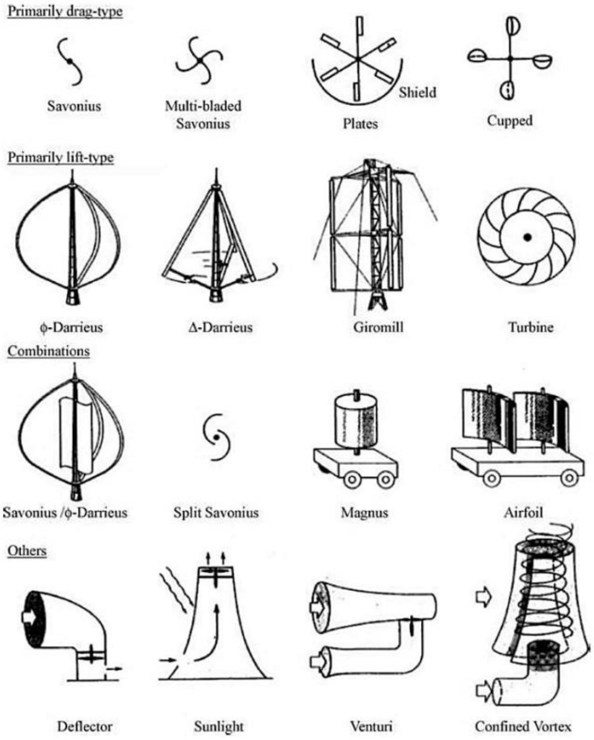

Fig 13: Various concepts of vertical axis turbines (Eldridge, 1980)

Advantages of Vertical Axis Wind Turbines (VAWT):

Wind Direction Independence: VAWTs do not require alignment with the wind direction, providing a notable advantage as they can capture wind from any direction without the need for complex orientation mechanisms.

Reduced Weight: VAWTs are lighter in weight compared to Horizontal Axis Wind Turbines (HAWTs), contributing to easier transportation, installation, and potentially lower structural support requirements.

Ease of Maintenance: Maintenance of VAWTs is simplified because the vertical shaft design allows for the placement of the transmission and generator at ground level. This accessibility facilitates easier inspection, repair, and maintenance tasks.

Lower Tower Costs: The vertical axis orientation of VAWTs allows for the use of less expensive tower structures, reducing overall construction costs associated with the support infrastructure.
But VAWT is not as efficient at collecting energy from the wind in comparison to HAWT.

4.17 PARAMETERS INFLUENCING WIND ENERGY CONVERSION

Optimal Tower Height: The efficiency of wind energy conversion is influenced by determining the most effective tower height. The selection of an optimal tower height is critical for harnessing wind resources at levels where they are most abundant and consistent.

Control Systems: Wind energy conversion systems are significantly impacted by the implementation of effective control systems. The performance and output of wind turbines are optimized through the use of control systems that adjust parameters such as blade pitch and rotor speed in response to changing wind conditions.

Number of Blades and Blade Shape: The design aspects of wind turbine blades, including the number of blades and their shape, play a crucial role in the efficient conversion of wind energy. The selection of an appropriate blade configuration is essential for maximizing the capture of wind and optimizing energy extraction from the wind stream.

4.18. DESIGNING OF WIND TURBINE

Wind turbine design incorporates various elements, including:

Number of Blades: The design decisions for wind turbines involve determining the optimal number of blades, which influences the turbine's efficiency in capturing wind energy.

Rotor Orientation: The orientation of the rotor, or the alignment of the turbine with the wind direction, is a crucial factor in wind turbine design to ensure effective energy capture.

Blade Material and Construction Method: Decisions regarding the materials used for the blades and the construction methods employed are key aspects of wind turbine design, influencing factors such as durability, weight, and overall performance.

Hub Design: The design of the hub, where the blades are attached, is an important consideration in wind turbine engineering, affecting the structural integrity and overall functionality of the turbine.

Power Control: Wind turbine design includes mechanisms for power control, allowing for adjustments in response to varying wind speeds to optimize energy output.

Rotor Speed (Fixed or Variable): The choice between fixed or variable rotor speeds is a design parameter that impacts the turbine's adaptability to different wind conditions and its overall efficiency.

Orientation of Turbine: The orientation of the entire turbine structure is a design consideration, ensuring that it is positioned correctly to capture wind from the prevailing direction.

Type of Generator: The selection of the generator type is a critical design decision, influencing the efficiency and overall performance of the wind turbine.

Gearbox or Direct Drive Generator: Wind turbine design includes the choice between a gearbox and direct drive generator, each having implications for the turbine's mechanical configuration and efficiency.

4.19. EFFECT OF WIND TURBINE ON GRID

The variable wind speed fluctuate the output voltage and power. It leads to

- ✓ flicker effects,
- ✓ voltage asymmetry,

This affects the power quality of the network or grid system.

Fixed-speed turbines produce a power pulsation emanating from the wind share over height. So variable-wind speed turbines are helpful as they are able to absorb short-term power fluctuations by using immediate storage of energy on the rotating drive train.

4.20 CONTROLLING PARAMETERS FOR POWER GENERATION OF WIND TURBINE

The process of controlling the velocity of the wind turbine is known as pitching. The speed of wind turbine is controlled by:

***Changing the orientation of wind turbine*:** By altering the pitch angle, the aerodynamics of the turbine blades are modified, allowing them to capture more or less wind energy depending on the desired speed of rotation. When wind speeds are too low, increasing the pitch angle can help the blades capture more wind and maintain rotation. Conversely, when wind speeds are too high, decreasing the pitch angle reduces the amount of wind the blades capture, preventing over speeding and potential damage to the turbine.

Pitch of the blades: Pitch control systems are an integral part of wind turbine operation, enabling efficient power generation across a wide range of wind speeds while also ensuring the safety and longevity of the turbine components.

This helps to modify the aerodynamics and efficiency of wind turbine.

4.21 SUMMARY

Wind energy, a cornerstone of the renewable energy landscape, involves the conversion of the kinetic energy from moving air into electricity. Harnessing the power of the wind through strategically placed wind turbines has become a mainstream and environmentally friendly method of electricity generation. As the turbines spin, they drive generators, producing clean and sustainable energy without emitting greenhouse gases. Wind energy's appeal lies in its scalability, adaptability to various geographic locations, and continually improving technology. While challenges such as intermittency and visual impact exist, ongoing innovation and global efforts to expand wind infrastructure underscore its pivotal role in mitigating climate change and shaping a cleaner energy future.

4.22 GLOSSARY

Wind Energy	The kinetic energy harnessed from the movement of air masses, primarily through the use of wind turbines, to generate electricity.
Wind Turbine	A device that converts the kinetic energy of wind into mechanical energy, which is then converted into electricity through a generator. Wind turbines can be of various types, including horizontal-axis and vertical-axis designs.
Rotor	The rotating component of a wind turbine that includes the blades. It captures wind energy and transfers it to the generator.
Capacity Factor	The ratio of the actual electricity generated by a wind turbine to its maximum potential output over a specific period. It indicates the efficiency of the turbine.
Wind Speed Distribution	A statistical analysis of wind speeds at a specific location over time, which helps assess the suitability for wind energy projects.
Turbulence	Irregular wind patterns that can affect the efficiency and structural integrity of wind turbines.
Wind Energy Density	The amount of energy available in the wind at a specific location, often measured in watts per square meter.
Wind Speed Distribution	A statistical analysis of wind speeds at a specific location over time, which helps assess the suitability for wind energy projects.

4.23 QUESTIONS

Multiple Choice Questions

1. What is the primary source of energy in wind energy generation?
   a. Solar radiation
   b. Fossil fuels
   c. Geothermal heat
   d. Nuclear fusion

2. Which of the following components of a wind turbine converts wind energy into mechanical energy?
   a. Rotor blades
   b. Gearbox
   c. Generator
   d. Tower

3. What is the typical range of wind speeds required for a wind turbine to generate electricity efficiently?
   a. 5-15 mph (8-24 km/h)
   b. 20-30 mph (32-48 km/h)
   c. 40-50 mph (64-80 km/h)
   d. 60-70 mph (96-112 km/h)

4. What is the primary advantage of offshore wind farms compared to onshore wind farms?
    a. Higher wind speeds
    b. Lower installation costs
    c. Less environmental impact
    d. Shorter transmission lines

5. Which of the following is a disadvantage of wind energy?
    a. No greenhouse gas emissions
    b. Intermittent energy production
    c. Low installation costs
    d. Minimal land use

6. What does the term "capacity factor" in wind energy refer to?
    a. The maximum energy output of a wind turbine
    b. The energy production of a wind turbine over a year
    c. The number of turbines in a wind farm
    d. The wind speed required to start a turbine

7. Which country is the largest producer of wind energy in the world as of my knowledge cutoff date in 2022?
    a. China
    b. United States
    c. Germany
    d. India

8. How can the environmental impact of wind energy, such as bird collisions, be reduced?
    a. By painting turbine blades a bright color
    b. By installing acoustic deterrents
    c. By using radar systems to detect birds
    d. By placing wind farms in densely populated bird habitats

9. Which renewable energy source is often used in conjunction with wind energy to provide a more consistent power supply?
    a. Solar energy
    b. Hydropower
    c. Biomass energy
    d. Geothermal energy

10. What is the future outlook for wind energy in terms of global energy production?
    a. It is expected to decline.
    b. It is expected to remain relatively constant.
    c. It is expected to significantly increase.
    d. It is too early to predict.

11. What is the typical lifespan of a wind turbine?
    a. 10-15 years
    b. 20-25 years
    c. 30-35 years
    d. 40-45 years

12. Which of the following devices is used to convert the kinetic energy of the wind into electricity?
    a. Windmill
    b. Windsock
    c. Wind vane
    d. Wind turbine

Answers

1: a); 2: a); 3: a); 4: a); 5: b); 6: b); 7: a); 8: c); 9: b); 10: c); 11: b); 12: d)

Short questions:

1. What is wind energy?
2. How is wind energy harnessed?
3. What is a wind turbine, and how does it work?
4. What are the advantages of using wind energy?
5. What are the disadvantages of wind energy?
6. How does the location impact the efficiency of wind energy generation?
7. What is the capacity factor of wind turbines?
8. What is the role of wind farms in wind energy production?
9. How does wind energy contribute to reducing greenhouse gas emissions?
10. What are some innovative technologies in wind energy generation?
11. What are the economic considerations for wind energy projects?
12. How does wind energy compare to other renewable energy sources like solar and hydropower?
13. What are the environmental impacts of wind energy, and how can they be mitigated?
14. What is the future outlook for wind energy development?
15. What are some of the largest wind energy-producing countries in the world?

Long Questions:

1. Explain the fundamental principles of how wind turbines capture and convert kinetic energy from the wind into electricity?
2. Describe the major components of a modern wind turbine, including the rotor, nacelle, and tower, and their functions in the energy conversion process.
3. How do variable-speed wind turbines differ from fixed-speed turbines, and what advantages do they offer in terms of energy capture and grid integration?

4. What are the positive environmental impacts of wind energy, such as reduced greenhouse gas emissions and air pollution, and how do they contribute to sustainability?
5. On the flip side, what negative environmental consequences can arise from wind energy projects, including habitat disruption and impacts on local wildlife, and what mitigation strategies can be employed to minimize these effects?
6. Discuss the importance of conducting thorough environmental impact assessments (EIAs) before constructing wind farms and share examples of effective EIAs in practice?

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UNIT 5

GEOTHERMAL ENERGY

Structure of the Unit

5.1 INTRODUCTION

In this unit we have the basic information about geothermal energy which originates from the heat within the earth. As the name suggests, the word geothermal comes from the Greek words *geo* (i.e. earth) and *therme* (i.e heat). Geothermal energy is a renewable energy resource derived from the heat stored beneath the Earth's surface or one can understand that the geothermal energy is a renewable energy source because heat is continuously produced inside the earth. People use geothermal heat for bathing, for heating buildings, and for generating electricity. It originates from the radioactive decay of minerals deep within the Earth, as well as from the heat remaining from the planet's formation. This heat is continuously produced and flows towards the Earth's surface.

5.2 OBJECTIVES

After studying the unit, the learners will be able to understand about

- Geothermal Energy
- Estimates of Geothermal power
- Nature of geothermal fileds
- Geothermal Resources and its type
- Direct uses of Geothermal Energy resources
- Interconnection of geothermal fossil systems
- Advantages of Geothermal Energy

5.3 ORIGIN OF GEOTHERMAL ENERGY

An renewable energy source that comes from the heat that is stored beneath the surface of the Earth is called geothermal energy. Radiating outward towards the surface, this energy comes from the Earth's core, where temperatures can reach several thousand degrees Celsius. There are several ways to use geothermal energy to generate hot water for homes, businesses, and industries, as well as power and heat structures.

The source of geothermal energy is deep within the earth. Geothermal energy is produced by the slow disintegration of radioactive particles in the earth's core, a process that occurs in all rocks.

The earth is divided into four main parts or layers which are mentioned below also shown in fig 01:

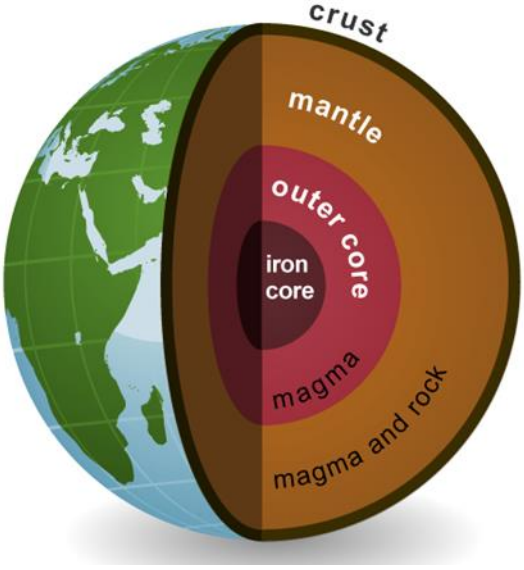

Fig.5.1: Formation of Earth

- An inner core of solid iron that is about 1,500 miles in diameter
- An outer core of hot molten rock called *magma* that is about 1,500 miles thick.
- A mantle of magma and rock surrounding the outer core that is about 1,800 miles thick
- A crust of solid rock that forms the continents and ocean floors that is 15 miles to 35 miles thick under the continents and 3 miles to 5 miles thick under the oceans

Researchers have found that the inner core of the planet is approximately 10,800 °F, or as hot as the sun's surface. In the mantle, temperatures vary from roughly 392°F at the mantle-crust boundary to roughly 7,230°F at the mantle-core border. Heat from subsurface magma is absorbed by rocks and water. The highest temperatures are found in the water and rocks located deeper below the surface.

5.4 NATURE OF GEOTHERMAL FIELDS

The area occupied by a geothermal system installation is known as a thermal field or geothermal field.

Wells are regularly built in the earth as part of a geothermal system. A thermal field, sometimes known as a geothermal field, is the area that these wells cover. Depending on the energy intensity being sought, the thermal field, also known as the geothermal field, may have a varied number of wells.

It is a region of the Earth where the transfer of heat is relatively high. The unusually high rate of heat transfer could be caused by radioactive decay of K, Th, and U isotopes, which are found in very high quantities in crustal granites, or by current or relatively recent orogenic or magmatic activity (hot dry rocks). High thermal gradients counterbalance the poor thermal conductivity values of the rocks in sedimentary basins, ensuring a steady flow of heat. Deep, permeating water is warmer due to the strong thermal gradients. Surface water at temperatures suitable for space heating is obtained by extracting water out of deep boreholes. Fumaroles and hot springs are two significant external manifestations of a geothermal area.

A thermal field, often known as a geothermal field, is the area where a geothermal system is installed. Regular intervals are used to drill wells in the earth for a geothermal system. The area these wells are located in is referred to as a thermal field or geothermal field. Depending on the intensity of energy sought, the number of wells in the thermal field, also known as the geothermal field, may vary.

The mechanisms involved in a geothermal system can be schematically defined as "the convection of water in the Earth's upper crust, which transfers heat from a heat source to a heat sink, usually the free surface, in a confined space" (Hochstein, 1990). There are three primary components to a geothermal system: a fluid that transports heat, a reservoir, and a heat source. As in certain low-temperature systems, the heat source can be either the Earth's normal temperature, which, as we previously mentioned, increases with depth, or a very high temperature (> 600 °C) magmatic intrusion that has reached relatively shallow depths (5–10 km). In the reservoir, heat is extracted by the circulating fluids from a volume of hot permeable rocks. The reservoir is often covered in impermeable rock and connected to a surficial recharge region where meteoric waters can partially or completely replace the fluids that leak out of the reservoir through springs or are drawn out by boreholes. In most cases, meteoric water in either the liquid or vapour phase, contingent upon temperature and pressure, is the geothermal fluid. Gases and compounds like CO_2, H_2S, and others are frequently present in this water. An ideal geothermal system is shown in the significantly simplified figure 02.

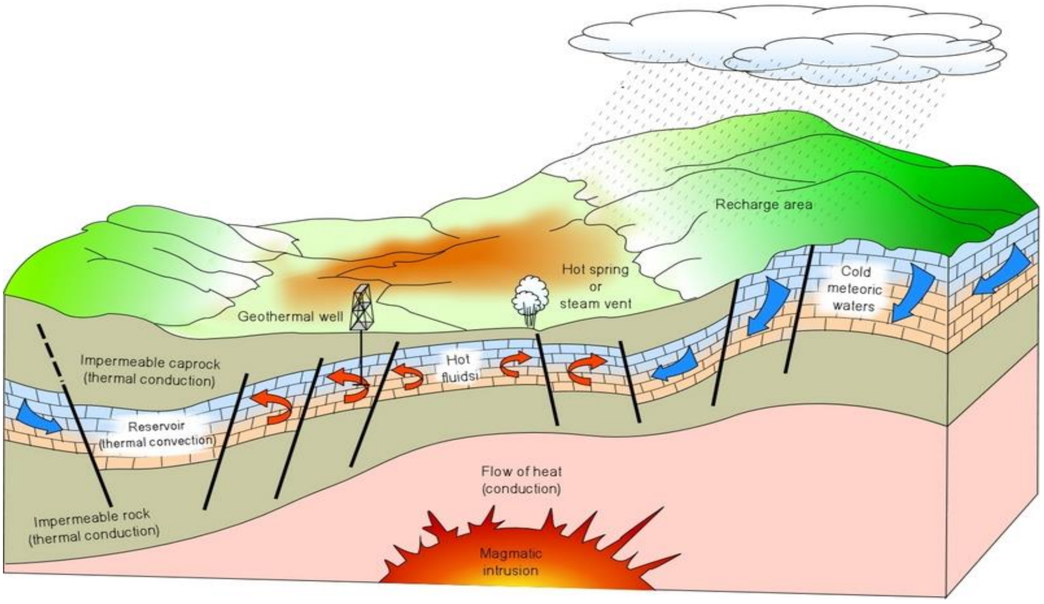

Figure 5.2: Geothermal steam field with its elements: recharge area, impermeable cover, reservoir, and heat source

The heat source is the only part of a geothermal system that doesn't appear to be natural. The other two components could be "artificial," if the circumstances are perfect. For instance, the geothermal fluids used in a geothermal power plant to power the turbine could be returned to the reservoir through designated injection wells once they have served their purpose. In this method, an artificial recharge integrates with the reservoir's natural recharge. Re-injection has also been used for a long time to significantly lessen the environmental impact of geothermal plant operations in many different locations of the world.

5.5 GEOTHERMAL RESOURCES

Geothermal resources are the naturally occurring heat energy that is stored in the Earth's crust and can be used for a variety of tasks, such as heating, cooling, and producing electricity. These resources are generally found in areas of active plate tectonic activity, while they can also be found in places where other geological processes have increased heat flow from the Earth's interior. These are a few important categories of geothermal energy.

5.5.1. Hydrothermal Reservoirs: The most common kind of geothermal resource is hydrothermal reservoir. These reservoirs are made up of steam or hot water that has been trapped in cavities, cracks, or porous rock formations in the crust of the Earth. Hydrothermal reservoirs have a wide range of temperatures, from high-temperature resources utilized to generate power to relatively low-temperature resources suitable for direct heating purposes.

5.5.2 Enhanced Geothermal Systems (EGS): Enhanced geothermal systems—also referred to as engineered geothermal systems—involve the creation of artificial reservoirs by using methods like hydraulic fracturing (fracking) and fluid injection to promote heat exchange within hot, dry rock formations. Beyond areas with naturally occurring hydrothermal reservoirs, geothermal energy production may be able to increase its geographic reach with the use of EGS.

5.5.3 Geopressured Reservoirs: High-temperature, high-pressure brine that is trapped in deep sedimentary formations under the Earth's surface is the hallmark of geopressured reservoirs. These reservoirs frequently have dissolved solids, natural gas, and water in them. Geopressured resources have the capacity to produce electricity as well as be used directly.

5.5.4 Hot Dry Rock (HDR): The process of collecting heat from impermeable rock formations by the drilling of deep wells and the circulation of water through fractures generated by hydraulic stimulation is known as hot dry rock resources. In order to extract heat from the rock and transport it to the surface for the purpose of generating electricity or direct heating, HDR systems need to inject a heat transfer fluid.

5.5.5 Magma Reservoirs: There are areas where there is active volcanic activity where there are magma reservoirs, or magmatic heat sources. Geothermal energy can be produced from the heat contained in molten magma beneath the crust of the Earth by means of technologies like binary cycle power plants, which use the heat exchange between fluids heated by the magma and a secondary working fluid to produce electricity.

5.6 TYPES OF GEOTHERMAL RESOURCES

5.6.1 HYDROTHERMAL RESOURCES

A particular type of geothermal resource is hydrothermal, which is based on the existence of steam or hot water that has been trapped in the crust of the Earth. These resources are typically found in areas that are experiencing active plate borders or volcanic activity. The following are some essential features of hydrothermal resources:

1. Formation: When groundwater seeps into the Earth's crust and is heated by the geothermal gradient—the rise in temperature with depth—hydrothermal resources are created.

Hydrothermal reservoirs are created when heated water rises back towards the surface via faults, fractures, and porous rock formations.

2. Reservoir Characteristics: The dimensions, fluid composition, depth, and temperature of hydrothermal reservoirs can all varies. The usual depths at which they can be found are several hundred meters to several kilometers below the surface of the Earth. Hydrothermal fluids can have temperatures that are extremely high (over 350°C) or comparatively low (less than 100°C). Water, steam, dissolved minerals, and gases (including carbon dioxide, hydrogen sulfide, and methane) can all be found in the fluid composition.

3. Geological Settings: Active fault zones, rift zones, and volcanic calderas are some examples of geological characteristics that are frequently linked to hydrothermal resources. These regions offer more direct routes for heat from the Earth's subsurface to reach the surface, leading to the development of hydrothermal systems.

4. Manifestations: Hot springs, geysers, fumaroles, and mud pots are common surface manifestations of hydrothermal resources. Hot springs are naturally occurring groundwater springs that have been heated by geothermal activity. Geysers are sporadic hot springs that release water and steam on occasion. Whereas mud pots are hot springs with mud or clay mixed into the water, fumeroles are vents in the Earth's surface that release gasses and steam.

5. **Utilization**: Hydrothermal resources can be used for a number of purposes, such as the production of energy, direct heating, and industrial and agricultural processes. Hydrothermal reservoirs' steam or hot water is used in geothermal power plants' turbines to create energy. Buildings, greenhouses, swimming pools, and industrial operations like desalination and drying are examples of direct-use applications.

5.6.2 GEO PRESSURED RESOURCES

Geopressured resources are a category of geothermal resources that are found deep inside sedimentary formations beneath the surface of the Earth. These resources often contain brine and are high-temperature, high-pressure fluids.. These resources are characterized by elevated pressure resulting from the weight of overlying rock layers and the presence of dissolved methane and other gases in the brine. Here are some key aspects of geopressured resources:

1. **Formation**: Geopressured reservoirs are formed when ancient seawater is trapped inside porous formations by deeply buried sedimentary rock layers over geologic time. The enclosed water becomes pressured due to the weight of the sedimentary layers above it, and its

temperature rises due to heat from the Earth's interior. The production of methane gas, which increases reservoir pressure, can result from the presence of organic material in sedimentary rocks.

2. Characteristics: Generally, geopressured reservoirs are found several thousand to tens of thousands of feet below the surface of the Earth. High pressure (typically greater than 6,900 kPa or 1,000 psi) and high temperatures (usually between 90°C and 150°C or higher) are characteristics of the reservoir fluids. In geopressured reservoirs, the brine is frequently quite saline and can include dissolved gases such as carbon dioxide, hydrogen sulfide, and methane.

3. Energy Potential: Geopressured resources have potential for direct use applications as well as the production of power. Geothermal power facilities can use the high-pressure, high-temperature brine to power turbines and produce electricity. Furthermore, district heating systems, greenhouse farming, and industrial activities can all directly benefit from the heat produced from geopressured fluids.

4. Challenges and Considerations: Geopressured resources provide a number of development and application-related difficulties. These include the brine's caustic properties, the possibility of induced seismicity linked to fluid extraction, the existence of dissolved gasses that may need to be treated or mitigated, the requirement for deep drilling and reservoir stimulation procedures, and others. In addition, the profitability of geopressured projects is contingent upon other factors, including the expense of drilling, the productivity of reservoirs, and the present condition of the electricity and heat.

5. Environmental Impact: The development of geopressured resources, like other energy extraction methods, may have an adverse effect on the environment. These effects could include habitat destruction, subsurface fluid migration, and contamination of groundwater. To reduce these effects and guarantee the sustainable use of geopressured resources, careful site selection, environmental monitoring, and mitigation strategies are required.

5.6.3 HOT DRY ROCK RESOURCES

Enhanced Geothermal Systems (EGS), commonly referred to as Hot Dry Rock (HDR) resources, are a kind of geothermal energy resource that uses the extraction of heat from impermeable rock formations located far below the surface of the Earth. HDR does not rely on naturally occurring hot water or steam reservoirs, in contrast to hydrothermal resources. Instead, it uses hydraulic stimulation techniques to create artificial reservoirs inside of hot, dry rock formations. Key features of HDR resources include the following:

1. Formation: HDR resources are generally located along tectonic plate borders or areas that have recently had volcanic activity, which are areas with increased heat flow from the Earth's mantle. The impermeable crystalline rocks, such as granite, basalt, or gneiss, that make up the hot, dry rock formations don't naturally have the permeability or cracks needed for fluid movement.

2. Technological Approach: In order to create artificial reservoirs using HDR resources, deep wells are drilled into hot rock formations. High-pressure water or other fluids are then injected to create fissures and encourage heat exchange. As the injected fluid travels through the fractures and returns to the surface through production wells, it absorbs heat from the surrounding rock. Here, it is collected and used directly to produce heat or electricity.

3. Heat Extraction: Heat is transferred from the heated rock to the injected fluid in HDR systems via a process called convective heat transfer. As the injected fluid passes through the fractured rock and absorbs heat, the temperature rises. Heat exchangers are used once the heated fluid is pumped to the surface in order to remove the heat, which is then utilized in binary cycle power plants to generate electricity or for direct heating purposes..

4. Potential: HDR resources can be used in areas where conventional hydrothermal resources are not easily accessible, which means that they have a great deal of potential for producing geothermal energy. The global prevalence of impermeable crystalline rock formations raises the possibility that HDR resources are accessible in a number of locations, hence broadening the potential geographic scope for geothermal energy development.

5. Challenges: HDR technology has many obstacles in spite of its potential, such as the requirement for deep drilling, the possibility of induced seismicity as a result of reservoir stimulation, and the expense of creating and managing HDR projects. Furthermore, variables including the temperature and permeability of the rock formations, as well as the success of reservoir stimulation methods, affect the productivity and efficiency of HDR systems.

5.6.4 MAGMA RESOURCES

One kind of geothermal energy resource that includes utilizing the heat contained in molten magma under the Earth's surface is a magma resource, also referred to as a magmatic heat source. Beneath the Earth's crust, partially melted rocks in the mantle combine to form magma, a mixture of molten rock, gasses, and suspended particulates. Key characteristics of magma resources are as follows:

1. Formation: Magma is produced through processes such as mantle convection, decompression melting, and the addition of volatiles (such as water and carbon dioxide) to the mantle rocks. By fissures, faults, and volcanic conduits, it rises toward the Earth's surface where it may either consolidate subterranean to create intrusive igneous rocks or erupt as lava during volcanic activity.

2. Heat Source: Depending on its composition, depth, and degree of crystallization, magma can have temperatures ranging from several hundred to over a thousand degrees Celsius. Magma is an abundant source of thermal energy. The primary source of heat inside magma on Earth is radioactive decay of isotopes in the mantle and core, along with residual heat from the planet's formation.

3. Geological Settings: Hotspots, rift zones, and volcanic arcs are examples of areas where there is currently significant volcanic activity and are often linked to magma resources. These regions offer access to magma reservoirs beneath the crust of the Earth, where heat can be captured for the production of geothermal energy.

4. Utilization: Magma heat can be used for a variety of geothermal energy uses, including as industrial processes, direct heating, and the production of electricity. Geothermal power plants can be constructed in locations with shallow and accessible magma reservoirs to use binary cycle or flash steam technologies to capture heat and generate energy. Buildings, spas, and greenhouses as well as industrial operations like desalination, mineral extraction, and drying are examples of direct use applications.

5.7 INTERCONNECTION OF GEOTHERMAL FOSSIL SYSTEMS

The possible synergies and interactions between the generation of geothermal energy and the extraction or consumption of fossil fuels are referred to as the interconnection of geothermal and fossil fuel systems. Although geothermal energy is a renewable and environmentally healthy energy source, there are circumstances in which the extraction and use of fossil fuels can have a positive or negative impact on geothermal resources. The following are some possible connections between systems that use fossil fuels and geothermal energy:

1. Co-located Operations: Geothermal resources are sometimes found adjacent to locations used to extract fossil fuels, including coal mines or oil and gas fields. Co-locating geothermal energy production facilities alongside fossil fuel activities can offer shared infrastructure opportunities, including power transmission lines, drilling rigs, and access roads, which could save costs and have a positive environmental impact.

2. Enhanced Oil Recovery (EOR): In order to maximize the extraction efficiency of oil from low-producing or depleted oil reservoirs, enhanced oil recovery (EOR) operations can make use of geothermal energy. Oil fields can have a longer productive life by injecting geothermally heated fluids into their reservoirs. This reduces viscosity in the oil, increases flow rates, and improves total oil recovery rates.

3. Geothermal Direct Use in Fossil Fuel Industries: Within the fossil fuel work, geothermal energy can be directly applied to a number of processes, including distillation for water-intensive operations like hydraulic fracturing (fracking), thermal drying of coal, and heating for oil refineries. Reducing greenhouse gas emissions and pollution in the environment can be achieved by replacing fossil fuels used for heating and other industrial activities with geothermal energy.

4. Geothermal Co-generation with Fossil Fuel Power Plants: To improve total energy efficiency and lower emissions, geothermal energy can be co-generated with fossil fuel power plants. Fossil fuel power plants can achieve higher thermal efficiency and lower fuel consumption, which will reduce greenhouse gas emissions per unit of electricity generated, by utilizing geothermal heat to warm boiler feedwater or provide supplemental heat for power generation.

5. Environmental Considerations: While there may be potential synergies between geothermal and fossil fuel systems, it's essential to consider potential environmental impacts and risks associated with co-located operations. These include groundwater contamination, subsurface fluid migration, induced seismicity, and land subsidence, which can result from the extraction or injection of fluids during both geothermal and fossil fuel operations.

5.8 ADVANTAGES OF GEOTHERMAL ENERGY OVER OTHER ENERGY SOURCES

Geothermal energy has many advantages, especially when compared to conventional sources of energy:

1. Geothermal Energy Sourcing is Good for the Environment

Primarily, geothermal energy is produced from the earth without involving the burning of fossil fuels, and emissions from geothermal areas are almost negligible. Furthermore, since geothermal energy can save you up to 80% on your traditional energy costs, it can be highly advantageous.

2. Geothermal Is a Reliable Source of Renewable Energy

When compared to other renewable energy sources like solar, wind, or biomass, geothermal energy also has a lot of advantages. It is an extremely dependable energy source that is available throughout the year and is not reliant on the sun or wind.

The availability factor, which rates the consistency and dependability of different energy sources, places geothermal energy far above the other categories supporting the claim that it is independent of variable external conditions when supplying energy

3. **High Efficiency of Geothermal Systems**

In comparison to conventional systems, geothermal heat pump systems require 25% to 50% less electricity for heating or cooling. Additionally, due to their adaptable design, they require less room for hardware and can be adjusted to various conditions.

4. Little to No Geothermal System Maintenance

The life expectancy of geothermal heat pump systems is comparatively long as they have few moving parts that are protected inside a structure. A heat pump's lifespan can typically span at least 20 years, but pipes can potentially have warranties ranging from 25 to 50 years.

5.9 DISADVANTAGES OF GEOTHERMAL ENERGY OVER OTHER ENERGY SOURCES

Learners will have a look at the major disadvantage of geothermal energy:

1. Greenhouse gas emissions raise environmental concerns.

Unfortunately, despite geothermal energy's pictures as an environmentally advantageous alternative energy source, there are a few small environmental hazards associated with it. Methane, ammonia, carbon dioxide, and hydrogen sulfide are among the greenhouse gases released during the process of extracting geothermal energy from the earth. Gas emissions are, nevertheless, far less than when fossil fuels are used.

2. Possibility of Depletion of Geothermal Sources

In addition, even though geothermal energy is thought to be sustainable and renewable, there's a potential that some places will eventually cool off and become unusable for further geothermal energy harvesting.

The only non-depletable approach is to directly obtain geothermal energy from magma, however this method is currently being developed technologically. The fact that magma would persist for billions of years is the primary factor making this choice financially worthwhile.

3. Geothermal System Investment Costs Are High

An additional drawback is the substantial starting cost for individual homes. The price increases significantly due to the requirement of drilling and installing an extremely complex system within one's home. Even still, the investment has a very promising return, with the money regained in two to ten years.

4. Land Requirements for the Installation of a Geothermal System

In the case of geothermal systems, installation requires an area of land near to the dwelling. Because of this, homeowners in large cities find it difficult to install geothermal systems unless they uses a vertical ground source heat pump.

5.10 SUMMARY

After studying the unit, the learners have learnt about

- Geothermal Energy
- Estimates of Geothermal power
- Nature of geothermal fileds
- Geothermal Resources and its type
- Direct uses of Geothermal Energy resources
- Interconnection of geothermal fossil systems
- Advantages and Disadvantages of Geothermal Energy

5.11 REFERENCES

1. "Geothermal Energy: Renewable Energy and the Environment" by William E. Glassley, David H. Bock, and Stephen R. Brown.
2. "Geothermal Power Plants: Principles, Applications, Case Studies and Environmental Impact" by Ronald DiPippo.

3. "Geothermal Energy: An Alternative Resource for the 21st Century" by Harsh K. Gupta and Sukanta Roy.
4. https://www.vskills.in/certification/tutorial/geothermal-fields/
5. https://www.thinkgeoenergy.com/geothermal/an-overview-of-geothermal-resources/

5.12 SUGGESTED READINGS

1. Geothermal Energy: Renewable Energy and the Environment by Tester, et al. (2006)
2. "Geothermal Energy Systems: Exploration, Development, and Utilization" by Ernst Huenges
3. Geothermal HVAC: Green Heating and Cooling" by Jay Egg and Brian Howard
4. "Geothermal Energy: Sustainable Heating and Cooling Using the Ground" by Marc A. Rosen and Seama Koohi-Fayegh.
5. "Geothermal Energy: From Theoretical Models to Exploration and Development" edited by Bahman Tohidi.

5.13 TERMINAL QUESTIONS

Short Answer Type Questions

1. What is geothermal energy?
2. What is the source of heat in geothermal energy?
3. What is a benefit of geothermal energy?
4. What is a disadvantage of geothermal energy?
5. How is geothermal energy harnessed for electricity generation?
6. What are the main types of geothermal resources?
7. What is the difference between hydrothermal and enhanced geothermal systems (EGS)?
8. What are the environmental benefits of geothermal energy?
9. How does a geothermal heat pump work?
10. What are some challenges associated with geothermal energy development?
11. How does the temperature gradient in the Earth's crust contribute to geothermal energy?
12. What are the potential applications of geothermal energy besides electricity generation?

Long Answer Type Questions

1. Describe the process of electricity generation from geothermal energy, including the different types of geothermal power plants and their operation.
2. Compare and contrast different types of geothermal resources, including hydrothermal systems, enhanced geothermal systems (EGS), geopressured systems, and magma resources. What are the geological characteristics and technological requirements of each type?
3. Describe the environmental impact of geothermal energy production. How does it compare to the environmental impact of traditional fossil fuel power plants?
4. Geothermal energy can be a valuable resource for developing countries. Discuss the economic and social benefits of geothermal energy development in these regions.
5. Forecast the future of geothermal energy, considering trends in technology, economics, policy, and global energy demand. What are the opportunities and potential barriers to achieving widespread adoption of geothermal energy as a mainstream energy source?

UNIT-6: OCEAN ENERGY

6.1. INTRODUCTION

Renewable energy derived from ocean sources represents a promising frontier in the quest for sustainable power generation. The oceans offer a vast and largely untapped reservoir of energy in various forms, including tidal and wave energy, ocean currents, and temperature differentials. As the world seeks alternatives to traditional fossil fuels, the ocean's immense potential has come into focus as a valuable contributor to the global renewable energy mix.

Tidal energy is harnessed through the rhythmic rise and fall of tides, while wave energy captures the kinetic energy from the motion of surface waves. Ocean currents, driven by natural forces like wind and temperature variations, present another avenue for extracting power. Additionally, the temperature gradient between the warm surface and colder depths can be leveraged through technologies such as Ocean Thermal Energy Conversion (OTEC).

This unit provides an in-depth exploration of ocean energy, which is a promising and renewable source of power. Learners will learn about the various types of ocean energy, the technologies used to harness it, environmental impacts, and its potential for sustainable energy generation. This unit covers the basics of ocean energy, including its types, technologies, environmental impacts, and potential for sustainable energy generation. It also includes suggested readings, learning objectives, and assessment methods.

6.2. LEARNING OBJECTIVES

After studying this unit, you should be able to:

- Define the different types of ocean energy and understand the fundamental principles behind them.
- Explain the technological advancements and challenges associated with harnessing ocean energy.
- Evaluate the environmental impacts of ocean energy technologies.
- Analyze the potential of ocean energy as a sustainable source of power.
- Discuss the current state of the ocean energy industry and its future prospects.

6.3. INTRODUCTION TO OCEAN ENERGY

Ocean energy refers to the vast and largely untapped renewable energy resources derived from the world’s oceans. This emerging field harnesses various forms of energy generated by oceanic elements such as tides, waves, currents, and temperature gradients. The utilization of ocean energy holds significant potential as a sustainable and environmentally friendly alternative to conventional fossil fuels. By tapping into these abundant resources, we can explore innovative technologies and solutions to meet our growing energy demands while minimizing the impact on the environment. This introduction sets the stage for the exploration of diverse ocean energy technologies and their role in shaping the future of clean and sustainable energy production.

6.3.1 Historical development and milestones

The development of ocean energy technologies has been a gradual process, covering several decades. The history of ocean energy is marked by significant milestones and innovations that have contributed to its current state. Now we will discuss some main historical developments and milestones in the field of ocean energy:

- **Early Experiments (18th and 19th centuries):** The earliest experiments with ocean energy can be traced back to the 18th and 19th centuries when inventors like Girard and St. Remy in France and John Jacob Astor in the United States attempted to use tidal energy for various industrial purposes. These initial endeavors laid the groundwork for further exploration.
- **La Rance Tidal Power Plant (1966):** This plant in France, built in 1966, was one of the first large-scale tidal power plants in the world. It verified the potential of tidal energy as a viable source of electricity generation.
- **The Tidal Stream Generator (1967):** British engineer Stephen Salter patented the first modern tidal stream generator in 1967. This device used the kinetic energy of moving water to generate electricity and marked an important advancement in tidal energy technology.
- **The Ocean Thermal Energy Conversion (OTEC) Concept (1881-1930s):** The idea of OTEC can be traced back to the late 19th century, with French engineer Jacques Arsène d'Arsonval proposing a heat engine powered by the temperature difference between warm surface water and cold deep water. OTEC research continued into the 1930s.
- **The Deep Water Experiment (1930s):** Georges Claude, a French engineer, led the Deep Water Experiment off the coast of Cuba in the 1930s. It demonstrated the feasibility of OTEC and laid the groundwork for further development.

- **The Sea Snake Project (1990s):** The Sea Snake project in Norway during the 1990s marked an important landmark in wave energy. It was one of the earliest attempts to develop a practical wave energy converter, demonstrating the potential of wave power.
- **European Marine Energy Centre (EMEC) (2003):** EMEC, located in Orkney, Scotland, was established in 2003 as the world's first grid-connected marine energy test center. It played a pivotal role in testing and demonstrating various ocean energy technologies.
- **MeyGen Tidal Energy Project (2016):** MeyGen, located in the Pentland Firth, Scotland, is one of the world's largest tidal energy projects. It successfully installed multiple tidal turbines, showcasing the commercial viability of tidal energy.
- **Commercial Wave Energy Projects (2010s):** In the 2010s, several commercial wave energy projects were set up, including the Pelamis Wave Power project off the coast of Portugal and the Carnegie Wave Energy project in Western Australia. These projects paid to the commercialization of wave energy technology.
- **Global Growth and Research Initiatives (21st Century):** In the 21st century, ocean energy has seen constant growth and investment. Numerous research initiatives, pilot projects, and commercial deployments have expanded our understanding and practical use of ocean energy.

These historical advancements and landmarks illustrate a development from early experiments to the construction of practical ocean energy plants. While ocean energy is still in its early stages of becoming a mainstream energy source, continued research and technical advances point to a bright future for this renewable and sustainable energy industry.

6.3.2 The role of ocean energy in the renewable energy sector

Ocean energy plays a promising and sustainable renewable energy source with numerous advantages, including predictability, low environmental impact, and diverse technological approaches. As technology advances and costs decrease, ocean energy is likely to play an increasingly important role in the global transition to clean and renewable energy sources.

1. **Abundant and Sustainable Resource:**

   Ocean energy is a virtually inexhaustible and sustainable energy source. Tides and waves are driven by the gravitational pull of the moon and the sun, while temperature differences in the ocean can be harnessed for power generation. Unlike fossil fuels, which are finite and contribute to climate change, ocean energy resources are constantly replenished.

2. **Predictable Energy Generation:**
   Tides and waves are highly predictable, making it easier to integrate them into the energy grid and plan for power generation. This predictability is advantageous compared to some other renewable sources like wind and solar, which are variable and dependent on weather conditions.
3. **Low Environmental Impact:**
   Ocean energy technologies have a relatively low environmental impact compared to traditional fossil fuel-based energy sources. They do not produce greenhouse gas emissions, air pollution, or water contamination. Properly designed facilities can also minimize disruption to marine ecosystems.
4. **Diverse Technologies:**
   Ocean energy encompasses various technologies, including tidal energy, wave energy, and ocean thermal energy conversion (OTEC). This diversity allows for the deployment of multiple solutions tailored to different geographical locations and energy needs.
5. **Energy Independence:**
   Coastal regions and islands can benefit from ocean energy as it reduces their reliance on imported fossil fuels, promoting energy independence and security.
6. **Job Creation:**
   The development and operation of ocean energy projects can create jobs in manufacturing, installation, maintenance, and research and development.
7. **Research and Innovation:**
   The ocean energy sector promotes technological innovation and research in fields like materials science, engineering, and environmental science.

6.4. IMPORTANCE OF OCEAN ENERGY

1. **Renewable and Sustainable:** The ocean energy is considered as a renewable resource, as the forces responsible for tides and waves are unlimited and continuous. Unlike fossil fuels, ocean energy does not reduce over time, making it a sustainable and environmentally friendly energy source.
2. **Low Carbon Emissions**: Ocean energy systems produce negligible greenhouse gas releases. These technologies play a crucial role in providing clean energy alternatives.

3. **Energy Security:** Ocean energy helps enhance energy security by reducing dependence on fossil fuels. Coastal areas and island countries, in specific, can benefit from local, reliable ocean energy sources.
4. **Predictable and Consistent:** Tidal and wave energy resources are highly predictable and follow regular patterns. This predictability allows for efficient grid integration and energy planning.
5. **Job Creation and Economic Growth:** The maintenance and development of ocean energy plans generate employment opportunities and stimulate economic growth in coastal communities.
6. **Reduced Environmental Impact:** In comparison to other fossil fuel-based power generation or traditional hydropower, ocean energy has a lower environmental impact. Properly managed projects can minimize disturbance to marine ecosystems.
7. **Global Potential:** Oceans cover over 70% of the Earth's surface, providing vast untapped energy potential. Many countries are investing in research and development to harness this energy, contributing to a global shift toward sustainable power sources.

6.5. TYPES OF OCEAN ENERGY

There are several types of ocean energy technologies that harness the power of the ocean's natural resources to generate electricity and other forms of energy. These technologies can be broadly categorized into the following types:

6.5.1 Tidal Energy

Tidal energy, also known as tidal power, is a form of renewable energy that harnesses the kinetic and potential energy of the ocean's tides to generate electricity. It relies on the gravitational interactions between the Earth, the Moon, and the Sun, which cause the rise and fall of ocean tides. There are several methods to capture and convert tidal energy into electricity:

1. Tidal Stream Systems (Tidal Turbines): Tidal stream systems are similar in concept to underwater wind turbines. They consist of underwater turbines or propellers installed on the seabed in areas with strong and predictable tidal currents. As the tides flow in and out, these turbines are rotated by the moving water, which drives generators to produce electricity. Tidal stream systems are often used in areas with strong tidal flows, such as straits and coastal regions.

2. Tidal Range Systems (Tidal Barrages and Tidal Lagoons): Tidal range systems capture the energy from the difference in water levels between high tide and low tide, known as the tidal range. There are two main types of tidal range systems:

a. Tidal Barrages: A tidal barrage is a dam-like structure built across the entrance of an estuary or bay. Sluice gates in the barrage allow water to flow into the estuary during high tide and then release it through turbines as the tide recedes. This cyclic filling and emptying of the estuary generates electricity.

b. Tidal Lagoons: Tidal lagoons are circular or semi-circular structures built along the coast that capture and release water as tides rise and fall. Similar to tidal barrages, turbines are used to generate electricity as water flows in and out of the lagoon.

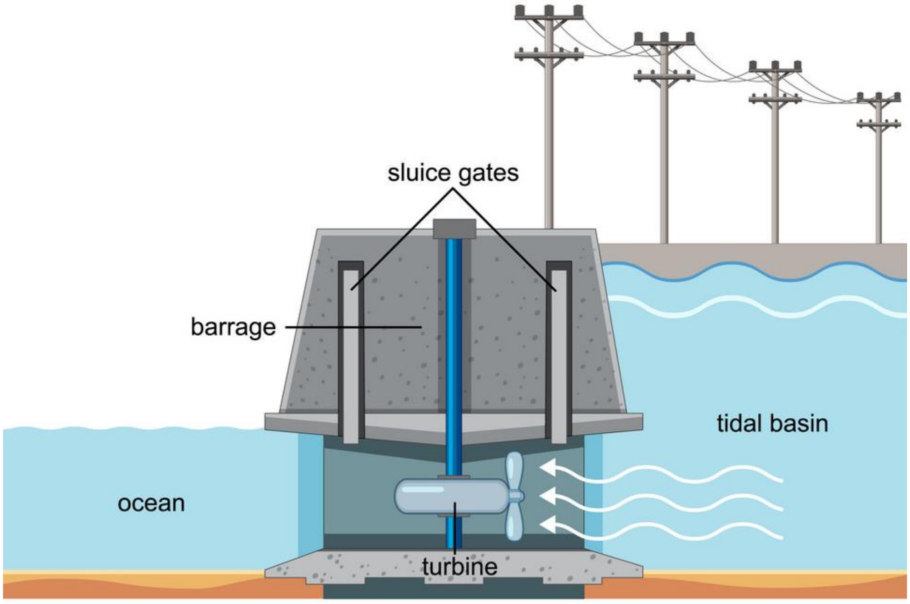

Figure 6.1: Tidal Power Station.

6.5.1.1 Tidal Energy Technologies and Projects

Several tidal energy technologies and projects have been developed and implemented worldwide to harness the power of ocean tides for electricity generation. These technologies can be broadly categorized into tidal stream systems and tidal range systems. Here are some notable tidal energy technologies and projects:

Tidal Stream Systems (Tidal Turbines):

MeyGen Project (Scotland, United Kingdom): The MeyGen project in the Pentland Firth off the coast of Scotland is one of the largest tidal energy projects in the world. It features an array of submerged tidal turbines that capture energy from the strong tidal currents in the region. The project has demonstrated the viability of tidal stream systems on a commercial scale.

Bay of Fundy (Canada): The Bay of Fundy, located between New Brunswick and Nova Scotia in Canada, is known for having some of the highest tidal ranges in the world. Several tidal stream projects have been proposed and are under development in this region, such as the Cape Sharp Tidal project and the Minas Passage project.

SeaGen (Northern Ireland): The SeaGen tidal turbine, located in Strangford Lough, Northern Ireland, was one of the world's first commercial-scale tidal energy projects. It has been in operation since 2008 and has provided valuable insights into the performance and environmental impacts of tidal turbines.

Tidal Range Systems (Tidal Barrages and Tidal Lagoons):

Sihwa Lake Tidal Power Station (South Korea): The Sihwa Lake Tidal Power Station is one of the largest tidal range projects in the world. It is located on the west coast of South Korea and utilizes a tidal barrage to generate electricity. The project has successfully demonstrated the use of tidal energy on a large scale.

Rance Tidal Power Station (France): The Rance Tidal Power Station, situated in the Rance River estuary in Brittany, France, has been in operation since 1966. It was one of the first tidal energy facilities in the world and uses a tidal barrage to generate electricity. It has provided valuable experience and data for tidal energy development.

Swansea Bay Tidal Lagoon (Wales, United Kingdom): The Swansea Bay Tidal Lagoon project proposed a tidal lagoon with a breakwater structure off the coast of Swansea, Wales. Although the project faced challenges and delays, it exemplified the potential of tidal lagoons for electricity generation.

La Rance II Tidal Barrage (France): France has plans to construct the La Rance II tidal barrage near the existing Rance Tidal Power Station. This project aims to expand the capacity of tidal energy generation in the region.

These tidal energy technologies and projects showcase the progress and potential of tidal energy as a renewable energy source. While they have encountered various challenges, including high initial costs and environmental considerations, they contribute to ongoing research and development efforts to make tidal energy a more practical and reliable component of the global energy mix.

6.5.1.2 Merits of Tidal Energy

Longevity: Tidal barrages can have a long operational life, typically around 100 years or more. This is significantly longer than the lifespan of many other renewable energy sources, such as solar panels and wind turbines, making tidal energy a durable and reliable energy source.

Clean and Renewable: Tidal energy is a clean and renewable energy source that does not produce greenhouse gas emissions or air pollution.

Low Environmental Impact: Tidal energy production typically has a minimal environmental impact compared to some other forms of energy generation. It doesn't produce harmful emissions or waste, reducing its contribution to air and water pollution. It also doesn't have a significant visual impact on the landscape, as most of the infrastructure is underwater.

Space Efficiency: Tidal energy infrastructure doesn't require large land areas. Tidal barrages and tidal stream systems are often compact and can be integrated into existing coastal infrastructure, which is beneficial in areas with limited available land for energy projects.

6.5.1.3 Demerits of Tidal Energy

Location Dependency: Tidal energy generation is highly dependent on suitable locations with strong tidal currents and significant tidal ranges. These locations are limited, which restricts the widespread adoption of tidal energy and necessitates the transportation of electricity to areas of demand.

High Initial Costs: Tidal energy projects can be expensive to build and install, particularly tidal barrages. The construction of underwater infrastructure, such as turbines and generators, can be technically challenging and costly. However, the long lifespan of tidal energy systems can offset these initial costs over time.

Environmental Impact: While tidal energy generally has a lower environmental impact compared to fossil fuels, it can still affect local marine ecosystems. Tidal turbines and barrages may pose risks to fish and marine life, and careful environmental monitoring and mitigation measures are needed to minimize these impacts.

Intermittency: Tidal energy generation is intermittent, as it depends on the tidal cycle. Energy production is most efficient during the ebb and flow of tides, and there are periods of low or no energy generation between these cycles. This intermittency necessitates the integration of energy storage or other complementary energy sources to maintain a stable energy supply.

Despite the challenges associated with tidal energy, it holds significant promise as a sustainable and reliable source of renewable electricity. Ongoing research and development efforts are focused on overcoming these challenges and making tidal energy a more feasible and integral component of the global energy mix. As technology advances and environmental considerations are addressed, the potential for tidal energy to contribute to clean and reliable power generation continues to grow.

6.5.2 WAVE ENERGY

Wave energy is a type of renewable energy that is harnessed from the kinetic and potential energy associated with the movement of ocean waves. It is considered a clean and sustainable source of energy with the potential to generate electricity. Here's an overview of how wave energy is harnessed:

Wave Energy Converters (WECs): Wave energy is captured using devices called Wave Energy Converters (WECs), which are specifically designed to extract energy from the motion of ocean waves. There are several types of WECs, including point absorbers, oscillating water columns, and attenuators, each with its own design and method of energy conversion.

Point Absorbers: These devices use a floating structure that moves with the motion of the waves. The relative motion between the floating structure and the seabed is used to generate electricity through mechanical systems like hydraulic pumps or generators.

Oscillating Water Columns: Oscillating water columns use the rising and falling of waves to displace air within a chamber. The movement of air powers a turbine or generator to produce electricity.

Attenuators: Attenuators are long, snake-like structures that move with the motion of the waves. They are designed to capture wave energy along their length, often through hydraulic systems or mechanical systems, and then convert it into electricity.

Point Absorbers: These devices use a floating structure that moves with the motion of the waves. The relative motion between the floating structure and the seabed is used to generate electricity through mechanical systems like hydraulic pumps or generators.

Power Take-Off (PTO): The PTO system converts the mechanical motion generated by the WECs into electricity. This can be achieved using hydraulic systems, linear generators, or other mechanical components, depending on the specific WEC design.

Grid Connection: The electricity generated by the WECs is then transmitted to the grid for distribution to consumers. This often involves underwater cables to connect the wave energy farms to onshore infrastructure.

6.5.2.1 Merits of Wave Energy

Wave energy has significant potential as a renewable energy source, but it also faces several challenges. Here are some key considerations regarding its potential and challenges:

Wave Energy Potential:

1. Abundant Resource: Ocean waves are a vast and abundant source of energy. They are driven by winds and tides, making them a consistent and reliable energy source.
2. Predictable: Waves are highly predictable, as they follow regular patterns influenced by factors such as wind speed, fetch (distance over which the wind blows), and geographical features. This predictability makes wave energy a reliable source of electricity.
3. High Energy Density: The energy carried by ocean waves is concentrated, meaning that even a small section of coastline can yield a significant amount of electricity.
4. Low Environmental Impact: Compared to some other forms of energy generation, wave energy has a relatively low environmental impact. It doesn't produce greenhouse gas emissions, and the underwater devices used for wave energy conversion are generally less intrusive to the environment than some other renewable technologies.

6.5.2.2 Demerits of Wave Energy

1. **High Initial Costs:** Developing and installing wave energy infrastructure can be expensive, especially in harsh marine environments. The cost of manufacturing, deploying, and maintaining the technology can be a significant barrier.
2. **Technological Challenges:** Designing and maintaining wave energy conversion devices that can withstand the harsh marine conditions, including saltwater corrosion, strong waves, and underwater operations, is a technological challenge.

3. **Environmental Impact:** While wave energy has a relatively low environmental impact compared to fossil fuels, it can still affect marine ecosystems, navigation, and coastal environments. Mitigation measures are necessary to minimize these impacts.
4. **Variable Energy Output:** The energy output of wave energy systems can vary due to changes in wave conditions and seasonal fluctuations. This variability can pose challenges for grid integration and meeting consistent energy demands.
5. **Competition with Other Renewable Sources:** Wave energy often competes with other renewable energy sources like wind and solar. In some regions, other renewables may be more cost-effective, making it harder for wave energy to gain market share.
6. **Lack of Standardization:** The wave energy industry lacks standardized technologies and designs, making it challenging to develop economies of scale and streamline manufacturing processes.
7. **Regulatory and Grid Integration Challenges:** Regulatory and permitting processes for marine energy projects can be complex, and integrating wave energy into existing power grids may require significant infrastructure updates.

Despite these challenges, ongoing research and development efforts, as well as pilot projects, aim to overcome these limitations and make wave energy a more viable and competitive source of renewable electricity. As technology advances and the industry matures, wave energy has the potential to play a more substantial role in the global energy mix and contribute to reducing greenhouse gas emissions.

6.6. OCEAN THERMAL ENERGY CONVERSION (OTEC)

What is OTEC: The sun heats the surface of the sea, capturing all its energy in a layer up to 100 meters deep known as the "mixed layer." This term is used because the temperature and salinity in this layer are made uniform by wind and wave actions. As we descend into the ocean, the water becomes progressively colder. A substantial volume of cold water is found at depths of around 1000 meters, resulting from the accumulation of frigid water that has melted from Polar Regions.

The Ocean Thermal Energy Conversion (OTEC) process harnesses the temperature contrast between warm surface water and cold deep water to drive a thermodynamic cycle, transforming a low-grade heat source into electricity. The efficiency of this cycle is dictated by the principles of the Carnot cycle, typically hovering around 7-8% in an ideal reversible heat engine scenario. However, in practical applications, various components like heat exchangers, turbines, pumps, generators, and others introduce significant inefficiencies, leading to a much lower efficiency compared to the ideal Carnot cycle.

6.6.1 Working principle of OTEC

Ocean Thermal Energy Conversion (OTEC) harnesses the temperature difference between warm surface seawater and cold deep seawater to generate electricity. The working principle of OTEC is based on the fundamental concept of thermodynamics, utilizing the natural temperature gradient found in tropical and subtropical regions. Warm surface seawater, typically around 25°C to 30°C, is pumped through a heat exchanger where it vaporizes a working fluid with a low boiling point, such as ammonia. This vapor drives a turbine connected to a generator, producing electricity. Subsequently, cold deep seawater, which can be as cold as 5°C to 10°C, is pumped through a separate loop to condense the vapor back into liquid form, completing the cycle. The continuous temperature differential between the warm surface water and the cold deep water ensures a sustained operation of the OTEC system, making it a promising renewable energy source with potential for large-scale implementation.

6.6.2 Brief History of Ocean Thermal Energy Conversion

In 1870, Jules Verne introduced the concept of Ocean Thermal Energy Conversion (OTEC) in his novel “Twenty Thousand Leagues under the Sea”. However, it was Jacques d'Arsonval and his student Georges Claude who are recognized as pioneers in the development of OTEC. Claude took a significant step by constructing the first onshore OTEC plant in 1930. The first successful offshore plant that produced net power was the mini-OTEC in Hawaii in 1979. Since then, numerous studies worldwide have explored the complexities of OTEC technology.

Saga University in Japan has been a notable contributor to OTEC research, focusing on optimizing thermal cycles in laboratory settings for several years. Simultaneously, the U.S. Department of Energy has played a role in advancing OTEC through research and development initiatives, collaborating with industry partners. These efforts underline the global interest and ongoing exploration of OTEC as a potential sustainable and renewable energy source.

Currently plants which have been installed are:-

1. Reunion Island - France – 15 kW (2012)
2. Kumejma, Japan - Saga University and xenesys

   - 100 kW (2013)

3. Hawaii, USA - Makai Ocean Engineering

- 105 kW (2015)

India had made attempts in as early as the year 2000 to set up a 1 MW floating barge mounted plant offshore.

6.6.3 OTEC CYCLE AND SYSTEM

The OTEC cycle can be classified into two types:

a) Open cycle:

In this, the working fluid is vented out after use. One way to use the open cycle is to run surface sea water through vacuum and the steam generated is used to run a turbine. The vapour is condensed using deep sea water to create fresh water.

(b) Closed cycle:

In this cycle a fluid with low boiling point like ammonia is used to rotate a turbine to generate power by using warm surface sea water to vaporize the fluid. Subsequently cold deep sea water condenses the vapour back to liquid state and this liquid is re-circulated in a closed loop to vaporize and drive the turbine. Hybrid cycles combine features of both open and closed cycle systems. A schematic closed cycle is shown in Figure 6.2.

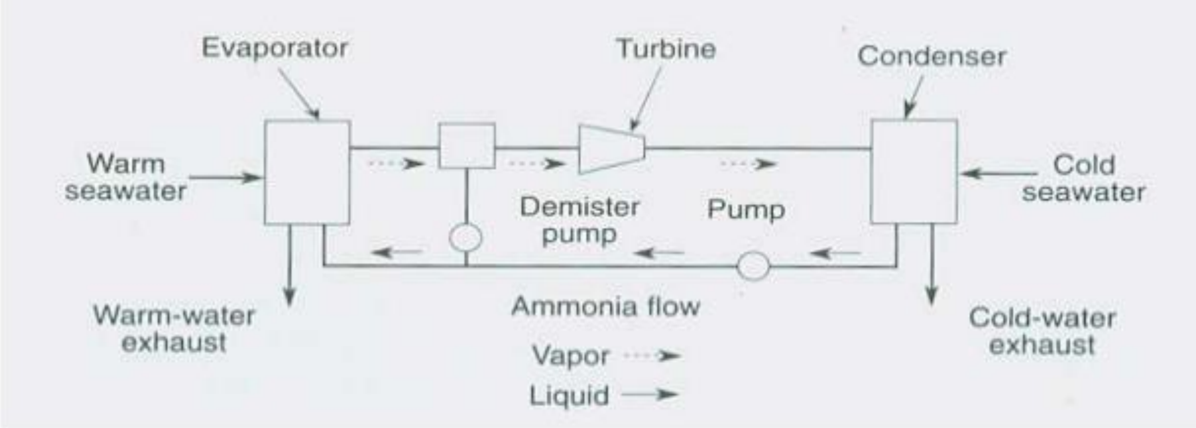

Figure 6.2: Closed Cycle.

Thermodynamically, for converting thermal energy to mechanical energy, cycles used generally are Rankine and Kalina cycles. The Uehara cycle developed in Japan also is important from an academic perspective

6.6.4 COMPONENTS OF AN OTEC SYSTEM

The major components of an OTEC system are

1. Heat Exchangers
2. Turbine
3. Seawater Pumps
4. Cold water conduit
5. Platform
6. Station keeping / mooring
7. Data acquisition & control systems
8. Startup and shutdown procedures & safety.

Before we discuss individual components it is important to understand the other parameters required for the design and installation of an OTEC plant.

These encompass:

(a) Bathymetry at the Desired Location:

To extract cold water effectively, access to depths of around 1000 meters below the sea surface is necessary. Certain locations, such as islands like the Lakshadweep islands in India, have deep waters very close to the shore. In India, along the coast, deep water is available approximately 40-50 km from the shore on the east coast and even farther on the west coast. This circumstance requires the establishment of a floating offshore plant. Therefore, understanding the bathymetry, or the depths of the seabed around the desired location, is crucial. Some locations feature shallow waters extending for a distance, with sudden deep depths occurring at the end of this plateau. Plants positioned at such sites are referred to as shelf-mounted.

(b) Environmental Parameters:

In the case of a floating or fixed platform-mounted plant in the open sea, the design must account for the most extreme wind, wave, and current conditions. The design of the cold water conduit is significantly influenced by these environmental parameters. Typically, for continuous operations, the design should accommodate extreme conditions such as those expected in 50-year and 100-year storms. Therefore, obtaining data for long-term predictions through modelling becomes essential. It's worth noting that many of these models lack validation due to the absence of actual data. Nevertheless, the design process should undergo rigorous analysis, considering all the loads imposed by environmental forces.

(c) Other issues

Seabed and soil information may be needed for moorings or fixed structures in the sea. Site specific issues like fishing zones and naval bases may also need to be considered for finalizing location. Certain locations are prone to seismic activity and hence this may need to be taken into account in the analysis.

6.6.4.1. Heat Exchangers

Before we talk about heat exchangers let us understand process parameters which go into heat exchanger design. Firstly a closed cycle needs a working fluid. The basic requirements for a candidate fluid are:-

(i) Low boiling point

(ii) Low volume of the fluid per kW of power produced.

(iii) High heat transfer characteristics

(iv) Environmental acceptability

(v) Acceptable cost

Most refrigerates could be used in an OTEC cycle. However in general ammonia is popularly considered for a closed loop OTEC cycle.

Heat exchangers come in either shell and tube or plate types, with plate heat exchangers generally considered more suitable for OTEC applications due to their compact design compared to shell and tube exchangers. In addition to designing for a maximized heat transfer coefficient, the choice of materials is crucial. Since one side involves seawater and the other the working fluid (such as ammonia and seawater), materials like stainless steel and titanium are viable options, given their compatibility with both seawater and the working fluid.

Various factors influence heat exchanger design, including the intake water temperature, the temperature as the water exits the heat exchanger, and losses within the heat exchanger that impact overall performance. The challenge lies in the relatively small temperature gradient, typically in the range of 20-12°C, available for the entire OTEC cycle.

6.6.4.2. Turbine

Generally axial and radial turbines of single or multiple stages are used. The pressure ratio across the turbine is dictated by the working fluid and speed of the turbine is important from the generator's perspective. The efficiency of the turbine – generator plays an important role in the overall efficiency of power generation.

6.6.4.3 Sea Water Pumps

Large volumes of sea water are required to be pumped up for the OTEC cycle. Generally the losses especially in the long cold water conduit are mostly due to frictional losses. Thus the pumps required are high discharge and low head pumps. The power requirement of the pumps governs the net power generated in the OTEC cycle.

6.6.4.4. Cold Water Conduit

The most complex and challenging component is the cold water conduit. An offshore floating plant will need to be positioned in deep waters with a long conduit hanging vertically down or supported in some configuration to draw cold water continuously from depths of around 1000m. The conduit has to be designed for loads due to waves and currents and also for installation and deployment scenarios. As the rating becomes larger and larger, the size of the conduit becomes very big and is known to be the single most complex unit in the entire system.

6.6.4.5. Platform

When land based or shelf mounted plants are not possible, a floating platform is required to support the process equipment as well as the conduit to draw cold water. Various platform configuration are being studied the world over including barges, semi-submersibles, spars, etc. The platform design is critical because it has to be an all-weather one and if it is directly supporting the conduit, forces induced by it due to environmental conditions on the conduit, can lead to high stresses in the conduit.

6.6.4.6. Station keeping and mooring

A floating platform needs to be kept in position or at station else the cold water conduit connected to it may start drawing warm water due to vessel drift. Moorings have to be designed to be all weather for this purpose. Current offshore practice has codal requirements for moorings in the oil industry however long term moorings for OTEC are yet to be attempted.

6.6.4.7. Data acquisition and control

The dependence on flow and temperatures of cold and warm sea water necessitate the measurements of these parameters. Hence a data acquisition system coupled with suitable instruments like pressure and temperature transmitters, flow meters, etc. are essential. Automatic control may also be required in the working fluid regime in case of temperature fluctuations.

6.6.4.8. Startup and Shutdown

Any OTEC system needs proper startup and shutdown procedures to be defined systematically a priori before installation. These procedures govern opening and closure of critical valves and commencing or stoppage of flows. Especially in case of working fluids like ammonia, which can have risk associated, the procedures need to be laid down properly from safety perspective.

6.6.5. INDIAN EFFORTS ON OTEC

In 1998, the National Institute of Ocean Technology (NIOT), operating under the Ministry of Earth Sciences, established a 1 MW floating Ocean Thermal Energy Conversion (OTEC) plant in Tuticorin at a water depth of 1000 meters. The key elements of the power module, responsible for converting heat energy into electrical energy, included an evaporator, turbine-generator, condenser, and pumps for circulating the working fluid and seawater. A specially designed storage tank was utilized for storing liquid ammonia. Following the evaporator, a mist eliminator ensured that the turbine received dry saturated vapor.

The power plant used titanium plate heat exchangers for the evaporators and condensers. These heat exchangers were the largest in size ever used for such an application. The evaporators were low chevron angle plates having a special steel coating on ammonia side to enhance the nucleation of liquid ammonia. The ammonia turbine was a 4-stage, axial flow, horizontal axis turbine working with a low pressure ratio of 1.4 and temperature range of 10o C. Computational

Fluid Dynamics (CFD) analysis was done to determine the blade profiles and it was predicted to operate at 87% adiabatic efficiency, which is significant for the OTEC power cycle. The power system flow rates and the net power are dependent on the turbine efficiency. Any fall in adiabatic efficiency adversely affects the performance of the OTEC power cycle. Vertical turbine pumps of low head were used to pump sea water. All the components were assembled on a floating barge.

The major challenge was the design of the platform and the cold water pipe. A non-self-propelled barge was designed to suit the purpose with special features like three moonpools and a retractable cold water sump to suit the NPSH requirements of the pumps. The final configuration of barge with pipe / mooring is shown in below Figure 6.3.

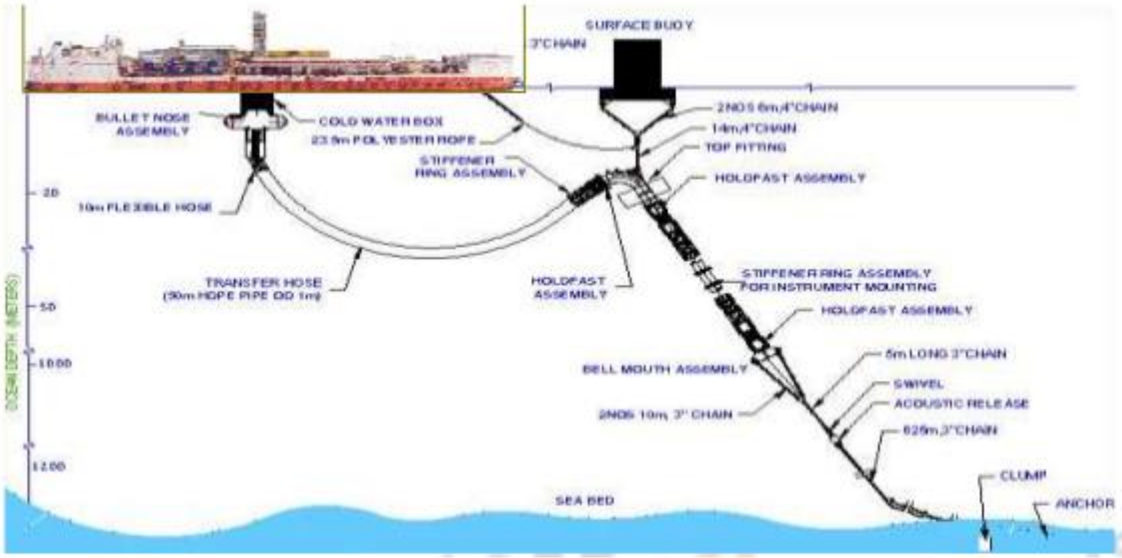

Figure 6.3: Final configuration of barge with pipe/mooring.

As part of the commissioning activities, various subsystem qualification tests were carried out on shore as well as in shallow waters. The OTEC barge SagarShakthi was berthed near the port and many subsystems trials were carried out. Several trials in shallow waters also were carried out and subsystems qualified successfully. Finally the 1000m long pipe of 1 m diameter was towed 40 km to the desired site. Sufficient offshore handling facilities were not available on the eastern coast of India, hence the deployment had to be carried out with serous limitations and the project could not be completed. Later the same barge was used for mounting desalination equipment and fresh water was first generated in shallow water. The learning was used for setting up desalination plants using thermal gradient successfully. India has the distinction of setting up a low temperature thermal desalination plant in Kavaratti, Lakshadweep for the first time ever in 2005. The plant is running successfully using thermal gradient in the ocean even today in 2016 generating 100,000 litres per day. Subsequently two more plants have been set up in islands of Agatti and Minicoy. A barge mounted plant of capacity 1 million litres per day was also demonstrated offshore on the same barge built for OTEC. Below Figure 6.4 shows the Barge mounted desalination plant of capacity 1 million litres per day

Figure 6.4: View of the Barge Mounted Desalination Plant.

Thermal Desalination expertise has now been developed along with offshore experience for deploying pipes for drawing cold water. NIOT is now setting up a laboratory to run the hybrid cycle of OTEC and desalination. Efforts are now on to power desalination using OTEC.

6.7. CHALLENGES AND FUTURE DIRECTIONS IN OCEAN ENERGY

Ocean energy holds significant promise as a source of clean and sustainable power, but it also faces several challenges on the path to becoming a mainstream energy source.

Challenges:

- **Technical Difficulties:** Creating cost-effective and reliable ocean energy technology is a significant problem. Devices must be able to survive extreme sea environments while still operating effectively.
- **Environmental Impact:** Ocean energy projects can have environmental consequences, and managing these consequences while maintaining sustainability is critical. Marine ecosystem protection is a top priority.

- **Economic viability:** It is hampered by the large upfront expenditures of ocean energy projects, as well as competition from well-established energy sources. It is vital to get finance and save expenditures.
- **Public Perception:** Overcoming public concerns about visual effect, safety, and potential harm to marine life is a task. It is critical to get public acceptability.

Future Prospects:

- **Technological Progress:** Ongoing research and development activities aim to increase the efficiency, dependability, and durability of ocean energy systems. Material and design advancements will help to reduce costs.
- **Global Expansion and Market Growth**: Extending ocean energy projects to different locations and markets would help it expand and integrate into local energy networks.
- **Policy and Regulation:** Governments play a critical role in influencing the future of maritime energy through supporting regulatory frameworks and incentives, g. Stable policies encourage investment and development.
- **Environmental Best Practices:** Identifying and implementing sustainable practices and mitigating strategies to reduce the environmental effect of ocean energy projects will be a future priority.
- **Public Engagement and Education:** It is critical to establish public support by engaging with local communities and educating the public about the advantages and safety of ocean energy.
- **Hybrid Systems:** Combining different ocean energy technologies or combining them with other renewable sources might improve energy generation and dependability.

Addressing the issues and pursuing future directions in ocean energy is critical for its effective integration into the global energy mix. Ocean energy is projected to play a larger part in the transition to a more sustainable and environmentally friendly energy future as technology progresses and legislation adapt.

6.8. SUMMARY

The unit concludes with a forward-looking perspective on the future of ocean energy. Ocean energy, a promising frontier in the realm of renewable resources, encompasses a diverse array of technologies harnessing the immense power latent in the world's oceans. Tidal energy capitalizes on the gravitational forces of the moon, wave energy taps into the kinetic energy of ocean waves, ocean thermal energy conversion leverages temperature differentials, and salinity gradient power extracts energy from variations in salt concentrations. As an emerging sector, ocean energy offers a clean and predictable source of power, presenting a potential solution to the global demand for sustainable energy. While facing challenges related to technology development, environmental impact, and economic feasibility, ongoing research and advancements in this field hold the promise of unlocking the vast, untapped energy potential of our oceans.

6.9. GLOSSARY

Ocean Energy	Energy derived from the natural movements and temperature differences in the ocean, including tidal energy, wave energy, ocean thermal energy, and salinity gradient power.
Tidal energy	Energy harnessed from the rise and fall of tides, typically through the use of tidal stream systems or tidal range systems.
Wave Energy	Energy generated from the motion of ocean waves using various devices, such as wave energy converters (WECs)
Ocean Thermal Energy Conversion (OTEC)	A method that uses the temperature difference between warm surface water and cold deep water in the ocean to produce electricity.
Energy Storage	Technologies used to store excess energy generated from ocean sources for use during periods of low energy production.
Wave Energy Converters (WECs)	Machines or systems designed to capture and convert the kinetic energy of ocean waves into electricity.
Ocean Current Energy	Energy generated by harnessing the kinetic energy of ocean currents.
Environmental Impact Assessment (EIA)	A process used to evaluate the potential environmental effects of ocean energy projects and ensure that appropriate measures are taken to minimize harm to ecosystems.
Marine Renewable Energy	A broader term that encompasses various forms of renewable energy derived from the ocean, including tidal and wave energy.

6.10. QUESTIONS

Short Answer questions

1. What is ocean energy, and how does it vary from other renewable energy sources?
2. What are the primary types of ocean energy technologies that are currently in use or under development?
3. How does tidal energy harness the strength of the ocean's tides?
4. What challenges and obstacles are associated with the commercial deployment of ocean energy technologies?
5. What parts of the world are particularly suitable for harnessing ocean energy?

6. What is wave energy, and how it is converted into electricity?
7. What is the difference between ocean thermal energy conversion (OTEC) and other ocean energy methods?
8. How do underwater turbines generate electricity from ocean currents?
9. What are the environmental advantages and disadvantages of harnessing ocean energy?
10. How does salinity gradient power work, and how is it related to ocean energy?
11. What is tidal energy?
12. What are the advantages of tidal energy?
13. List the disadvantages of tidal energy.

Long Answer questions

1. What are the different forms of ocean energy, and how do they work? Provide detailed explanations for each method, including tidal energy, wave energy, ocean thermal energy, and ocean current energy.
2. Discuss the environmental impacts of harnessing ocean energy. How do these impacts compare to traditional fossil fuels and other renewable energy sources? What measures can be taken to mitigate potential negative effects?
3. Describe the potential benefits and challenges associated with the commercialization and widespread adoption of ocean energy technologies. How might they contribute to the global energy mix and reduce greenhouse gas emissions?
4. Explain the technical and engineering challenges of capturing and converting energy from the ocean, considering factors such as energy conversion efficiency, device durability, and maintenance in harsh marine environments.
5. Explore the economic viability of ocean energy projects. What are the key factors affecting the cost-effectiveness of harnessing energy from the ocean, and how do they compare to other renewable energy sources?
6. Discuss the role of government policies and incentives in promoting the development and deployment of ocean energy technologies. How have various countries and regions supported this industry, and what lessons can be learned from their experiences?
7. Analyze the global potential for ocean energy resources. Which regions are most suitable for different types of ocean energy technologies, and how might this affect the distribution of energy resources and energy security on a global scale?

8. How does the intermittency and variability of ocean energy sources, such as waves and tides, impact energy production and grid integration? What solutions and technologies are available to address these challenges?
9. Compare and contrast ocean energy technologies with other renewable energy sources, such as wind and solar power, in terms of their scalability, reliability, and energy generation potential.

Multiple Choice Questions

1. What is the primary source of energy harnessed in ocean thermal energy conversion (OTEC) systems?
   A) Tides
   B) Solar radiation
   C) Wind
   D) Geothermal heat

2. Which of the following is a key technology used to capture wave energy?
   A) Solar panels
   B) Tidal turbines
   C) Wave buoys
   D) Wind turbines

3. What is the primary factor responsible for the rise and fall of ocean tides?
   A) Wind patterns
   B) Gravitational pull of the moon and the sun
   C) Earth's rotation
   D) Ocean temperature

4. Which ocean energy technology involves the use of underwater turbines to harness the kinetic energy of ocean currents?
   A) Tidal energy
   B) Wave energy
   C) Ocean thermal energy conversion
   D) Salinity gradient power

5. In which ocean energy technology is the difference in temperature between warm surface water and cold deep water used to generate electricity?
   - A) Wave energy
   - B) Tidal energy
   - C) Ocean thermal energy conversion (OTEC)
   - D) Salinity gradient power

6. What is the primary source of energy in salinity gradient power systems?
   - A) Ocean currents
   - B) Differences in water density
   - C) Solar radiation
   - D) Wind

7. Which of the following regions is generally considered to have the greatest potential for harnessing ocean energy?
   - A) Landlocked countries
   - B) Coastal areas with weak tides
   - C) Areas with low wave energy
   - D) Coastal areas with strong tidal and wave energy

8. What is the major advantage of ocean energy when compared to fossil fuels?
   - A) Abundant resource availability
   - B) Minimal environmental impact
   - C) High energy conversion efficiency
   - D) Low initial infrastructure costs

9. Which ocean energy technology is often associated with the predictability and reliability of energy generation due to the regularity of tides?
   - A) Wave energy
   - B) Ocean thermal energy conversion
   - C) Tidal energy
   - D) Salinity gradient power

10. What is one of the main challenges facing the commercial deployment of ocean energy technologies?
    - A) Limited availability of suitable ocean locations
    - B) High cost of energy conversion equipment
    - C) Low energy production potential
    - D) Minimal environmental impact

ANSWERS: 1 (B); 2 (C); 3 (B); 4 (A); 5 (C); 6 (B); 7 (D); 8 (A); 9 (C); 10 (A)

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UNIT 7

BIO-ENERGY

Structure of the Unit

7.1 INTRODUCTION

Biomass energy, where solar energy is utilized indirectly, has been the major source of energy to human beings throughout the history of civilization. Biomass energy is the outcome of the photosynthesis. It is bestowed in the materials such as live plant material and their dried residues; fresh water and marine algae; and agricultural and forest residues of plant and animal origin. Apart from these materials, biomass also includes biodegradable organic wastes from industries like sugar mills, breweries etc. Biomass fuel may be solid such as wood, animal dung, peat, charcoal etc. used for burning; liquid such as methanol or ethanol used in internal combustion engines of automobiles; or gas such as animal waste produced biogas: a mixture of gases mainly methane and some carbon dioxide produced in biogas digesters. Biogas is a clean anaerobic fuel of organic origin whose combustion produces fewer pollutants than other combustible energy sources. Although production of energy requires sufficient area of land and water, but in its various forms, biomass energy appears to have a bright future as a source of energy. At least half of the global population relies upon biomass as main s source of energy for domestic use. Firewood is most widely used biomass quite common fuel in the world.

7.2 OBJECTIVES

After studying this unit, you should be able to explain about -

- What is Biomass.
- Sources of Biomass.
- Advantages and Disadvantages of Biomass.
- Processes involved in conversion of Biomass into fuels.
- Formation of Bio-Energy
- Working of Biogas Plant.
- Properties and characteristics of Biogas

7.3 DEFINITION OF BIOMASS

Biomass is a Greek word where bio means life and maza means mass. Biomass refers to no fossilized biological material derived from living/recently living organisms and biodegradable organic or carbon-based material originating from plants, animals, vegetable-derived materials, and microorganisms. Biomass is the world's fourth largest energy source, following coal, oil, and natural gas. Biomass is made up of products, by-products, residues, and waste from agriculture; wood from forests; agricultural residues like straw, stover, and cane trash; green agricultural wastes; forestry; and biodegradable organic fractions of industrial/municipal solid wastes (sewage, human, and animal wastes), like rice husk, sugarcane bagasse, and black liquor from paper manufacturing. Manures, slurries, animal bedding (such as chicken litter), and grass silage are examples of animal wastes. In addition, it comprises liquids and gases that are recovered from the breakdown of organic materials that are not fossilized and biodegradable, as well as food wastes from a variety of food items that are processed to eliminate unnecessary or inedible ingredients like peels, skins, husks, cores, pips, and stones, fish heads, pulp from juice, and oil extraction.

The most popular industrial biomass can be produced from a wide range of plant species, such as sugarcane, eucalyptus, hemp, miscanthus, switch grass, corn, poplar, willow, sorghum, bamboo, and oil palm (palm oil).Biomass resources can be broadly categorized as either woody or nonwoody, regardless of their source. While agriculture provides both woody and nonwoody biomass for the generation of bioenergy, forests solely provide woody resources.

The primary sources of woody biomass are agricultural and forestry leftovers. Additionally, agriculture provides the nonwoody components needed to produce bioenergy, including sugar, starch (found in grains), cellulose materials like plant leaves, stems, and stalks, and oil-producing plant materials (like soybeans). Biomass materials used in agriculture comes from annual commodity crops like corn and soybeans, perennial crops like grass and tree crops, and crop leftovers gathered after annual crops intended for food or feed are harvested.

An organic substance derived by living things, including plants and animals, is called biomass. Plants, wood, and waste products are the most often utilized biomass feedstock for energy production. Among the renewable energy sources is biomass. Both direct and indirect methods can be used to convert the energy from these animals into useful energy. Biomass can be converted into biofuel (indirect method) or burned directly to produce heat. A number of methods, including direct firing, co-firing, pyrolysis, gasification, and anaerobic decomposition, can be used to produce different kinds of energy. These methods all involve heat conversion. Heat is applied to the biomass feedstock during thermal conversion in order to burn, dehydrate, or stabilize it. The most well-known biomass feedstocks for thermal conversion are leftovers from paper or timber mills and municipal solid waste (MSW). The biomass needs to be dried before it can be burned. Torrefaction is the name given to this chemical reaction. Biomass undergoes torrefaction at temperatures of at least 200 °C. 90% of the energy in the biomass is retained even if it dries out entirely, losing only 20% of its initial mass. Dried mass briquettes have a high energy density. Moreover, biomass can be co-fired, or burned alongside a fossil fuel. The majority of the time, biomass is co-fired in coal plants. By cofiring, the need for additional factories to process the biomass is eliminated. This lessens the quantity of greenhouse gasses, such as carbon dioxide, that are only generated when fossil fuels are burned.

7.4 SOURCES OF BIOMASS

Different sources of biomass are classified as given below

1.Wood:

Wood biomass is defined as any product obtained from timber (hardwood or softwood) that may be gasified or burned directly to produce energy.Wood can be pelletized to provide solid fuel or converted through a variety of other methods into liquid fuel.Although wood biomass can comefrom any portion of the tree, the main constraint is the difference in cost between the components

2. Agricultural crops: Products produced from agricultural biomass include wheat, rice, corn, sugarcane, sunflower seeds, soybeans, wheat, and sugar beets. Fermenting sugar from corn, sugar beets, and sugar cane is a common method of producing ethanol. Oilseed crops, such as rapeseed, sunflower, and soy beans, can be refined to create biodiesel..

3. Animal waste: Animal biomass, such as cow dung, can be gasified to produce energy, making it one of the renewable energy sources. Cow manure can occasionally be fed to a biodigester with ease in order to generate biogas because it is so abundant.

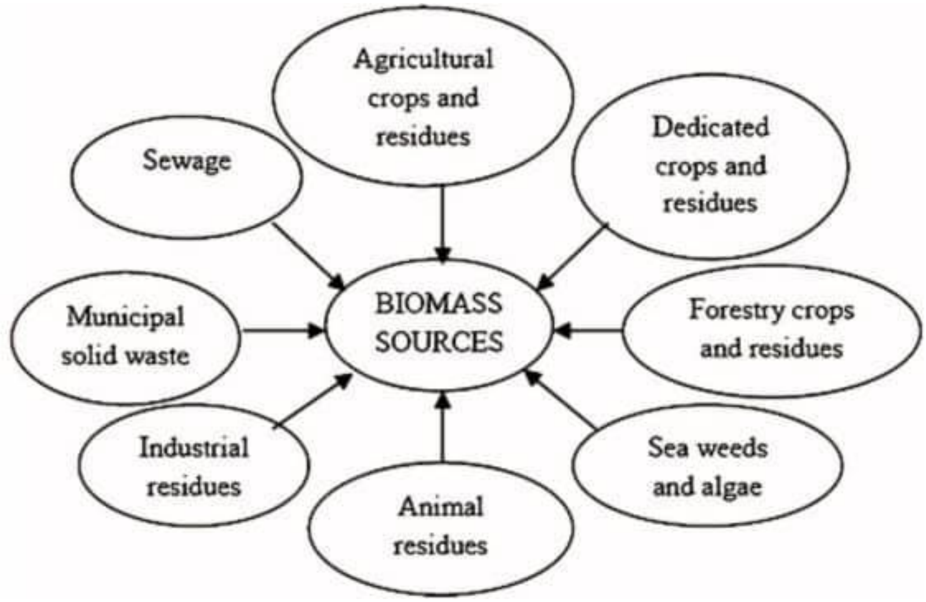

Fig.7.1: Different Biomass sources

4. Algae: These organisms have a huge potential for biomass energy production. Seaweed is the most well-known type of algae because it can be produced in oceanic water without depleting freshwater supplies. Additionally, since it doesn't require soil, it doesn't take up any more arable land that might be used to grow food crops. Oils found in algae can be transformed into biofuel. When algae is treated at a specific temperature and pressure, "green crude," which resembles crude oil in certain ways and can be utilized as biofuel, is produced.

5. Sewage sludge: Another source of biomass is produced by the treatment of sewage. This sludge is mostly made up of secondary (microbiological) sludge mixed with harmless organic substances, making up the majority of its dry matter composition. In addition, there are significant amounts of inorganic material and trace amounts of hazardous substances in the sludge. As a result, generating energy—heat, electricity, or biofuel—is a viable alternative for one of the primary treatment processes.

6. Industrial residues: Include wastes from several industrial sectors, particularly the food business (meat processing, fruit and vegetable peeling solid wastes, and food that doesn't fulfill quality control criteria). That entire amount of garbage can be converted into biomass energy. These industrial wastes have the ability to be fermented to make ethanol or anaerobically digested to produce biogas, and there are already a number of commercial examples of waste-to-energy conversion. .

7.4.1 Advantages of biomass

Renewable and sustainable energy comes from biomass. Plants and algae can regenerate their biomass quickly in the light, which provides the energy for it initially. The following are always available and sustainable to manage: crops, trees, and municipal solid trash. Through their ability to respire and absorb carbon dioxide, sustainably cultivated trees and crops can offset carbon emissions. Carbon emissions emitted during fuel processing or utilization are not equal to the quantity of carbon reabsorbed in certain bioenergy processes.In marginal lands or pastures, several biomass feed supplies, including switch grass, can be gathered without interfering with food crops. Biomass energy may be gathered as required, unlike other renewable energy sources like solar or wind. It is stored within the organism.

7.4.2 Disadvantages of biomass

Biomass feedstocks become non-renewable if they are not replaced as rapidly as they are used up. For example, it can take hundreds of years for a forest to fully regenerate. Compared to a fossil fuel like peat, this is still a considerably shorter time frame. A meter (3 feet) of peat might take up to 900 years to renew itself. For biomass to grow, most areas need to be arable. This implies that land used for biofuel crops, such soybeans and corn, cannot be used to support natural habitats or food production. For the majority of biomass facilities to operate profitably, fossil fuels are necessary. Compared to fossil fuels, biomass has a lower "energy density."

Water makes up as much as 50% of biomass, and this water is lost throughout the energy conversion process. On the other hand, turning biomass into pellets rather of wood chips or bigger briquettes can improve the fuel's energy density and make it more transportable. Carbon monoxide, carbon dioxide, nitrogen oxides, and other pollutants and particles are released during the burning of biomass. Burning biomass can produce haze and add to the pollutants generated by fossil fuels if these pollutants are not caught and recycled.

7.5 CONVERSION OF BIOMASS INTO FUELS

Several procedures are used to convert organic resources into fuels like biofuels in the conversion of biomass to fuels. Numerous materials can be used to produce biomass, such as forestry waste, organic municipal solid waste, specialized energy crops, and agricultural residues. The conversion techniques fall into two general categories: thermochemical and biochemical processes.

7.5.1 Biochemical Processes:

a. Fermentation: Biomass is broken down by microbes to produce fuels like butanol and ethanol. This is frequently applied to feedstocks that contain sugar or starch.

b. Anaerobic Digestion: When organic materials are broken down by bacteria in the absence of oxygen, methane and carbon dioxide are released as biogas. Biomethane can be produced from biogas or utilized directly as a fuel for vehicles.

7.5.2 Thermochemical Processes:

a. Pyrolysis: When biomass is heated without the presence of oxygen, char, gas, and bio-oil are produced. Biofuels can be produced by further refining the bio-oil..

b. Gasification: The conversion of biomass produces syngas, which is made up of methane, carbon monoxide, and hydrogen. Syngas can be transformed into liquid biofuels like aviation fuel or synthetic diesel and used as fuel..

c. Torrefaction: A more stable and energy-dense product that can be utilized as a feedstock for a number of applications, including bioenergy, is created by heating biomass in a low-oxygen atmosphere.

7.5.3 Hydrothermal Processes:

a. Hydrothermal Liquefaction (HTL): When biomass is exposed to high temperatures and high pressures while being mixed with water, a liquid bio-oil is produced that can be further processed into biofuels.

7.5.4 Biodiesel Production: The process of transesterification can be used to turn biomass such as vegetable or animal fats into biodiesel. Through this method, glycerol and biodiesel are created by reacting the oils or fats with an alcohol (often methanol or ethanol) and a catalyst.

7.5.5 Alcohol Fermentation: Butanol and ethanol are examples of bio alcohols that can be made through fermentation of sugars derived from biomass. Transport fuels or fuel additives can be made from these bio alcohols.
The kind of biomass, the intended final product, and financial factors all influence the conversion process choice. Research is still being done to increase sustainability, lower costs, and enhance efficiency in the conversion of biomass to fuels. Each process has pros and cons.

7.6 FORMATION OF BIO-ENERGY

7.6.1 Energy through Fermentation: Anaerobic Fermentation

Anaerobic respiration is a type of cellular respiration where respiration takes place in the absence of oxygen. Fermentation is an anaerobic pathway- a common pathway in the majority of prokaryotes and unicellular eukaryotes. In this process, glucose is partially oxidised to form acids and alcohol.

Carbon dioxide (CO2) and ethanol are produced from the pyruvic acid that is created when glucose partially oxidizes in organisms such as yeasts. The term "ethanol" or "alcoholic fermentation" refers to this anaerobic state. Pyruvic acid decarboxylase and alcohol dehydrogenase are the enzymes that catalyze the entire reaction. Lactate dehydrogenase is a bacterium that breaks down pyruvic acid into lactic acid in anaerobic circumstances in muscle cells of animals. We term this fermentation of lactic acid. These anaerobic reactions are dangerous because of their byproducts. Yeast cells have the ability to self-destruct if their alcohol concentration exceeds 13 percent.

NADH+H+ is the reducing agent that is reduced to NAD+ during the fermentation of lactic acid and alcohol. In comparison to aerobic respiration, very little energy is released during either phase, and only two ATP molecules are created overall throughout fermentation. Nonetheless, the food and beverage as well as pharmaceutical businesses use this on a commercial basis.

In this process, the substance is broken down by microorganisms like bacteria in the absence of oxygen. In landfills, anaerobic decomposition plays a significant role in the crushing and compression of biomass to produce an oxygen-poor environment known as an anaerobic system. Biomass breaks down in an anaerobic environment to produce methane, a useful energy source. "Anaerobic digestion" is the process of creating biogas in an anaerobic environment. Anaerobic digestion is a naturally occurring waste-to-energy process that breaks down organic matter through fermentation. Food scraps, sewage, and animal dung are a few examples of organic materials that anaerobic digestion can break down into biogas.

Biogas is combustible and produces a deep blue flame because of its high methane content (usually between 50 and 75 percent). Generally speaking, organic materials are fed into biogas digesters where they break down in a digestion chamber. The entire digestive chamber is submerged in water, creating an oxygen-free, anaerobic environment. Microorganisms are able to decompose the organic material and turn it into biogas in the anaerobic environment. Nutrients in the waste dissolve into the water as a result of the organic material breaking down in a liquid environment, producing a nutrient-rich sludge that is usually applied as plant fertilizer. This daily fertilizer output is produced by anaerobic digestion, making it an extremely fruitful by-product.

The organic material is transformed into biogas through four phases of fermentation, which are as follows:

When insoluble organic polymers, such carbohydrates, are broken down in the first stage, known as the hydrolysis stage, it becomes possible for bacteria known as "acidogenic bacteria" to work with the material.

2. Ammonia, carbon dioxide, hydrogen, and organic acids are produced from sugar and amino acids by acideogenic bacteria.

3. The last stage, the methanogens, are then made possible by the acetogenic bacteria, which transform the organic acids into acetic acid, hydrogen, ammonia, and carbon dioxide. Methane and carbon dioxide are produced from these final components by the methanogens, and these can be utilized as flammable, renewable energy.

7.6.2 Pyrolysis

Pyrolysis is the process of undergoing relatively inert atmospheres with very high temperatures to aid in the thermal breakdown of substances. It's crucial to remember that pyrolysis changes the substance it touches chemically—the final product's composition differs from that of the reactant feedstock used in the process. The Greek word "pyrolysis" means "fire separating," to put it roughly. Chemical decomposition reactions result in the breakdown of substances into various product chemicals during pyrolysis.

Pyrolysis is a commonly employed method for the degradation of organic materials. For instance, the process of pyrolysis is involved in the charring of wood, or incomplete combustion of wood, which forms charcoal. When an organic molecule is pyrolyzed, it usually yields a solid residue that is frequently substantially enriched in carbon along with a number of volatile compounds. Note that carbonization is the term used to describe excessive pyrolysis, which frequently results in only carbon remaining as a residue. Furthermore, it should be mentioned that pyrolysis is frequently regarded as the first stage of related processes like gasification and combustion..

Pyrolysis is a technique widely used in the chemical industry.Using coal and petroleum to produce ethylene and other significant carbon compounds is one of this process's most significant uses. It should be mentioned that these substances can also be derived from specific organic materials, such wood. Pyrolysis can be used to extract coke from coal in addition to a variety of other chemicals.

The pyrolysis feedstock is heated above the temperature at which it breaks down. The chemical bonds holding the feedstock's molecules together have now broken. As a result, the feedstock's molecules break apart into smaller ones. These smaller molecules frequently take part in chemical interactions with one another within the pyrolysis setup to generate other larger compounds. Some of these molecules even proceed to create amorphous solids with covalent bonds.

Most of the time, pyrolysis is done without the presence of water or oxygen. Making the atmosphere as inert as possible is the goal of this. But occasionally, a very tiny amount of oxygen and water are permitted to enter the pyrolysis setup. This is carried out to enable the occurrence of other significant processes, such hydrolysis and combustion, which may modify the kinds of products that result from the pyrolysis of supply. In order to achieve particular results from the pyrolysis process, additional chemicals may be added to the feedstock.

Following are the known processes that occur when pyrolysis is applied to some organic feedstock. Water is one of the volatile substances in the feedstock mixture that evaporates when the surrounding temperature drops below 100 degrees Celsius. Additionally, the heat-sensitive components of the feedstock, like proteins, vitamin C, and ascorbic acid, experience partial chemical composition changes. This stage of the breakdown process is not unusual for these vitamins and proteins.

All water that the feedstock may have absorbed is eliminated when the surrounding temperature reaches 100 degrees Celsius. It's possible that higher temperatures are still necessary for the water that is trapped inside hydrated crystals to escape and evaporate. In order to turn all of the liquid water into water vapor, the feedstock must now absorb a significant amount of energy. The organic feedstock may melt at this temperature and the sugars, lipids, and waxes inside it may separate for good.

The majority of common organic compounds found in organic feedstock undergo a breakdown reaction and fragment into smaller molecules within the temperature range of 100 to 500 degrees Celsius. Under these circumstances, the optimal temperature range for a breakdown reaction involving sugars is 160–180 degrees Celsius. When the environment exceeds 350 degrees Celsius, any cellulose that is present in the feedstock will begin to decompose. Another frequent substance that starts to break down at these temperatures is lignin, which is an essential part of wood.

Even at temperatures as high as 500 degrees Celsius, lignin has been shown to release volatile compounds during pyrolysis procedures. In addition to carbon dioxide and carbon monoxide, water is another noteworthy byproduct of this breakdown process.

Ash, a powdery substance that remains after all carbonaceous leftovers have burned completely, is the final result. It is known that the components of this ash are oxidized inorganic materials. Despite being subjected to extremely high temperatures during the pyrolysis process, these inorganic compounds manage to maintain their solid state due to their extremely high melting points. When certain metals are present in the original organic feedstock that is pyrolyzed, it is vital to remember that these metals are typically concentrated in the ash as metal oxides or metal carbonates.

Examples of Pyrolysis:-

Pyrolysis is known to occur in a number of processes. The following is a list of typical instances of the various processes that might lead to pyrolysis.

One example of the pyrolysis of solids is the process of dry distillation, which is heating solid materials to produce gaseous processes. The extraction of sulfuric acid from sulphates is a typical use for these procedures.

Destructive distillation is yet another significant use for pyrolysis. In order to promote the breakdown of unprocessed material into smaller molecules, it is typically organic in nature and is heated to high temperatures in generally inert atmospheres. This method helps to extract coal from coal and produce coke and coal ash.

The process of browning sugar, also referred to as caramelization, is a crucial illustration of pyrolysis.

Pyrolysis is a typical component of many other cooking methods. Roasting, toasting, frying, and grilling are a few notable examples.

One significant use of pyrolysis is the process of producing tar by placing wood in tar kins and heating it at high temperatures.

Pyrolysis is another technique that is utilized in the oil refining process. Heat is used in this business to split relatively big hydrocarbons into smaller hydrocarbons by causing fractures in them.

Pyrolysis is another natural process that occurs during the formation of fossil fuels. A particular kind of pyrolysis is known as catagenesis, which is the process of exposing buried organic matter to high temperatures and pressures for very long periods of time in order to eventually turn the organic matter into coal and other fossil fuels.

7.6.3 Gasification Process

Gasification is a thermochemical process that involves adding a gasifying agent to a solid or liquid material having a carbonic composition to turn it into a gaseous fuel. The way it operates is different from regular burning since less oxygen is used during the process than is required for combustion. When the gas is produced without any contaminants, it is referred to as producer gas. Synthesis gas, which is primarily made up of hydrogen and carbon monoxide, is the result. The four distinct sub-processes that make up the process are pyrolysis, combustion, oxidation, and reduction.

1. Drying: The fuel particles are heated to 200 oC as the initial step in the gasification process to reduce the amount of water in the material. Water enters the biomass process or evaporates on the surface, lowering the biomass's moisture content to less than 5%.

2. Pyrolysis: Pyrolysis is necessary for the heat-induced material deterioration. It is a complex process that is reliant on pressure, temperature, and heat loss. Only water is driven off below 200ºC. Between 200ºC and 280ºC, water and acetic acid are generated. Genuine pyrolysis takes place between 280 and 500 degrees Celsius, generating copious amounts of CO and CO_2. The majority of the gas produced is hydrogen and occurs in the 500–700 oC range. A liquid substance known as tar is created when some of the volatile gases cool down and condense. It consists of two phases: an aqueous phase that contains low-molecular-weight organic compounds and a non-aqueous phase that contains high-molecular-weight organic compounds. The overall process is generalized by the equation:

$$\text{Solid fuel} \rightarrow CO + CO_2 + CH_4 + H_2 + H_2O + \text{Tar} + \text{Charcoal}$$

3. Combustion or oxidation: In this stage, the volatile vapors and charcoal produced during the pyrolysis stage react with an oxidation agent that is provided externally. Three common oxidation agents are water vapor, pure oxygen, and air. The net exothermic result of any gasification process is combustion. That is, it serves as the system's primary energy source. It is the area of the gasifier with the maximum temperature, with some designs being able to reach temperatures as high as 1700ºC. At this point, it's critical to get a thorough mixing and a temperature high enough to allow the tar and pyrolysis gasses to be utilized to produce heat.The following reactions may occur in the combustion stage:

$$C + O_2 \rightarrow CO_2 - 392 \text{ kJ/mol}$$

$$C + 1/2\, O_2 \rightarrow CO - 110 \text{ kJ/mol}$$

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O - 803 \text{ kJ/mol}$$

$$2H_2 + O_2 \rightarrow 2H_2O - 242 \text{ kJ/mol}$$

4. Reduction: In this stage, a number of primarily endothermic processes occur, producing fuel that is high in volatile gasses like hydrogen, methane, and carbon monoxide. This fuel is more environmentally friendly than solid fuels since it burns cleaner and releases fewer pollutants into the atmosphere. Carbon often reacts with carbon dioxide at temperatures higher than 725ºC. The water gas reaction typically happens in low-pressure, high-temperature environments. A temperature rise may also cause an imbalance in the molecules of CO, CO_2, H_2, and H_2O, which will cause the water-gas shift process.

7.6.3.1 Types of Gasifiers

A gasifier's design, pressure profile, heating source, gasyfing agent, and other characteristics can all be used to distinguish it from another. Despite this, there are four main types of gasifiers that dominate the market: fixed bed categories such as updraft or downdraft, and fluidized bed categories such as bubbling or circulation.

A. Fixed bed gasifiers: The direction in which the fuel flows in relation to the direction in which the gasifying agent flows is used to classify these basic varieties. Gasifying agents are supplied from the bottom of the gasifier (gas is withdrawn from up), and co-current or downdraft (gas is withdrawn from down) gasifiers are those that receive their agent supply above the reduction zone. This is because the gasifier is normally fed from the top. A downdraft type is typically smaller and less efficient than an updraft type, but it is cleaner because it creates less tar. This is because it is challenging to regulate the temperature profile between the operations, causing the gas to exit at a very high temperature and with a lower heat value.

B. Fluidized bed gasifiers: These are cylindrical columns with free passageways for liquids, gases, or particles to go through. The particles become suspended at a specific fluid velocity. The particles are considered fluidized and the velocity is referred to as the “minimum fluidization velocity” when the fluids ascending force equals the weight of the particles. The main benefit in this category is the resultant high surface area to make contact with the fuel. The temperature along the bed is consistent as a result of the intensive mixing of the different zones, which makes it impossible to distinguish between the different stages of the gasification process. They have more variable biomass qualities, lower ash melting points, and higher heat exchange rates than fixed bed gasifiers. The fluid velocity in the circulating type is higher than in the bubbling type, and it also necessitates the addition of a cyclone separator in order to return elutriated bed material to the gasifier. Because of this, the circulating type gasifies and converts tar more quickly, making it better suited for large-scale applications.

7.7 BIO-GAS PLANT

A device that creates an oxygen-free atmosphere for bacteria to convert biomass into biogas is known as a biogas plant. It generates carbon-neutral energy and is available in many shapes and sizes.

7.7.1 What is a Biogas Plant?

An oxygen-free environment conducive to anaerobic digestion is what a biogas plant provides. To put it plainly, it's an artificial system that allows garbage to be converted into environmentally friendly fertilizers and sustainable electricity.

To enable the production of biogas, a biogas plant consists of three primary parts:

- a reception area
- a digester (or fermentation tank)
- a gas holder

The raw materials are brought in and ready for anaerobic digestion at the receiving room. Pre-treatments are frequently used in industrial biogas plants to speed up fermentation and boost biogas production. Because each type of biomass has a unique fermentation process, the total duration of the biogas production process varies depending on the raw materials employed.

Crop residues, industrial and municipal sewage, agricultural material, livestock manures, seaweed, food processing wastes, and paper wastes are some of the most commonly used biomass options; however, the list of raw materials used is much wider.

The digester is a watertight, airtight container that has a biomass intake point. This is where you present the raw materials that will be converted to energy. After that, agitators move the biomass around occasionally to release gasses and stop layers from forming. After the fermentation process is finished, the digester has a pipe that makes it possible to evacuate the digestate.

Gas produced during fermentation is collected in an airtight container known as a "gas holder," which is ideally made of steel. It has a gas outlet that enables biogas to exit the system and supply heat and electricity.
A plant could have multiple digesters and gas holders, depending on how much trash it wants to remove from the environment or how much biogas it needs to create.

7.7.3 Working of a Biogas Plant

Producing biogas is easy and carbon neutral because biogas plants use an automated, uncomplicated process designed to mimic the anaerobic digestion process in a synthetic setting. The majority of facilities follow the same procedure to manufacture biogas, while some phases may differ depending on the biogas plant. The procedure is described in the animation below, along with some of its long-term advantages.

Step 1 – Pre-treatment and filling the digester

The digester is filled with a variety of organic materials known as substrates. Certain substrates include biodegradable raw materials (such corn or grass), liquid manure, and food industry waste. It could be necessary for some of them to be pre-treated and kept in cement containers before being placed inside the airtight tank. Depending on its size, a single facility may contain many digesters.

Step 2 – The fermentation process

In the absence of light and oxygen, a variety of microorganisms begin to break down the organic matter when the substrates inside the fermenter are heated to different degrees. The organic matter is moved throughout the procedure to stop layers from accumulating at the tank's top and bottom.

Step 3 – Producing biogas

Methane is the primary constituent in the biogas that is created inside the fermenters as a result of fermentation. Water and hydrogen sulfide are present in the gas at this stage of the process in addition to methane and carbon dioxide, which is one of the main reasons steel containers are recommended since they can survive the gas's effects for extended periods of time.

Step 4 – Pulling out the residues

The digestate, or leftover material from fermentation, is removed from the tank and used as premium, environmentally friendly fertilizer. In this sense, the process of producing biogas turns into a zero-waste method of removing trash from landfills and simultaneously offering an improvement in crops.

Step 5 – Eliminating impurities

Water, hydrogen sulfide, and other pollutants are eliminated from the biogas during the purification process, which yields biomethane, which can then be used to produce energy and heat. In order to guarantee the quality of the finished product, the biogas is continuously observed.

7.7.4 USES OF A BIOGAS PLANT

Biogas facilities can serve a variety of functions and play two roles in the economy and ecology. On the one hand, biogas plants can provide us with warmth and energy that is carbon neutral. Bio methane, which can be produced by compressing biogas, can replace natural gas in residential, commercial, and industrial settings. Transporting the fuel to gas stations is a simple process. Since biogas doesn't release carbon dioxide during combustion, it is completely renewable and carbon neutral. Furthermore, the production process has a favorable environmental impact by preventing the release of methane into the atmosphere.

After receiving a small amount of treatment, the biogas can be burned in household stoves for cooking. On the other hand, it can be utilized to create electricity, heat, or, in the case of heat and power (CHP) facilities, both. Depending on the scale of the plant, the energy generated by biogas plants can either serve one or more communities directly or be directly supplied into the electricity grid. In addition, houses or swimming pools can be heated using the heat produced during the procedure.

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more communities directly or be directly supplied into the electricity grid. In addition, houses or swimming pools can be heated using the heat produced during the procedure.

7.7.5 ADVANTAGES AND DISADVANTAGES OF BIOGAS PLANTS

Because they provide renewable energy for both residential and commercial usage, biogas plants have several environmental benefits. Reducing reliance on fossil fuel energy can help lower our carbon footprint. This energy can be stored or pumped into the electrical grid.

In other words, biogas facilities have the potential to mitigate global warming. Greenhouse gas emissions decrease as residential and industrial users use less energy generated from fossil fuels. Simultaneously, removing organic matter from the air and managing the fermentation process reduce methane emissions into the environment, improving air quality.

Communities manage food waste and keep trash out of landfills to achieve these goals. Recycling organic waste has several benefits, including reduced odors, a lower chance of disease transmission, and protection of water resources.
The fact that digestate from biogas plants replaces synthetic fertilizers is another benefit of these plants. It recycles several nutrients, including phosphorus, which is necessary for crops to grow healthily.

Biogas plants not only benefit the environment but also help create a circular economy by enabling more enterprises to become self-sufficient and sustainable through the use of waste as a source of heat or electricity. Expanding facilities lead to the creation of new jobs in a variety of verticals, which has a big influence on living standards in many communities throughout the globe.

7.8 SUMMARY

After studying the unit students will be able to understand

1. Biomass and its sources
2. Processes involved in conversion of Biomass into Fuels.
3. Formation of Bio Energy
4. Anaerobic Fermentation.
5. Pyrolysis
6. Different types of Gasifiers
7. Biogas plant and its working

7.9 REFERENCES

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7.10 SUGGESTED READINGS

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4. "Biomass Processing Technologies" by Vladimir Strezov and Tim J. Evans.

7.11 TERMINAL QUESTIONS

1. Define biomass and provide three examples of biomass resources.
2. Explain the process of combustion in the context of biomass energy.
3. Describe two different types of biochemical conversion processes used in biomass energy production.
4. What is anaerobic digestion, and how is it utilized in biomass energy production?
5. List two challenges associated with the logistics of biomass energy, and suggest possible solutions for one of them.
6. How does biomass contribute to carbon neutrality, and what role does photosynthesis play in this process?
7. Name two common applications of biomass energy other than electricity generation.
8. Differentiate between woody biomass and agricultural biomass, providing an example of each.
9. Explain the concept of carbon sequestration in the context of biomass energy.
10. Discuss one environmental benefit and one environmental challenge associated with the use of biomass energy.

UNIT 8 ENERGY STORAGE

Structure

8.1 INTRODUCTION

A hybrid energy system combines multiple types of energy generation and/or storage or uses two or more kinds of fuel to power a generator. Hybridization is a combination of different storage technologies with various characteristics to downsize the overall system and direct the unfavorable load conditions such as severe charge or discharge current fluctuations to a sturdier ESS (i.e., SC). Energy storage is an attractive tool to support grid electrical supply, transmission and distribution systems. Our Utilities, grid system operators and regulators benefit from it as switching to storage mechanism strengthens grid resiliency and reliability. Primary batteries are one shot deals, once they are drained, it is all over. A battery management system (BMS) is any electronic system that manages a rechargeable battery (cell or battery pack), such as by protecting the battery from operating outside its safe operating area, monitoring its state, calculating secondary data, reporting that data, controlling its environment, authenticating it and / or balancing it. n order to maximize the battery's capacity, and to prevent localized under-charging or over-charging, the BMS may actively ensure that all the cells that compose the battery are kept at the same voltage or State of Charge, through balancing. Flywheel energy storage (FES) works by accelerating a rotor (flywheel) to a very high speed and maintaining the energy in the system as rotational energy. Fuel cells are a type of energy conversion technology which take the chemical energy contained within a fuel and transform it into electricity along with certain by-products (depending on the fuel used).

8.2 OBJECTIVES

After studying this unit, you should be able to-

- understand hybrid energy system
- energy storage system
- Different types of batteries
- About ultra-capacitor

8.3. HYBRID ENERGY SYSTEM

A hybrid energy system combines multiple types of energy generation and/or storage or uses two or more kinds of fuel to power a generator. A hybrid energy system is a valuable method in the transition away from fossil fuel- based economies.

An energy storage system, often abbreviated as ESS, is a device or group of devices assembled together, capable of storing energy in order to supply electrical energy at a later time. Battery ESS are the most common type of new installation and are the focus of our free fact sheet.

Another example of a hybrid energy system is a photovoltaic array coupled with a wind turbine. This would create more output from the wind turbine during the winter, whereas during the summer, the solar panels would produce their peak output.

Hybrid power systems are those that generate electricity from two or more sources, usually renewable, sharing a single connexion point. Although the addition of powers of hybrid generation modules are higher than evacuation capacity, inverted energy never can exceed this limit.

Hybridization is a combination of different storage technologies with various characteristics to downsize the overall system and direct the unfavorable load conditions such as severe charge or discharge current fluctuations to a more sturdy ESS (i.e., SC).

Efficiency is a crucial aspect of any energy storage system. Hybrid storage capacitors and dry cells optimize the efficiency of energy conversion and storage processes. Capacitors can rapidly charge and discharge energy with minimal losses, reducing energy wastage.

Batteries. There are various forms of batteries, including: lithium-ion, flow, lead acid, sodium, and others designed to meet specific power and duration requirements. Thermal. Thermal systems use heating and cooling methods to store and release energy Mechanical Systems and Emerging Technologies.

Hybrid energy systems combine multiple sources of energy, such as solar and wind power, with traditional grid electricity to meet the energy demands of buildings. Improved battery storage technology allows for the storage of excess energy generated by renewable sources for use during times of high demand.

Hybrid systems simplify technology refreshment by easing the process of combing existing equipment with newer technologies. This way you maximize use out of both existing hardware and software but can still take advantage of other technologies.

8.4. ENERGY STORAGE SYSTEM

Improved and reliable electric supply: Storage can also support the efficient delivery of electricity for base load plants like coal that have slow ramp-up times when responding to grid. Electrical grid infrastructure: Energy storage options can hugely alleviate the operational costs of the entire grid infrastructure.

Energy storage is an attractive tool to support grid electrical supply, transmission and distribution systems. Our Utilities, grid system operators and regulators benefit from it as switching to storage mechanism strengthens grid resiliency and reliability. This in turn ensures higher efficiencies across the grid as well as eliminates the need for reliance on other higher greenhouse gas (GHG) footprint options that would otherwise be preferred with zero storage options.

Energy storage benefits can be grouped up into six broad application/use categories:

Renewables integration with Grid: Helps to integrate more solar, wind, and distributed energy resources.

Higher Grid Efficiency: This can improve the efficiency of the grid by increasing the capacity factor of existing resources and offset the need to depend on pollution-emitting peak power plants.

Improved and reliable electric supply: Storage can also support the efficient delivery of electricity for base load plants like coal that have slow ramp-up times when responding to grid.

Electrical grid infrastructure: Energy storage options can hugely alleviate the operational costs of the entire grid infrastructure.

Overall Savings in Money: Overall incorporation of storage is beneficial to all end-users as it saves costs to society by enabling storage of low-cost energy and retrieving it later when electricity prices are low.

8.4.1. TYPES OF ENERGY STORAGE SCENARIOS

In Electricity Grid- For example, the energy retrieved from batteries can be used in times of peak demand. This prevents the grid from becoming overloaded and proceeding towards any possible outages.

Remote/ off the Grid locations- For example for people living in remote off-grid locations, battery energy storage is quite helpful as storage can be easily connected to solar panels to provide a reliable and grid-free electricity supply.

Rooftop Solar Panels- For example, homeowners installing their own energy storage can store more power generated by their rooftop panels, and save more money on their electricity bills.

Electric Vehicles (EVs) –EVs operate with energy stored in batteries. Also, the regenerative braking method absorbs energy, converts it back to electrical energy, and returns the energy to the batteries

8.5. TYPES OF BATTERIES

8.5.1. PRIMARY BATTERIES: Primary batteries are one shot deals, once they are drained, it is all over. Common primary batteries include carbon zinc batteries, alkaline batteries, mercury batteries, silver oxide batteries, zinc air batteries, and silver zinc batteries. Here are some common battery packages and their characteristics:

1. CARBON ZINC BATTERIES: George Leclanche invented the carbon zinc battery in 1866. By 1868 it was adopted by the Belgium telegraph service and ultimately went on to be the standard for portable batteries around the world. The original leclanche cell was a wet cell, with the electrodes immersed in liquid electrolyte. Later developments moved the electrolyte to a wet paste, giving us the carbon zinc dry cell. A heavy duty version uses a zinc carbon zinc chloride chemistry, for a higher capacity.

Carbon zinc batteries are general purpose, non-rechargeable batteries made from cells that have open circuit voltages of 1.6 V. They are used for low to moderate current drains. The voltage discharge curve over time for a carbon zinc battery is nonlinear, whereas the current output efficiency decreases at high current drains. Carbon zinc batteries have poor low temperature performance but good shelf lives. This battery is susceptible to leaking its corrosive electrolyte. Carbon zinc batteries are used to power such devices as power toys, consumer electronic products, flashlights, cameras, watches, and remote control transmitters.

2. ZINC CHLORIDE BATTERIES: A zinc chloride battery is a heavy duty variation of a zinc carbon battery. It is used in applications that require moderate to heavy current drains. Zinc chloride batteries have better voltage discharge per time characteristics and better low temperature performance than carbon zinc batteries. Zinc chloride batteries are used in radios, flashlights, lanterns, fluorescent lanterns, motor driven devices, portable audio equipments, communications equipments, electronic games, calculators, and remote control transmitters.

3. ALKALINE BATTERIES: Alkaline batteries, as a class, were developed between 1895 and 1905 and were finally commercialized in the mid-1950s. This coincided with the rising popularity of electronic flash units in small portable cameras, which required the high power output the alkaline chemistry provided.

Alkaline batteries are general purpose batteries that are highly efficient under moderate continuous drain and are used in heavy current or continuous drain applications. Their open circuit voltage is about 0.1 V less than that of carbon zinc cells, but compared with carbon zinc cells, they have longer shelf lives, higher power capacities, better cold temperature performance, more leak resistant and weigh about 50 percent less. One drawback of the rechargeable alkaline is its capacity fade. After each discharge, the battery will lose some of its capacity. After about 25 cycles, it is at 50% capacity, 50 cycles sees it at 20% capacity, where it appears to stay until the 100 cycle point at the end of its rated life. Alkaline batteries are interchangeable with carbon zinc and zinc chloride batteries. Alkaline batteries are used to power such things like video cameras, motorized toys, photoflashes, electric shavers, motor driven devices, portable audio equipments, communications equipment's, smoke detectors, and calculators. As it turns out, alkaline batteries come in both non rechargeable and rechargeable forms.

4. MERCURY BATTERIES: Mercury batteries are very small, non-rechargeable batteries that have open circuit voltages of around 1.4 V per cell. Unlike carbon zinc and alkaline batteries, mercury batteries maintain their voltage up to a point just before the die. They have greater capacities, better shelf lives, and better low temperature performance than carbon zinc, zinc chloride, and alkaline batteries. Mercury batteries are designed to be used in small devices such as hearing aids, calculators, pagers, and watches.

5. LITHIUM BATTERIES: Lithium batteries are non-rechargeable batteries that use a lithium anode, one of a number of cathodes, and an organic electrolyte. Lithium batteries come with open circuit voltages of 1.5 or 3.0 V per cell. They have high energy densities, outstanding shelf lives (8 to 10 years), and can operate in a wide range of temperatures, but they have limited high current drain capabilities. Lithium batteries are used in such device like cameras, meters, cardiac pacemakers, CMOS memory storage devices, and liquid crystal displays (LCDs) for watches and calculators.

6. SILVER OXIDE BATTERIES: Silver oxide batteries come with open circuit voltages of 1.85 V per cell. They are used in applications that require high current pulsing. Silver oxide batteries have flat voltage discharge characteristics up until death but also have poor shelf lives and are expensive. These batteries are used in such devices like alarms, backup lighting, and analog devices. As it turns out, like alkaline batteries, they too come in non-rechargeable and rechargeable forms.

7. ZINC AIR BATTERIES: Zinc air batteries are small, non-rechargeable batteries with open circuit voltages of 1.15 to 1.4 V per cell. They use surrounding air (O_2) as the cathode ingredient and contain air vents that are taped over during storage. Zinc air batteries are long lasting, high performance batteries with excellent shelf lives and have reasonable temperature performance (about 0 to 50 ^{o} C, or 32 to 122 ^{o} F). These batteries typically are used in small devices such as hearing aids and pagers.

8.5.2. SECONDARY BATTERIES

1. LEAD ACID BATTERIES: Secondary batteries became practical in 1860 with the invention of the lead acid battery by Raymon Gaston Plante. In 1881, Faure (and others) improved the yield of the lead acid cell by substituting a lead oxide paste for the pure lead of the plante cell.

The largest problem associated with this battery is the damage caused by leaking acid. German researchers addressed this problem in the early 1960s by developing a gelled electrolyte. Working from another direction, other researchers developed a way to completely sealed the battery, preventing leaks. Either way, the sealed lead acid battery needs a little or no maintenance, which, while costing more, can be an advantage in some situations.

A completely sealed battery, whether it is a gel cell or not, also prevents hydrogen gas from escaping when you recharge the battery, which is an improvement in safety when the battery is to be used indoors, such as on a robot or wheelchair. A gelled battery won't leak even if it is punctured, but it can also have a slightly lower energy density than its liquid counterpart, at about 80% or so.

Deep cycle batteries are a special variety of lead acid battery that can be discharged to low voltage levels without coming on to harm. Deep cycle batteries are typically used in marine or wheelchair applications. Regular car batteries are designed for short bursts of high ampere use to start the vehicle, with no deep discharges allowed. The electrode plates in a deep cycle battery are made thicker and less porous than the car battery, and will last two to four times longer than the car battery in deep cycle applications. Dual marine batteries are a compromise of the two types.

Lead acid batteries are rechargeable batteries with open circuit voltages of 2.15 V per cell while maintaining a voltage range under a load from 1.75 to 1.9 V per cell. The cycling life (number of times the battery can recharged) for lead acid batteries is around 1000 cycles. They come in rapid, quick, standard, and trickle charging rate types. Lead acid batteries have a charge retention time (time until the battery reaches 80 percent of maximum) of about 18 months. They contain a liquid electrolyte that requires servicing (replacement). Six lead acid cells make up a car battery.

2. NICKEL CADMIUM (NiCd): The technology behind the nickel cadmium battery was invented in 1899 by Waldmar Jungner, but the battery didn't reach commercial use until the 1930s when new electrodes were developed. The original version of the NiCd battery used a vented, unsealed cell that required regular maintenance. In the 1940s they perfected the sealed NiCd cell, though the cell do retain a need to breathe a bit, which is maintenance free, and the battery came to the fore in the 1950s. In 2000, it accounted for more than 50% of the world's rechargeable batteries for portable applications. Today's NiCd batteries can take a lot of abuse, both mechanical and electrical, and are cheaper than other batteries in cost per hour of use.

The capacity of a Nicd isn't seriously affected by the discharge rate. If you extract current from the cell at a lower than specified rate, you get a little more life. Extracting current from the cell at a rate ten times the specified rate only lowers the capacity to about 70% of its rated level, so a 1000Ah battery would only give 700Ah.

This battery has a surprisingly high capacity for current delivery. The AA battery shown has a recommended maximum continuous current draw of 9 amps, with 18 amp pulses allowed. There are two issues you face when you use a NiCd battery. One is the dreaded memory effect (which doesn't seem to plague other batteries), and the other is cell reversal. Though hotly disputed in hobbyist circles, the memory effect is very real in some, but not all, NiCd batteries. This effect appears because the battery retains the characteristics of previous discharges that is, after repeated shallow discharges, the battery may be unable to discharge beyond the earlier points. It would seem that, under certain conditions, electrodes in the cell can develop a crystalline growth. This growth reduces the area of the electrode exposed to the electrolyte. This leads to a voltage reduction and a loss of performance. Avoiding the memory effect is fairy simple. Fist, quick charge rather than trickle charge your NiCd batteries. Quick charging helps negate the effect of NiCd memory. Second, be sure to fully discharge your batteries to their 1 volt level, under a light load, on a regular basis.

Cell reversal is a condition that can occur with multiple NiCd cells connected in series, such as in a multiple cell battery or a battery pack. Since not all cells are exactly the same, one cell in a chain may use up all of its charge before the others. As the pack continues to be used, a reverse charge is sent through the empty cell due to its charged neighbors. This reacts the water with the cathode, bonding the oxygen to the electrode and releasing hydrogen, which is then vented. This loss of water reduces the life of the cell. To prevent cell reversal, don't perform a deep discharge on a battery pack. It is save to cycle an individual cell to zero volts. In fact, timing the discharge cycle of a cell is one way of determining its exact capacity. With this information, a cell can be matched with other equivalent cell into a battery pack that is less prone to reversal.

Nickel cadmium batteries contain rechargeable cells that have open circuit voltages of about 1.2 V. They are often interchangeable with carbon zinc and alkaline batteries. For the first 2/3 of its life, a nickel cadmium battery's discharge curve is relatively flat, but after that, its curve begins to drop. Nickel cadmium batteries weigh about a third as much as carbon zinc batteries. Placing these batteries in parallel is not rec

8.6. BATTERY MANAGEMENT SYSTEM

A battery management system (BMS) is any electronic system that manages a rechargeable battery (cell or battery pack), such as by protecting the battery from operating outside its safe operating area, monitoring its state, calculating secondary data, reporting that data, controlling its environment, authenticating it and / or balancing it.

A battery pack built together with a battery management system with an external communication data bus is a smart battery pack. A smart battery pack must be charged by a smart battery charger.

8.6.1. FUNCTIONS

8.6.1.1. MONITOR: A BMS may monitor the state of the battery as represented by various items, such as:

- **Voltage:** total voltage, voltages of individual cells, or voltage of periodic taps
- **Temperature:** average temperature, coolant intake temperature, coolant output temperature, or temperatures of individual cells
- **Coolant flow:** for liquid cooled batteries
- Current: current in or out of the battery
- Health of individual cells
- State of balance of cells

8.6.1.2. ENERGY RECOVERY: The BMS will also control the recharging of the battery by redirecting the recovered energy (i.e., from regenerative braking) back into the battery pack (typically composed of a number of battery modules, each composed of a number of cells).

Battery thermal management systems can be either passive or active, and the cooling medium can either be air, liquid, or some form of phase change. Air cooling is advantageous in its simplicity. Such systems can be passive, relying only on the convection of the surrounding air, or active, using fans for airflow. Commercially, the Honda Insight and Toyota Prius both use active air cooling of their battery systems. The major disadvantage of air cooling is its inefficiency. Large amounts of power must be used to operate the cooling mechanism, far more than active liquid cooling. The additional components of the cooling mechanism also add weight to the BMS, reducing the efficiency of batteries used for transportation.

Liquid cooling has a higher natural cooling potential than air cooling as liquid coolants tend to have higher thermal conductivities than air. The batteries can either be directly submerged in the coolant or coolant can flow through the BMS without directly contacting the battery. Indirect cooling has the potential to create large thermal gradients across the BMS due to the increased length of the cooling channels. This can be reduced by pumping the coolant faster through the system, creating a tradeoff between pumping speed and thermal consistency.

8.6.1.3. COMPUTATION: Additionally, a BMS may calculate values based on the below items, such as:

- Voltage: minimum and maximum cell voltage
- State of charge (SoC) or depth of discharge (DoD), to indicate the charge level of the battery
- State of health (SoH), a variously defined measurement of the remaining capacity of the battery as a fraction of the original capacity
- State of power (SoP), the amount of power available for a defined time interval given the current power usage, temperature and other conditions
- State of safety (SOS)
- Maximum charge current as a charge current limit(CCL)
- Maximum discharge current as a discharge current limit (DCL)
- Energy delivered since last charge or charge cycle
- Internal impedance of a cell (to determine open circuit voltage)
- Charge delivered or stored (sometimes this feature is called coulomb counting)
- Total operating time since first use
- Total number of cycles
- Temperature monitoring
- Coolant flow for air or liquid cooled batteries

8.6.1.4. COMMUNICATION: The central controller of a BMS communicates internally with its hardware operating at a cell level, or externally with high level hardware such as laptops or an HMI.

High level external communication are simple and use several methods:

- Different types of serial communications.
- CAN bus communications, commonly used in automotive environments.
- Different types of wireless communications.

Low-voltage centralized BMSes mostly do not have any internal communications.

Distributed or modular BMSes must use some low-level internal cell–controller (modular architecture) or controller–controller (distributed architecture) communication. These types of communications are difficult, especially for high-voltage systems. The problem is voltage shift between cells. The first cell ground signal may be hundreds of volts higher than the other cell ground signal. Apart from software protocols, there are two known ways of hardware communication for voltage shifting systems, optical isolator and wireless communication. Another restriction for internal communications is the maximum number of cells. For modular architecture most hardware is limited to maximum 255 nodes. For high-voltage systems the seeking time of all cells is another restriction, limiting minimum bus speeds and losing some hardware options. Cost of modular systems is important, because it may be comparable to the cell price. Combination of hardware and software restrictions results in a few options for internal communication:

- Isolated serial communications
- Wireless serial communications

To bypass power limitations of existing USB cables due to heat from electric current, communication protocols implemented in mobile phone chargers for negotiating an elevated voltage have been developed, the most widely used of which are Qualcomm Quick Charge and Media Tek Pump Express. ‘’VOOC’ by Oppo (also branded as "Dash Charge" with "OnePlus") increases the current instead of voltage with the aim to reduce heat produced in the device from internally converting an elevated voltage down to the battery's terminal charging voltage, which however makes it incompatible with existing USB cables and relies on special high-current USB cables with accordingly thicker copper wires. More recently, the USB Power Delivery standard aims for a universal negotiation protocol across devices of up to 240 watts.

8.6.1.5. PROTECTION: A BMS may protect its battery by preventing it from operating outside its safe operating area, such as:

- Over-charging
- Over-discharging
- Over-current during charging
- Over-current during discharging
- Over-voltage during charging, especially important for lead acid, Li- ion and LiFePO4 cells
- Under-voltage during discharging, especially important for Li-ion and LiFePO4 cells
- Over-temperature
- Under-temperature
- Over-pressure (NiMH batteries)
- Ground fault or leakage current detection (system monitoring that the high voltage battery is electrically disconnected from any conductive object touchable to use like vehicle body)

The BMS may prevent operation outside the battery's safe operating area by:

- Including an internal swith (such as a relay or mosfet) which is opened if the battery is operated outside its safe operating area
- Asking the devices to reduce or even stop using or charging the battery.
- Actively controlling the environment, such as through heaters, fans, air conditioning or liquid cooling
- Reduce processor speed to reduce heats.

8.6.2. BATTERY CONNECTION TO LOAD CIRCUIT: A BMS may also feature a precharge system allowing a safe way to connect the battery to different loads and eliminating the excessive inrush currents to load capacitors.

The connection to loads is normally controlled through electromagnetic relays called contactors. The precharge circuit can be either power resistors connected in series with the loads until the capacitors are charged. Alternatively, a switched mode power supply connected in parallel to loads can be used to charge the voltage of the load circuit up to a level close enough to battery voltage in order to allow closing the contactors between battery and load circuit. A BMS may have a circuit that can check whether a relay is already closed before precharging (due to welding for example) to prevent inrush currents to occur.

8.6.3. BALANCING: In order to maximize the battery's capacity, and to prevent localized under-charging or over-charging, the BMS may actively ensure that all the cells that compose the battery are kept at the same voltage or State of Charge, through balancing. The BMS can balance the cells by:

- Wasting energy from the most charged cells by connecting them to a load (such as through passive regulators)
- Shuffling energy from the most charged cells to the least charged cells (balancers)
- Reducing the charging current to a sufficiently low level that will not damage fully charged cells, while less charged cells may continue to charge (does not apply to Lithium chemistry cells)

8.6.4. TOPOLOGIES: BMS technology varies in complexity and performance:

- Simple passive regulators achieve balancing across batteries or cells by bypassing charging current when the cell's voltage reaches a certain level. The cell voltage is a poor indicator of the cell's SC (and for certain lithium chemistries, it is no indicator at all), thus, making cell voltages equal using passive regulators does not balance SoC, which is the goal of a BMS. Therefore, such devices, while certainly beneficial, have severe limitations in their effectiveness.
- Active regulators intelligently turning on and off a load when appropriate, again to achieve balancing. If only the cell voltage is used as a parameter to enable the active regulators, the same constraints noted above for passive regulators apply.
- A complete BMS also reports the state of the battery to a display, and protects the battery.

8.6.4.1. BMS TOPOLOGIES FALL IN THREE CATEGORIES:

- Centralized: a single controller is connected to the battery cells through a multitude of wires
- Distributed: a BMS board is installed at each cell, with just a single communication cable between the battery and a controller

- Modular: a few controllers, each handling a certain number of cells, with communication between the controllers

Centralized BMSs are most economical, least expandable, and are plagued by a multitude of wires. Distributed BMSs are the most expensive, simplest to install, and offer the cleanest assembly. Modular BMSes offer a compromise of the features and problems of the other two topologies.

The requirements for a BMS in mobile applications (such as electric vehicles) and stationary applications (like stand-by UPSes in a server room) are quite different, especially from the space and weight constraint requirements, so the hardware and software implementations must be tailored to the specific use. In the case of electric or hybrid vehicles, the BMS is only a subsystem and cannot work as a stand-alone device. It must communicate with at least a charger (or charging infrastructure), a load, thermal management and emergency shutdown subsystems. Therefore, in a good vehicle design the BMS is tightly integrated with those subsystems. Some small mobile applications (such as medical equipment carts, motorized wheelchairs, scooters, and fork lifts) often have external charging hardware, however the on-board BMS must still have tight design integration with the external charger. Various battery balancing methods are in use, some of them based on state of charge theory.

8.7. FLYWHEEL ENERGY STORAGE

Flywheel energy storage (FES) works by accelerating a rotor (flywheel) to a very high speed and maintaining the energy in the system as rotational energy. When energy is extracted from the system, the flywheel's rotational speed is reduced as a consequence of the principle of conservation of energy; adding energy to the system correspondingly results in an increase in the speed of the flywheel. Most FES systems use electricity to accelerate and decelerate the flywheel, but devices that directly use mechanical energy are being developed.

Advanced FES systems have rotors made of high strength carbon-fiber composites, suspended by magnetic bearings, and spinning at speeds from 20,000 to over 50,000 rpm in a vacuum enclosure. Such flywheels can come up to speed in a matter of minutes – reaching their energy capacity much more quickly than some other forms of storage.

8.7.1. MAIN COMPONENTS: A typical system consists of a flywheel supported by rolling element bearing connected to a motor generator. The flywheel and sometimes motor–generator may be enclosed in a vacuum chamber to reduce friction and energy loss.

First generation flywheel energy-storage systems use a large steel flywheel rotating on mechanical bearings. Newer systems use carbon fiber composite rotors that have a higher tensile strength than steel and can store much more energy for the same mass. To reduce friction magnetic bearings are sometimes used instead of mechanical bearings. Possible future use of superconducting bearings. The expense of refrigeration led to the early dismissal of low-temperature superconductors for use in magnetic bearings. However, high temperature superconductors (HTSC) bearings may be economical and could possibly extend the time energy could be stored economically. Hybrid bearing systems are most likely to see use first. High-temperature superconductor bearings have historically had problems providing the lifting forces necessary for the larger designs but can easily provide a stabilizing force. Therefore, in hybrid bearings, permanent magnets support the load and high-temperature superconductors are used to stabilize it. The reason superconductors can work well stabilizing the load is because they are perfect diamagnetic. If the rotor tries to drift off-center, a restoring force due to flux pining restores it. This is known as the magnetic stiffness of the bearing. Rotational axis vibration can occur due to low stiffness and damping, which are inherent problems of superconducting magnets, preventing the use of completely superconducting magnetic bearings for flywheel applications.

Since flux pinning is an important factor for providing the stabilizing and lifting force, the HTSC can be made much more easily for FES than for other uses. HTSC powders can be formed into arbitrary shapes so long as flux pinning is strong. An ongoing challenge that has to be overcome before superconductors can provide the full lifting force for an FES system is finding a way to suppress the decrease of levitation force and the gradual fall of rotor during operation caused by the flux creep of the superconducting material.

8.7.2. PHYSICAL CHARACTERISTICS

8.7.2.1. GENERAL: Compared with other ways to store electricity, FES systems have long lifetimes (lasting decades with little or no maintenance; full-cycle lifetimes quoted for flywheels range from in excess of 10^5, up to 10^7, cycles of use), high specific energy (100–130 W·h/kg, or 360–500 kJ/kg), and large maximum power output. The energy efficiency (ratio of energy out per energy in) of flywheels, also known as round-trip efficiency, can be as high as 90%. Typical capacities range from 3 kWh to 133 kWh. Rapid charging of a system occurs in less than 15 minutes. The high specific energies often cited with flywheels can be a little misleading as commercial systems built have much lower specific energy, for example 11 W·h/kg, or 40 kJ/kg.

8.7.2.2. MATERIAL PROPERTIES: For energy storage, materials with high strength and low density are desirable. For this reason, composite materials are frequently used in advanced flywheels. The strength to density ratio of a material can be expressed in Wh/kg (or Nm/kg); values greater than 400 Wh/kg can be achieved by certain composite materials.

8.7.2.3. ROTOR MATERIALS: Several modern flywheel rotors are made from composite materials. Examples include the carbon-fiber composite flywheel from Beacon Power Corporation and the Power Thru flywheel from Phillips Service Industries. Alternatively, Calnetix utilizes aerospace-grade high-performance steel in their flywheel construction. For these rotors, the relationship between material properties, geometry and energy density can be expressed by using a weighted average approach.

8.7.2.4. TENSILE STRENGTH AND FAILURE MODES: One of the primary limits to flywheel design is the tensile strength of the rotor. Generally speaking, the stronger the disc, the faster it may be spun, and the more energy the system can store. (Making the flywheel heavier without a corresponding increase in strength will slow the maximum speed the flywheel can spin without rupturing, hence will not increase the total amount of energy the flywheel can store.)

When the tensile strength of a composite flywheel's outer binding cover is exceeded, the binding cover will fracture, and the wheel will shatter as the outer wheel compression is lost around the entire circumference, releasing all of its stored energy at once; this is commonly referred to as "flywheel explosion" since wheel fragments can reach kinetic energy comparable to that of a bullet. Composite materials that are wound and glued in layers tend to disintegrate quickly, first into small-diameter filaments that entangle and slow each other, and then into red-hot powder; a cast metal flywheel throws off large chunks of high-speed shrapnel.

For a cast metal flywheel, the failure limit is the binding strength of the grain boundaries of the polycrystalline molded metal. Aluminum in particular suffers from fatigue and can develop micro fractures from repeated low energy stretching. Angular forces may cause portions of a metal flywheel to bend outward and begin dragging on the outer containment vessel, or to separate completely and bounce randomly around the interior. The rest of the flywheel is now severely unbalanced, which may lead to rapid bearing failure from vibration, and sudden shock fracturing of large segments of the flywheel.

Traditional flywheel systems require strong containment vessels as a safety precaution, which increases the total mass of the device. The energy release from failure can be dampened with a gelatinous or encapsulated liquid inner housing lining, which will boil and absorb the energy of destruction. Still, many customers of large-scale flywheel energy-storage systems prefer to have them embedded in the ground to halt any material that might escape the containment vessel.

8.7.2.5. ENERGY STORAGE EFFICIENCY: Flywheel energy storage systems using mechanical bearings can lose 20% to 50% of their energy in two hours. Much of the friction responsible for this energy loss results from the flywheel changing orientation due to the rotation of the earth (an effect similar to that shown by a Foucault pendulum). This change in orientation is resisted by the gyroscopic forces exerted by the flywheel's angular momentum, thus exerting a force against the mechanical bearings. This force increases friction. This can be avoided by aligning the flywheel's axis of rotation parallel to that of the earth's axis of rotation. Conversely, flywheels with magnetic bearings and high vacuum can maintain 97% mechanical efficiency, and 85% round trip efficiency.

8.7.3. EFFECTS OF ANGULAR MOMENTUM IN VEHICLES: When used in vehicles, flywheels also act as gyroscopes, since their angular momentum is typically of a similar order of magnitude as the forces acting on the moving vehicle. This property may be detrimental to the vehicle's handling characteristics while turning or driving on rough ground; driving onto the side of a sloped embankment may cause wheels to partially lift off the ground as the flywheel opposes sideways tilting forces. On the other hand, this property could be utilized to keep the car balanced so as to keep it from rolling over during sharp turns.

When a flywheel is used entirely for its effects on the attitude of a vehicle, rather than for energy storage, it is called a reaction wheel or a control momentum gyroscope.

The resistance of angular tilting can be almost completely removed by mounting the flywheel within an appropriately applied set of gimbals, allowing the flywheel to retain its original orientation without affecting the vehicle. This doesn't avoid the complication of gimbal lock, and so a compromise between the number of gimbals and the angular freedom is needed.

The center axle of the flywheel acts as a single gimbal, and if aligned vertically, allows for the 360 degrees of yaw in a horizontal plane. However, for instance driving up-hill requires a second pitch gimbal, and driving on the side of a sloped embankment requires a third roll gimbal.

8.7.3.1. FULL MOTION GIMBALS: Although the flywheel itself may be of a flat ring shape, a free-movement gimbal mounting inside a vehicle requires a spherical volume for the flywheel to freely rotate within. Left to its own, a spinning flywheel in a vehicle would slowly precess following the Earth's rotation, and precess further yet in vehicles that travel long distances over the Earth's curved spherical surface. A full-motion gimbal has additional problems of how to communicate power into and out of the flywheel, since the flywheel could potentially flip completely over once a day, precessing as the Earth rotates. Full free rotation would require slip rings around each gimbal axis for power conductors, further adding to the design complexity.

8.7.3.2. LIMITED-MOTION GIMBALS: To reduce space usage, the gimbal system may be of a limited-movement design, using shock absorbers to cushion sudden rapid motions within a certain number of degrees of out-of-plane angular rotation, and then gradually forcing the flywheel to adopt the vehicle's current orientation. This reduces the gimbal movement space around a ring-shaped flywheel from a full sphere, to a short thickened cylinder, encompassing for example ± 30 degrees of pitch and ± 30 degrees of roll in all directions around the flywheel.

8.7.3.3. COUNTERBALANCING OF ANGULAR MOMENTUM: An alternative solution to the problem is to have two joined flywheels spinning synchronously in opposite directions. They would have a total angular momentum of zero and no gyroscopic effect. A problem with this solution is that when the difference between the momentums of each flywheel is anything other than zero the housing of the two flywheels would exhibit torque. Both wheels must be maintained at the same speed to keep the angular velocity at zero. Strictly speaking, the two flywheels would exert a huge torqueing moment at the central point, trying to bend the axle. However, if the axle were sufficiently strong, no gyroscopic forces would have a net effect on the sealed container, so no torque would be noticed.

To further balance the forces and spread out strain, a single large flywheel can be balanced by two half-size flywheels on each side, or the flywheels can be reduced in size to be a series of alternating layers spinning in opposite directions. However this increases housing and bearing complexity.

8.7.4. APPLICATIONS

8.7.4.1. TRANSPORTATION: In the 1950s, flywheel-powered buses, known as gyrobuses, were used in Yverdon (Switzerland) and Ghent (Belgium) and there is ongoing research to make flywheel systems that are smaller, lighter, and cheaper and have a greater capacity. It is hoped that flywheel systems can replace conventional chemical batteries for mobile applications, such as for electric vehicles. Proposed flywheel systems would eliminate many of the disadvantages of existing battery power systems, such as low capacity, long charge times, heavy weight and short usable lifetimes.

Flywheels have also been proposed for use in continuously variable transmissions. Punch Powertrain is currently working on such a device.

During the 1990s, Rosen Motors developed a gas turbine powered series hybrid automotive powertrain using a 55,000 rpm flywheel to provide bursts of acceleration which the small gas turbine engine could not provide. The flywheel also stored energy through regenerative braking. The flywheel was composed of a titanium hub with a carbon fiber cylinder and was glimbal mounted to minimize adverse gyroscopic effects on vehicle handling. The prototype vehicle was successfully road tested in 1997 but was never mass-produced.

In 2013, Volvo announced a flywheel system fitted to the rear axle of its S60 sedan. Braking action spins the flywheel at up to 60,000 rpm and stops the front-mounted engine. Flywheel energy is applied via a special transmission to partially or completely power the vehicle. The 20-centimetre (7.9 in), 6-kilogram (13 lb) carbon fiber flywheel spins in a vacuum to eliminate friction. When partnered with a four-cylinder engine, it offers up to a 25 percent reduction in fuel consumption versus a comparably performing turbo six-cylinder, providing an 80 horsepower (60 kW) boost and allowing it to reach 100 kilometres per hour (62 mph) in 5.5 seconds. The company did not announce specific plans to include the technology in its product line.

8.7.4.2. RAIL ELECTRIFICATION: FES can be used at the lineside of electrified railways to help regulate the line voltage thus improving the acceleration of unmodified electric trains and the amount of energy recovered back to the line during regenerative braking, thus lowering energy bills. Trials have taken place in London, New York, Lyon and Tokyo, and New York MTA’s Long Island Rail Road is now investing $5.2m in a pilot project on LIRR's West Hempstead Branch line. These trials and systems store kinetic energy in rotors consisting of a carbon-glass composite cylinder packed with neodymium-iron-boron powder that forms a permanent magnet. These spin at up to 37,800 rpm, and each 100 kW (130 hp) unit can store 11 megajoules (3.1 kWh) of re-usable energy, approximately enough to accelerate a weight of 200 metric tons (220 short tons; 197 long tons) from zero to 38 km/h (24 mph).

8.7.4.3. UNINTERRUPTIBLE POWER SUPPLIES: Flywheel power storage systems in production as of 2001 had storage capacities comparable to batteries and faster discharge rates. They are mainly used to provide load leveling for large battery systems, such as an uninterruptible power supply for data centers as they save a considerable amount of space compared to battery systems.

Flywheel maintenance in general runs about one-half the cost of traditional battery UPS systems. The only maintenance is a basic annual preventive maintenance routine and replacing the bearings every five to ten years, which takes about four hours. Newer flywheel systems completely levitate the spinning mass using maintenance-free magnetic bearings, thus eliminating mechanical bearing maintenance and failures.

8.7.4.4. TEST LABORATORIES: A long-standing niche market for flywheel power systems are facilities where circuit breakers and similar devices are tested: even a small household circuit breaker may be rated to interrupt a current of 10,000 or more amperes, and larger units may have interrupting ratings of 100,000 or 1,000,000 amperes. The enormous transient loads produced by deliberately forcing such devices to demonstrate their ability to interrupt simulated short circuits would have unacceptable effects on the local grid if these tests were done directly from building power. Typically such a laboratory will have several large motor–generator sets, which can be spun up to speed over several minutes; then the motor is disconnected before a circuit breaker is tested.

8.7.4.5. PHYSICS LABORATORIES: Tokamak fusion experiments need very high currents for brief intervals (mainly to power large electromagnets for a few seconds).

- JET (the Joint European Torus) has two 775 t (854 short tons; 763 long tons) flywheels (installed in 1981) that spin up to 225 rpm. Each flywheel stores 3.75 GJ and can deliver at up to 400 MW (540,000 hp).
- The Helically symmetric Experiment at the University of Wisconsin - Madison has 18 one-ton flywheels, which are spun to 10,000 rpm using repurposed electric train motors.
- ASDEX Upgrade has 3 flywheel generators.

8.7.4.6. AIRCRAFT LAUNCHING SYSTEMS: The Gerald R. Ford class aircraft carrier will use flywheels to accumulate energy from the ship's power supply, for rapid release into the electromagnetic aircraft launch system. The shipboard power system cannot on its own supply the high power transients necessary to launch aircraft. Each of four rotors will store 121 MJ (34 kWh) at 6400 rpm. They can store 122 MJ (34 kWh) in 45 secs and release it in 2–3 seconds. The flywheel energy densities are 28 kJ/kg (8 W·h/kg); including the stators and cases this comes down to 18.1 kJ/kg (5 W·h/kg), excluding the torque frame.

8.7.4.7. NASA G2 FLYWHEEL FOR SPACECRAFT ENERGY STORAGE: This was a design funded by NASA’s Glenn Research Center and intended for component testing in a laboratory environment. It used a carbon fiber rim with a titanium hub designed to spin at 60,000 rpm, mounted on magnetic bearings. Weight was limited to 250 pounds (110 kilograms). Storage was 525 Wh (1.89 MJ) and could be charged or discharged at 1 kW (1.3 hp), leading to a specific energy of 5.31 W·h/kg and power density of 10.11 W/kg. The working model shown in the photograph at the top of the page ran at 41,000 rpm on September 2, 2004.

8.7.4.8. AMUSEMENT RIDES: The Montezooma's Revenge roller coaster at Knott's Berry Farm was the first flywheel-launched roller coaster in the world and is the last ride of its kind still operating in the United States. The ride uses a 7.6 tonnes flywheel to accelerate the train to 55 miles per hour (89 km/h) in 4.5 seconds. The Incredible Hulk roller coaster at Universal's Islands of Adventure features a rapidly accelerating uphill launch as opposed to the typical gravity drop. This is achieved through powerful traction motors that throw the car up the track. To achieve the brief very high current required to accelerate a full coaster train to full speed uphill, the park utilizes several motor-generator sets with large flywheels. Without these stored energy units, the park would have to invest in a new substation or risk browing out the local energy grid every time the ride launches.

8.7.4.9. PULSE POWER: Flywheel Energy Storage Systems (FESS) are found in a variety of applications ranging from grid-connected energy management to uninterruptible power supplies. With the progress of technology, there is fast renovation involved in FESS application. Examples include high power weapons, aircraft powertrains and shipboard power systems, where the system requires a very high-power for a short period in order of a few seconds and even milliseconds. Compensated pulsed alternator (compulsator) is one of the most popular choices of pulsed power supplies for fusion reactors, high-power pulsed lasers, and hypervelocity electromagnetic launchers because of its high energy density and power density, which is generally designed for the FESS. Compensators (low-inductance alternators) act like capacitors, they can be spun up to provide pulsed power for railguns and lasers. Instead of having a separate flywheel and generator, only the large rotor of the alternator stores energy.

8.7.4.10. GRID ENERGY STORAGE: Flywheels are sometimes used as short term spinning reserve for momentary grid frequency regulation and balancing sudden changes between supply and consumption. No carbon emissions, faster response times and ability to buy power at off-peak hours are among the advantages of using flywheels instead of traditional sources of energy like natural gas turbines. Operation is very similar to batteries in the same application, their differences are primarily economic.

8.7.4.11. WIND TURBINES: Flywheels may be used to store energy generated by wind turbines during off-peak periods or during high wind speeds. In 2010, Beacon Power began testing of their Smart Energy 25 (Gen 4) flywheel energy storage system at a wind farm in Tehachapi, California. The system was part of a wind power/flywheel demonstration project being carried out for the California Energy Commission.

8.7.4.12. TOYS: Friction motors used to power many toy cars, trucks, trains, action toys and such, are simple flywheel motors.

8.7.4.13. TOGGLE ACTION PRESSES: In industry, toggle action presses are still popular. The usual arrangement involves a very strong crankshaft and a heavy duty connecting rod which drives the press. Large and heavy flywheels are driven by electric motors but the flywheels turn the crankshaft only when clutches are activated.

8.7.4.14. BEYOND ENERGY STORAGE: Flywheels can be used for attitude control. There is also some research into motion control, mostly to stabilize systems using the gyroscopic effect.

8.7.4.15. COMPARISON TO ELECTRIC BATTERIES: Flywheels are not as adversely affected by temperature changes, can operate at a much wider temperature range, and are not subject to many of the common failures of chemical rechargeable batteries. They are also less potentially damaging to the environment, being largely made of inert or benign materials. Another advantage of flywheels is that by a simple measurement of the rotation speed it is possible to know the exact amount of energy stored.

Unlike most batteries which operate only for a finite period (for example roughly 10 years in the case of lithium iron phosphate batteries), a flywheel potentially has an indefinite working lifespan. Flywheels built as part of James Watt steam engine have been continuously working for more than two hundred years. Working examples of ancient flywheels used mainly in milling and pottery can be found in many locations in Africa, Asia, and Europe.

Most modern flywheels are typically sealed devices that need minimal maintenance throughout their service lives. Magnetic bearing flywheels in vacuum enclosures, such as the NASA model depicted above, do not need any bearing maintenance and are therefore superior to batteries both in terms of total lifetime and energy storage capacity, since their effective service lifespan is still unknown. Flywheel systems with mechanical bearings will have limited lifespans due to wear.

High performance flywheels can explode, killing bystanders with high speed shrapnel.Flywheels can be installed below-ground to reduce this risk. While batteries can catch fire and release toxins, there is generally time for bystanders to flee and escape injury.

The physical arrangement of batteries can be designed to match a wide variety of configurations, whereas a flywheel at a minimum must occupy a certain area and volume, because the energy it stores is proportional to its rotational inertia and to the square of its rotational speed. As a flywheel gets smaller, its mass also decreases, so the speed must increase, and so the stress on the materials increases. Where dimensions are a constraint, (e.g. under the chassis of a train), a flywheel may not be a viable solution.

8.8. FUEL CELL:

Fuel cells are a type of energy conversion technology which take the chemical energy contained within a fuel and transform it into electricity along with certain by-products (depending on the fuel used). It's important to note that fuel cells are not heat engines, so they can have incredibly high efficiencies. However, when a heat engine is used to power a fuel cell, the heat engine still has a limiting thermal efficiency.

Fuel cells can be seen as an energy storage device, as energy can be input to create hydrogen and oxygen, which can remain in the cell until its use is needed at a later time. In this sense they work much like a battery. There are multiple types of fuel cells, but two common types are the solid oxide fuel cell (SOFC) and the polymer electrolyte membrane fuel cell (PEMFC).

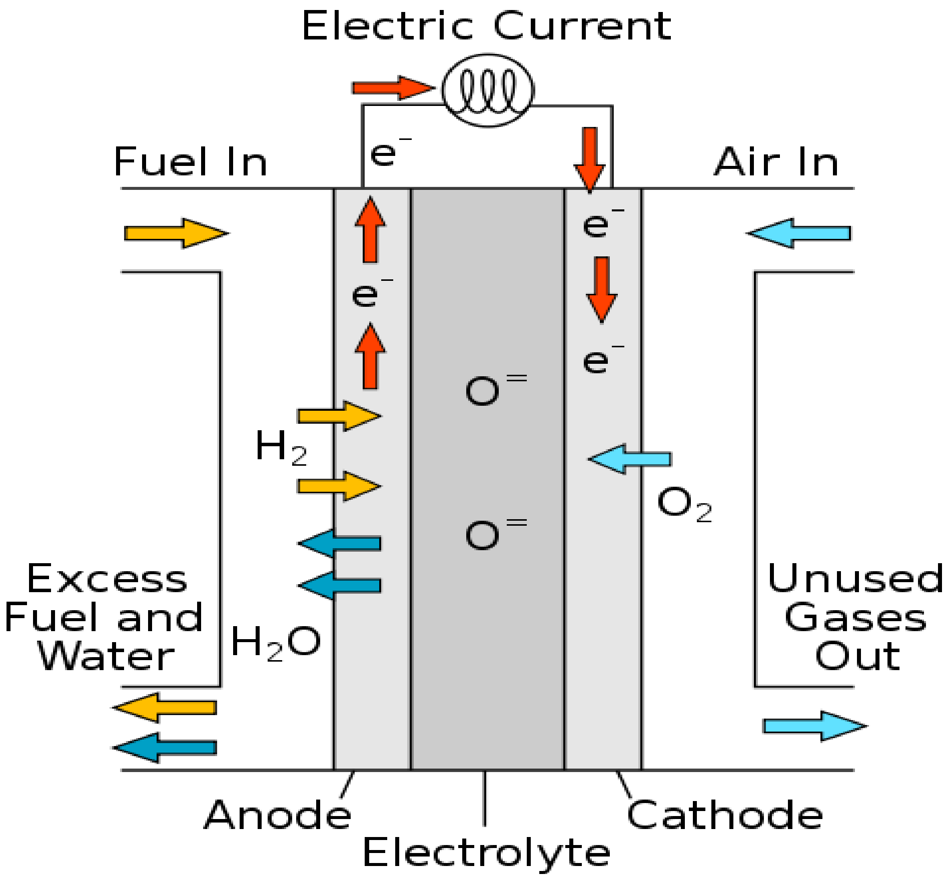

Figure 8.1: A diagram of a solid oxide fuel cell. Molecular oxygen becomes oxide ions (O^{2-}) and combines with hydrogen to form water, while simultaneously producing electricity.

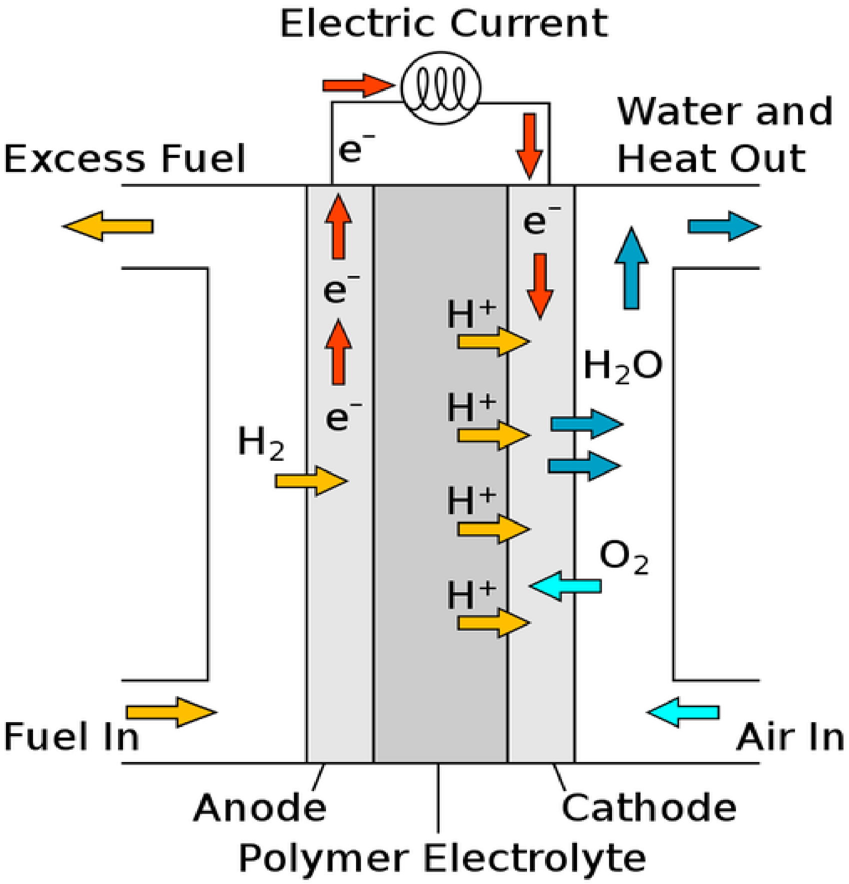

Figure 8.2: A diagram of a polymer electrolyte membrane fuel cell (PEMFC). Molecular hydrogen fuel becomes hydrogen ions (H^+) that travel through a polymer electrolyte. The hydrogen ions combine with oxygen to form water, while simultaneously producing electricity.

To produce electricity in a solid oxide fuel cell, oxygen in the air combines with free electrons to form oxide ions. The oxide ions travel through a ceramic electrolyte and react with molecular hydrogen to form water. The reaction that makes water also releases electrons which travel through an external electrical circuit, producing electricity. This process can be seen in figure8.1.

To produce electricity in a polymer electrolyte membrane fuel cell, a gaseous fuel is input and reacts with a catalyst made of platinum nanoparticles. When molecular hydrogen comes into contact with this, it splits into two H^+ ions and two electrons. The electrons are conducted through an electromotive force and electricity is produced. The hydrogen ions pass through a proton exchange membrane (also known as a polymer electrolyte) where it reaches the cathode and combines with oxygen to form water. This process can continue as long as there is hydrogen and oxygen supplied to the cell. Figure 8.2 shows this process in a PEMFC.

8.8.1. HYDROGEN: An attractive fuel for use in fuel cells is hydrogen, which is actively being researched and developed. The reasons for hydrogen use is not only because of its high energy density (121 MJ/kg), but because the only by-product aside from electricity is water. Although hydrogen is the most abundant element in the universe, it doesn't exist in its elemental form on Earth. Therefore hydrogen must be manufactured by inputting energy into hydrogen compounds like hydrocarbons or water. Depending on how this is done, the process may also release pollutants. Around 96% of hydrogen produced is done by using natural gas and other fossil fuels, resulting in considerable carbon di oxide emissions. However, for the future, cleaner methods of attaining hydrogen (ie. water) are preferred. An alternative way to produce hydrogen comes from nuclear power. During off-peak periods (when the electrical grid does not require as much electricity) nuclear power plants may use their electricity for the production of hydrogen. The heat generated by the nuclear reactor could also be used for the production of hydrogen. Combined cycle plants producing both hydrogen and electricity may reach an efficiency of 60%. Many Generation IV nuclear reactors are being designed with the purpose of hydrogen production.

8.8.2. USE OF FUEL CELLS: Many countries are spending enormous amounts of money into the development of hydrogen fuel cells. Burning oil products (or any other fossil fuels) produces pollution; most specifically, burning releases carbon dioxide which contributes to global warming and ultimately changing climate. Uses of fuel cells range from large electricity generating plants to small devices like cell phones or laptops. The most promising use for hydrogen as fuel (for the immediate future at least) are in vehicles and there are already hydrogen based vehicles on the road today. The theoretical maximum efficiency of hydrogen fuel cells is 83%, with realistic efficiencies around 60%. Combined with an electric motor of 90% efficiency, the vehicles can achieve an efficiency of 54% before factoring in other energy losses. This is around 2 - 2.5 times higher than a typical gasoline powered vehicle. There is plenty of criticism for these types of vehicles, as many claim the cost of these vehicles will never be practical. The platinum in the fuel cells has made them expensive, but advances are bringing the price down. The durability and performance of such systems, along with the infrastructure necessary to accommodate them, is also under scrutiny.

8.9. SUPERCAPACITOR / ULTRA-CAPACITOR:

A supercapacitor (SC), also called an ultra-capacitor, is a high-capacity capacitor, with a capacitance value much higher than solid-state capacitors but with lower voltage limits. It bridges the gap between electrolytic capacitors and rechargeable batteries. It typically stores 10 to 100 times more energy per unit volume or mass than electrolytic capacitors, can accept and deliver charge much faster than batteries, and tolerates many more charge and discharge cycles than rechargeable batteries. Unlike ordinary capacitors, supercapacitors do not use the conventional solid dielectric, but rather, they use electrostatic double layer capacitance and electrochemical pseudo capacitance, both of which contribute to the total capacitance of the capacitor.

Supercapacitors are used in applications requiring many rapid charge/discharge cycles, rather than long-term compact energy storage: in automobiles, buses, trains, cranes and elevators, where they are used for regenerative braking, short-term energy storage, or burst-mode power delivery. Smaller units are used as power backup for static random acces memory (SRAM).

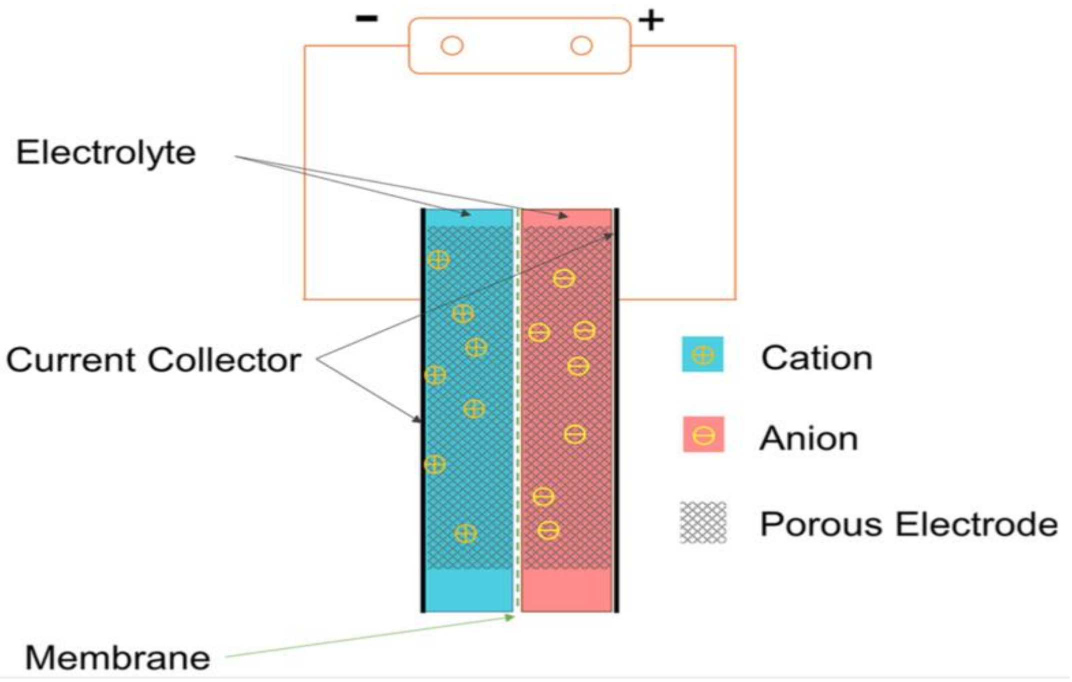

Figure 8.3: ULTA CAPACITOR

8.9.1. BACKGROUND: The electrochemical charge storage mechanisms in solid media can be roughly (there is an overlap in some systems) classified into 3 types:

- Electrostatic double-layer capacitors (EDLCs) use carbon electrodes or derivatives with much higher electrostatic double-layer capacitance than electrochemical pseudo capacitance, achieving separation of charge in a Helmholtz double layer at the interface between the surface of a conductive electrode and an electrolyte. The separation of charge is of the order of a few angstroms (0.3–0.8 nm), much smaller than in a conventional capacitor. The electric charge in EDLCs is stored in a two-dimensional interphase (surface) of an electronic conductor (e.g. carbon particle) and ionic conductor.
- Batteries with solid electroactive materials store charge in bulk solid phases by virtue of redox chemical reactions.
- Electrochemical supercapacitors (ECSCs) fall in between EDLs and batteries. ECSCs use metal oxide or conducting polymer electrodes with a high amount of electrochemical pseudo capacitance additional to the double-layer capacitance. Pseudocapacitance is achieved by Faradaic electron charge transfer with redox reactions, intercalation or electrosorrption.

In solid-state capacitors, the mobile charges are electrons, and the gap between electrodes is a layer of a dielectric. In electrochemical double layer capacitors, the mobile charges are solvated ions (cations and anions), and the effective thickness is determined on each of the two electrodes by their electrochemical double layer structure. In batteries the charge is stored in the bulk volume of solid phases, which have both electronic and ionic conductivities. In electrochemical supercapacitors, the charge storage mechanisms either combine the double-layer and battery mechanisms, or are based on mechanisms, which are intermediate between true double layer and true battery.

8.9.2. STORAGE PRINCIPLES: Electrochemical capacitors use the double-layer effect to store electric energy; however, this double-layer has no conventional solid dielectric to separate the charges. There are two storage principles in the electric double-layer of the electrodes that contribute to the total capacitance of an electrochemical capacitor:

- Double layer capacitance, electrostatic storage of the electrical energy achieved by separation of charge in a Helmholtz double layer.
- Pseudo capacitance electrochemical, storage of the electrical energy. The original type uses faradaic redox reactions with charge-transfer.

Both capacitances are only separable by measurement techniques. The amount of charge stored per unit voltage in an electrochemical capacitor is primarily a function of the electrode size, although the amount of capacitance of each storage principle can vary extremely.

8.9.3. ELECTRICAL DOUBLE-LAYER CAPACITANCE: Every electrochemical capacitor has two electrodes, mechanically separated by a separator, which are ionically connected to each other via the electrolyte. The electrolyte is a mixture of positive and negative ions dissolved in a solvent such as water. At each of the two electrode surfaces originates an area in which the liquid electrolyte contacts the conductive metallic surface of the electrode. This interface forms a common boundary among two different phases of matter, such as an insoluble solid electrode surface and an adjacent liquid electrolyte. In this interface occurs a very special phenomenon of the double layer effect.

Applying a voltage to an electrochemical capacitor causes both electrodes in the capacitor to generate electrical double-layers. These double-layers consist of two layers of charges: one electronic layer is in the surface lattice structure of the electrode, and the other, with opposite polarity, emerges from dissolved and solvated ions in the electrolyte. The two layers are separated by a monolayer of solvent molecules, e.g., for water as solvent by water molecules, called inner Helmholtz plane (IHP). Solvent molecules adhere by physical adsorption on the surface of the electrode and separate the oppositely polarized ions from each other, and can be idealised as a molecular dielectric. In the process, there is no transfer of charge between electrode and electrolyte, so the forces that cause the adhesion are not chemical bonds, but physical forces, e.g., electrostatic forces. The adsorbed molecules are polarized, but, due to the lack of transfer of charge between electrolyte and electrode, suffered no chemical changes.

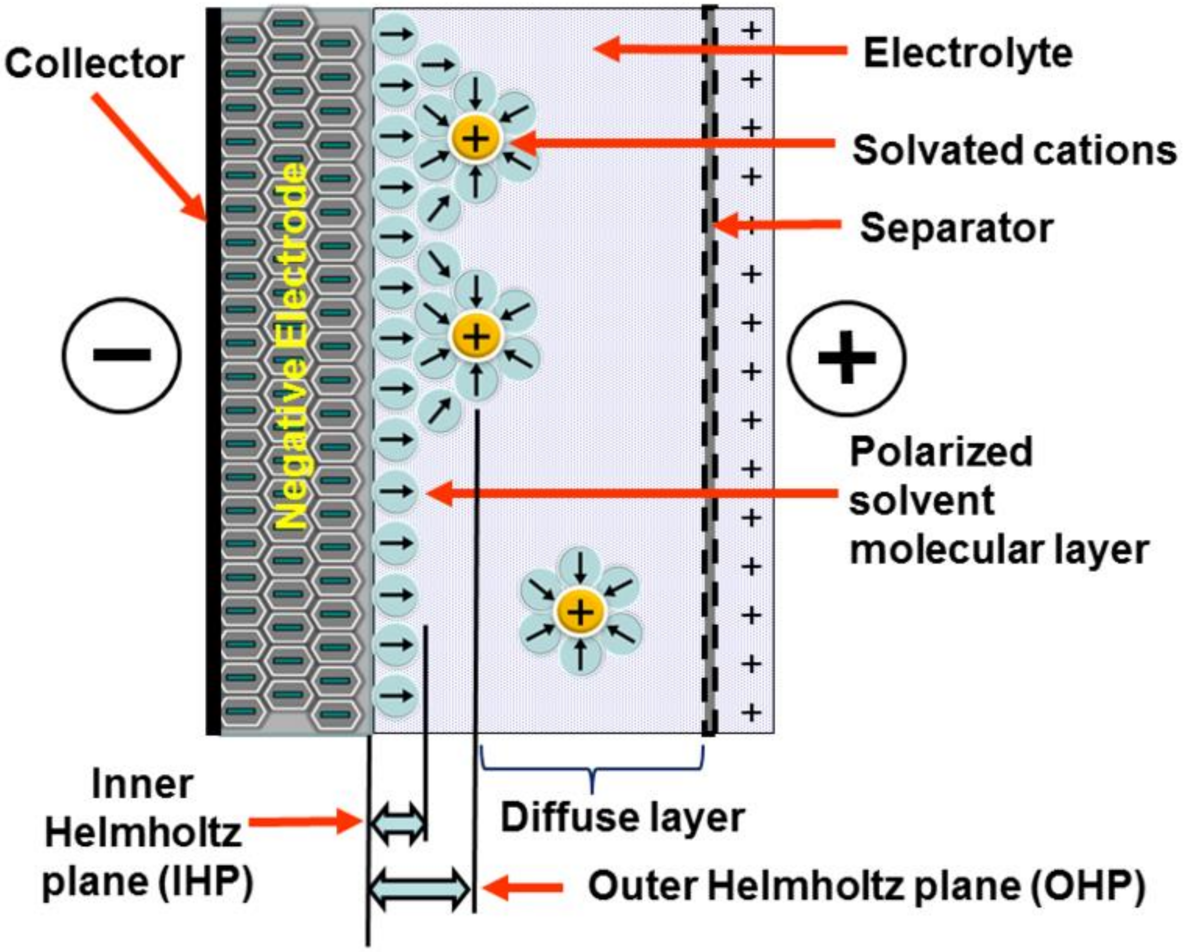

Figure 8.4: double layer of negative ions in the electrode and solvated positive ions in the liquid electrolyte, separated by a layer of polarized solvent molecules

The amount of charge in the electrode is matched by the magnitude of counter-charges in outer Helmholtz plane (OHP). This double-layer phenomena stores electrical charges as in a conventional capacitor. The double-layer charge forms a static electric field in the molecular layer of the solvent molecules in the IHP that corresponds to the strength of the applied voltage.

The main drawback of carbon electrodes of double-layer SCs is small values of quantum capacitance which act in series with capacitance of ionic space charge. Therefore, further increase of density of capacitance in SCs can be connected with increasing of quantum capacitance of carbon electrode nanostructures.

8.9.4. ELECTROCHEMICAL PSEUDOCAPACITANCE

Applying a voltage at the electrochemical capacitor terminals moves electrolyte ions to the opposite polarized electrode and forms a double-layer in which a single layer of solvent molecules acts as separator. Pseudo capacitance can originate when specifically adsorbed ions out of the electrolyte pervade the double-layer. This pseudo capacitance store electrical energy by means of reversible faradaic redox reactions on the surface of suitable electrodes in an electrochemical capacitor with an electric double layer. Pseudo capacitance is accompanied with an electron charge transfer between electrolyte and electrode coming from a de-solvated and absorbed ion whereby only one electron per charge unit is participating. This faradaic charge transfer originates by a very fast sequence of reversible redox, interaction or electro sorption processes. The adsorbed ion has no chemical reaction with the atoms of the electrode (no chemical bonds arise since only a charge-transfer take place.

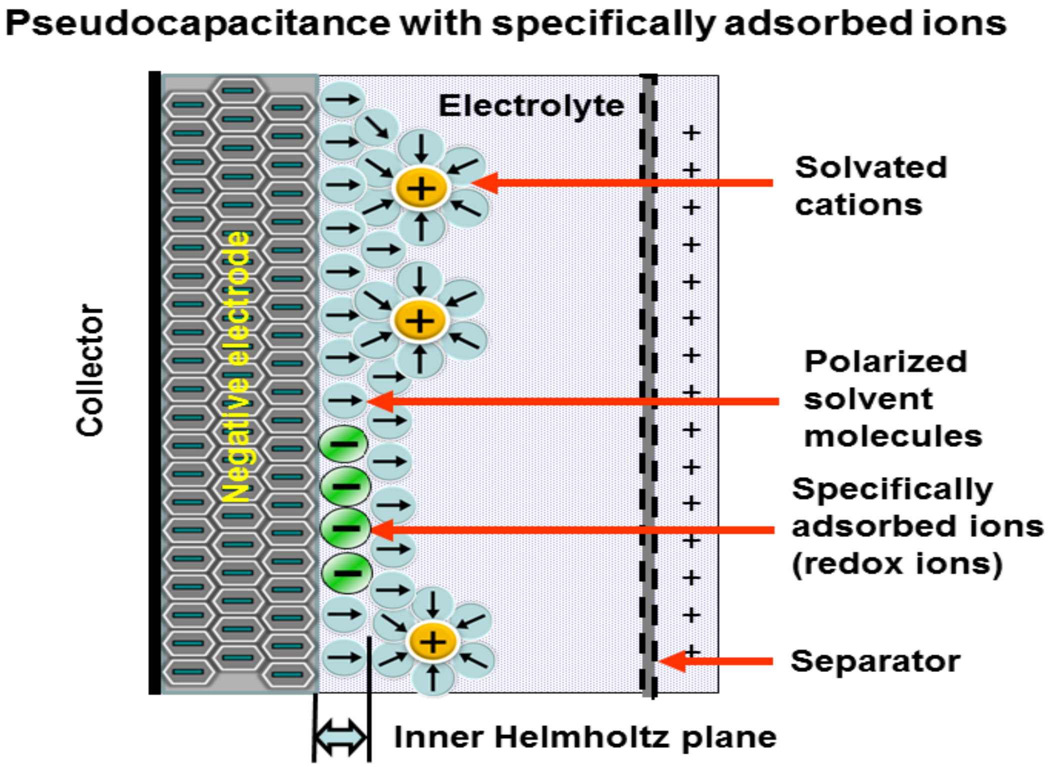

Figure 8.5: a double layer with specifically adsorbed ions which have submitted their charge to the electrode to explain the faradaic charge-transfer of the pseudo capacitance

The electrons involved in the faradaic processes are transferred to or from valence electron states (orbitals) of the redox electrode reagent. They enter the negative electrode and flow through the external circuit to the positive electrode where a second double-layer with an equal number of anions has formed. The electrons reaching the positive electrode are not transferred to the anions forming the double-layer, instead they remain in the strongly ionized and "electron hungry" transition-metal ions of the electrode's surface. As such, the storage capacity of faradaic pseudo capacitance is limited by the finite quantity of reagent in the available surface.

A faradaic pseudo capacitance only occurs together with a static double layer capacitance, and its magnitude may exceed the value of double-layer capacitance for the same surface area by factor of 100, depending on the nature and the structure of the electrode, because all the pseudo capacitance reactions take place only with de-solvated ions, which are much smaller than solvated ion with their solvating shell. The amount of pseudo capacitance has a linear function within narrow limits determined by the potential dependent degree of surface coverage of the adsorbed anions.

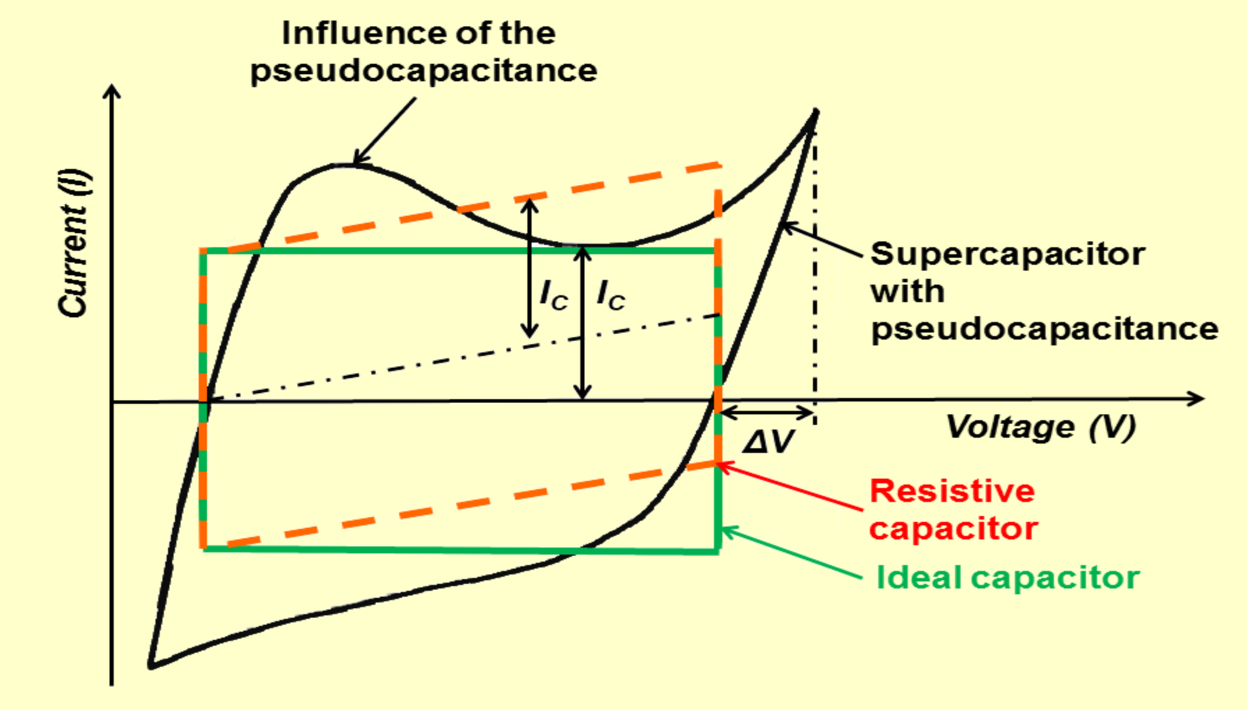

Figure 8.6: cyclic voltammogram

A cyclic voltammogram (CV) shows the fundamental differences between static capacitance (rectangular) and pseudo capacitance (curved)

The ability of electrodes to accomplish pseudo capacitance effects by redox reactions, intercalation or electro sorption strongly depends on the chemical affinity of electrode materials to the ions adsorbed on the electrode surface as well as on the structure and dimension of the electrode pores. Materials exhibiting redox behavior for use as electrodes in pseudo capacitors are transition-metal oxides like RuO_2, IrO_2, or MnO_2 inserted by doping in the conductive electrode material such as active carbon, as well as conducting polymers such as polyaniline or derivatives of polythiophene covering the electrode material.

The amount of electric charge stored in a pseudo capacitance is linearly proportional to the applied voltage. The unit of pseudo capacitance is farad, same as that of capacitance.

Although conventional battery-type electrode materials also use chemical reactions to store charge, they show very different electrical profiles, as the rate of discharge is limited by the speed of diffusion. Grinding those materials down to nanoscale frees them of the diffusion limit and give them a more pseudo capacitive behavior, making them extrinsic pseudo capacitors.

8.10. BIOMASS AND BIOFUELS:

Biomass is a term used in several contexts: in the context of ecology it means living organisms, and in the context of bioenergy it means matter from recently living (but now dead) organisms. In the latter context, there are variations in how biomass is defined, e.g. only from plants, from plants and algae, from plants and animals. The vast majority of biomass used for bioenergy does come from plants. Bioenergy is a type of renewable energy with potential to assist with climate change mitigation.

8.10.1. USES IN DIFFERENT CONTEXTS

8.10.1.1. ECOLOGY: Biomass (ecology), the mass of living biological organisms in a given area or ecosystem at a given time. This can be the biomass of particular species or the biomass of a particular community or habitat.

8.10.1.2. ENERGY: Biomass (energy), biomass used for energy production or in other words: biological mass used as a renewable energy source (usually produced through agriculture, forestry or aquaculture metods)

- Bioenergy, energy sources derived from biological material
    - Solid fuel, forms of bioenergy that are solid
    - Biofuel
    - Energy crops

8.10.1.3. BIOTECHNOLOGY: Biomass is also used as a term for the mass of microorganisms that are used to produce industrial products like enzymers and medicines.

8.10.1.4. BIOPRODUCTS: Examples of emerging bio products or bio based products include biofuels, bioenergy, biochar, starch-based and cellulose-based ethanol, bio-based adhesives, biochemical, bioplastics, etc.

8.10.1.5. BIOLOGICAL WASTEWATER TREATMENT: In biological waste water treatment processes, such as the activated sludge process, the term "biomass" is used to denote the mass of bacteria and other microorganisms that break down pollutants in wastewater. The biomass forms part of sewage sludge.

8.11 SUMMARY

In this unit, you have studied about Hybrid Energy System and Energy Storage System. You have also studied Types of Energy Storage Scenarios and Types Of Batteries and their different types Primary Batteries as well Secondary Batteries. You have also learnt about Battery Management System, balancing and their function Functions. About the Flywheel Energy Storage and Main Components, Physical Characteristics and applications. You have studied about ultra-capacitor.

8.12 GLOSSARY

BMS: battery management system

OHP: outer Helmholtz plane

CV: cyclic voltammogram

8.13 TERMINAL QUESTIONS

1. Explain Battery management system. Discuss its function in details.

2. Explain Flywheel energy storage system.

3. Discuss various types of batteries

4. What do you understand by Flywheel Energy Storage? Discuss its various component and physical characteristics.

5. What do you understand by ultra-capacitor? Discuss its storage principle.

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UNIT 9 ENVIRONMENTAL EFFECT

Structure

9.1 INTRODUCTION

Environmental degradation is the term used to describe how the environment deteriorates due to pollution, ecosystem devastation, species extinction, habitat destruction, and the loss of resources like clean air, water, and soil. It is described as any alteration or disruption to the surroundings that is thought to be harmful or unfavorable.

The detrimental impacts of any human activity on the environment are referred to as environmental concerns. Included are both the physical and biological aspects of the surroundings. Pollution of the air, water, natural environment, garbage, and so on are some of the main environmental issues that are causing a lot of concern.

The High level Panel on Threats, Challenges and Change of the United Nations has formally warned of ten threats, including environmental degradation. Environmental degradation is defined as "the reduction of the environment's capacity to meet social and ecological objectives, and needs" in the United Nations International Strategy for Disaster Reduction.

Numerous forms of environmental degradation exist. The state of the environment deteriorates when natural resources are exhausted or natural habitats are destroyed. Environmental resource management and protection are two strategies used to address this issue. Environmental conflict arises when communities organize against the forces responsible for the degradation of the environment due to mismanagement.

9.2 OBJECTIVES

After studying this unit, you should be able to-

- Understand Environmental Degradation
- Learn about Environmental Effect of Thermal Power Station
- Learn about Geothermal Power
- Learn about Wind Energy Harvesting

9.3. ENVIRONMENTAL DEGRADATION:

Environmental degradation is the deterioration of the environment through depletion of resources such as quality of air, water and soil; the destruction of ecosystems; habitat destruction; the extinction of wildlife; and pollution. It is defined as any change or disturbance to the environment perceived to be deleterious or undesirable.

Environmental concerns can be defined as the negative effects of any human activity on the environment. The biological as well as the physical features of the environment are included. Some of the primary environmental challenges that are causing great worry are air pollution, water pollution, natural environment pollution, rubbish pollution, and so on.

Environmental degradation is one of the ten threats officially cautioned by the High level Panel on Threats, Challenges and Change of the United Nations. The United Nations International Strategy for Disaster Reduction defines environmental degradation as "the reduction of the capacity of the environment to meet social and ecological objectives, and needs". Environmental degradation comes in many types. When natural habitats are destroyed or natural resources are depleted, the environment is degraded. Efforts to counteract this problem include environmental protection and environmental resources management. Mismanagement that leads to degradation can also lead to environmental conflict where communities organize in opposition to the forces that mismanaged the environment.

9.3.1. BIODIVERSITY LOSS:

Scientists assert that human activity has pushed the earth into a sixth mass extinction event. The loss of biodiversity has been attributed in particular to human overpopulation, continued human population growth and overconsumption of natural resources by the world's wealthy. A 2020 report by the World Wildlife Fund found that human activity specifically overconsumption, population growth and intensive farming has destroyed 68% of vertebrate wildlife since 1970. The Global Assessment Report on Biodiversity and Ecosystem Services, published by the United Nation's IPBES in 2019, posits that roughly one million species of plants and animals face extinction from anthropogenic causes, such as expanding human land use for industrial agriculture and livestock rearing, along with overfishing.

Since the establishment of agriculture over 11,000 years ago, humans have altered roughly 70% of the earth's land surface, with the global biomass of vegetation being reduced by half, and terrestrial animal communities seeing a decline in biodiversity greater than 20% on average. A 2021 study says that just 3% of the planet's terrestrial surface is ecologically and faunally intact, meaning areas with healthy populations of native animal species and little to no human footprint. Many of these intact ecosystems were in areas inhabited by indigenous peoples. With 3.2 billion people affected globally, degradation affects over 30% of the world's land area and 40% of land in developing countries.

The implications of these losses for human livelihoods and wellbeing have raised serious concerns. With regard to the agriculture sector for example, The State of the World's Biodiversity for Food and Agriculture, published by the Food and Agriculture Organization of the United Nations in 2019, states that "countries report that many species that contribute to vital ecosystem services, including pollinators, the natural enemies of pests, soil organisms and wild food species, are in decline as a consequence of the destruction and degradation of habitats, overexploitation, pollution and other threats" and that "key ecosystems that deliver numerous services essential to food and agriculture, including supply of freshwater, protection against hazards and provision of habitat for species such as fish and pollinators, are declining."

9.3.2. IMPACTS OF ENVIRONMENTAL DEGRADATION ON WOMEN'S LIVELIHOODS: On the way biodiversity loss and ecosystem degradation impact livelihoods, the Food and Agriculture Organization of the United Nations finds also that in contexts of degraded lands and ecosystems in rural areas, both girls and women bear heavier workloads.

Women's livelihoods, health, food and nutrition security, access to water and energy, and coping abilities are all disproportionately affected by environmental degradation. Environmental pressures and shocks, particularly in rural areas, force women to deal with the aftermath, greatly increasing their load of unpaid care work.

This implies, for example, longer journeys to get primary necessities and greater exposure to the risks of human trafficking, rape, and sexual violence.

9.3.3. WATER DEGRADATION: One major component of environmental degradation is the depletion of the resource of fresh water on Earth. Approximately only 2.5% of all of the water on Earth is fresh water, with the rest being salt water. 69% of fresh water is frozen in ice caps located on Antarctica and Greenland, so only 30% of the 2.5% of fresh water is available for consumption. Fresh water is an exceptionally important resource, since life on Earth is ultimately dependent on it. Water transports nutrients, minerals and chemicals within the biosphere to all forms of life, sustains both plants and animals, and moulds the surface of the Earth with transportation and deposition of materials.

The current top three uses of fresh water account for 95% of its consumption; approximately 85% is used for irrigation of farmland, golf courses, and parks, 6% is used for domestic purposes such as indoor bathing uses and outdoor garden and lawn use, and 4% is used for industrial purposes such as processing, washing, and cooling in manufacturing centres. It is estimated that one in three people over the entire globe are already facing water shortages, almost one-fifth of the world population live in areas of physical water scarcity, and almost one quarter of the world's population live in a developing country that lacks the necessary infrastructure to use water from available rivers and aquifers. Water scarcity is an increasing problem due to many foreseen issues in the future including population growth, increased urbanization, higher standards of living, and climate change.

Industrial and domestic sewage, pesticides, fertilizers, plankton blooms, silt, oils, chemical residues, radioactive material, and other pollutants are some of the most frequent water pollutants. These have a huge negative impact on the water and can cause degradation in various levels.

9.3.4. CLIMATE CHANGE AND TEMPERATURE: Climate change affects the Earth's water supply in a large number of ways. It is predicted that the mean global temperature will rise in the coming years due to a number of forces affecting the climate. The amount of atmospheric carbon dioxide (CO2) will rise, and both of these will influence water resources; evaporation depends strongly on temperature and moisture availability which can ultimately affect the amount of water available to replenish groundwater supplies.

Transpiration from plants can be affected by a rise in atmospheric CO2, which can decrease their use of water, but can also raise their use of water from possible increases of leaf area. Temperature rise can reduce the snow season in the winter and increase the intensity of the melting snow leading to peak runoff of this, affecting soil moisture, flood and drought risks, and storage capacities depending on the area.

Warmer winter temperatures cause a decrease in snowpack, which can result in diminished water resources during summer. This is especially important at mid-latitudes and in mountain regions that depend on glacial runoff to replenish their river systems and groundwater supplies, making these areas increasingly vulnerable to water shortages over time; an increase in temperature will initially result in a rapid rise in water melting from glaciers in the summer, followed by a retreat in glaciers and a decrease in the melt and consequently the water supply every year as the size of these glaciers get smaller and smaller.

Thermal expansion of water and increased melting of oceanic glaciers from an increase in temperature gives way to a rise in sea level. This can affect the freshwater supply to coastal areas as well. As river mouths and deltas with higher salinity get pushed further inland, an intrusion of saltwater results in an increase of salinity in reservoirs and aquifers. Sea-level rise may also consequently be caused by a depletion of groundwater, as climate change can affect the hydrologic cycle in a number of ways. Uneven distributions of increased temperatures and increased precipitation around the globe results in water surpluses and deficits, but a global decrease in groundwater suggests a rise in sea level, even after meltwater and thermal expansion were accounted for, which can provide a positive feedback to the problems sea-level rise causes to fresh water supply.

A rise in air temperature results in a rise in water temperature, which is also very significant in water degradation as the water would become more susceptible to bacterial growth. An increase in water temperature can also affect ecosystems greatly because of a species' sensitivity to temperature, and also by inducing changes in a body of water's self-purification system from decreased amounts of dissolved oxygen in the water due to rises in temperature.

9.3.5. CLIMATE CHANGE AND PRECIPITATION: A rise in global temperatures is also predicted to correlate with an increase in global precipitation but because of increased runoff, floods, increased rates of soil erosion, and mass movement of land, a decline in water quality is probable, because while water will carry more nutrients it will also carry more contaminants. While most of the attention about climate change is directed towards global warming and greenhouse effect, some of the most severe effects of climate change are likely to be from changes in precipitation, evapotranspiration, runoff, and soil moisture. It is generally expected that, on average, global precipitation will increase, with some areas receiving increases and some decreases.

Climate models show that while some regions should expect an increase in precipitation, such as in the tropics and higher latitudes, other areas are expected to see a decrease, such as in the subtropics. This will ultimately cause a latitudinal variation in water distribution. The areas receiving more precipitation are also expected to receive this increase during their winter and actually become drier during their summer, creating even more of a variation of precipitation distribution. Naturally, the distribution of precipitation across the planet is very uneven, causing constant variations in water availability in respective locations.

Changes in precipitation affect the timing and magnitude of floods and droughts, shift runoff processes, and alter groundwater recharge rates. Vegetation patterns and growth rates will be directly affected by shifts in precipitation amount and distribution, which will in turn affect agriculture as well as natural ecosystems. Decreased precipitation will deprive areas of water causing water tables to fall and reservoirs of wetlands, rivers, and lakes to empty. In addition, a possible increase in evaporation and evapotranspiration will result, depending on the accompanied rise in temperature. Groundwater reserves will be depleted, and the remaining water has a greater chance of being of poor quality from saline or contaminants on the land surface.

Climate change is resulting into a very high rate of land degradation causing enhanced desertification and nutrient deficient soils. The menace of land degradation is increasing by the day and has been characterized as a major global threat. According to Global Assessment of Land Degradation and Improvement (GLADA) a quarter of land area around the globe can now be marked as degraded. Land degradation is supposed to influence lives of 1.5 billion people and 15 billion tons of fertile soil is lost every year due to anthropogenic activities and climate change.

9.3.6. POPULATION GROWTH: The human population on Earth is expanding rapidly, which together with even more rapid economic growth is the main cause of the degradation of the environment. Humanity's appetite for resources is disrupting the environment's natural equilibrium. Production industries are venting smoke into the atmosphere and discharging chemicals that are polluting water resources. The smoke includes detrimental gases such as carbon monoxide and Sulphur dioxide. The high levels of pollution in the atmosphere form layers that are eventually absorbed into the atmosphere. Organic compounds such as chlorofluorocarbons (CFCs) have generated an opening in the ozone layer, which admits higher levels of ultraviolet radiation, putting the globe at risk.

The available fresh water being affected by the climate is also being stretched across an ever-increasing global population. It is estimated that almost a quarter of the global population is living in an area that is using more than 20% of their renewable water supply; water use will rise with population while the water supply is also being aggravated by decreases in streamflow and groundwater caused by climate change. Even though some areas may see an increase in freshwater supply from an uneven distribution of precipitation increase, an increased use of water supply is expected.

An increased population means increased withdrawals from the water supply for domestic, agricultural, and industrial uses, the largest of these being agriculture, believed to be the major non-climate driver of environmental change and water deterioration. The next 50 years will likely be the last period of rapid agricultural expansion, but the larger and wealthier population over this time will demand more agriculture.

Population increase over the last two decades, at least in the United States, has also been accompanied by a shift to an increase in urban areas from rural areas, which concentrates the demand for water into certain areas, and puts stress on the fresh water supply from industrial and human contaminants. Urbanization causes overcrowding and increasingly unsanitary living conditions, especially in developing countries, which in turn exposes an increasingly number of people to disease. About 79% of the world's population is in developing countries, which lack access to sanitary water and sewer systems, giving rises to disease and deaths from contaminated water and increased numbers of disease-carrying insects.

9.3.7. WATER MANAGEMENT: Water management is the process of planning, developing, and managing water resources across all water applications, in terms of both quantity and quality." Water management is supported and guided by institutions, infrastructure, incentives, and information systems.

The issue of the depletion of fresh water has stimulated increased efforts in water management. While water management systems are often flexible, adaptation to new hydrologic conditions may be very costly. Preventative approaches are necessary to avoid high costs of inefficiency and the need for rehabilitation of water supplies, and innovations to decrease overall demand may be important in planning water sustainability.

Water supply systems, as they exist now, were based on the assumptions of the current climate, and built to accommodate existing river flows and flood frequencies. Reservoirs are operated based on past hydrologic records, and irrigation systems on historical temperature, water availability, and crop water requirements; these may not be a reliable guide to the future. Re-examining engineering designs, operations, optimizations, and planning, as well as re-evaluating legal, technical, and economic approaches to manage water resources are very important for the future of water management in response to water degradation. Another approach is water privatization; despite its economic and cultural effects, service quality and overall quality of the water can be more easily controlled and distributed. Rationality and sustainability is appropriate, and requires limits to overexploitation and pollution and efforts in conservation.

9.3.8. CONSUMPTION INCREASES: As the world's population continues to grow larger by the minute, the demand for natural resources increases as well. With the need for more production of increases comes more damage to the environments and ecosystems those resources are housed in. According to United Nations' population growth predictions, there could be up to 170 million more births by the year 2070. The need for more fuel, energy, food, buildings, and water sources grows with the number of people on the planet.

9.3.9. DEFORESTATION: As the need for new agricultural areas and road construction increases, the deforestation processes stay in affect. Deforestation is the "removal of forest or stand of trees from land that is converted to non-forest use.” Since the 1960s close to 50% of tropical forests have been destroyed, but this process is not limited to tropical forest areas. Europe's forests are also destroyed by a number of factors; livestock, insects, diseases, invasive species, and other human activities. A large number of the world's terrestrial biodiversity can be found living in the different types of forests. Tearing down these areas for increased consumption directly decreases the world's biodiversity of plant and animal species native to those areas. Along with the destruction of habitats and ecosystems, the decrease of the world's forest contributes to the amount of CO2 in the atmosphere. By taking away forested areas, we are limiting the amount of carbon reservoirs, limiting it to the largest ones; the atmosphere and oceans. While one of the biggest reasons for deforestation is for agriculture use for the world's food supply, removing trees from landscapes also increases erosion rates in areas, making it harder to produce crops in those soil types.

9.4. ENVIRONMENTAL EFFECT OF THERMAL POWER STATION:

The environmental impact of energy use has received considerable attention. Energy generation and conversion are closely related to various environmental problems such as air pollution, climate change, waste disposal, habitat destruction of species, and forest damage. Given that climate change has emerged as a major global issue, it is important to holistically understand the interrelationship between energy and the environment.

In recent years, numerous countries have promoted electricity generation using renewable sources. On the other hand, traditional coal-fired power plants have been identified as the major cause of environmental problems, especially air pollution. Coal fired power plants not only emit many air pollutants during the mining, transport, storage, and combustion of coal but also adversely affect groundwater, soil, and marine ecosystems. Therefore, from the perspective of environmental sustainability, it is necessary to reduce electricity generation from and prohibit any new construction of coal-fired power plants. However, there are advantageous as they generate electricity at low costs. In 2021, the share of coal in global electricity generation was 36%, which was the highest among all sources, although this share is expected to decrease in the long-run. Moreover, a number of countries marked a return to coal-fired power in 2022 during the economic recovery from COVID-19 and as concerns rise about high natural gas prices and energy security. Therefore, reducing the environmental impacts of existing coal-fired power plants is urgently important.

The literature on air pollution from coal-fired power plants has mainly focused on air pollutants that are emitted during combustion and those that remain after combustion (coal ash or fly ash). However, it should be noted that coal use can adversely affect public health and the environment at all stages. A significant amount of air pollution is generated during the storage and handling of coal, especially from the wind blowing over uncovered coal stockpiles. In fact, in most coal-fired power plants, vast amounts of coal stockpiles are placed in open air, where a significant amount of fugitive dust is produced and emitted. Therefore, it is necessary not only to reduce the pollutants emitted during or after the combustion of coal, but also to decrease the fugitive dust emitted during the transportation and storage of coal.

The coal stockpile of a coal fired power plant can be located either outdoors or indoors. Outdoor coal storage requires a larger area and leads to a considerable amount of fugitive dust emissions, but it has the advantage of lower cost of construction and operation. On the other hand, an indoor coal storage, such as a shed, silo, or dome, has lower fugitive dust emissions and effective drainage control. Therefore, some countries are encouraging the use of indoor coal storage. Indoor or underground coal storages have already been in operation in a few countries, such as Japan, Germany, South Korea, and Finland. It is the most effective method for reducing fugitive dust from a coal stockpile. Among the different methods to reduce fugitive dust in mines and coal yards, the reduction efficiency of an indoor structure is 99% to 100% . In principle, the construction of an indoor coal storage is justified only when the environmental benefits of reducing fugitive dust emissions are considered.

However, the construction of an indoor coal storage is expensive. Depending on the size and form of the structure, it can cost several hundred billion Korean Won (KRW) (about several hundred million USD). Therefore, it is important to understand the economic feasibility of the project, as public money is utilized to construct these indoor coal storages.

Against this background, the main purpose of this study is to estimate the economic benefits and calculate the economic feasibility of an indoor coal storage in coal-fired power plants. The reduction of coal fugitive dust is an environmental non-market good. Therefore, to elicit its monetary value, the public's willingness to pay (WTP) is estimated and determinants of the WTP are identified. To this end, the contingent valuation method (CVM) is used for collecting and analyzing the statement preference (SP) data for indoor coal storage. Additionally, based on the derived WTP, a simple cost–benefit analysis is conducted for the six planned indoor coal storages in South Korea.

9.5. ENVIRONMENTAL EFFECT OF NUCLEAR POWER STATION:

Nuclear power is the use of nuclear reactions to produce electricity. Nuclear power can be obtained from nuclear fission, nuclear decay and nuclear fusion reactions. Presently, the vast majority of electricity from nuclear power is produced by nuclear fission of uranium and plutonium in nuclear power plants. Nuclear decay processes are used in niche applications such as radioisotope thermoelectric generators in some space probes such as Voyager 2. Generating electricity from fusion power remains the focus of international research.

Nuclear power has various environmental impacts, both positive and negative, including the construction and operation of the plant, the nuclear fuel cycle, and the effects of nuclear accidents. Nuclear power plants do not burn fossil fuels and so do not directly emit carbon dioxide. The carbon dioxide emitted during mining, enrichment, fabrication and transport of fuel is small when compared with the carbon dioxide emitted by fossil fuels of similar energy yield, however, these plants still produce other environmentally damaging wastes. Nuclear energy and renewable energy have reduced environmental costs by decreasing CO2 emissions resulting from energy consumption.

There is a catastrophic risk potential if containment fails, which in nuclear reactors can be brought about by overheated fuels melting and releasing large quantities of fission products into the environment. In normal operation, nuclear power plants release less radioactive material than coal power plants whose fly ash contains significant amounts of thorium, uranium and their daughter nuclides.

A large nuclear power plant may reject waste heat to a natural body of water; this can result in undesirable increase of the water temperature with adverse effect on aquatic life. Alternatives include cooling towers. As most commercial nuclear power plants are incapable of online refueling and need periodic shutdowns to exchange spent fuel elements for fresh fuel, many operators schedule this unavoidable downtime for the peak of summer when rivers tend to run lower and the issue of waste heat potentially harming the fluvial environment is most acute.

Mining of uranium ore can disrupt the environment around the mine. However, with modern in-situ leaching technology this impact can be reduced compared to "classical" underground or open pit mining. Disposal of spent nuclear fuel is controversial, with many proposed long-term storage schemes under intense review and criticism. Diversion of fresh or low burnup spent fuel to weapons production presents a risk of nuclear proliferation, however all nuclear weapons states derived the material for their first nuclear weapon from (non-power) research reactors or dedicated "production reactors" and/or uranium enrichment. Finally, some parts the structure of the reactor itself becomes radioactive through neutron activation and will require decades of storage before it can be economically dismantled and in turn disposed of as waste. Measures like reducing the cobalt content in steel to decrease the amount of cobalt-60 produced by neutron capture can reduce the amount of radioactive material produced and the radiotoxicity that originates from this material. However, part of the issue is not radiological but regulatory as most countries assume any given object that originates from the "hot" (radioactive) area of a nuclear power plant or a facility in the nuclear fuel cycle is ipso facto radioactive, even if no contamination or neutron irradiation induced radioactivity is detectable

Large reservoirs associated with traditional hydroelectric power stations result in submersion of extensive areas upstream of the dams, sometimes destroying biologically rich and productive lowland and riverine valley forests, marshland and grasslands. Damming interrupts the flow of rivers and can harm local ecosystems, and building large dams and reservoirs often involves displacing people and wildlife. The loss of land is often exacerbated by habitat fragmentation of surrounding areas caused by the reservoir.

9.6. ENVIRONMENTAL EFFECT OF HYDROELECTRIC POWER PROJECT: Hydroelectric projects can be disruptive to surrounding aquatic ecosystems both upstream and downstream of the plant site. Generation of hydroelectric power changes the downstream river environment. Water exiting a turbine usually contains very little suspended sediment, which can lead to scouring of river beds and loss of riverbanks. The turbines also will kill large portions of the fauna passing through, for instance 70% of the eel passing a turbine will perish immediately. Since turbine gates are often opened intermittently, rapid or even daily fluctuations in river flow are observed.

9.7. GEOTHERMAL POWER: Geothermal power is electrical generated from geothermal energy. Technologies in use include dry steam power stations, flash steam power stations and binary cycle power stations. Geothermal electricity generation is currently used in 26 countries, while geothermal heating is in use in 70 countries.

As of 2019, worldwide geothermal power capacity amounts to 15.4 gigawatts (GW), of which 23.9% (3.68 GW) are installed in the United States. International markets grew at an average annual rate of 5 percent over the three years to 2015, and global geothermal power capacity is expected to reach 14.5–17.6 GW by 2020. Based on current geologic knowledge and technology the Geothermal energy association (GEA) publicly discloses, the GEA estimates that only 6.9% of total global potential has been tapped so far, while the IPCC reported geothermal power potential to be in the range of 35 GW to 2 TW. Countries generating more than 15 percent of their electricity from geothermal sources include EI Salvador, Kenya, the Philippines, Iceland, New Zealand, and Costa Rica. Indonesia has an estimated potential of 29 GW of geothermal energy resources, the largest in the world; in 2017, its installed capacity was 1.8 GW.

Geothermal power is considered to be a sustainable, renewable source of energy because the heat extraction is small compared with the Earth’s heat content. The greenhouse gas emissions of geothermal electric stations average 45 grams of carbon dioxide per kilowatt-hour of electricity, or less than 5% of those of conventional coal-fired plants.

As a source of renewable energy for both power and heating, geothermal has the potential to meet 3 to 5% of global demand by 2050. With economic incentives, it is estimated that by 2100 it will be possible to meet 10% of global demand with geothermal power.

The Earth's heat content is about 1×10^{19} TJ (2.8×10^{15} TWh). This heat naturally flows to the surface by conduction at a rate of 44.2 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.

Electricity generation requires high-temperature resources that can only come from deep underground. The heat must be carried to the surface by fluid circulation, either through magma conduits, hot springs, hydrothermal circulation, oil wells, drilled water wells, or a combination of these. This circulation sometimes exists naturally where the crust is thin: magma conduits bring heat close to the surface, and hot springs bring the heat to the surface. If a hot spring is not available, a well must be drilled into a hot aquifer. Away from tectonic plate boundaries the geothermal gradient is 25–30 °C per kilometer (km) of depth in most of the world, so wells would have to be several kilometers deep to permit electricity generation. The quantity and quality of recoverable resources improves with drilling depth and proximity to tectonic plate boundaries.

In ground that is hot but dry, or where water pressure is inadequate, injected fluid can stimulate production. Developers bore two holes into a candidate site, and fracture the rock between them with explosives or high pressure water. Then they pump water or liquefied carbon dioxide down one borehole, and it comes up the other borehole as a gas. This approach is called hot dry rock geothermal energy in Europe, or enhanced geothermal systems in North America. Much greater potential may be available from this approach than from conventional tapping of natural aquifers.

Estimates of the electricity generating potential of geothermal energy vary from 35 to 2000 GW depending on the scale of investments. This does not include non-electric heat recovered by co-generation, geothermal heat pumps and other direct use. A 2006 report by the Massachuesetts Institute of Technology (MIT) that included the potential of enhanced geothermal systems estimated that investing US$1 billion in research and development over 15 years would allow the creation of 100 GW of electrical generating capacity by 2050 in the United States alone. The MIT report estimated that over 200×10^{9} TJ (200 ZJ; 5.6×10^{7} TWh) would be extractable, with the potential to increase this to over 2,000 ZJ with technology improvements – sufficient to provide all the world's present energy needs for several millennia.

At present, geothermal wells are rarely more than 3 km (1.9 mi) deep. Upper estimates of geothermal resources assume wells as deep as 10 km (6.2 mi). Drilling near this depth is now possible in the petroleum industry, although it is an expensive process. The deepest research well in the world, the Kola Superdeep Borehole (KSDB-3), is 12.261 km (7.619 mi) deep. Wells drilled to depths greater than 4 km (2.5 mi) generally incur drilling costs in the tens of millions of dollars. The technological challenges are to drill wide bores at low cost and to break larger volumes of rock.

9.7.1. POWER STATION TYPES: Geothermal power stations are similar to other steam turbine thermal power stations in that heat from a fuel source (in geothermal's case, the Earth's core) is used to heat water or another working fluid. The working fluid is then used to turn a turbine of a generator, thereby producing electricity. The fluid is then cooled and returned to the heat source.

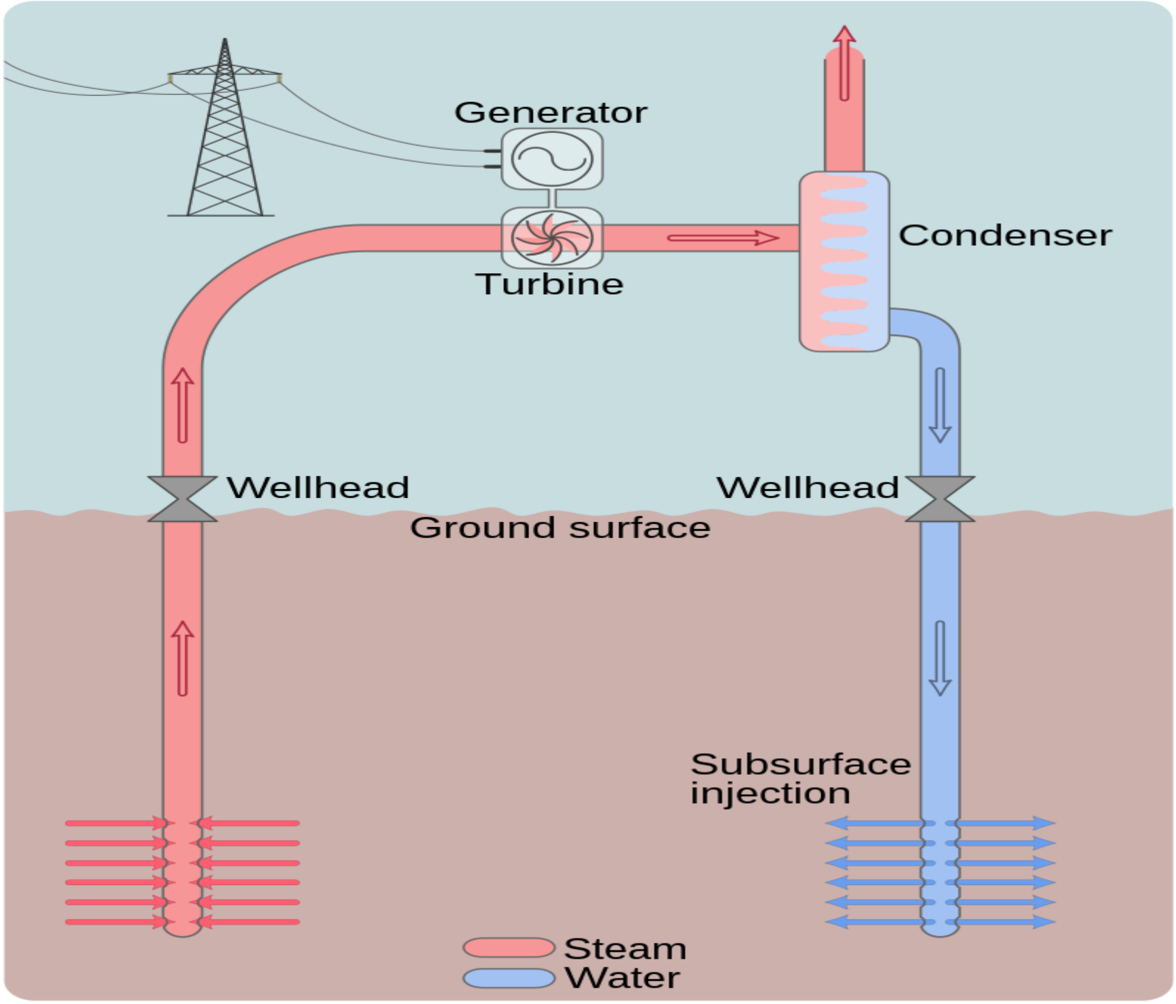

Fig. 9.1: Electricity generation in a vapor dominated hydrothermal system

Diagram 9.1 showing how electricity is generated in a vapor-dominated hydrothermal system. Steam is used directly from the wells to drive a turbine generator. Wastewater from the condenser is injected back into the subsurface to help extend the useful life of the hydrothermal system.

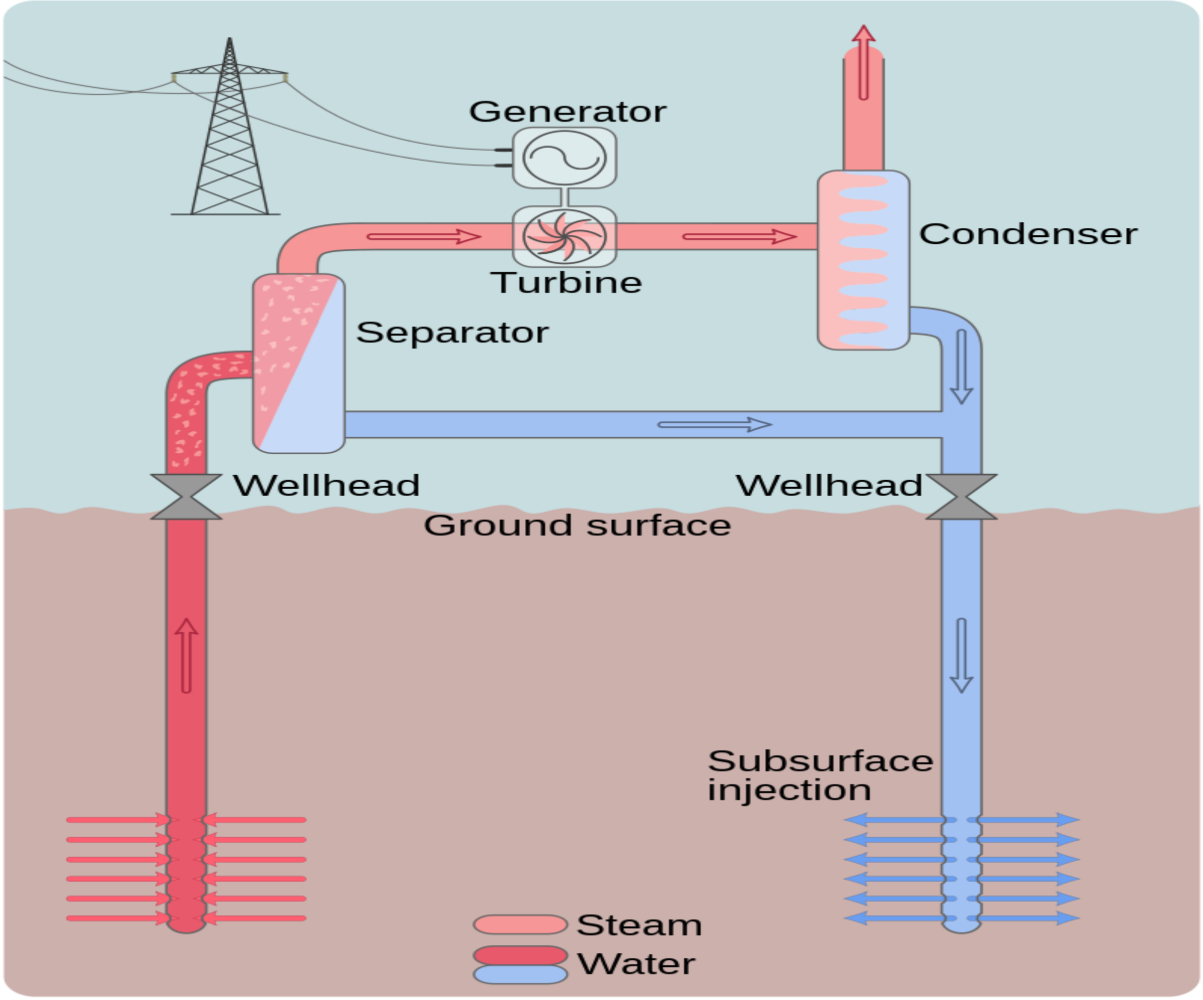

Fig. 9.2: Electricity generation from a hot water hydrothermal system

Diagram 9.2 showing how electricity is generated from a hot-water hydrothermal system. The part of the hydrothermal water that flashes to steam is separated and used to drive a turbine generator. Wastewater from separator and condenser is injected back into the subsurface to help extend the life of the hydrothermal system.

Diagram 9.3 showing how electricity is generated in a vapor-dominated hydrothermal system. Steam is used directly from the wells to drive a turbine generator. Wastewater from the condenser is injected back into the subsurface to help extend the useful life of the hydrothermal system.

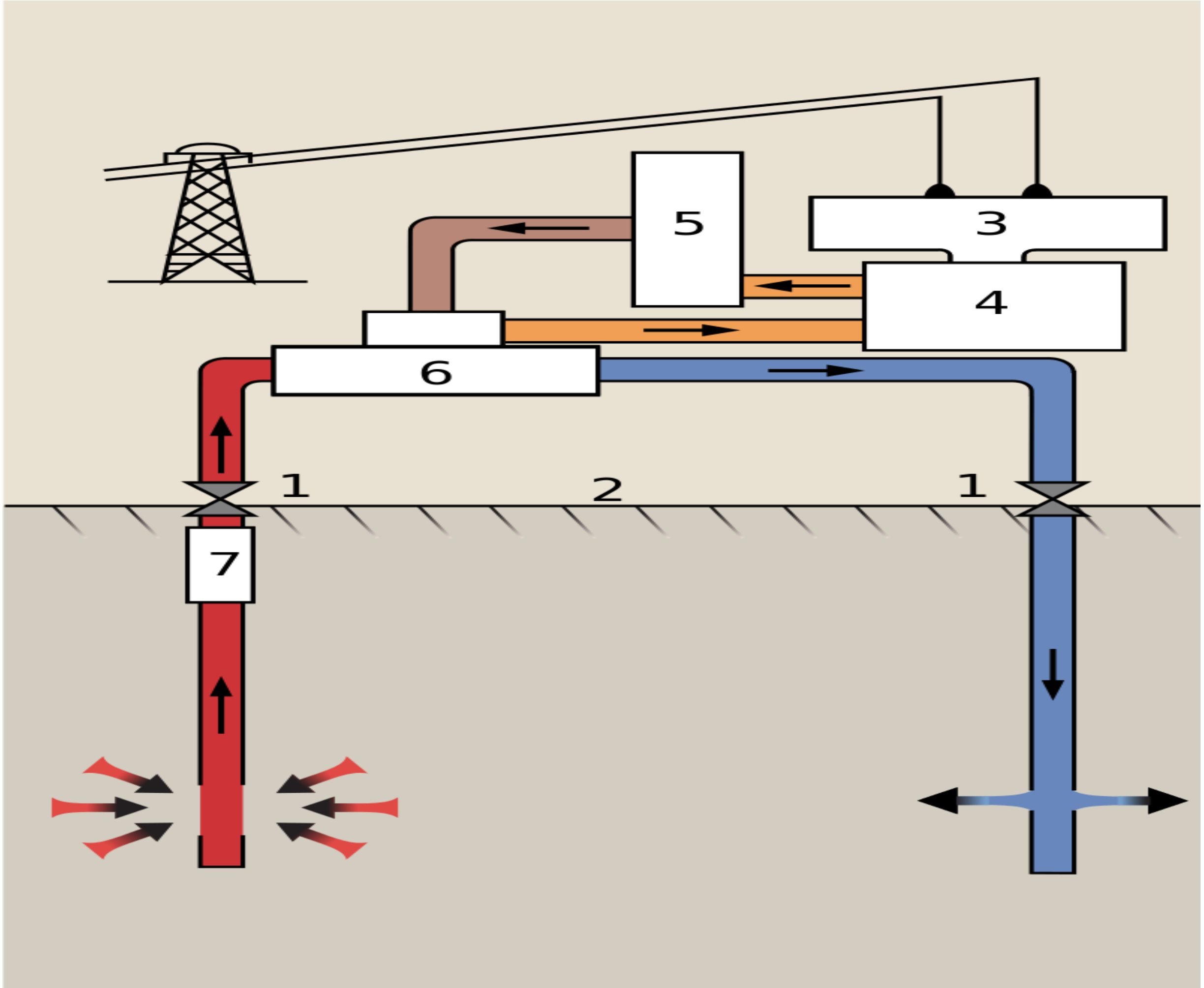

Fig. 9.3: Electricity generation in a vapor dominated hydrothermal system

9.7.1.1. DRY STEAM POWER STATIONS: Dry steam stations are the simplest and oldest design. There are few power stations of this type, because they require a resource that produces dry steam, but they are the most efficient, with the simplest facilities. At these sites, there may be liquid water present in the reservoir, but only steam, not water, is produced to the surface. Dry steam power directly uses geothermal steam of 150 °C or greater to turn turbines. As the turbine rotates it powers a generator that produces electricity and adds to the power field. Then, the steam is emitted to a condenser, where it turns back into a liquid, which then cools the water. After the water is cooled it flows down a pipe that conducts the condensate back into deep wells, where it can be reheated and produced again. At the Geysers in California, after the first 30 years of power production, the steam supply had depleted and generation was substantially reduced. To restore some of the former capacity, supplemental water injection was developed during the 1990s and 2000s, including utilization of effluent from nearby municipal sewage treatment facilities.

9.7.1.2. FLASH STEAM POWER STATIONS: Flash steam stations pull deep, high-pressure hot water into lower-pressure tanks and use the resulting flashed steam to drive turbines. They require fluid temperatures of at least 180 °C, usually more. This is the most common type of station in operation today Flash steam plants use geothermal reservoirs of water with temperatures greater than 360 °F (182 °C). The hot water flows up through wells in the ground under its own pressure. As it flows upward, the pressure decreases and some of the hot water is transformed into steam. The steam is then separated from the water and used to power a turbine/generator. Any leftover water and condensed steam may be injected back into the reservoir, making this a potentially sustainable resource.

9.7.1.3. BINARY CYCLE POWER STATIONS: Binary cycle power stations are the most recent development, and can accept fluid temperatures as low as 57 °C. The moderately hot geothermal water is passed by a secondary fluid with a much lower boiling point than water. This causes the secondary fluid to flash vaporize, which then drives the turbines. This is the most common type of geothermal electricity station being constructed today. Both Organic Rankine and Kalina cycles are used. The thermal efficiency of this type of station is typically about 10–13%. Binary cycle power plants have an average unit capacity of 6.3 MW, 30.4 MW at single-flash power plants, 37.4 MW at double-flash plants, and 45.4 MW at power plants working on superheated steam

9.7.2. ENVIRONMENTAL IMPACT: Existing geothermal electric stations, that fall within the 50th percentile of all total life cycle emissions studies reviewed by the IPCC, produce on average 45 kg of CO_2 equivalent emissions per megawatt-hour of generated electricity (kg CO_2eq/MW·h). For comparison, a coal-fired power plant emits 1,001 kg of CO_2 equivalent per megawatt-hour when not coupled with carbon capture and storage (CCS). As many geothermal projects are situated in volcanically active areas that naturally emit greenhouse gases, it is hypothesized that geothermal plants may actually decrease the rate of de-gassing by reducing the pressure on underground reservoirs.

Stations that experience high levels of acids and volatile chemicals are usually equipped with emission-control systems to reduce the exhaust. Geothermal stations can also inject these gases back into the earth as a form of carbon capture and storage, such as in New Zealand and in the CarbFix project in Iceland.

Other stations like the Kızıldere geothermal power plant, exhibit the capability to utilize geothermal fluids to process carbon dioxide gas into dry ice at two nearby plants resulting in very little environmental impact.

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

Station construction can adversely affect land stability. Subsidence has occurred in the Wairakei field in New Zealand. Enhanced geothermal systems can trigger earthquakes due to water injection. 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. The risk of geothermal drilling leading to uplift has been experienced in Staufen in Breisgau.

Geothermal has minimal land and freshwater requirements. Geothermal stations use 404 square meters per GW·h versus 3,632 and 1,335 square meters for coal facilities and wind farms respectively. They use 20 litres of freshwater per MW·h versus over 1000 litres per MW·h for nuclear, coal, or oil.

Geothermal power stations can also disrupt the natural cycles of geysers. For example, the Beowawe, Nevada geysers, which were uncapped geothermal wells, stopped erupting due to the development of the dual-flash station.

Local climate cooling is possible as a result of the work of the geothermal circulation systems. However, according to an estimation given by Leningrad Mining Institute in 1980s, possible cool-down will be negligible compared to natural climate fluctuations.

While volcanic activity produces geothermal energy, it is also risky. As of 2022 the Puna Geothermal Venture has still not returned to full capacity after the 2018 lower Puna eruption.

9.7.3. ECONOMICS: Geothermal power requires no fuel; it is therefore immune to fuel cost fluctuations. However, capital costs tend to be high. Drilling accounts for over half the costs, and exploration of deep resources entails significant risks. A typical well doublet in Nevada can support 4.5 megawatts (MW) of electricity generation and costs about $10 million to drill, with a 20% failure rate. In total, electrical station construction and well drilling costs about 2–5 million € per MW of electrical capacity, while the levelised energy cost is 0.04–0.10 € per kW·h. Enhanced geothermal systems tend to be on the high side of these ranges, with capital costs above $4 million per MW and levelized costs above $0.054 per kW·h in 2007.

Research suggests in reservoir storage could increase the economic viability of enhanced geothermal systems in energy systems with a large share of variable renewable energy sources. Geothermal power is highly scalable: a small power station can supply a rural village, though initial capital costs can be high. The most developed geothermal field is the Geysers in California. In 2008, this field supported 15 stations, all owned by Calpine, with a total generating capacity of 725 MW.

9.8. OCEAN WAVE ENERGY HARVESTING:

Ocean energy harvesting is the process of taking the kinetic, thermal, or chemical energy from the ocean and turning it into energy that can be used, like electricity. Depending on the kind of energy source you are aiming for, there are many different technologies and methods for harvesting ocean energy. Tidal energy, wave energy, ocean current energy, ocean thermal energy, and salinity gradient energy are some of the main methods used to harvest ocean energy. Let us examine the ocean energy harvesting system that is used to generate electricity, as well as its benefits and drawbacks.

Wave power harvested from ocean waves is used for a variety of purposes, such as pumping water, desalinating water, and producing and distributing electricity. Numerous nations, such as the United States, the United Kingdom, Canada, Australia, and New Zealand, are endorsing the advancement of ocean energy systems.

9.8.1. SOURCES OF HARVESTING OCEAN ENERGY: Temperature gradients, ocean currents, waves, tides, and other water movement are the main sources of energy produced by this renewable energy source. In addition to assisting in the decrease of greenhouse gas emissions and dependency on fossil fuels, ocean energy has the ability to offer a steady and dependable supply of clean energy. While wave energy includes almost 1000 times the kinetic energy of wind, ocean energy is superior to other renewable energies since it is available around the clock, every day of the year. Out of all the renewable energy sources, wave energy has the highest energy density.

There are several key technologies for harnessing ocean energy which include tidal energy, wave energy, Ocean current energy, ocean thermal energy and salinity gradient energy as described below.

1. Using Tidal Energy: The gravitational attraction of the sun and moon produces tidal energy, which is responsible for the rise and fall of the tides. Systems for capturing tidal energy include tidal lagoons, tidal stream systems, and tidal range systems. Underwater turbines are used in tidal stream systems to harness the kinetic energy of flowing water. In contrast, tidal range systems use the height differential between high and low tides to produce energy. Creating artificial lagoons to catch and release water when the tides change is known as a tidal lagoon system.

2. Using Wave Energy: Wave Energy is generated by movement of surface of the ocean waves back/forth and up/down. This energy is captured and converted to electrical power. This wave energy has capability to provide 10% of energy need of the entire world. Various technologies, such as point absorbers, oscillating water columns, and attenuators, are used to capture the energy from waves. These devices typically involve the movement of buoyant structures that drive generators as they move with the waves.

3. Using Ocean Current Energy: It is possible to harness ocean currents, like the Gulf Stream, to produce electricity. Underwater turbines and other devices are positioned in these currents to harvest the kinetic energy of the flowing water.

4. Using Ocean Thermal Energy: Ocean thermal energy takes advantage of the temperature difference that exists between the warm surface water and the cold deep water of the ocean. This temperature gradient has the potential to power a heat engine; these engines are often closed-loop devices with ammonia as the working fluid.

5. Using Salinity Gradient Energy: This technology, which is sometimes referred to as blue energy or osmotic power, uses the difference in salt content between freshwater and saltwater to produce electricity. Among the techniques used for this are membrane-based procedures and pressure-retarded osmosis (PRO).

According to ongoing research and experimentation in this field, additional methods for harvesting ocean wave energy include offshore wind energy, hydrokinetic energy, vortex induced vibrations, bioenergy from marine organisms, piezoelectric materials, hydraulic energy storage, hydrothermal vent energy, biomechanical energy, wave reflectors, underwater kites, and so forth.

9.9. WIND ENERGY HARVESTING: Wind energy is a form of solar energy. Earth’s atmosphere is unevenly heated by solar radiation and the air is in constant motion to find equilibrium. Air is easily affected by pressure and temperature so methods of heat transfer such as convection, conduction, radiation, and advection relieve the temperature imbalances and are driving forces for wind. Wind is an intermittent source of energy with many factors affecting wind flow patterns, such as geological features of Earth’s surface, bodies of water, vegetation, and the Earth’s rotation.1 Wind is harvested through wind turbines, which generate electricity by converting the kinetic energy of the wind into mechanical energy.

Electricity generation from renewable energy (RE) technologies such as solar, wind, hydro, biomass and geothermal offers sustainable energy sources of energy, and mitigates against detrimental environmental issues such as global warming and climate change. RE also has economic importance, as the economy benefits from reduced cost of electricity generation, with RE generation derived from natural, renewable resources. According to the International Energy Agency (IEA) and their global energy review in 2021, the total renewable energy usage has shown a significant increase, from 4098 TWh in 2010 to 7627 TWh in 2020. Whereas hydropower contributes the largest portion of renewable energy capacity around the world for electricity generation, wind energy generation also shows a significant increasing trend. The 2021 International Renewable Energy Agency (IRENA) report presents the economics for renewable energy in 2021. The report indicates that global weighted average levelized cost of energy (LCOE) of new onshore wind projects added in 2021 fell by 15%, year-on-year (to USD 0.033/kWh), whereas the cost of electricity for new onshore wind projects, excluding China, fell by a more modest 12% year-on-year to USD 0.037/kWh. The offshore wind market, saw unprecedented expansion in 2021 (21 GW added), as China increased its new capacity additions and the global weighted average cost of electricity fell by 13% year-on-year (to USD 0.075/kWh). If these figures are considered over a ten-year period, the LCOE has actually dropped by 68% and 60%, respectively, for onshore and offshore wind energy.

Wind energy harvesting for electricity generation, which was first introduced in 1970, has gained large popularity as the world moves to a carbon neutral renewable energy focus. Wind energy has a significant role in overcoming the challenges associated with fossil fuel depletion and environmental concerns it creates, as well as the ever-rising energy demand owing to population growth, economic growth, urbanization, lifestyle changes, and technological development .It is abundant, extensively distributed, and ecofriendly. As explained by Aun et al. the majority of wind energy capture opportunities are situated onshore. However, there is significant growth in offshore wind energy capacity, especially in Europe with turbine capacity growing at a constant rate of 16% since 2016. The location selection for wind turbines depends on the localized wind resource, which should be sufficient to generate the estimated power. For example, widespread land with high elevation or seashore is ideal for onshore wind energy harvesting. The wind power market, which is resilient and cost-competitive, has quadrupled in the last decade. According to the wind energy report by the Global Wind Energy Council (GWEC) in 2021, newly added wind energy capacity exceeded 93 GW (onshore 86.9 GW and offshore 6.1 GW) which is a 53% year-over-year increase compared to 2019 and it sums the global cumulative wind power capacity to 743 GW. Global wind power capacity statistics in 2021, reported by GWEC.. Wind energy, perceived to be a socio-economically and environmentally viable source of energy, is forecasted to contribute 22% of the global electrical energy by 2030.

Wind speed is subject to complex seasonal and stochastic characteristics. Variability in wind speed directly affects the wind power, resulting in unsteady power generation, which affects the power grid with voltage and frequency fluctuations. This causes a significant challenge in the integration of wind power into the grid and may lead to system failures and performance degradation, which incur additional operation and maintenance costs

Another issue, and particularly important in the context of grid integration, is that wind energy sources behave quite differently from conventional, synchronous generators. Synchronous generators have mechanical inertia and are therefore capable of storing kinetic energy in their rotating mass and these machines are directly linked with the network. Therefore, during disturbances, energy is inherently exchanged with the system, which makes the network less prone to frequency fluctuations in case of an imbalance between generation and demand. In general, renewable or asynchronous generation units (e.g., photovoltaic solar and wind power), on the other hand, are equipped with power electronic converters, which decouple the generators from the grid and as such provide no inertia to the system, leading to the reduction, and even in some cases a shortage, of system strength and inertia. As discussed by Eggleston et al., lower levels of available 'system strength', contribute to inverter instabilities affecting fault ride through (FRT) performance, inverter interactions and general issues with voltage control and power quality. Moreover, reduced levels of synchronous inertia, which affects the rate-of-change-of-frequency (ROCOF) that can be experienced, particularly after large contingency events.

The performance of wind turbines relies on many parameters, which need to be controlled for better performance. In the operation of wind turbines, system optimization is required to achieve objectives such as power maximization, energy cost minimization, and system safety. Maximum power point tracking control is used for high efficiency and pitch control facilitates power and load control for optimal operation of the wind turbines. Variable-speed wind turbines are commonly used and are generally more efficient with maximum power point tracking control. Further, the maximum power point tracker (MPPT) controls the restoring torque of the electrical generator for optimum system operation.

In consideration of wind turbine installations, and before a wind turbine is installed, the most appropriate location needs to be determined. The major objective of the siting process is to locate a wind turbine (or turbines) such that net revenue is maximized while minimizing noise pollution, environmental and visual impacts, and overall cost of energy. The scope of this process can have

a very wide range, which could include everything from wind prospecting for suitable turbine sites over a wide geographical area to considering the placement of a single wind turbine on a site or of multiple wind turbines in a wind farm; this is generally called micro-siting. Software tools assist in the micro-siting process with optimization algorithms maximizing annual energy production while minimizing the cost of energy generation and considering environmental and social issues.
Most hybrid systems, or systems that involve more than one energy producer and which may include storage options, are stand-alone systems, which operate “off-grid” or not connected to an electricity distribution system. The battery bank or engine generator is used to fulfill the demand as wind and solar generations change continuously. In a hybrid system, component size needs to be optimized for minimizing the cost of energy generation to fulfill demand with resource availability.

9.9.1. WIND ENERGY HARVESTING TECHNOLOGY: Today’s wind-harvesting technology includes blades connected to a rotor, a gear box, a braking system, a turbine, and a generator. A nacelle is the compartment that houses the generating components of the wind turbine. Illustrated in Figure, the rotor connects the blades to a shaft within the nacelle, which connects to a generator. The blades are aerodynamically designed to create a lifting force as the wind flows towards the turbine, which causes the rotor to spin. The rotational speed of the turning blades is not fast enough to generate electricity, so a gear box is needed to increase the rotational speed of the shaft. The U.S. Department of Energy defines the gear box as connecting the “low speed shaft to the high-speed shaft and increases the rotational speeds from about 30-60 rotations per minute (rpm), to about 1,000-1,800 rpm; this is the rotational speed required by most generators to produce electricity”.2 An anemometer and wind vane connected to the top of the wind turbine measure wind speed and direction to send signals to a yaw and pitch system. These mechanisms ensure that the wind turbine is facing the incoming wind flow (yaw) and the blades are tilted enough (pitch) to cause efficient lift force from the wind. Additionally, if the wind speed becomes too turbulent, the anemometer sends a signal to the braking system to prevent damage to the rotor, gear box, and generator. Generally, you will find wind turbines grouped together to form a wind farm. They can generate bulk electrical power and can be sized to the site, application, and energy needs.

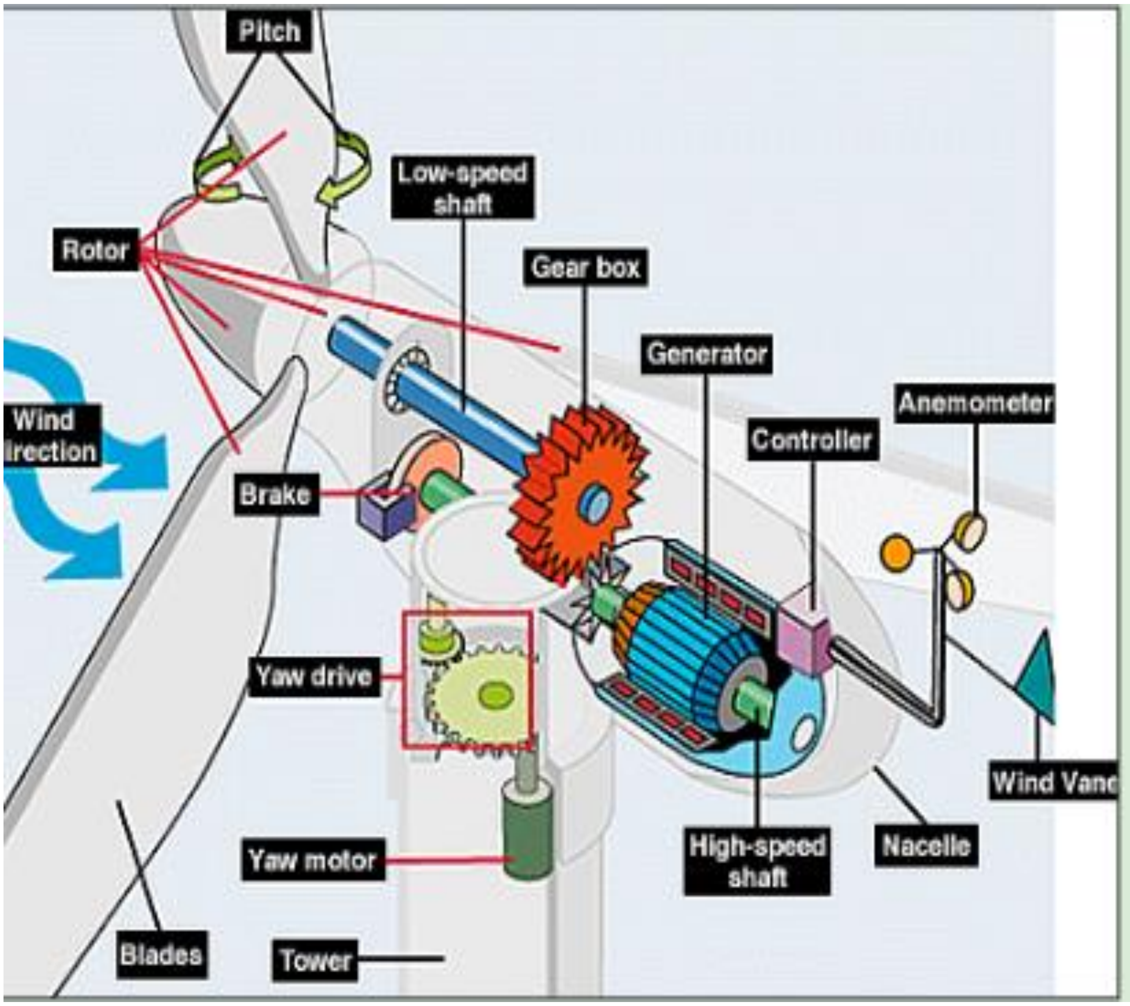

Fig. 9.4: Wind Turbine

WORKING OF WIND TURBINE: A wind turbine turns wind energy into electricity using the aerodynamic force from the rotor blades, which work like an airplane wing or helicopter rotor blade. When wind flows across the blade, the air pressure on one side of the blade decreases. The difference in air pressure across the two sides of the blade creates both lift and drag. The force of the lift is stronger than the drag and this causes the rotor to spin. The rotor connects to the generator, either directly (if it's a direct drive turbine) or through a shaft and a series of gears (a gearbox) that speed up the rotation and allow for a physically smaller generator. This translation of aerodynamic force to rotation of a generator creates electricity.

WORKING OF WIND PLANT: Wind power plants produce electricity by having an array of wind turbines in the same location. The placement of a wind power plant is impacted by factors such as wind conditions, the surrounding terrain, access to electric transmission, and other siting considerations. In a utility-scale wind plant, each turbine generates electricity which runs to a substation where it then transfers to the grid where it powers our communities.

TRANSMISSION: Transmission lines carry electricity at high voltages over long distances from wind turbines and other energy generators to areas where that energy is needed.

TRANSFORMERS: Transformers receive AC (alternating current) electricity at one voltage and increase or decrease the voltage to deliver the electricity as needed. A wind power plant will use a step-up transformer to increase the voltage (thus reducing the required current), which decreases the power losses that happen when transmitting large amounts of current over long distances with transmission lines. When electricity reaches a community, transformers reduce the voltage to make it safe and useable by buildings and homes in that community.

SUBSTATION: A substation links the transmission system to the distribution system that delivers electricity to the community. Within the substation, transformers convert electricity from high voltages to lower voltages which can then be delivered safely to electricity consumers.

WIND TURBINE TOWER: Made from tubular steel, the tower supports the structure of the turbine. Towers usually come in three sections and are assembled on-site. Because wind speed increases with height, taller towers enable turbines to capture more energy and generate more electricity. Winds at elevations of 30 meters (roughly 100 feet) or higher are also less turbulent.

WIND DIRECTION: Determines the design of the turbine. Upwind turbines like the one shown here face into the wind while downwind turbines face away. Most utility-scale land-based wind turbines are upwind turbines.

WIND VANE: The wind vane measures wind direction and communicates with the yaw drive to orient the turbine properly with respect to the wind.

ANEMOMETER: The anemometer measures wind speed and transmits wind speed data to the controller.

BLADES: Most turbines have three blades which are made mostly of fiberglass. Turbine blades vary in size, but a typical modern land-based wind turbine has blades of over 170 feet (52 meters). The largest turbine is GE's Haliade-X offshore wind turbine, with blades 351 feet long (107 meters) about the same length as a football field. When wind flows across the blade, the air pressure on one side of the blade decreases. The difference in air pressure across the two sides of the blade creates both lift and drag. The force of the lift is stronger than the drag and this causes the rotor to spin.

NACELLE: The nacelle sits atop the tower and contains the gearbox, low and high speed shafts, generator, and brake. Some nacelles are larger than a house and for a 1.5 MW geared turbine, can weigh more than 4.5 tons.

YAW SYSTEM: The yaw drive rotates the nacelle on upwind turbines to keep them facing the wind when wind direction changes. The yaw motors power the yaw drive to make this happen. Downwind turbines don’t require a yaw drive because the wind manually blows the rotor away from it.

PITCH SYSTEM: The pitch system adjusts the angle of the wind turbine's blades with respect to the wind, controlling the rotor speed. By adjusting the angle of a turbine's blades, the pitch system controls how much energy the blades can extract. The pitch system can also "feather" the blades, adjusting their angle so they do not produce force that would cause the rotor to spin. Feathering the blades slows the turbine's rotor to prevent damage to the machine when wind speeds are too high for safe operation.

HUB: Part of the turbine's drivetrain, turbine blades fit into the hub that is connected to the turbine's main shaft.

GEARBOX: The drivetrain is comprised of the rotor, main bearing, main shaft, gearbox, and generator. The drivetrain converts the low-speed, high-torque rotation of the turbine's rotor (blades and hub assembly) into electrical energy.

ROTOR: The blades and hub together form the turbine's rotor.

LOW SPEED SHAFT: Part of the turbine's drivetrain, the low-speed shaft is connected to the rotor and spins between 8–20 rotations per minute.

MAIN SHAFT BEARING: Part of the turbine's drivetrain, the main bearing supports the rotating low-speed shaft and reduces friction between moving parts so that the forces from the rotor don't damage the shaft.

HIGH SPEED SHAFT: Part of the turbine's drivetrain, the high-speed shaft connects to the gearbox and drives the generator.

GENERATOR: The generator is driven by the high-speed shaft. Copper windings turn through a magnetic field in the generator to produce electricity. Some generators are driven by gearboxes (shown here) and others are direct-drives where the rotor attaches directly to the generator.

CONTROLLER: The controller allows the machine to start at wind speeds of about 7–11 miles per hour (mph) and shuts off the machine when wind speeds exceed 55–65 mph. The controller turns off the turbine at higher wind speeds to avoid damage to different parts of the turbine. Think of the controller as the nervous system of the turbine.

BRAKE: Turbine brakes are not like brakes in a car. A turbine brake keeps the rotor from turning after it's been shut down by the pitch system. Once the turbine blades are stopped by the controller, the brake keeps the turbine blades from moving, which is necessary for maintenance.

9.10. SOLAR ENERGY HARVESTING: Solar energy harvesting is most commonly associated with the solar panels you see sitting on residential rooftops. However, the commercialized adoption of solar energy harvesting spans a variety of applications that provide astounding amounts of energy to the world. Let's look at five innovative solar energy harvesting technologies.

9.10.1. PHOTOVOLTAIC SOLAR PANELS: Photovoltaic (PV) solar panels use the sun's power to create a flow of electricity. This is the most widely adopted method of harvesting solar energy today. These panels, which range in size from a few square centimeters to a few square meters, are constructed from many PV cells arranged in an intricate matrix. Intuitively, the larger the surface area available for sunlight to penetrate the PV cells, the more solar energy that gets harvested.

Each PV solar cell is generally made up of a compound semiconductor wafer structure, which can either be a monocrystalline or polycrystalline structure. The structure's two thin semiconductor wafers, one P-type and one N-type, are each grown separately. The two wafers are placed on top of each other, and the natural reaction that occurs between the two semiconductor types creates a depletion zone that reaches an equilibrium point, without generating any electricity. Due to the PV cell, when light photons pass through and connect with the semiconductor wafers, their interaction releases enough energy to create an equilibrium disruption in the depletion region. That action subsequently creates a brief flow of electricity. However, because of the constant presence of light, this interaction occurs continuously and can produce massive amounts of electrical energy.

The power produced by a single photon interaction replicates across the entire surface of the PV cell. It's compounded into a whole panel of solar cells and then into a vast PV panel array. This minor interaction in the depletion zone can be repeated and multiplied, resulting in a significant amount of electricity. PV solar arrays, however, produce DC power. To be integrated with modern power transmission technology, such as the outlets in your home, this DC energy must be converted to AC power using an inverter. There are a variety of proprietary iterations of this fundamental technology that seek to optimize the efficiency of each PV cell on a molecular level, the assembly of the panel, and the panel's ability to be integrated into a larger solar array.

9.10.2. THERMAL ENERGY HARVESTING: ENERGY OF ELECTROMAGNETIC RADIATION:

The sun produces a broad spectrum of radiation of many different wavelengths, including infrared. This spectrum efficiently transfers thermal energy to bodies that can absorb it. Elements that can effectively absorb this thermal electromagnetic energy are referred to as 'black bodies,' as the color black absorbs all wavelengths of radiation that are visible to the human eye. An ideal black body can correctly absorb, and emit, all wavelengths of the electromagnetic radiation spectrum.

Electromagnetic radiation has long been used for heating in many passive heating systems, such as the egg cooking example, in Roman bathhouses and Ancient Egyptian homes, and modern solutions such as thermal solar panels and thermosiphons. These thermal solar energy harvesting strategies rely heavily on black body radiation physics and their ability to absorb and transfer electromagnetic radiation. On a residential level, thermal energy is gathered most often for use in water heating systems. However, these solutions are less suitable for energy generation on an industrial scale.

9.10.3. SOLAR WATER HEATERS: A great example of a thermal solar energy harvesting application that's commonly implemented in sunny climates around the globe is a solar water heater. The simplest version of a solar water heater system uses a pump to circulate cool water through a black body panel. This visually resembles a PV solar panel, where the black surface efficiently absorbs thermal energy, which is then cooled by the circulated water, thereby heating the water. The water is continually circulated through this loop, creating warm water throughout the solar activity. Some systems can forgo a pump system by utilizing the buoyancy created by the heated water. This warmer water 'floats' and the colder water sinks, producing low amounts of flow in the system, creating a thermosiphon. These systems require the storage tank to be above the solar absorption source, as shown here.

9.10.4. VACUUM TUBE SOLAR WATER HEATER: More advanced and efficient solar water heating systems utilize vacuum tubes and self-contained heat pipes to transfer thermal energy to a secondary tank. The vacuum tube ensures that radiant energy can enter the system, but all energy that gets turned into thermal energy is contained in the tube. The heat pipe absorbs this energy and subsequently transfers it to the large water tank. These systems are significantly more efficient at heating water during cold months, as minimal amounts of thermal energy escape the vacuum tube, allowing nearly all radiant energy to be converted into thermal energy.

9.10.5. MOLTEN SALT SOLAR POWER: Relatively recent breakthroughs in molten salt systems are pushing the boundaries of power generation using solar energy. However, much like the previously discussed solar-powered water heating systems, molten salt power plants utilize electromagnetic radiation to melt salt. This molten salt then gets transferred to a heat exchanger, which heats water into steam that is then driven through a steam turbine to generate electricity. Molten salt power plants, such as the Ivana Solar Plant, rely on an extensive network of heliostat mirrors to redirect sunlight to a single point, most often referred to as a power tower or central tower. This tower collects the energy from all surrounding heliostats, which is enough power to melt the salt at nearly 1500°F. This molten salt is then stored in insulated tanks, allowing for the energy to be used even when the sun is no longer shining.

9.10.6. THE FUTURE OF HARVESTING SOLAR ENERGY: Solar energy harvesting technology is increasingly utilized as an alternative to electricity generated by fossil fuel. While various methods of solar energy harvesting exist, they all fundamentally use the sun to perform work in a specifically desired way, something we traditionally rely on electricity to do. Increases in efficiencies and process optimizations will continue to unveil the productivity of solar harvesting efforts into the future and may eliminate the need for fossil fuel use altogether.

9.11. BIOENERGY: Biomass is a versatile renewable energy source. It can be converted into liquid transportation fuels that are equivalent to fossil-based fuels, such as gasoline, jet, and diesel fuel. Bioenergy technologies enable the reuse of carbon from biomass and waste streams into reduced-emissions fuels for cars, trucks, jets and ships; bio products; and renewable power. Biomass is one type of renewable resource that can be converted into liquid fuels—known as biofuels for transportation. Biofuels include cellulosic ethanol, biodiesel, and renewable hydrocarbon "drop in" fuels. The two most common types of biofuels in use today are ethanol and biodiesel. Biofuels can be used in airplanes and most vehicles that are on the road. Renewable transportation fuels that are functionally equivalent to petroleum fuels lower the carbon intensity of our vehicles and airplanes. Bio power technologies convert renewable biomass fuels into heat and electricity using processes like those used with fossil fuels. There are three ways to harvest the energy stored in biomass to produce bio power: burning, bacterial decay, and conversion to a gas or liquid fuel. Bio power can offset the need for carbon fuels burned in power plants, thus lowering the carbon intensity of electricity generation. Unlike some forms of intermittent renewable energy, bio power can increase the flexibility of electricity generation and enhance the reliability of the electric grid.

Bioenergy is one of many diverse resources available to help meet our demand for energy. It is a form of renewable energy that is derived from recently living organic materials known as biomass, which can be used to produce transportation fuels, heat, electricity, and products.

Biomass resources that are available on a renewable basis and are used either directly as a fuel or converted to another form or energy product are commonly referred to as “feedstocks.”

9.11.1. BIOMASS FEEDSTOCKS: Biomass feedstocks include dedicated energy crops, agricultural crop residues, forestry residues, algae, wood processing residues, municipal waste, and wet waste (crop wastes, forest residues, purpose-grown grasses, woody energy crops, algae, industrial wastes, sorted municipal solid waste [MSW], urban wood waste, and food waste).

9.11.2. DEDICATED ENERGY CROPS: Dedicated energy crops are non-food crops that can be grown on marginal land (land not suitable for traditional crops like corn and soybeans) specifically to provide biomass. These break down into two general categories: herbaceous and woody. Herbaceous energy crops are perennial (plants that live for more than 2 years) grasses that are harvested annually after taking 2 to 3 years to reach full productivity. These include switchgrass, miscanthus, bamboo, sweet sorghum, tall fescue, kochia, wheatgrass, and others. Short-rotation woody crops are fast-growing hardwood trees that are harvested within 5 to 8 years of planting. These include hybrid poplar, hybrid willow, silver maple, eastern cottonwood, green ash, black walnut, sweetgum, and sycamore. Many of these species can help improve water and soil quality, improve wildlife habitat relative to annual crops, diversify sources of income, and improve overall farm productivity.

9.11.3. AGRICULTURAL CROP RESIDUE: There are many opportunities to leverage agricultural resources on existing lands without interfering with the production of food, feed, fiber, or forest products. Agricultural crop residues, which include the stalks and leaves, are abundant, diverse, and widely distributed across the United States. Examples include corn Stover (stalks, leaves, husks, and cobs), wheat straw, oat straw, barley straw, sorghum stubble, and rice straw. The sale of these residues to a local bio refinery also represents an opportunity for farmers to generate additional income.

9.11.4. FORESTRY RESIDUES: Forest biomass feedstocks fall into one of two categories: forest residues left after logging timber (including limbs, tops, and culled trees and tree components that would be otherwise unmerchantable) or whole-tree biomass harvested explicitly for biomass. Dead, diseased, poorly formed, and other unmerchantable trees are often left in the woods following timber harvest. This woody debris can be collected for use in bioenergy, while leaving enough behind to provide habitat and maintain proper nutrient and hydrologic features.

There are also opportunities to make use of excess biomass on millions of acres of forests. Harvesting excessive woody biomass can reduce the risk of fire and pests, as well as aid in forest restoration, productivity, vitality, and resilience. This biomass could be harvested for bioenergy without negatively impacting the health and stability of forest ecological structure and function.

9.11.5. ALGAE: Algae as feedstocks for bioenergy refers to a diverse group of highly productive organisms that include microalgae, microalgae (seaweed), and cyanobacteria (formerly called “blue-green algae”). Many use sunlight and nutrients to create biomass, which contains key components including lipids, proteins, and carbohydrates that can be converted and upgraded to a variety of biofuels and products. Depending on the strain, algae can grow by using fresh, saline, or brackish water from surface water sources, groundwater, or seawater. Additionally, they can grow in water from second-use sources, such as treated industrial wastewater; municipal, agricultural, or aquaculture wastewater; or produced water generated from oil and gas drilling operations.

9.11.6. WOOD PROCESSING RESIDUES: Wood processing yields byproducts and waste streams that are collectively called wood processing residues and have significant energy potential. For example, the processing of wood for products or pulp produces unused sawdust, bark, branches, and leaves/needles. These residues can then be converted into biofuels or bio products. Because these residues are already collected at the point of processing, they can be convenient and relatively inexpensive sources of biomass for energy.

9.11.7. SORTED MUNICIPAL WASTE: MSW resources include mixed commercial and residential garbage, such as yard trimmings, paper and paperboard, plastics, rubber, leather, textiles, and food wastes. MSW for bioenergy also represents an opportunity to reduce residential and commercial waste by diverting significant volumes from landfills to the refinery.

9.11.8. WET WASTE: Wet waste feedstocks include commercial, institutional, and residential food wastes (particularly those currently disposed of in landfills); organic rich bio solids (i.e., treated sewage sludge from municipal wastewater); manure slurries from concentrated livestock operations; organic wastes from industrial operations; and biogas (the gaseous product of the decomposition of organic matter in the absence of oxygen) derived from any of the above feedstock streams. Transforming these “waste streams” into energy can help create additional revenue for rural economies and solve waste-disposal problems.

9.12 SUMMARY

In this unit, you have studied about environmental degradation which includes biodiversity losses, water degradation, climate change and temperature, climate change and precipitation, population growth, water management, consumption increases and deforestation. You have also learnt environmental effect of thermal power station, environmental effect of nuclear power station, environmental effect of hydroelectric power project and environmental effect of hydroelectric power project. You have also studied harvesting various types of energy which includes Ocean Wave Energy, Wind Energy, Solar Energy and Bioenergy.

9.13 GLOSSARY

MSW: municipal solid waste

PV: Photovoltaic

MW: Mega watt

GW: Giga watt

9.14 TERMINAL QUESTIONS

1. What do you understand by environmental degradation? Discuss effect on climatic change due to environmental degradation.
2. Explain harvesting ocean energy.
3. Explain impacts of environmental degradation on women's livelihoods.
4. Discuss Environmental Effect of Thermal Power Station and Nuclear Power Station.
5. What do you understand by geothermal power? Explain different types of power station.
6. What do you understand by ocean wave energy? How is it Harvested?
7. Give a comparison between Ocean Energy and Bio energy harvesting.

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