MUTHAYAMMAL ENGINEERING COLLEGE

(An Autonomous Institution)

(Approved by AICTE, New Delhi, Accredited by NAAC & Affiliated to Anna University)

Rasipuram - 637 408, Namakkal Dist., Tamil Nadu

Estd. 2000

L1

LECTURE HANDOUTS

EEE | **II / III**

Course Name with Code : 19GES20 / RENEWABLE ENERGY SOURCES

Course Faculty : Mr.C.RAMKUMAR

Unit : 1-INTRODUCTION **Date of Lecture:**

Topic of Lecture: World Energy Use

Introduction :

- World energy supply and consumption is global production and preparation of fuel, generation of electricity, energy transport and energy consumption. It is a basic part of economic activity.
- It does not include energy from food. Many countries publish statistics on the energy supply and consumption of their own country or of other countries or the world. One of the largest organizations in this field, the International Energy Agency (IEA), publishes yearly comprehensive energy data.
- This collection of energy balances is very large. This article provides a brief description of energy supply and consumption, using statistics summarized in tables, of the countries and regions that produce and consume most.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Environmental Science
- Material Science
- Basics of Electrical & Electronics sciences

Detailed content of the Lecture:

Primary energy production

World total primary energy consumption by fuel in 2020

Oil (31.2%)

Coal (27.2%)

Natural Gas (24.7%)

Hydro (renewables) (6.9%)

Nuclear (4.3%)

Others (renewables) (5.7%)

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.

Energy production is usually classified as:

- fossil, using coal, crude oil, and natural gas;
- nuclear, using uranium;
- renewable, using biomass, geothermal, hydropower, solar, tidal, wave, wind, and among others.

- Primary energy assessment follows certain rules to ease measurement of different kinds of energy. These rules are controversial.
- 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 3 times the electric energy.
- This measurement difference can lead to underestimating the economic contribution of renewable energy.
- The table lists the worldwide PE and the countries/regions producing most (90%) of that. The amounts are rounded and given in million tonnes of oil equivalent per year (1 Mtoe = 11.63 TWh, 1 TWh = 10^9 kWh). The data are of 2018.

Total Energy Supply

- 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 im- and exports cancel out, but for countries/regions 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.

Final consumption

- Total final consumption (TFC) is the worldwide consumption of energy by end-users (whereas primary energy consumption (Eurostat) or total energy supply (IEA) is total energy demand and thus also includes what the energy sector uses itself and transformation and distribution losses).
- This energy consists of fuel (78%) and electricity (22%). The tables list amounts, expressed in million tonnes of oil equivalent per year (1 Mtoe = 11.63 TWh) and how much of these is renewable energy. Non-energy products are not considered here. The data are of 2018.

Fuel:

- Fossil: natural gas, fuel derived from petroleum (LPG, gasoline, kerosene, gas/diesel, fuel oil), from coal (anthracite, bituminous coal, coke, blast furnace gas).
- Renewable: Biofuels and fuel derived from waste.
- The amounts are based on lower heating value.
- The first table lists final consumption in the countries/regions which use most (85%), and per person.
- In developing countries fuel consumption per person is low and more renewable. Canada, Venezuela and Brazil generate most electricity with hydropower.

Alternative scenarios

- Alternative Achieving the Paris Climate Agreement Goals scenarios are developed by a team of 20 scientists at the University of Technology of Sydney, the German Aerospace Center, and the University of Melbourne, using IEA data but proposing transition to nearly 100% renewables by mid-century, along with steps such as reforestation. Nuclear power and carbon capture are excluded in these scenarios.
- The researchers say the costs will be far less than the $5 trillion per year governments currently spend subsidizing the fossil fuel industries responsible for climate change.
- In the +2.0 C (global warming) Scenario total primary energy demand in 2040 can be 450 EJ = 10755 Mtoe, or 400 EJ = 9560 Mtoe in the +1.5 Scenario, well below the current production. Renewable sources can increase their share to 300 EJ in the +2.0 C Scenario or 330 PJ in the +1.5 Scenario in 2040. In 2050 renewables can cover nearly all energy

demand.

- Non-energy consumption will still include fossil fuels.
- Global electricity generation from renewable energy sources will reach 88% by 2040 and 100% by 2050 in the alternative scenarios. "New" renewables — mainly wind, solar and geothermal energy — will contribute 83% of the total electricity generated.
- The average annual investment required between 2015 and 2050, including costs for additional power plants to produce hydrogen and synthetic fuels and for plant replacement, will be around $1.4 trillion (p.182).
- Shifts from domestic aviation to rail and from road to rail are needed. Passenger car use must decrease in the OECD countries (but increase in developing world regions) after 2020.
- The passenger car use decline will be partly compensated by strong increase in public transport rail and bus systems.
- CO_2 emission can reduce from 32 Gt in 2015 to 7 Gt (+2.0 Scenario) or 2.7 Gt (+1.5 Scenario) in 2040, and to zero in 2050.

Video Content / Details of website for further learning (if any):

- **https://study.com/academy/lesson/energy-consumption-of-the-world-the-differences-in-consumption-between-developing-and-developed-nations.html**

Important Books/Journals for further learning including the page nos.:

- B H Khan, Non – Conventional Energy Resources ,Tata McGraw Hill Education Private Limited , New Delhi 2010-Page no (15-19)

Course Faculty

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L2

LECTURE HANDOUTS

EEE **II / III**

Course Name with Code :**19GES20 / RENEWABLE ENERGY SOURCES**

Course Faculty : **Mr.C.RAMKUMAR**

Unit : **1-INTRODUCTION** **Date of Lecture:**

Topic of Lecture: Reserves of Energy Resources

Introduction :

- World energy resources are the estimated maximum capacity for energy production given all available resources on Earth.
- They can be divided by type into fossil fuel, nuclear fuel and renewable resources.These are the proven energy reserves; real reserves may be four or more times larger.
- These numbers are very uncertain. Estimating the remaining fossil fuels on the planet depends on a detailed understanding of Earth's crust.
- With modern drilling technology, we can drill wells in up to 3 km of water to verify the exact composition of the geology; but half of the ocean is deeper than 3 km, leaving about a third of the planet beyond the reach of detailed analysis.
- There is uncertainty in the total amount of reserves, but also in how much of these can be recovered gainfully, for technological, economic and political reasons, such as the accessibility of fossil deposits, the levels of sulphur and other pollutants in the oil and the coal, transportation costs, and societal instability in producing regions.
- In general the easiest to reach deposits are the first extracted.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Environmental Science
- Material Science
- Basics of Electrical & Electronics sciences

Detailed content of the Lecture:

Coal

- Coal is the most abundant and burned fossil fuel.
- This was the fuel that launched the industrial revolution and continued to grow in use; China, which already has many of the world's most polluted cities, was in 2007 building about two coal-fired power plants every week.
- Coal's large reserves would make it a popular candidate to meet the energy demand of the global community, short of global warming concerns and other pollutants.

Natural gas:

- Natural gas is a widely available fossil fuel with estimated 850 000 km^3 in recoverable reserves and at least that much more using enhanced methods to release shale gas.
- Improvements in technology and wide exploration led to a major increase in recoverable natural gas reserves as shale fracking methods were developed.
- At present usage rates, natural gas could supply most of the world's energy needs for between 100 and 250 years, depending on increase in consumption over time.

Oil

- It is estimated that there may be 57 ZJ of oil reserves on Earth (although estimates vary from a low of 8 ZJ, consisting of currently proven and recoverable reserves, to a maximum of 110 ZJ) consisting of available, but not necessarily recoverable reserves, and including optimistic estimates for unconventional sources such as oil sands and oil shale.
- Current consensus among the 18 recognized estimates of supply profiles is that the peak of extraction will occur in 2020 at the rate of 93-million barrels per day (mbd).
- Current oil consumption is at the rate of 0.18 ZJ per year (31.1 billion barrels) or 85 mbd.
- There is growing concern that peak oil production may be reached in the near future, resulting in severe oil price increases.
- A 2005 French Economics, Industry and Finance Ministry report suggested a worst-case scenario that could occur as early as 2013.
- There are also theories that peak of the global oil production may occur in as little as 2–3 years. The ASPO predicts peak year to be in 2010.
- Some other theories present the view that it has already taken place in 2005. World

crude oil production (including lease condensates) according to US EIA data decreased from a peak of 73.720 mbd in 2005 to 73.437 in 2006, 72.981 in 2007, and 73.697 in 2008.

- According to peak oil theory, increasing production will lead to a more rapid collapse of production in the future, while decreasing production will lead to a slower decrease, as the bell-shaped curve will be spread out over more years.
- In a stated goal of increasing oil prices to $75/barrel, which had fallen from a high of $147 to a low of $40, OPEC announced decreasing production by 2.2 mbd beginning 1 January 2009.

Sustainability:

- Political considerations over the security of supplies, environmental concerns related to global warming and sustainability are expected to move the world's energy consumption away from fossil fuels.
- The concept of peak oil shows that about half of the available petroleum resources have been produced, and predicts a decrease of production.
- A government moves away from fossil fuels would most likely create economic pressure through carbon emissions and green taxation.
- Some countries are taking action as a result of the Kyoto Protocol, and further steps in this direction are proposed.
- For example, the European Commission has proposed that the energy policy of the European Union should set a binding target of increasing the level of renewable energy in the EU's overall mix from less than 7% in 2007 to 20% by 2020.
- The antithesis of sustainability is a disregard for limits, commonly referred to as the Easter Island Effect, which is the concept of being unable to develop sustainability, resulting in the depletion of natural resources.
- Some estimate that, assuming current consumption rates, current oil reserves could be completely depleted by 2050.

Nuclear energy

- The International Atomic Energy Agency estimates the remaining uranium resources to be equal to 2500 ZJ. This assumes the use of breeder reactors, which are able to create more fissile material than they consume.
- IPCC estimated currently proved economically recoverable uranium deposits for once-

through fuel cycles reactors to be only 2 ZJ. The ultimately recoverable uranium is estimated to be 17 ZJ for once-through reactors and 1000 ZJ with reprocessing and fast breeder reactors.

- Resources and technology do not constrain the capacity of nuclear power to contribute to meeting the energy demand for the 21st century.
- However, political and environmental concerns about nuclear safety and radioactive waste started to limit the growth of this energy supply at the end of last century, particularly due to a number of nuclear accidents.
- Concerns about nuclear proliferation (especially with plutonium produced by breeder reactors) mean that the development of nuclear power by countries such as Iran and Syria is being actively discouraged by the international community.
- Although at the beginning of the 21st century uranium is the primary nuclear fuel worldwide, others such as thorium and hydrogen had been under investigation since the middle of the 20th century.
- Thorium reserves significantly exceed those of uranium, and of course hydrogen is abundant. It is also considered by many to be easier to obtain than uranium.
- While uranium mines are enclosed underground and thus very dangerous for the miners, thorium is taken from open pits, and is estimated to be roughly three times as abundant as uranium in the Earth's crust.
- Since the 1960s, numerous facilities throughout the world have burned Thorium.

Nuclear fusion

- Alternatives for energy production through fusion of hydrogen have been under investigation since the 1950s. No materials can withstand the temperatures required to ignite the fuel, so it must be confined by methods which use no materials.
- Magnetic and inertial confinement are the main alternatives (Cucaracha, Inertial confinement fusion) both of which are hot research topics in the early years of the 21st century.
- Fusion power is the process driving the sun and other stars.
- It generates large quantities of heat by fusing the nuclei of hydrogen or helium isotopes, which may be derived from seawater.
- The heat can theoretically be harnessed to generate electricity. The temperatures and

pressures needed to sustain fusion make it a very difficult process to control.

- Fusion is theoretically able to supply vast quantities of energy, with relatively little pollution.
- Although both the United States and the European Union, along with other countries, are supporting fusion research (such as investing in the ITER facility), according to one report, inadequate research has stalled progress in fusion research for the past 20 years.

Video Content / Details of website for further learning (if any):

- https://energyeducation.ca/encyclopedia/Reserve

Important Books/Journals for further learning including the page nos.:

- B H Khan, Non – Conventional Energy Resources ,Tata McGraw Hill Education Private Limited , New Delhi 2010-Page no (4-6)

Course Faculty

LECTURE HANDOUTS

EEE | **II/ III**

Course Name with Code : **19GES20 / RENEWABLE ENERGY SOURCES**

Course Faculty : **Mr.C.RAMKUMAR**

Unit : **1-INTRODUCTION** **Date of Lecture:**

Topic of Lecture: Environmental Aspects of Energy Utilization

Introduction :

- The environmental problems directly related to energy production and consumption includes air pollution, climate change, water pollution, thermal pollution, and solid waste disposal.
- The emission of air pollutants from fossil fuel combustion is the major cause of urban air pollution.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Environmental Science
- Material Science
- Basics of Electrical & Electronics sciences.

Detailed content of the Lecture:

Impacts of renewable energy resources:

a. **Social impacts**

- These resources also provide social benefits like improvement of health, according to choice of consumer, advancement in technologies, and opportunities for the work, but some basic considerations should be taken for the benefit of humans, for example, climate conditions, level of education and standard of living, and region whether urban or rural from agricultural point of view.
- Social aspects are the basic considerations for the development of any country.
- The following social benefits can be achieved by renewable energy systems: local employment, better health, job opportunities, and consumer choice.
- The study concluded that the total emission reduction is exponentially increasing in different years after the installation of renewable energy projects in remote areas.

b. **Economics**

- It was discovered that renewable energy projects provide benefits in economic point of view because they utilize local labor from rural areas, local material and business, local shareholders, and services of local banks.
- In addition, the renewable energy projects have facilitated the communities by establishing a trust fund that aims to invest the money earned by selling electricity in local economy.
- This makes it easy for a few communities to invest money on any small business of their own choice.
- Biofuels projects created large number of jobs; however, very low jobs were created by solar power plants, as the ratio of people working in different companies' increase that will create more jobs for others by using the part of their economy for entertainment, leisure, restaurant, etc.
- The consumers will be provided with electric power at a low cost as compared to that of conventional energy sources, and overall economy will be enhanced because there will be multiple options to generate power using different renewable energy sources present in that region.

c. **Environmental impacts**

- Renewable energy projects have also contributed in improving environmental impacts such as reduction of carbon dioxide gas, awakening community about the climate change.
- The study observed very small impacts on the people living in a particular area, tourism, cost of energy supply, and educational impacts.
- Significant impacts were observed in improvement of life standard, social bonds creation, and community development.
- They also observed that the renewable energy projects are complex to install and are local environmental and condition sensitive.
- Their forecasting, execution, and planning require more consideration and knowledge as compared to other projects.
- The two main aspects of environment are air and water pollution, normally created by the discharged water from houses, industries, and polluted rain, and discharge of used oils and liquids contains poisonous chemicals and heavy metals like mercury, lead, etc.
- Along with water pollution, natural resources can be maintained and greenhouse effect and air pollution can be mitigated by the proper usage of renewable energy sources .
- Carbon dioxide emission with the generation of electric power using different energy resources.

d. **Sociopolitical impacts**

- Solar panels are usually installed at the roofs of the buildings that increase the job opportunities in the PV system fabrication and installation.
- This increases the regional development and reduces the usage of energy from nonrenewable energy projects.
- It is very useful at the regions where there is no access of electricity.
- The major problem with solar system is the high investment and maintenance cost. Biomass energy projects have great contribution in the local job creation and the development of rural areas.
- Such types of power plants have large opportunities of jobs in construction of plants, management, and maintenance of plants, production, and preparation of biomass. Only the noise production and unpleasant smell are the negative impacts of these plants.
- Fuel cells have slow implementation because of their high cost of plant construction and energy generation. Their construction and operation create jobs in almost all technical activities.
- In hydro power plants, the major sociopolitical problem is the shifting of the people from the areas where the plant is going to be constructed.
- These plants provide significant jobs for local community and also play an important role in the economic development of the community. The construction of tidal energy plants has no effect on humans, and they have better contribution in the local and official employment. These plants are very expensive and are not common.
- Wind energy projects do not have any emigration problem, and they create large number of job opportunities especially for engineers.
- Geo thermal energy projects provide the following sociopolitical benefits: improvement in the education of local people, improvement in living standards, and improvement in the care of health issues.

e. **Impacts on grid**

- When the solar panels are connected to the distribution system, the cost of safety equipment is reduced because their short circuit current is higher than the nominal value.
- Biomass power plants have the same effects on the gird as do conventional plants.
- The integration of wind energy plants, tidal energy, and geothermal energy is complex

f. **Socioeconomic impacts**

- Three case studies were made to investigate the socioeconomic benefits of renewable energy projects, and the three cases were solar, wind, and Biofuels energy projects;

empirical method was used to collect data.

- The basic aim of study was to know the contribution of renewable energy projects to local sustainability, which includes social, economic, and environmental, and to identify the socioeconomic benefits of REPs through the concerned community. It was done by doing survey of the communities.
- Eleven parameters were used including job creation, impacts on education, easy usage of energy, income development, demographic impacts, social bonds creation and community development, usage of native resources, and tourism.
- They concluded that the impacts of REPs on employment are positive, and indirect employment is high in comparison with the size of community, whereas direct employment is moderate.

Video Content / Details of website for further learning (if any):

- https://www.iea.org/commentaries/the-environmental-case-for-natural-gas

Important Books/Journals for further learning including the page nos.:

- B H Khan, Non – Conventional Energy Resources ,Tata McGraw Hill Education Private Limited , New Delhi 2010-Page no (8-13)

Course Teacher

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L4

LECTURE HANDOUTS

EEE

II/ III

Course Name with Code : 19GES20 / RENEWABLE ENERGY SOURCES

Course Faculty : Mr.C.RAMKUMAR

Unit : 1-INTRODUCTION **Date of Lecture:**

Topic of Lecture: Renewable Energy Scenario in Tamil Nādu
Introduction : • A 2018 report lists Tamil Nadu as one of the top nine renewable energy markets in the world. Today, 14.3 per cent of all the energy demand in the state is met by renewable energy, primarily solar and wind. • Wind power capacity in Tamil Nadu increased from a meager 877 MW in 2002 to 7,652 MW in 2017. Persistent load shedding by the Tamil Nadu Generation and Distribution Corporation Limited (TANGEDCO) has been a huge problem for the local industry. • The policies and incentives offered by the government — bundling of wind power projects, accelerated depreciation, a Technology Up gradation Fund etc — have driven the state's power-intensive industries to invest in captive wind power plants. Of the total capacity today, nearly 5,500 MW36 of captive plants have been set up by textile mills and cement industries. • The Tamil Nadu Spinning Mills Association (TASMA) was an early adopter of the 'bundled wind project' model—several small power consumers formed cooperatives to invest in wind turbines. Today, TASMA cooperatives own a total of 3,500 MW of wind energy capacity, 45 per cent of the state's wind-generation capacity.
Prerequisite knowledge for Complete understanding and learning of Topic: • Environmental Science • Material Science • Basics of Electrical & Electronics sciences

Detailed content of the Lecture:

- Even the reintroduction of accelerated depreciation could not revive the regional wind market. This can be attributed to evacuation problems, history of curtailment and payment delays, all of which are acute in Tamil Nadu because of the large shares of renewable energy in its power mix.
- A TASMA official said, "The curtailment averaged around 30-35 per cent of the generation in the peak season during 2012-15 and averages at 20-25 per cent today.
- A conservative figure of 15 per cent back down translates to an annual loss of 2,000 to 2,500 million units."
- TASMA has filed a case to ensure compliance of a must-run provision for windmills.
- The Association claims that the older wind turbine generators with higher tariffs were curtailed more compared to the newer, more efficient ones and payments continue to be delayed by 12-18 months.
- Wind generation peaks during the southwest and northeast monsoon months, followed by below average generation for the remaining months.
- The state introduced banking of energy, which allows the cooperatives to supply to the grid when there is excess generation, in exchange for free supply during low generation periods. According to TASMA, TANGEDCO seldom honors these banking obligations since power purchase costs are high during the low generation period.
- Addressing these challenges should be the priority; if that is not done, they can wreak havoc in the renewable energy industry. While these issues are more serious in Tamil Nadu, they are slowly creeping into the other high potential states of India as well, since discoms across the country are struggling with poor financial health.

Renewable energy in India: In 33 years, India struggled to exploit just 12% of its wind energy potential

- Close to 33 years after India set up its first wind energy demonstration project of 1.15 MW in 1986 at Tuticorin, it emerges that a big source of clean energy has not been given the policy focus it deserves.
- The latest wind energy potential study carried out by Chennai-based National Institute of Wind Energy (NIWE) estimates 302 gigawatts (GW) at 100 meter above ground level (AGL). With only 35 GW installed so far, the country has a sizable untapped potential. It's not just the low potential exploitation, but also its pan-India spread that is worrying—almost 90 per cent of this potential is concentrated in just five states.
- Given the high variability of wind energy, this has important implications on the

evacuation infrastructure needed and grid integration measures adopted.

- In 2015, the Ministry of New and Renewable Energy (MNRE) set a target for 60 GW of wind installations by 2022. While the capacity additions in 2016-17 were a sizable 5.4 GW, the pace slowed down considerably in 2017-18, with only 1.7 GW of projects commissioned, against a target of 4.1 GW.
- Most of these installations (~1.2 GW) came online only after December 2017.
- Lately, the industry's performance has been mixed. Between January and September 2018, a sizable 5.2 GW of auctions were planned—these included the three tranches of auctions led by the Solar Energy Corporation of India (SECI) Tranche-III of 2 GW, Tranche-IV of 2 GW and Tranche-V of 1.2 GW and 1.2 GW of NTPC auctions.
- However, some of the auctions were reduced or cancelled on account of concerns about lack of evacuation capacity.
- If the wind energy industry is planning to meet the target of 60 GW by 2022, it must auction 20 GW of capacity within the next two years, considering the two to three years needed to commission wind projects.
- The industry blamed the abrupt introduction of reverse auctions and bidding—moves that it felt were not fully thought through—in addition to the untimely withdrawal of support mechanisms. In contrast, the MNRE called the move a necessary "course correction" to develop a competitive market.
- However, over the last decade, wind has become the largest contributor to renewable energy capacity additions in India.
- It now accounts for 50 per cent of all renewable energy capacity and 10 per cent of the total installed power capacity in India.
- The sector's growth has come on the back of a favorable policy environment, including a host of subsidies and incentives.
- At the end of 2017, India was in the fourth spot globally for cumulative installed capacity—behind USA, China and Germany—and fifth for annual capacity installations.
- This growth, however, has been turbulent, with the government erratically introducing and withdrawing incentives.
- In the past, the government has announced incentives that were subsequently reduced and when faced with a sudden drop in the market, it has reintroduced incentives.
- The latest abrupt change in policy occurred in 2016 when the government introduced competitive auctions to determine tariffs and award contracts; the change stalled the market for around a year as the industry was unclear about certain provisions and

protections in the auction mechanism.

- However, over the last year, the new regime did result in a sharp fall in tariffs.
- The sector has been marked by the introduction of large incentives and sudden withdrawals that has, alternately, boosted installations and disrupted the market.
- Growth began with the introduction of high feed-in tariffs (Fits), which ensured long-term guaranteed sale of power at attractive tariffs.
- At the same time, accelerated depreciation (AD) and generation-based incentives (GBI) were employed to draw in investors.
- But these policies were periodically withdrawn or reduced and, subsequently, reintroduced when installations slowed down.
- Historically, the growth in wind energy capacity has followed a pattern, with individual states dominating for a few years before the focus shifts to another state.
- In the first phase, before 2004-05, Tamil Nadu was responsible for a majority of the capacity addition—in March 2005, its share of the country's total wind energy capacity was around 56 per cent.
- Subsequently, Maharashtra, Gujarat and Karnataka began making sizable investments in wind energy. Rajasthan was the next state to show rapid growth beginning in 2009-10, followed by Andhra Pradesh where installations increased sharply post 2012-2013.
- During 2014-16, Madhya Pradesh was the clear leader.

Video Content / Details of website for further learning (if any):

- https://earthjournalism.net/video-highlight/renewable-energy-in-tamil-nadu

Important Books/Journals for further learning including the page nos.:

- B H Khan, Non – Conventional Energy Resources ,Tata McGraw Hill Education Private Limited , New Delhi 2010-Page no (19-21)

Course Faculty

LECTURE HANDOUTS

EEE **II / III**

Course Name with Code : **19GES20 / RENEWABLE ENERGY SOURCES**

Course Faculty : **Mr.C.RAMKUMAR**

Unit : **1-INTRODUCTION** **Date of Lecture:**

Topic of Lecture: Renewable Energy Scenario in India

Introduction :

- Energy is regarded as the most important building block in human development and it is a key factor that influences the sustainable development of any nation.
- The conventional sources have an intimidating shadow on our present and future global safety, environmental values, health and society in general.
- Hence, there is an urgent need to promote renewable energy in Indian power sector. Renewable energy is the energy collected from renewable resources, which are naturally replenished on human timescale such as sunlight, wind, rain, tides, waves and geothermal heat.
- It is the cleanest source of energy with least carbon emissions or pollution. This helps on reducing reliance on coal and other fossil fuels.
- With the expansion of renewable energy, India can improve air quality, reduce global warming emissions, create new industries and jobs, and help to move world towards a cleaner, safer, and affordable energy.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Environmental Science
- Material Science
- Basics of Electrical & Electronics sciences

Detailed content of the Lecture

Current Scenario of Renewable Energy in India:

- Over the years, renewable energy sector has emerged as a significant player in India especially affecting the power generation capacity.
- This supports the government's agenda of sustainable development while becoming an integral part in meeting the nation's energy needs.
- For past two years, the Indian Government has taken several initiatives such as introduction of the concept of solar parks, organizing RE-Invest 2015—a global investors' meet, launching of a massive grid connected rooftop solar programme, earmarking of Rs.38,000 crore (Euros 4 billion) for a Green Energy Corridor, eight-fold increase in clean environment from Rs.50 per tonne to Rs.400 per tonne (Euro 0.62 to Euros 5 per tonne) , solar pump scheme with a target of installing 100,000 solar pumps and programme to train 50,000 people for solar installations under the Surya Mitra scheme, no inter-state transmission charges and losses to be levied for solar and wind power, compulsory procurement of 100 per cent power from waste to energy plants, and Renewable Generation Obligations on new thermal and lignite plants, etc.

Advantages of India:

1. **Robust Demand:** With the growing Indian economy, the electricity consumption is projected to reach 15,280 TWh by 2040.
2. **Increasing Investments:** With Indian government's ambitious targets, the sector has become quite attractive to foreign and Indian investors. It is expected to attract investments upto USD 80 billion (Euros 70 billion) in next four years.
3. **Competitive Advantage:** Indian has sunlight available throughout the year and has a large hydropower potential.

Renewable Energy Targets:

The Indian Government has increased the target of renewable energy capacity to 175 GW by the year 2022 which includes 100 GW from solar, 60 GW from wind, 10 GW from bio-power and 5 GW from small hydro-power.

Video Content / Details of website for further learning (if any):

- https://www.indiary.org/en/legal-advice/Renewable-Energy-in-India-Current-Status-and-Future-Potential-2-79-429

Important Books/Journals for further learning including the page nos.:

- B H Khan, Non – Conventional Energy Resources ,Tata McGraw Hill Education Private Limited , New Delhi 2010-Page no (22-24)

Course Faculty

LECTURE HANDOUTS

EEE

II / III

Course Name with Code : **19GES20 / RENEWABLE ENERGY SOURCES**

Course Faculty : **Mr.C.RAMKUMAR**

Unit : **1-INTRODUCTION** **Date of Lecture:**

Topic of Lecture: Renewable Energy Scenario around the world.

Introduction :

- Global renewable energy capacity additions in 2020 beat earlier estimates and all previous records despite the economic slowdown that resulted from the COVID-19 pandemic.
- According to data released today by the International Renewable Energy Agency (IRENA) the world added more than 260 gigawatts (GW) of renewable energy capacity last year, exceeding expansion in 2019 by close to 50 per cent.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Environmental Science
- Material Science
- Basics of Electrical & Electronics sciences

Detailed content of the Lecture

- Renewable' rising share of the total is partly attributable to net decommissioning of fossil fuel power generation in Europe, North America and for the first time across Eurasia (Armenia, Azerbaijan, Georgia, Russian Federation and Turkey).
- Total fossil fuel additions fell to 60 GW in 2020 from 64 GW the previous year highlighting a continued downward trend of fossil fuel expansion.
- "These numbers tell a remarkable story of resilience and hope.
- Despite the challenges and the uncertainty of 2020, renewable energy emerged as a source of undeniable optimism for a better, more equitable, resilient, clean and just future," said IRENA Director-General Francesco La Camera.
- "The great reset offered a moment of reflection and chance to align our trajectory with

the path to inclusive prosperity, and there are signs we are grasping it.

- "Despite the difficult period, as we predicted, 2020 marks the start of the decade of renewable," continued Mr. La Camera.
- "Costs are falling, clean tech markets are growing and never before have the benefits of the energy transition been so clear. This trend is unstoppable, but as the review of our *World Energy Transitions Outlook* highlights, there is a huge amount to be done.
- Our 1.5 degree outlook shows significant planned energy investments must be redirected to support the transition if we are to achieve 2050 goals. In this critical decade of action, the international community must look to this trend as a source of inspiration to go further," he concluded.
- The 10.3 per cent rise in installed capacity represents expansion that beats long-term trends of more modest growth year on year. At the end of 2020, global renewable generation capacity amounted to 2 799 GW with hydropower still accounting for the largest share (1 211 GW) although solar and wind are catching up fast.
- The two variable sources of renewables dominated capacity expansion in 2020 with 127 GW and 111 GW of new installations for solar and wind respectively.
- China and the United States of America were the two outstanding growth markets from 2020. China, already the world's largest market for renewables added 136 GW last year with the bulk coming from 72 GW of wind and 49 GW of solar.
- The United States of America installed 29 GW of renewables last year, nearly 80 per cent more than in 2019, including 15 GW of solar and around 14 GW of wind. Africa continued to expand steadily with an increase of 2.6 GW, slightly more than in 2019, while Oceania remained the fastest growing region (+18.4%), although its share of global capacity is small and almost all expansion occurred in Australia.
- Highlights by technology:

o **Hydropower:** Growth in hydro recovered in 2020, with the commissioning of several large projects delayed in 2019. China added 12 GW of capacity, followed by Turkey with 2.5 GW.

o **Wind energy:** Wind expansion almost doubled in 2020 compared to 2019 (111 GW compared to 58 GW last year). China added 72 GW of new capacity, followed by the United States of America (14 GW). Ten other countries increased wind capacity by more than 1 GW in 2020. Offshore wind increased to reach around 5% of total wind capacity in 2020.

o **Solar energy:** Total solar capacity has now reached about the same level as wind capacity thanks largely to expansion in Asia (78 GW) in 2020. Major capacity increases in

China (49 GW) and Viet Nam (11 GW). Japan also added over 5 GW and India and Republic of Korea both expanded solar capacity by more than 4 GW. The United States of America added 15 GW.

- **Bioenergy:** Net capacity expansion fell by half in 2020 (2.5 GW compared to 6.4 GW in 2019). Bioenergy capacity in China expanded by over 2 GW. Europe the only other region with significant expansion in 2020, adding 1.2 GW of bioenergy capacity, a similar to 2019.
- **Geothermal energy:** Very little capacity added in 2020. Turkey increased capacity by 99 MW and small expansions occurred in New Zealand, the United States of America and Italy.
- **Off-grid electricity:** Off-grid capacity grew by 365 MW in 2020 (2%) to reach 10.6 GW. Solar expanded by 250 MW to reach 4.3 GW and hydro remained almost unchanged at about 1.8 GW.

Video Content / Details of website for further learning (if any):

- https://www.indiary.org/en/legal-advice/Renewable-Energy-in-India-Current-Status-and-Future-Potential-2-79-429

Important Books/Journals for further learning including the page nos.:

- B H Khan, Non – Conventional Energy Resources ,Tata McGraw Hill Education Private Limited , New Delhi 2010-Page no (25 -27)

Course Faculty

L7

LECTURE HANDOUTS

EEE

III / V

Course Name with Code : 19GES20 / RENEWABLE ENERGY SOURCES

Course Faculty : Mr.S.SARANRAJ

Unit : 1-INTRODUCTION **Date of Lecture:**

Topic of Lecture: Potentials

Introduction :

- The most sustainable energy sources are renewable Bioenergy (wood, biomass, energy crops), geothermal (deep or shallow), solar energy (photovoltaic, solar thermal), hydro and wind energy. Since much more, orders of magnitudes more, solar energy hits the earth than is required for human needs, the total potential of renewable energies seems to be almost infinite.
- It should be noted that, with respect to our discussion about energy here, the term "potential" is not the same as in physics.
- A better term would be "availability". Also, the terms "renewable energy" and "energy sources" do not make sense physically, since in physics the energy conservation law prohibits a source or renewal of energy; only transformations are allowed.
- From a physical point of view, it would be better to formulate this as "availability of sustainable energies" instead of "potential of renewable energies".

Prerequisite knowledge for Complete understanding and learning of Topic:

- Environmental Science
- Material Science
- Basics of Electrical & Electronics sciences

Detailed content of the Lecture:

- India became the world's third largest producer of electricity in the year 2013 and accounts for 4.8% of global share in electricity generation.
- But its per capita electricity consumption is only 746 kWh, which is lower compared to

many countries, though electricity tariff is cheaper in India. Energy is the basic input in all sectors of the nation's economy, and the standard of living is directly related to per capita energy consumption.

- As the country is heavily populated, provision of adequate quantities and kinds of energy is a challenge to the government, and the institutions in the country engaged in tasks relating to energy supply and transport.
- The commercial energy inputs to the Indian economy are from conventional sources like coal, hydroelectricity and nuclear energy. The country currently has total installed capacity of thermal 70%, hydroelectric 16%, nuclear 2% and renewable 12%.
- For long-term sustainability, minimum utilization of fossil fuel for energy and maximum utilization of renewable energy are to be considered.
- At the same time, minimum losses during generation transport and utilization sector is also important.

Renewable sources and their potential for supplying electricity:

- Renewable energy is generally defined as energy that comes from resources, which are naturally replenished on their own.
- Renewable energy sources are all essentially based on the direct or indirect use of solar energy. The only exception is tidal energy, which essentially derives its power from the interaction between the earth and the moon.
- Renewable energy can replace conventional fuels in the distinct areas like electricity generation, water heating, space heating, motor fuels, and rural energy services.
- The important renewable energy sources, which can be utilized for generating electricity in our country are as follows:
- Solar energy (direct): Solar thermal power and solar photovoltaic (PV) power, Solar energy
- Hydroelectric power (large and small units)
- Wind energy (on land and offshore)
- Biomass power
- Wave energy, marine currents, and ocean thermal energy conversion
- Tidal energy

Solar thermal power and PV power:

- Solar energy is utilized for direct thermal applications and for solar-electric applications.
- Solar thermal applications include water heating, space heating, drying, cooking etc.

- Generation of electricity is possible in solar thermal-electric power plants.
- These plants use concentrating collectors to collect the sun's energy at high temperatures and use this energy to generate high-pressure steam.
- The steam in turn is used in a conventional Rankine cycle to generate electricity. India is ranked number one in terms of solar electricity production per watt installed.
- As on 30 March 2015, the installed grid connected solar power capacity is 3,383 MW, and India expects to install an additional 10,000 MW by 2017 and a total of 100,000 MW by 2022.
- Photovoltaic conversions are also a direct method of utilizing solar energy, which makes use of solar cells to convert solar energy directly into electrical energy.
- The electrical energy requirement for localized use in the remote locations all over India is estimated at about 11,000 MW – a substantial part of which is expected to come from PV systems that are not connected to the grid.
- These systems may be located as far as possible on rooftops, so that no land space is used. India has total installed capacity of almost 4101.68 MW grid-connected PV power systems having small capacities.
- Indirect solar energy is the solar power that goes through more than one change to become in the useful form of energy. Examples of indirect solar energy are hydropower, biomass and wind energy.

Hydroelectric power:

- India is ranked as the 6th largest producer of hydroelectric power in the world and has great potential for hydro-electric power.
- Hydroelectric power projects are the largest contributors amongst renewable energy sources in our country.
- Apart from generating electricity, they provide water for irrigation, help in flood control and drinking water purposes.
- Hydroelectric power is the generation of electric power which utilizes the potential energy of water at a high level.
- A hydroelectric facility requires a dependable flow of water – and the water head is created by constructing a dam across the river.
- In a typical installation, water is fed from a reservoir through a channel or pipe into a turbine and the pressure of the flowing water on the turbine blades causes the shaft to rotate, which, in turn, is connected to an electrical generator, which converts the motion

of the shaft into electrical energy.

- The present installed capacity is approximately 40,661.41 MW, which is 16.36% of total electricity generation in India and small hydro power capacity is 4101MW.
- India has huge hydro potential of about 84,000 MW at 60% load factor, which can be economically exploited. Almost 49 large hydropower projects are under construction in India, which will be completed by the year 2022 with a cumulative capacity of 15,006 MW.
- In addition, a potential of 6,740 MW of installed capacity from small, mini and micro hydel schemes have been assessed – and pumped storage schemes with an aggregate installed capacity of 94,000 MW have been identified.
- Pumped storage schemes would be helpful for meeting peak load demand and storing the surplus electricity, which can also produce power at no additional cost when rivers are flooding. India has already established nearly 6,800 MW pumped storage capacity.
- For small units, 5,718 sites with a total capacity of 15,384 MW have been identified all over the country.

Wind energy:

- India has great potential of wind energy to project as an alternate source of energy.
- Electricity can be generated from wind power by converting the kinetic energy in the wind into mechanical energy utilizing wind turbines.
- The energy in the wind is utilized to turn propeller shaped blades around a rotor, which when connected to the main shaft can spin a generator to produce electricity.
- The power that can be extracted theoretically from wind is proportional to the cube of its velocity and the energy generated depends on wind speed and rotor size of the turbine.
- Wind energy is regarded as a means of saving fuel by injecting power into an electrical grid and to run wind power plant in conjunction with a pumped storage plant.
- Wind power has application to rotate machinery to do physical work, such as crushing grain or pumping water and has application to desalinate water.
- The estimation of the potential wind resources in India is 102,788 MW assessed at 80m Hub height. The installed capacity of wind power in India was 22,645 MW as of 30 March 2015.
- The target set for wind power generation capacity is 60,000 MW by the year 2022. The preliminary assessments along the 7,600 km long Indian coastline have indicated prospects of development of offshore wind power as the wind speeds offshore are usually higher and steadier.

Energy from biomass:

- Biomass energy has been an important alternate energy source for the country and more than 70% of the country's population depends on biomass for energy needs.
- It is renewable, widely available, and free from greenhouse gases. Biomass is biological material derived from agricultural and forest resources including plant and animal manure.
- As an energy source, biomass can be used directly via combustion to produce heat.
- Indirectly, biomass can be converted into forms of bio fuel, like ethanol and methanol, to be used in engines; gaseous fuel called biogas can be obtained from biomass by anaerobic fermentation.
- Biomass fuels can be most efficiently used when generating both power and heat through a combined heat and power (or cogeneration) system.
- A total of 288 biomass power and cogeneration projects with 2,665 MW capacities have been installed in the country for feeding power to the grid.
- Biogases cogeneration projects in sugar mills have capacity aggregating to 1,666 MW. A target of 10,000 MW has set for biomass energy till 2022.

Wave energy:

- Wave energy is indirectly derived from solar energy and is available at the ocean surface – because of the interaction of the wind with water surface.
- Wave energy can be generated directly from surface waves or from pressure variations below the surface.
- Wave energy converters are devices, which can capture wave power for generating electricity and extract useful work like water desalination or pumping of water.
- India has a coastline of 7,500 km with an estimated wave energy potential of about 40,000 MW.

Tidal energy:

- Tides are the largest source of short-term sea-level fluctuations and caused by the combined effects of gravitational forces of sun and moon and the rotation of the earth.
- When the gravitational forces due to the Sun and the Moon add together, tides of maximum range called spring tides form, and when the two forces oppose each other, tides of minimum range, called neap tides, are obtained.
- Electrical energy can be extracted from tides in several ways by constructing a reservoir behind a barrage, and then tidal water is allowed to pass through turbines in the barrage to generate electricity.
- India has a potential of 8,000 MW of tidal energy as per the estimates.

- Despite the huge potential, there is no progress in extracting tidal energy.
- Agreement is signed to implement India's first 3.75 MW mini-tidal power project in West Bengal.

Ocean Thermal Energy Conversion (OTEC):

- Ocean thermal energy conversion uses difference in ocean temperature from the surface to depths lower than 1,000 meters, to extract energy.
- A temperature difference of only 20°C can yield usable energy.
- The closed cycle and open cycle OTEC technologies are commonly used to extract thermal energy and convert it to electric power.
- The total OTEC potential around India is estimated as 180,000 MW considering 40% of gross power for parasitic losses.
- The Government of India proposed to establish a 1 MW gross OTEC plant in India, which will be the first ever MW range plant established anywhere in the world.

Geothermal energy:

- Geothermal energy is the thermal energy stored in the earth's interior.
- The steam and hot water at high temperature and pressure come naturally to the surface of the earth at some places that can be utilized for electricity generation, residential and industrial heating, greenhouses and other local uses.
- According to the estimates, India has 10,600 MW potential in the geothermal energy sector but it still needs to be exploited. Union Ministry of New and Renewable Energy (MNRE) recently drafted a national policy, which intends to exploit the sector by generating 1,000 MW in phase-one by 2022.

Total installed power generation capacity:

- The total installed power generation capacity is the sum of utility capacity, captive power capacity and other non-utilities.
- Utility power: The utility electricity sector (Table-1) in India had an installed capacity of 274,817.94 MW as of end June 2015.
- Renewable Power plants constituted 28% of the total installed capacity and Non-Renewable Power Plants constituted the remaining 72%.
- Captive power: Presently India has a total installed captive power generation capacity (above 1 MW capacity) of 47,082 MW in the industries and almost 75,000 MW capacities with diesel power generation sets.
- In addition, there are a large number of DG sets of capacity less than 100 kVA cater to emergency power needs in all sectors such as industrial, commercial, domestic and agriculture.

Video Content / Details of website for further learning (if any): • https://energypedia.info/wiki/Renewable_Energy_Resources_in_Powering_Agriculture
Important Books/Journals for further learning including the page nos.: • B H Khan, Non – Conventional Energy Resources ,Tata McGraw Hill Education Private Limited , New Delhi 2010-Page no (29-31)

Course Faculty

L8

LECTURE HANDOUTS

EEE

II / III

Course Name with Code : **19GES20 / RENEWABLE ENERGY SOURCES**

Course Faculty : **Mr.C.RAMKUMAR**

Unit : **1-INTRODUCTION** **Date of Lecture:**

Topic of Lecture: Achievements applications of renewable energy sources

Introduction :

Renewable energy technologies that can be incorporated with building energy systems include:

- **Solar electric** or photovoltaic (PV), systems,
- Solar thermal, including solar hot water (domestic water heating and space heating)
- solar ventilation air preheating
- Geothermal heat pump
- Wind turbines

Prerequisite knowledge for Complete understanding and learning of Topic:

- Environmental Science
- Material Science
- Basics of Electrical & Electronics sciences

Detailed content of the Lecture:

- Renewable energy resources commonly used for building applications include solar, wind, geothermal, and biomass.
- Before selecting an appropriate renewable energy technology to apply to an existing building retrofit project, it is important to first consider a number of factors.

Examples of these factors include:

- Available renewable energy resource at or near the building site
- Available area for sitting of the renewable energy technology
- Cost of energy purchased from the electrical or thermal energy provider for the building
- Available incentives for offsetting the installation cost of the renewable energy system
- Local regulations affecting renewable energy systems

- Desire to preserve or not alter existing architectural features
- Characteristics of the energy profiles to be offset by the renewable energy installation.

- European renewable energy resource data are available through organizations such as the Global Energy Network Institute (GENI 2007).
- Renewable energy resource maps are a starting point to determine if a building site is located in an area with acceptable amounts of renewable energy resource.
- However, other factors such as the cost of alternative energy sources and available local incentives for renewable energy installations often make installing renewable energy systems cost effective even if the resource is not ideal.
- For example, Germany leads Europe in solar electric system installations with 5,351,000 megawatts peak (MWp) of cumulated installed capacity in 2008, yet, most of the country has a modest average annual solar resource of less than 1,000 kilowatt hours per square meter (kWh/m2).
- Solar electric, or photovoltaic (PV), systems
- Solar thermal, including solar hot water (domestic water heating and space heating), and solar ventilation air preheating
- Geothermal heat pump
- Wind turbines
- Biomass systems.
- More information on each technology is provided in the following sections.
- Geothermal heat pumps use the constant temperature of the earth as an exchange medium for heat.
- Although many parts of the world experience seasonal temperature extremes—from scorching heat in the summer to sub-zero cold in the winter—the ground a meter or so below the surface remains at a relatively constant temperature.
- Geothermal heats pumps are able to heat, cool, and, if so equipped, supply homes and buildings with hot water.
- A geothermal heat pump system consists of a heat pump, an air delivery system (ductwork), and a heat exchanger—a system of pipes buried in shallow ground.
- In the winter, the heat pump removes heat from the heat exchanger and pumps it into the indoor air delivery system.
- In the summer, the process is reversed, and the heat pump moves heat from the indoor air into the heat exchanger.

- The heat removed from the indoor air during the summer can also be used to provide a free source of hot water. There are four types of geothermal heat pump systems. Three of these—horizontal, vertical, and pond/lake—are closed-loop systems.
- The fourth type of system is open-loop.
- Which system is best for a particular site depends on the climate, soil conditions, available land, and local installation costs.
- All of these approaches can be used for residential and commercial building applications (DOE 2011b).
- Installing geothermal heat pumps in building retrofit projects impose an added level of complexity of locating the loops on site and tying the geothermal heat pump system to the existing building heating, ventilating, and air-conditioning system.
- These and other design factors should be carefully considered early in the process when geothermal heat pump systems are being considered to determine if installing such a system can be done cost effectively.
- Wind energy is created by uneven solar heating of the Earth's surface. This wind flow, or motion energy, can be harnessed by modern wind turbines to generate electricity.
- Wind turbines use rotating propeller-like blades to harness the energy in the wind and drive a turbine that generates electricity. Before installing a wind turbine, it must be established that the wind resource in a specific location is adequate. Wind resource is classified according to its potential to produce electricity over an annual basis.
- Wind resource maps can determine if an area of interest should be further explored, but wind resource at a micro level can vary significantly.
- Therefore, it is important to evaluate the specific area of interest before deciding to invest in wind systems.
- Wind Resource Classifications. Wind Power Class Resource Potential Wind Speed at 50m (m/s) 1 Poor.
- If the site has a class 3 wind resource, consider small wind turbine (100 kW or less) or large, low wind speed turbine opportunities.
- If the site has a class 4 or greater wind resource, wind may be a good option and even larger, utility-scale turbines may provide economic options.
- Lower wind resources are less likely to be economically feasible, but should be reviewed if the site is in a class 2 area and there are nearby pockets of class 3 resources (DOE 2011c).
- Most wind turbines are designed for an operating life of up to 20 years and require little maintenance during this period.

- Wind turbines require land area, so on-site wind power generation usually occurs for projects having space for installing the turbines.
- Roof-mounted wind systems are beginning to be used in some building projects. However, building designers should carefully consider issues such as maintaining the building's structural integrity, noise, and the added cost before determining if building-mounted systems are appropriate for a specific project.
- The City of Medford, Massachusetts, USA owns a Northern Power Systems North wind 100 wind turbine sited at McGlynn Elementary and Middle School. Source: Photo from Northern Power Systems.
- Bioenergy There are many types of biomass—organic matter such as plants, residue from agriculture and forestry, and the organic component of municipal and industrial wastes—that can be used to produce fuels, chemicals, and power.
- Wood has been used to provide heat for thousands of years. This flexibility in materials has resulted in increased use of biomass technologies (DOE 2011d).
- Biomass technologies break down organic matter to release stored energy from the sun.
- The process used depends on the type of biomass and its intended end use. For example, biofuels and biopower can be used to provide heat or electricity for buildings. Biofuels are liquid or gaseous fuels produced from biomass.
- Most biofuels are used for transportation, but some are used as fuels to produce electricity (DOE 2011e).
- Biofuels include ethanol and biodiesel.
- Biopower is the production of electricity or heat from biomass resources.
- Biopower technologies include direct combustion, co-firing, and anaerobic digestion (DOE 2011f).
- Connecting to the Electrical Grid Building-sited renewable energy systems generating electricity and connected to the electrical utility grid (known as "grid-tied" systems) are known as distributed generation (DG) systems.
- It is important to consider all issues of connecting the DG system to the grid when such systems are part of a building project.
- Project leads should communicate with the utility on topics such as technical design requirements, which the utility may mandate for interconnection and net metering agreements, including rates the utility will pay for excess renewable energy power generations supplied back to the grid.
- Net metering allows for the flow of electricity from a grid-connected DG system both to and from the customer typically through a single, bi-directional meter.

- When a customer's generation exceeds usage, electricity flows back onto the grid.
- This effectively offsets electricity consumed by the customer at a different time during the same billing cycle or is carried over as a credit on future billing cycles. Net metering policies vary widely.
- Some net metering programs reimburse customers for excess generation at 10 the wholesale rate, while others reimburse at the retail value.
- Some policies specify a limit on the capacity of renewable energy systems that can participate in the net metering program. Interconnection standards specify the technical and procedural process by which a customer connects a renewable energy system to the grid.
- Such standards include the technical and contractual arrangements by which system owners and utilities must abide.
- Utilities can be reluctant to allow interconnection of DG systems.
- The reasons for this are often associated with concerns over ensuring high-quality, reliable power to all customers, load management when considering the intermittency of renewable energy power generation, safety of those maintaining the utility distribution systems, and other similar issues.
- Even with the increased number of DG systems being added to grid systems, many utilities still have limited experience with these systems.
- As a result, these utilities address the interconnection questions on a case-by-case basis, which can result in a significant amount of time needed to develop interconnection agreements. Grants, tax credits, or other incentives are available to encourage historic preservation in many areas, which further urge investment into existing building retrofit projects.
- However, without proper planning, installing a renewable energy system on or near the building can comprise both the architectural aesthetics and structural integrity of the building.
- Historic preservation entities from the national to the local levels exist in many nations.
- These entities are often responsible for designating historic properties, providing guidance and resources for historic preservation projects, and imposing regulatory restrictions with which historic projects must comply.
- Therefore, it is important to understand what regulations apply to historic building projects before investigating renewable energy installation options.
- In general, when embarking on an historic building project, it is advised to first determine what energy efficiency features included in the building's original design can

be rehabilitated, such as day lighting, natural ventilation, and thermal storage features.

- The next step is to consider how to incorporate on-site renewable energy installations. Some technologies can be hidden from view, such as installing a bio-fuel generator or geothermal heat pump.
- Solar electric and solar thermal systems can be integrated into the building "skin", such as the roofing material or shading devices.
- These systems can also be installed out of the view of building visitors, such as on a roof, facing away from where visitors view the building, behind roof parapets, on other structures located on the site such as a parking structure, or ground-mounted away from the historic building.
- The process for implementing renewable energy projects for existing buildings is described in the following steps.

Video Content / Details of website for further learning (if any):

- https://www.imaginovation.net/blog/artificial-intelligence-in-renewable-energy/

Important Books/Journals for further learning including the page nos.:

- B H Khan, Non – Conventional Energy Resources ,Tata McGraw Hill Education Private Limited , New Delhi 2010-Page no (33 -36)

Course Faculty

LECTURE HANDOUTS

EEE **III / V**

Course Name with Code : **19GES20 / RENEWABLE ENERGY SOURCES**

Course Faculty : **Mr.S.SARANRAJ**

Unit : **1-INTRODUCTION** **Date of Lecture:**

Topic of Lecture: Economics of renewable energy systems

Introduction :

- The cost advantage that fossil fuels used to have over renewable energy sources has been decreasing recently, with some renewable technologies (Solar PV, wind, and hydropower) already competing fossil fuels directly on the financial frontier.
- Increasing prices of oil and gas.
- The histories of energy transitions, development of economies and industrial civilizations, all go hand in hand. Going back in time, people only needed to cover their basic needs, such as food, which -at the very beginning- was met by using firewood for cooking and heating.
- Further in time, people started practicing agriculture in the first formed human communities, essentially depending on the sun for that practice, in combination with biomass.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Environmental Science
- Material Science
- Basics of Electrical & Electronics sciences

Detailed content of the Lecture:

- As economies evolved and developed into complex forms, firewood and other biomass were no longer able to meet the increasing demand in energy.
- So people started turning into hydropower, then to coal during the 19^{th} century, oil and natural gas in the 20^{th}, in addition to nuclear that was introduced in mid-20^{th} century as well.
- Therefore, it is apprehend able that each critical change in the economic system -along history- was always accompanied with a major energy transition -and vice versa-, shifting from one major energy source to another.
- Currently, while fossil fuels (coal, oil and natural gas) are the dominant energy sources, the transition is already taking place from these sources into renewable (solar, wind, hydro... etc.).
- Though, the 21^{st} century energy transition is going underway, not mainly because of change in human needs, but due to other factors as well:
- Concerns about environmental impacts (degradation, greenhouse gas emissions GHG, climate change… etc.).
- The ongoing depletion of current energy sources, as they are limited and on the decline (millions of years to form, decades or less to consume).
- The continuous price and technological change of different energy sources and their technologies.
- Considering the added costs to mitigate, adapt to or fight the environmental side effects of using fossil fuels, renewable might be the only option
- People/societies/governments have to adopt, in order to reform the current economic system at least in the energy sector- into a new one.

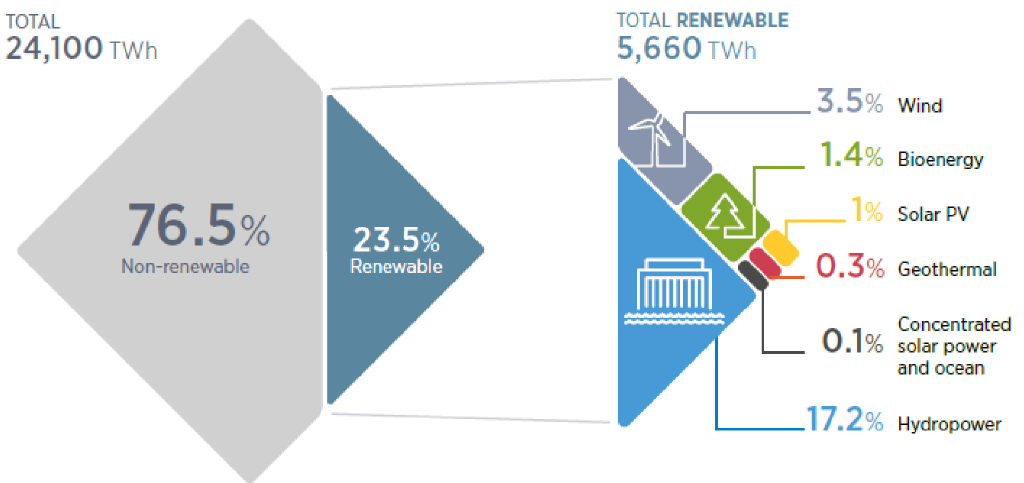
- The fact that fossil fuels are finite, and negatively affecting the climate and polluting the air.
- The current critical environmental and climatic conditions, which drive the need to redirect energy technologies into more diverse, environmentally sustainable supply sources.
- The need to ensure future energy security.
- Mostly for developing countries in particular: Rapid urbanization, economic growth, uprising demographic trends and severe climate change conditions.

Global Investment's in Renewable

- In 2011, the global investment in renewable power and fuels increased to a new record. Significantly, developing economies made up 35% of this total investment.
- In addition, the whole period 2004-2017 has witnessed a remarkable increase in investments in renewables, either in different sectors, or for different technologies, in different countries with different economic systems.
- However, recent years have seen investments in renewable energy in the power sector stagnate. Yet, renewable power generation capacity continued to be installed at record pace mainly thanks to continuously falling technology cost.
- Notable trends for 2018 were that investments continued to be geographically more widely spread, with 29 countries now recording USD 1bn or more in investments (25 countries in 2017), and an additional 14 countries exceeding USD 500m.
- 2018 also marked the fourth year in a row, where investments in developing countries were higher than in developed countries.

Economic Rationale for Renewable

While by 2014 the world was getting about 80% of its electricity supplies from fossil fuels that percentage has gone down 3.5-4% only within 3-4 years. In 2017/18 fossil fuels contributed approximately 76.5% to the global electricity supply, reflecting the rise in the global renewable' market.



- The renewable' market development during the past 10-15 years had few moving factors, which can be summarized as follows:
- One outcome of the Kyoto Protocol, entering into force in early 2005, was the exponential growth of global investment in renewables.
- Rapid growth in energy demand for emerging economies, such as the cases of China &

India, which are driven by transforming their energy industries.

- Uprising competition for energy sources.
- Inclining geopolitical tension.
- Energy security concerns.
- Increasing prices of oil and gas.
- Technological developments in the renewable' sector and the emergence of more technology applications, especially generation of solar PV and wind power, which actually alone makes renewable more competitive, even without investment support.
- The need to commit to a long-term sustainable energy targets has further improved the climate for investments in renewables.

Video Content / Details of website for further learning (if any):

- https://www.youtube.com/watch?v=Fc01HalhoNc

Important Books/Journals for further learning including the page nos.:

- B H Khan, Non – Conventional Energy Resources ,Tata McGraw Hill Education Private Limited , New Delhi 2010-Page no (39-41)

Course Faculty

L10

LECTURE HANDOUTS

EEE **II / III**

Course Name with Code :19GES20 / RENEWABLE ENERGY SOURCES

Course Faculty : Mr.C.RAMKUMAR

Unit : 2-SOLAR ENERGY **Date of Lecture:**

Topic of Lecture: Solar Radiation

Introduction :
Solar radiation, often called the solar resource or just sunlight, is a general term for the electromagnetic radiation emitted by the sun. Solar radiation can be captured and turned into useful forms of energy, such as heat and electricity, using a variety of technologies.

Prerequisite knowledge for Complete understanding and learning of Topic:
Basics of Energy.

Detailed content of the Lecture:

Solar radiation, often called the solar resource or just sunlight, is a general term for the electromagnetic radiation emitted by the sun. Solar radiation can be captured and turned into useful forms of energy, such as heat and electricity, using a variety of technologies. However, the technical feasibility and economical operation of these technologies at a specific location depends on the available solar resource.

BASIC PRINCIPLES

Every location on Earth receives sunlight at least part of the year. The amount of solar radiation that reaches any one spot on the Earth's surface varies according to:

- Geographic location
- Time of day
- Season
- Local landscape
- Local weather.

Because the Earth is round, the sun strikes the surface at different angles, ranging from 0° (just above the horizon) to 90° (directly overhead). When the sun's rays are vertical, the Earth's surface gets all the energy possible. The more slanted the sun's rays are, the longer they travel through the atmosphere, becoming more scattered and diffuse. Because the Earth is round, the frigid polar regions never get a high sun, and because of the tilted axis of rotation, these areas receive no sun at all during part of the year.

The Earth revolves around the sun in an elliptical orbit and is closer to the sun during part of the year. When the sun is nearer the Earth, the Earth's surface receives a little more solar energy. The Earth is nearer the sun when it is summer in the southern hemisphere and winter in the northern hemisphere. However, the presence of vast oceans moderates the hotter summers and colder winters one would expect to see in the southern hemisphere as a result of this difference.

The 23.5° tilt in the Earth's axis of rotation is a more significant factor in determining the amount of sunlight striking the Earth at a particular location. Tilting results in longer days in the northern hemisphere from the spring (vernal) equinox to the fall (autumnal) equinox and longer days in the southern hemisphere during the other 6 months. Days and nights are both exactly 12 hours long on the equinoxes, which occur each year on or around March 23 and September 22.

Countries such as the United States, which lie in the middle latitudes, receive more solar energy in the summer not only because days are longer, but also because the sun is nearly overhead. The sun's rays are far more slanted during the shorter days of the winter months. Cities such as Denver, Colorado, (near 40° latitude) receive nearly three times more solar energy in June than they do in December.

The rotation of the Earth is also responsible for hourly variations in sunlight. In the early morning and late afternoon, the sun is low in the sky. Its rays travel further through the atmosphere than at noon, when the sun is at its highest point. On a clear day, the greatest amount of solar energy reaches a solar collector around solar noon.

DIFFUSE AND DIRECT SOLAR RADIATION

As sunlight passes through the atmosphere, some of it is absorbed, scattered, and reflected by:

- Air molecules
- Water vapor
- Clouds
- Dust
- Pollutants
- Forest fires
- Volcanoes.

This is called diffuse solar radiation. The solar radiation that reaches the Earth's surface without being diffused is called direct beam solar radiation. The sum of the diffuse and direct solar radiation is called global solar radiation. Atmospheric conditions can reduce direct beam radiation by 10% on clear, dry days and by 100% during thick, cloudy days.

MEASUREMENT

Scientists measure the amount of sunlight falling on specific locations at different times of the year. They then estimate the amount of sunlight falling on regions at the same latitude with similar climates. Measurements of solar energy are typically expressed as total radiation on a horizontal surface, or as total radiation on a surface tracking the sun.

Radiation data for solar electric (photovoltaic) systems are often represented as kilowatt-hours per square meter (kWh/m^2). Direct estimates of solar energy may also be expressed as watts per square meter (W/m^2).

Radiation data for solar water heating and space heating systems are usually represented in British thermal units per square foot (Btu/ft^2).

DISTRIBUTION

The solar resource across the United States is ample for photovoltaic (PV) systems because they use both direct and scattered sunlight. Other technologies may be more limited. However, the amount of power generated by any solar technology at a particular site depends on how much of the sun's energy reaches it. Thus, solar technologies function most efficiently in the southwestern United States, which receives the greatest amount of solar energy.

Video Content / Details of website for further learning (if any):

1. **https://www.youtube.com/watch?v=fjITrKs1uNk**

Important Books/Journals for further learning including the page nos.:

Course Faculty

L11

LECTURE HANDOUTS

EEE **II / III**

Course Name with Code : **19GES20 / RENEWABLE ENERGY SOURCES**

Course Faculty : **Mr.C.RAMKUMAR**

Unit : **2-SOLAR ENERGY** **Date of Lecture:**

Topic of Lecture: Measurements of Solar Radiation

Introduction :

Solar radiance measurements consist of global and/or direct radiation measurements taken periodically throughout the day. The measurements are taken using either a pyranometer (measuring global radiation) and/or a pyrheliometer (measuring direct radiation).In PV system design it is essential to know the amount of sunlight available at a particular location at a given time. The two common methods which characterize solar radiation are the solar radiance (or radiation) and solar insolation. The solar radiance is an instantaneous power density in units of kW/m^2. The solar radiance varies throughout the day from 0 kW/m^2 at night to a maximum of about 1 kW/m^2. The solar radiance is strongly dependent on location and local weather.

Prerequisite knowledge for Complete understanding and learning of Topic:

Basics of Energy.

Detailed content of the Lecture:

An alternative method of measuring solar radiation, which is less accurate but also less expensive, is using a sunshine recorder. These sunshine recorders (also known as Campbell-Stokes recorders), measure the number of hours in the day during which the sunshine is above a certain level (typically 200 MW/cm^2). Data collected in this way can be used to determine the solar insolation by comparing the measured number of sunshine hours to those based on calculations and including several correction factors.

A final method to estimate solar insolation is cloud cover data taken from existing satellite images.

While solar irradiance is most commonly measured, a more common form of radiation data used in system design is the solar insolation. The solar insolation is the total amount of solar energy received at a particular location during a specified time period, often in units of kWh/(m^2 day).

While the units of solar insolation and solar irradiance are both a power density (for solar insolation the "hours" in the numerator are a time measurement as is the "day" in the denominator), solar insolation is quite different than the solar irradiance as the solar insolation is the instantaneous solar irradiance averaged over a given time period. Solar insolation data is commonly used for simple PV system design while solar radiance is used in more complicated PV system performance which calculates the system performance at each point in the day. Solar insolation can also be expressed in units of MJ/m^2 per year and other units and conversions are given in the units page.

Solar radiation for a particular location can be given in several ways including:

- Typical mean year data for a particular location
- Average daily, monthly or yearly solar insolation for a given location
- Global isoflux contours either for a full year, a quarter year or a particular month
- Sunshine hours data
- Solar Insolation Based on Satellite Cloud-Cover Data
- Calculations of Solar Radiation

Ultraviolet Measurements

For the measurement of sun and sky ultraviolet radiation in the wavelength interval 0.295 to 0.385 µm, which is particularly important in environmental, biological, and pollution studies the Total Ultraviolet Radiometer (Model TUVR) was developed. This instrument utilizes a photoelectric cell protected by a quartz window. A specially designed Teflon diffuser not only reduces the radiant flux to acceptable levels but also provides close adherence to the Lambert cosine law. An encapsulated narrow bandpass (interference) filter limits the spectral response of the photocell to the wavelength interval 0.295-.0385 µm.

Shortwave Measurements

As solar radiation passes through the earth's atmosphere, some of it is absorbed or scattered by air molecules, water vapor, aerosols, and clouds. The solar radiation that passes through directly to the earth's surface is called Direct Normal Irradiance (DNI). The radiation that has been scattered out of the direct beam is called Diffuse Horizontal Irradiance (DHI).

The direct component of sunlight and the diffuse component of skylight falling together on a horizontal surface make up Global Horizontal Irradiance (GHI). The three components have a geometrical relationship.

Direct radiation is best measured by use of a pyrheliometer, which measures radiation at normal incidence. The Normal Incidence Pyrheliometer (Model sNIP) consists of a wire wound thermopile at the base of a tube with a viewing angle of approximately 5° which limits the radiation that the thermopile receives to direct solar radiation only.

Video Content / Details of website for further learning (if any):

1. https://www.youtube.com/watch?v=WtZgsyhA294

Important Books/Journals for further learning including the page nos.:

Course Faculty

LECTURE HANDOUTS

EEE **II / III**

Course Name with Code : **19GES20 / RENEWABLE ENERGY SOURCES**

Course Faculty : **Mr.C.RAMKUMAR**

Unit : **2 – SOLAR ENERGY** **Date of Lecture:**

Topic of Lecture : Flat Plate and Concentrating Collectors

Introduction :

The difference between them is that concentrating collectors **have a bigger interceptor than** the absorber, while the non-concentrating collectors have them both with same sizes. Flat-plate and evacuated-tube solar collectors are used for domestic purposes, such as space heating, hot water or cooling

Prerequisite knowledge for Complete understanding and learning of Topic:

Basics of Energy.

Detailed content of the Lecture:

Although **solar panels** are the most known device when it comes to solar energy, Solar thermal collectors are also very efficient and are used to collect heat by absorbing sunlight. **Solar thermal** is also used for capturing solar radiation, which is energy in the form of electromagnetic radiation consisting of both infrared and ultraviolet waves. This can occur due to the huge quantity of sunlight that hits Earth's surface on a daily basis.Solar collectors can be either **non-concentrating** or **concentrating**.

Flat-Plate Collectors

Flat-plate solar collectors are the most common ones. They consist of an absorber, a transparent cover and insulation.The main use of the technology is usually in residential buildings where the demand for hot water is big and affects bills. Commercial application of flat-plate collectors is usually seen in car washes, laundromats, military laundry facilities or restaurants.

Solar water heating systems are expected to be much more **cost efficient**, especially for facilities with huge hot water demand (kitchens, laundries and etc.) Flat-plate solar collectors show a good price-performance ratio and also give a lot of mounting options (on the roof, within the roof itself or standalone).

Evacuated-Tube Collector

This is a type of a vacuum collector, its absorber strip is placed in an evacuated and pressure proof glass tube. The heat transfer fluid flows directly the absorber into a U-tube or in a tube-in-tube system. The heat pipe collector integrates a special fluid, which evaporates even at low temperatures, thus the steam rises in the individual heat pipes and warms up the fluid in the main pipe, generating heat. **Thermodynamic panels** are also based on such a refrigerant fluid but are exploiting the heat in the ambient air, and, therefore, are only suitable for hot water.The technology is very **reliable** as it has an estimated lifespan of 25 years. The vacuum that surrounds the outside of the tubes greatly reduces the risk of heat loss, therefore efficiency is greater than it is with flat-plate collectors.There are also solar collectors that can be used for generating electricity. Parabolic troughs, solar parabolic dishes and power towers are used in solar power stations or for research purposes.

Parabolic Trough

This specific type of solar collector is mainly used in solar power plants. The technology utilizes trough-shaped parabolic reflector to concentrate sunlight on an insulated tube or a heat pipe, placed in the focal point. Thus the generated heat is transferred to the boilers in the power station.

Parabolic Dish

What differentiates this technology is that with this solar collector, a few dishes can be utilized and they can concentrate solar energy at the same focal point. Like the other collectors, it's mainly used in solar power plants and also for researchers. The dish is aligned in a way that allows it to collect almost all of the solar radiation that hits Earth's surface. Most efficiency losses come because of slight imperfections in the shape of the dish. Losses due to weather conditions are usually minimal, however, on a rainy foggy day, sun rays are usually distributed in all directions.

Power Tower

A power tower is a big tower fenced by tracking mirrors called heliostats. They align themselves in order to track the sunlight, collect it and transfer it to the top of the tower, where the receiver is, the received heat is transferred to a power station below. The power tower makes it cheaper to cover much larger area with relatively inexpensive mirrors opposed to the traditional solar cells.However efficiency can be a problem as the power tower needs perfect weather conditions at almost all the time, while solar cells still produce very good amount of energy even when the sky is completely cloudy.

Solar Collectors or Solar Cells

Solar collectors are a great invention, however they are not quite perfect for the regular customer who just wants to generate his own electricity. The collectors need perfect weather conditions, which is hard to get in many parts of the world. On the other hand solar cells and panels are a perfect solution for the people who want to generate their own eco friendly energy. Even though price-wise they could end up costing you more, the government has launched schemes that benefits people who are willing to go solar.

Video Content / Details of website for further learning (if any):

1. https://www.youtube.com/watch?v=PyvP80UataI

Important Books/Journals for further learning including the page nos.:

Course Faculty

L13

LECTURE HANDOUTS

EEE

II/III

Course Name with Code : 19GES20/ Renewable Energy Sources

Course Faculty : Mr.C.RAMKUMAR

Unit : 2-Solar Energy **Date of Lecture:**

Topic of Lecture: Solar Direct Thermal Applications.

Introduction :

- Solar thermal energy can generate power 24hours a day. This is made possible as solar thermal power plants store the energy in the form of molten salt etc.
- Other forms of Renewable energy like solar PV and wind energy are intermittent in nature.

Prerequisite knowledge for Complete understanding and learning of Topic:

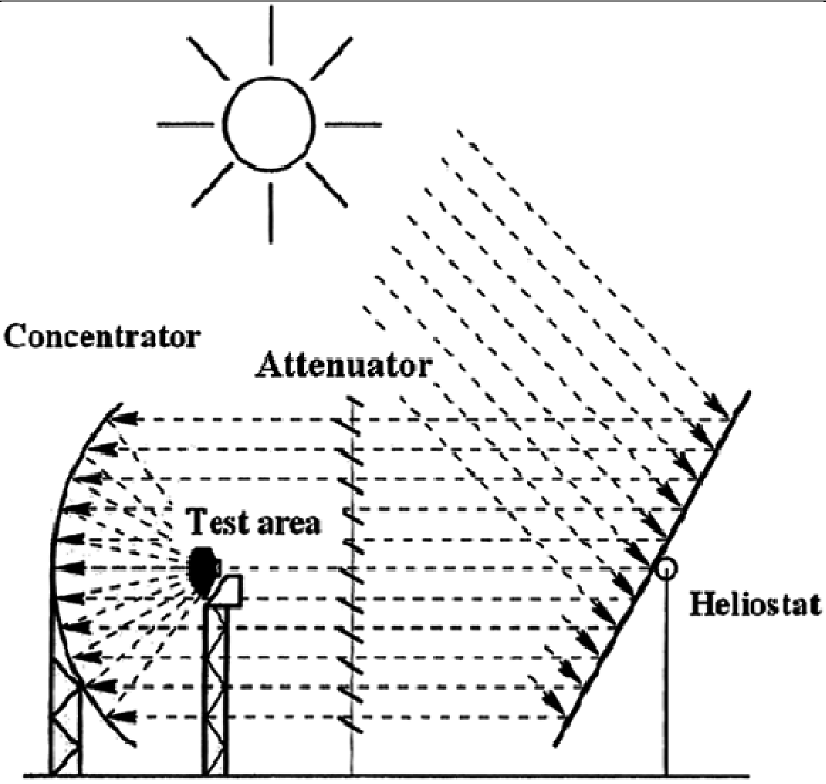
1.Environmental Science

2.Solar Radiation

Solar Direct Thermal Applications

In a Solar furnace, high temperature is obtained by concentrating the solar radiations onto a specimen using a number of heliostats (turn-able mirrors) arranged on a sloping surface. The solar furnace is used for studying the properties of ceramics at extremely high temperatures above the range measurable in laboratories with flames and electric currents.

Heating can be accomplished without any contamination and temperature can be easily controlled by changing the position of the material in focus. This is especially useful for metallurgical and chemical operations. Various property measurements are possible on an open specimen. An important future application of solar furnaces is the production of nitric acid and fertilizers from air.



Video Content / Details of website for further learning (if any):

https://www.e-education.psu.edu/eme807/node/651

https://www.youtube.com/watch?v=z60-59hJp4E

Important Books/Journals for further learning including the page nos.:

- G.D.Rai, 'Non-Conventional Energy Sources', Khanna Publishers , 2011. (Page No:142-144)

Course Faculty

L14

LECTURE HANDOUTS

EEE **II/III**

Course Name with Code : 19GES20/ Renewable Energy Sources

Course Faculty : Mr.C.RAMKUMAR

Unit : 2-Solar Energy **Date of Lecture:**

Topic of Lecture: Solar Thermal Power Generation

Introduction :
The process of converting solar energy into electricity so as to utilize its energy in day-to-day activities is given below:

- Absorption of energy carrying particles in Sun's rays called photons.
- Photovoltaic conversion, inside the solar cells.
- Combination of current from several cells. This step is necessary since a single cell has a voltage of less than 0.5 V.
- Conversion of the resultant DC to AC.

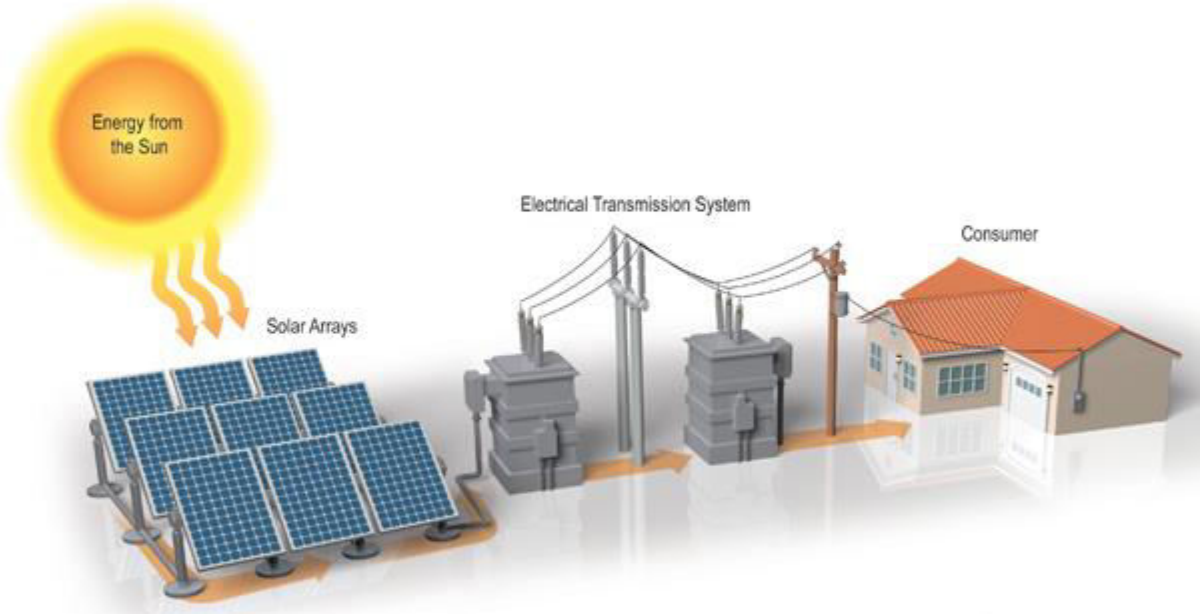
Prerequisite knowledge for Complete understanding and learning of Topic:
1.Solar Collectors

2.Energy Conversion Techniques

Solar Electric Power Generation

Electric energy or electricity can be produced directly from solar energy by means of photovoltaic cells. The photovoltaic cell is an energy conversion device which is used to convert photons of sunlight directly into electricity. It is made of semi conductors which absorb the photons received from the sun, creating free electrons with high energies.

These high energy free electrons are induced by an electric field, to flow out of the semiconductor to do useful work. This electric field in photovoltaic cells is usually provided by a p-n junction of materials which have different electrical properties. There are different fabrication techniques to enable these cells to achieve maximum efficiency.
These cells are arranged in parallel or series combination to form cell modules. Some of the special features of these modules are high reliability, no expenditure on fuel, minimum cost of maintenance, long life, portability, modularity, pollution free working etc.



Photovoltaic cells have been used to operate irrigation pumps, rail road crossing warnings, navigational signals, highway emergency call systems, automatic meteorological stations etc. in areas where it is difficult to lay power lines.They are also used for weather monitoring and as portable power sources for televisions, calculators, watches, computer card readers, battery charging and in satellites etc. Besides these, photovoltaic cells are used for the energisation of pump sets for irrigation, drinking water supply and for providing electricity in rural areas i.e. street lights etc.

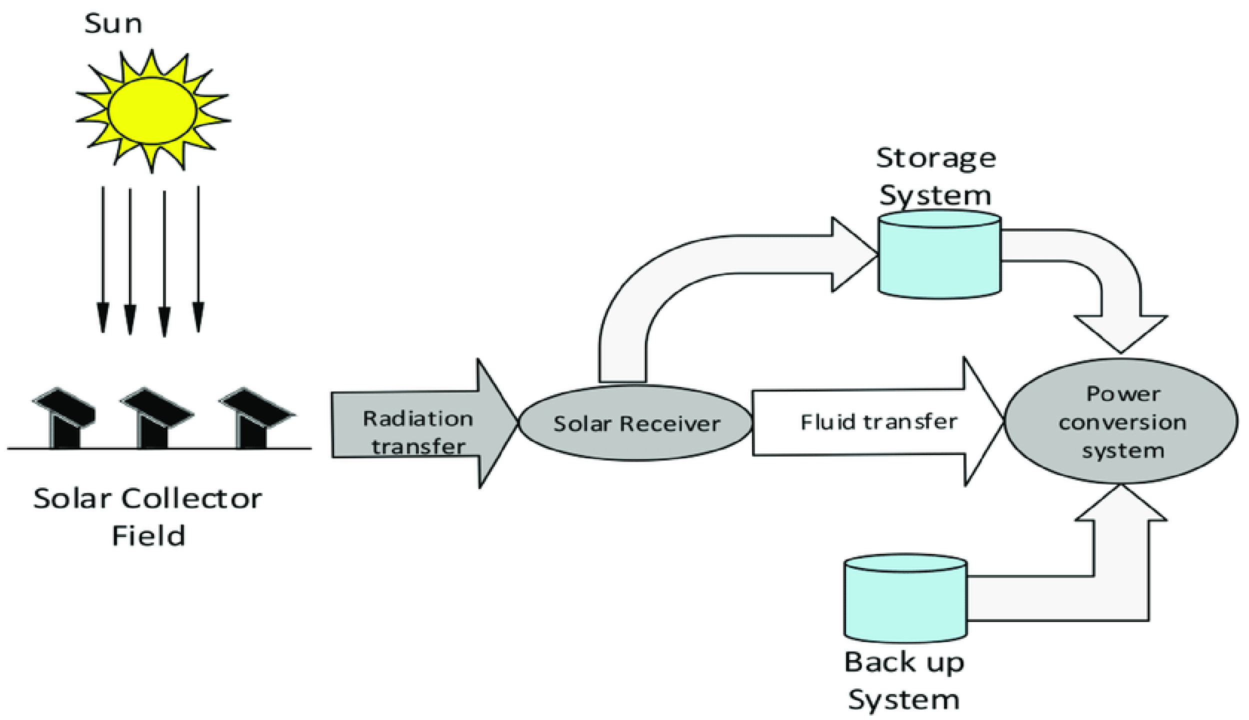
Solar Thermal Power Production

Solar thermal power production means the conversion of solar energy into electricity through thermal energy. In this procedure, solar energy is first utilized to heat up a working fluid, gas, water or any other volatile liquid. This heat energy is then converted into mechanical energy m a turbine. Finally a conventional generator coupled to a turbine converts this mechanical energy into electrical energy.

Production of Power through Solar Ponds:

A solar pond is a natural or artificial body of water utilized for collecting and absorbing solar radiation and storing it as heat. It is very shallow (5-10 cm deep) and has a radiation absorbing (black plastic) bottom. It has a curved fiber glass cover over it to permit the entry of solar radiation but reduces losses by radiation and convection (air movement). Loss of heat to the ground is minimized by providing a bed of insulating material under the pond.

Solar ponds utilize water for collecting and storing the solar energy which is used for many applications such as space heating, industrial process heating and to generate electricity by driving a turbine powered by evaporating an organic fluid with a low boiling point.



Video Content / Details of website for further learning (if any):

1. https://dir.indiamart.com/impcat/solar-thermal-power-plant.html
2. https://onlinecourses.nptel.ac.in/noc20_me10/preview

Important Books/Journals for further learning including the page nos.:

- G.D.Rai, 'Non-Conventional Energy Sources', Khanna Publishers, 2011. (Page No:125-129)

Course Faculty

LECTURE HANDOUTS

L15

EEE

II/III

Course Name with Code : **19GES20/ Renewable Energy Sources**

Course Faculty : **Mr.C.RAMKUMAR**

Unit : **2-Solar Energy** **Date of Lecture:**

Topic of Lecture: Fundamentals of Solar Photo Voltaic Conversion

Introduction :

- Solar thermal energy can generate power 24hours a day. This is made possible as solar thermal power plants store the energy in the form of molten salt etc.
- Other forms of Renewable energy like solar PV and wind energy are intermittent in nature.

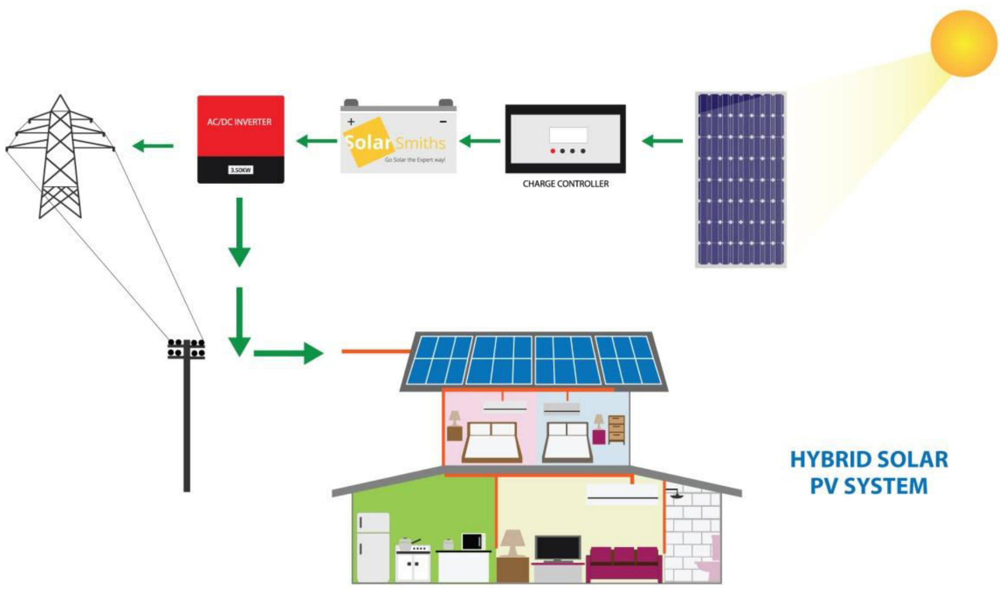
Prerequisite knowledge for Complete understanding and learning of Topic:

1.Environmental Science

2.Solar Radiation

Fundamentals of Solar Photo Voltaic Conversion

Solar energy is the energy obtained by capturing heat and light from the Sun. Energy from the Sun is referred to as solar energy. Technology has provided a number of ways to utilize this abundant resource. It is considered a green technology because it does not emit greenhouse gases. Solar energy is abundantly available and has been utilized since long both as electricity and as a source of heat.



Solar technology can be broadly classified as −

- **Active Solar** − Active solar techniques include the use of photovoltaic systems, concentrated solar power and solar water heating to harness the energy. Active solar is directly consumed in activities such as drying clothes and warming of air.
- **Passive Solar** − Passive solar techniques include orienting a building to the Sun, selecting materials with favorable thermal mass or light-dispersing properties, and designing spaces that naturally circulate air.

Conversion of Solar Energy

The solar energy is the energy obtained by capturing heat and light from the Sun. The method of obtaining electricity from sunlight is referred to as the Photovoltaic method. This is achieved using a semiconductor material.

The other form of obtaining solar energy is through thermal technologies, which give two forms of energy tapping methods.

- The first is solar concentration, which focuses solar energy to drive thermal turbines.
- The second method is heating and cooling systems used in solar water heating and air conditioning respectively.

The process of converting solar energy into electricity so as to utilize its energy in day-to-day activities is given below −

- Absorption of energy carrying particles in Sun's rays called photons.
- Photovoltaic conversion, inside the solar cells.
- Combination of current from several cells. This step is necessary since a single cell has a voltage of less than 0.5 V.
- Conversion of the resultant DC to AC.

Video Content / Details of website for further learning (if any):

https://www.coursera.org/lecture/photovoltaic-solar-energy/3-solar-cell-fundamentals-oEvwK

https://nptel.ac.in/courses/115/107/115107116/

Important Books/Journals for further learning including the page nos.:

- G.D.Rai, 'Non-Conventional Energy Sources', Khanna Publishers , 2011. (Page No:178-180)

Course Faculty

L16

LECTURE HANDOUTS

EEE **II/III**

Course Name with Code : **19GES20/ Renewable Energy Sources**

Course Faculty : **Mr.C.RAMKUMAR**

Unit : **2-Solar Energy** **Date of Lecture:**

Topic of Lecture: Solar Cells

Introduction :
The process of converting solar energy into electricity so as to utilize its energy in day-to-day activities is given below −

- Absorption of energy carrying particles in Sun's rays called photons.
- Photovoltaic conversion, inside the solar cells.
- Combination of current from several cells. This step is necessary since a single cell has a voltage of less than 0.5 V.
- Conversion of the resultant DC to AC.

Prerequisite knowledge for Complete understanding and learning of Topic:
1.Solar Radiation

2.Energy Conversion Techniques

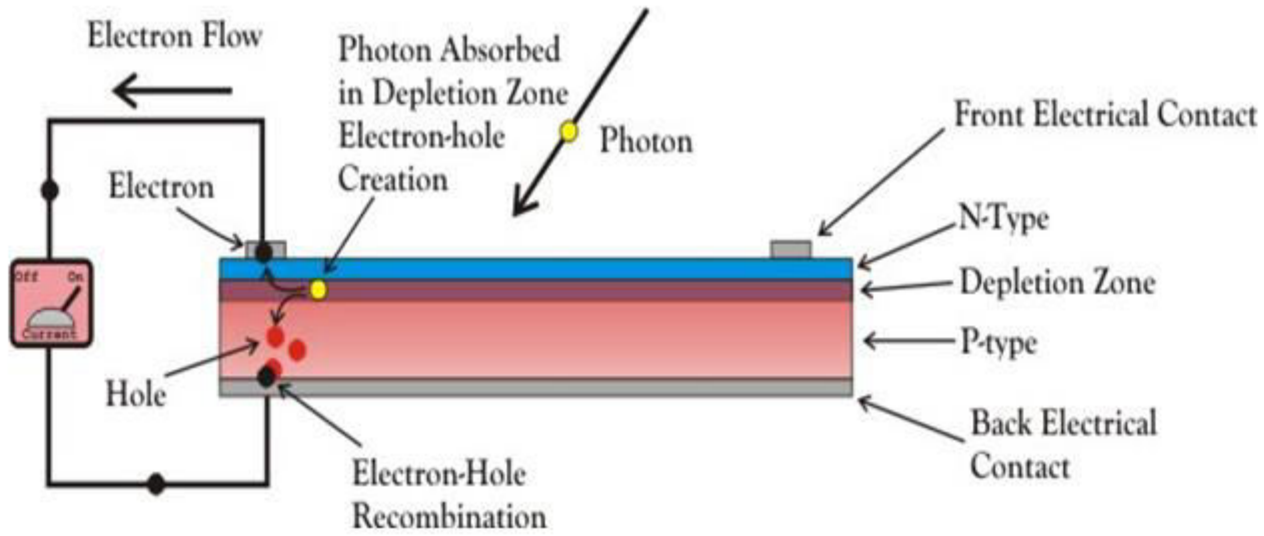
Solar Cells

A **solar cell** (also known as a photovoltaic cell or PV cell) is defined as an electrical device that converts light energy into electrical energy through the photovoltaic effect. A solar cell is basically a p-n junction diode. Solar cells are a form of photoelectric cell, defined as a device whose electrical characteristics – such as current, voltage, or resistance – vary when exposed to light.

Individual solar cells can be combined to form modules commonly known as solar panels. The common single junction silicon solar cell can produce a maximum open-circuit voltage of approximately 0.5 to 0.6 volts. By itself this isn't much – but remember these solar cells are tiny. When combined into a large solar panel, considerable amounts of renewable energy can be generated.

Construction of Solar Cell

A solar cell is basically a junction diode, although its construction it is little bit different from conventional p-n junction diodes. A very thin layer of p-type semiconductor is grown on a relatively thicker n-type semiconductor. We then apply a few finer electrodes on the top of the p-type semiconductor layer.These electrodes do not obstruct light to reach the thin p-type layer. Just below the p-type layer there is a p-n junction. We also provide a current collecting electrode at the bottom of the n-type layer. We encapsulate the entire assembly by thin glass to protect the **solar cell** from any mechanical shock.



Working Principle of Solar Cell

When light reaches the p-n junction, the light photons can easily enter in the junction, through very thin p-type layer. The light energy, in the form of photons, supplies sufficient energy to the junction to create a number of electron-hole pairs. The incident light breaks the thermal equilibrium condition of the junction. The free electrons in the depletion region can quickly come to the n-type side of the junction.Similarly, the holes in the depletion can quickly come to the p-type side of the junction. Once, the newly created free electrons come to the n-type side, cannot further cross the junction because of barrier potential of the junction.

Similarly, the newly created holes once come to the p-type side cannot further cross the junction became of same barrier potential of the junction. As the concentration of electrons becomes higher in one side, i.e. n-type side of the junction and concentration of holes becomes more in another side, i.e. the p-type side of the junction, the p-n junction will behave like a small battery cell. A voltage is set up which is known as photo voltage. If we connect a small

load across the junction, there will be a tiny current flowing through it.
Video Content / Details of website for further learning (if any): https://www.energy.gov/eere/solar/solar-photovoltaic-technology-basics https://news.energysage.com/solar-panels-work/
Important Books/Journals for further learning including the page nos.: ➢ G.D.Rai, 'Non-Conventional Energy Sources', Khanna Publishers, 2011. (Page No:47,73)

Course Faculty

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LECTURE HANDOUTS

EEE **II/III**

Course Name with Code : **19GES20/ Renewable Energy Sources**

Course Faculty : **Mr.C.RAMKUMAR**

Unit : **2-Solar Energy** **Date of Lecture:**

Topic of Lecture: Solar PV Power Generation

Introduction :

The process of converting solar energy into electricity

Photovoltaics (PV) is the conversion of light into electricity using semiconducting materials that exhibit the photovoltaic effect, a phenomenon studied in physics, photochemistry, and electrochemistry.

The photovoltaic effect is commercially utilized for electricity generation and as photosensors.

A photovoltaic system employs solar modules, each comprising a number of solar cells, which generate electrical power.

PV installations may be ground-mounted, rooftop-mounted, wall-mounted or floating. The mount may be fixed or use a solar tracker to follow the sun across the sky.

Some hope that photovoltaic technology will produce enough affordable sustainable energy to help mitigate global warming .

Solar PV has specific advantages as an energy source: once installed, its operation generates no pollution and no greenhouse gas emissions, it shows simple scalability in respect of power needs and silicon has large availability in the Earth's crust, although other materials required in PV system manufacture such as silver will eventually constrain further growth in the technology.

Prerequisite knowledge for Complete understanding and learning of Topic:

1.Solar Radiation

2.Energy Conversion Techniques

Solar PV Power Generation

Photovoltaic systems have long been used in specialized applications as stand-alone installations and grid-connected PV systems have been in use since the 1990s.Photovoltaic modules were first mass-produced in 2000, when German environmentalists and the Euro solar organization received government funding for a ten thousand roof program.

Decreasing costs has allowed PV to grow as an energy source. This has been partially driven by massive Chinese government investment in developing solar production capacity since 2000, and achieving economies of scale. Much of the price of production is from the key component polysilicon, and most of the world supply is produced in China, especially in Xinjiang.

Beside the subsidies, the low prices of solar panels in the 2010s has been achieved through the low price of energy from coal and cheap labour costs in Xinjiang, as well as improvements in manufacturing technology and efficiency. Advances in technology and increased manufacturing scale have also increased the efficiency of photovoltaic installations. Net metering and financial incentives, such as preferential feed-in tariffs for solar-generated electricity, have supported solar PV installations in many countries.

Panel prices dropped by a factor of 4 between 2004 and 2011. Module prices dropped 90% of over the 2010s, but began increasing sharply in 2021.

In 2019, worldwide installed PV capacity increased to more than 635 gigawatts (GW) covering approximately two percent of global electricity demand.After hydro and wind powers, PV is the third renewable energy source in terms of global capacity. In 2019 the International Energy Agency expected a growth by 700 - 880 GW from 2019 to 2024. In some instances, PV has offered the cheapest source of electrical power in regions with a high solar potential, with a bid for pricing as low as 0.01567 US$/kWh in Qatar in 2020.

Effect of the temperature

The performance of a photovoltaic module depends on the environmental conditions, mainly on the global incident irradiance G on the module plane. However, the temperature T of the p–n junction also influences the main electrical parameters: the short-circuit current ISC, the open-circuit voltage VOC, and the maximum power Pmax. The first studies about the behavior of PV cells under varying conditions of G and T date back several decades ago.1-4 In general, it is known that VOC shows a significant inverse correlation with T, whereas for ISC that correlation is direct, but weaker, so that this increment does not compensate for the decrease of VOC. As a consequence, Pmax reduces when T increases. This correlation between the output power of a solar cell and its junction working temperature depends on the semiconductor material,2 and it is due to the influence of T on the concentration, lifetime, and mobility of the intrinsic carriers, that is, electrons and holes, inside the PV cell.

The temperature sensitivity is usually described by some temperature coefficients, each one expressing the derivative of the parameter it refers to with respect to the junction temperature.

Video Content / Details of website for further learning (if any):

https://www.energy.gov/eere/solar/solar-photovoltaic-technology-basics

https://news.energysage.com/solar-panels-work/

Important Books/Journals for further learning including the page nos.:

- G.D.Rai, 'Non-Conventional Energy Sources', Khanna Publishers , 2011. (Page No:47,73)

Course Faculty

LECTURE HANDOUTS

L18

EEE

II/III

Course Name with Code : **19GES20/ Renewable Energy Sources**

Course Faculty : **Mr.C.RAMKUMAR**

Unit : **2-Solar Energy** **Date of Lecture:**

Topic of Lecture: Solar PV Applications.

Introduction :

The process of converting solar energy into electricity so as to utilize its energy in day-to-day activities is given below −

- Absorption of energy carrying particles in Sun's rays called photons.
- Photovoltaic conversion, inside the solar cells.
- Combination of current from several cells. This step is necessary since a single cell has a voltage of less than 0.5 V.
- Conversion of the resultant DC to AC.

Prerequisite knowledge for Complete understanding and learning of Topic:

1.Solar cell

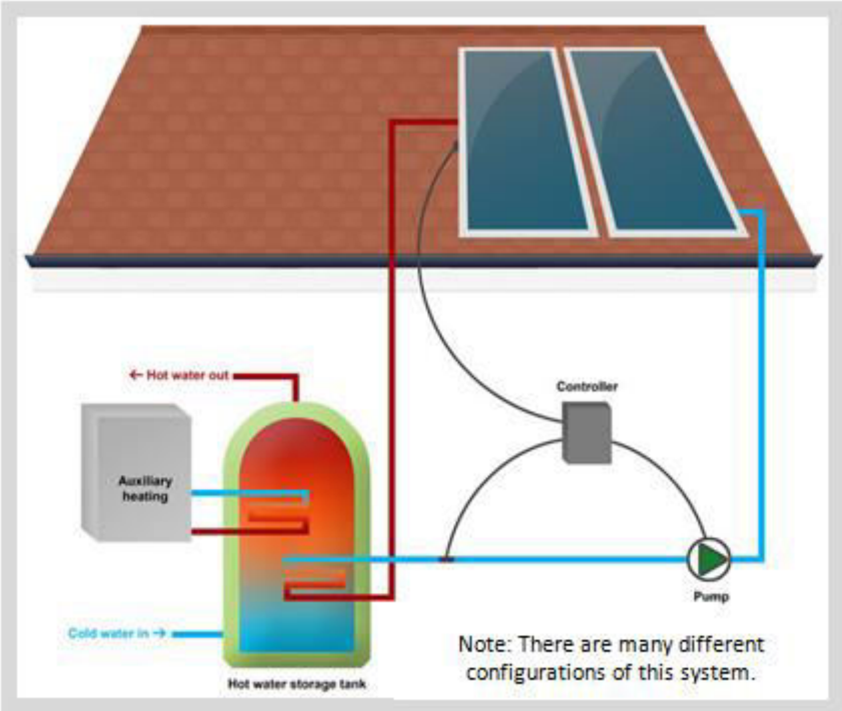
2.Solar Radiation

Solar PV Applications

(1)Solar Water Heating

A solar water heating unit comprises a blackened flat plate metal collector with an associated metal tubing facing the general direction of the sun. The plate collector has a transparent glass cover above and a layer of thermal insulation beneath it.

The metal tubing of the collector is connected by a pipe to an insulated tank that stores hot water during cloudy days. The collector absorbs solar radiations and transfers the heat to the water circulating through the tubing either by gravity or by a pump.This hot water is supplied to the storage tank via the associated metal tubing. This system of water heating is commonly used in hotels, guest houses, tourist bungalows, hospitals, canteens as well as domestic and industrial units.

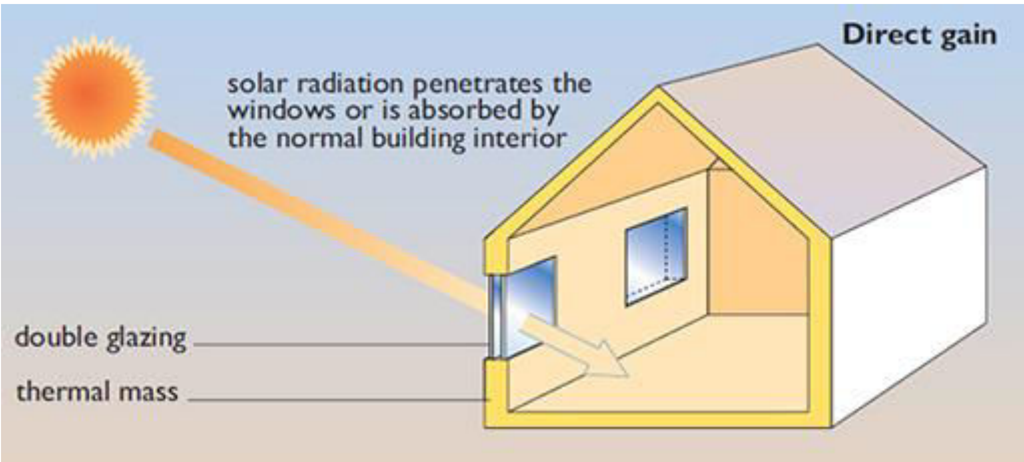


An active solar water heating system.
Source: Emerald Energy Solutions.

(2)Solar Heating of Buildings

Solar energy can be used for space heating of buildings in many ways namely:
(a) Collecting the solar radiation by some element of the building itself i.e. solar energy is admitted directly into the building through large South-facing windows.

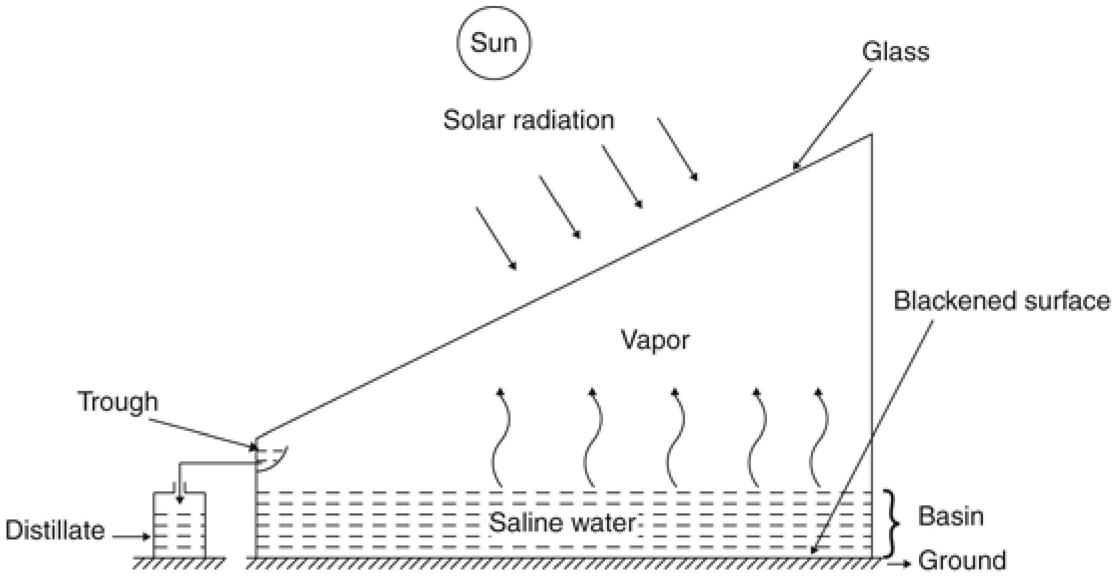
(b) Using separate solar collectors which may heat either water or air or storage devices which can accumulate the collected solar energy for use at night and during inclement days.



When the building requires heat then from these collectors or storage devices, the heat is transferred by conventional equipment such as fan, ducts, air outlets, radiators and hot air registers etc. to warm up the living spaces of a building.When the building does not require heat, the heated air or water from the collector can be moved to the heat storage device such as well insulated water tank or other heat holding material. For inclement days, an auxiliary heating system using gas, oil or electricity is required as a backup system.

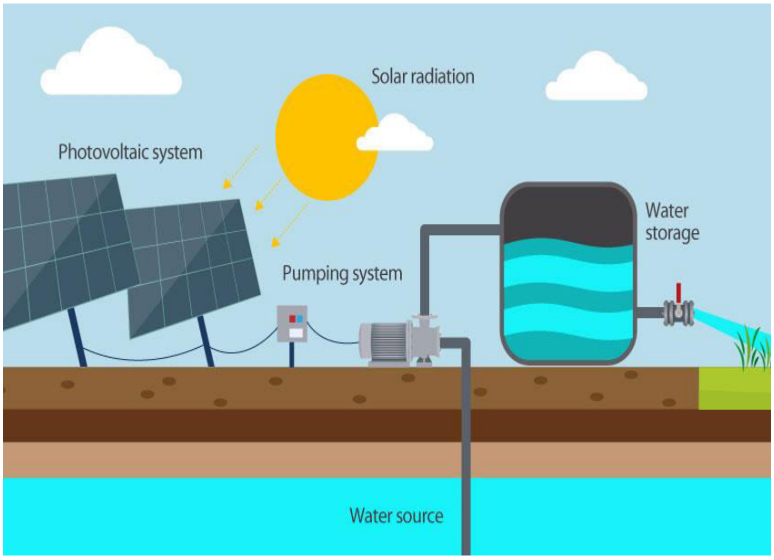
(3)Solar-distillation

In arid semi and or coastal areas there is scarcity of potable water. The abundant sunlight in these areas can be used for converting saline water into potable distilled water by the method of solar distillation. In this method, solar radiation is admitted through a transparent air tight glass cover into a shallow blackened basin containing saline water.



Solar radiation passes through the covers and is absorbed and converted into heat in the blackened surface causing the water to evaporate from the brine (impure saline water). The vapors produced get condensed to form purified water in the cool interior of the roof.The condensed water flows down the sloping roof and is collected in the troughs placed at the bottom and from there into a water storage tank to supply potable distilled water in areas of scarcity, in colleges, school science laboratories, defense labs, petrol pumps, hospitals and pharmaceutical industries. Per liter distilled water cost obtained by this system is cheaper than distilled water obtained by other electrical energy-based processes.

(4)**Solar-pumping**



In solar pumping, the power generated by solar-energy is utilized for pumping water for irrigation purposes. The requirement for water pumping is greatest in the hot summer months which coincide with the increased solar radiations during this period and so this method is most appropriate for irrigation purpose. During periods of inclement weather when solar radiations are low then the requirement for water pumping is also relatively less as the transpiration losses from the crops are also low.

Video Content / Details of website for further learning (if any):

https://www.youtube.com/watch?v=8S5hNYepw14

https://interestingengineering.com/solar-water-still-the-no-cost-method-to-distill-pure-water

Important Books/Journals for further learning including the page nos.:

- G.D.Rai, 'Non-Conventional Energy Sources', Khanna Publishers , 2011. (Page No:146-197)

Course Faculty

MUTHAYAMMAL ENGINEERING COLLEGE

(An Autonomous Institution)

(Approved by AICTE, New Delhi, Accredited by NAAC & Affiliated to Anna University)
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LECTURE HANDOUTS

EEE **II/III**

Course Name with Code : **19GES20/ Renewable Energy Sources**

Course Faculty : **Mr.C.RAMKUMAR**

Unit : **3-Wind Energy** **Date of Lecture:**

Topic of Lecture: Wind Energy Estimation

Introduction :

- Winds are caused by pressure difference between different regions. They carry enormous quantity of energy.
- Regions in which strong winds prevails for a sufficient time during the year can profitably use wind energy for different purpose.

Prerequisite knowledge for Complete understanding and learning of Topic:

1.Basics of Civil & Mechanical

2.Environmental Science

Wind Energy Estimation

The Nature of Wind

The circulation of air in the atmosphere is caused by the non-uniform heating of the earth's surface by the sun. The air immediately above a warm area expands; it is forced upward by cool, denser air which flows in from surrounding areas causing wind. The nature of the terrain, the degree of cloud and the angle of the sun in the sky are all factors which influences this process.

In general, during the day the air above the land mass tends to heat up more rapidly than the air over water. In coastal regions this manifests itself in a strong onshore wind. At night the process is reversed because the air cools down more rapidly over the land and the breeze therefore blows off shore. Despite the wind's intermittent nature, wind patterns at any particular site remain remarkably constant year by year. Average wind speeds are greater in hilly and costal area than they are well inland. The winds also tend to blow more consistently and with greater strength over the surface of the water where there is a less surface drag.

The Power in Wind

Wind possesses energy by virtue of its motion. Any device capable of slowing down the mass of moving air, like a sail or propeller, can extract part of the energy and convert is into useful work.

There are three factors determine the output power generated from the wind mill, they are

(1) The wind speed

(2) The cross section of wind swept by rotor, and

(3) The overall conversion efficiency of rotor, transmission system and generator or pump.

No device, however well-designed, can extract all of the wind's energy because the wind would have to be brought to a halt and this would prevent the passage of more air through the rotor. The most that is possible is for the rotor to decelerate to whole horizontal column of intercepted air to about one-third of its free velocity. A 100% efficient aero generator would therefore only be able to convert up to a maximum of around 60% of the available energy in wind into mechanical energy. A well-designed blades will typically extract 70% of the theoretical maximum, but losses incurred in the gear box, transmission system and generator or pump could decrease overall wind turbine efficiency to 35% or less.

Calculation of Power in the Wind

The power in the wind can be computed by using of Kinetics (Kinetic means relating to or resulting from motion). The wind mill works on the principle of converting Kinetic energy of the wind to mechanical energy. We know that power is equal to energy per unit time. The energy available is the kinetic energy of the wind. The kinetic energy of any particle is equal to one half its mass times the square of its velocity.

Kinetic Energy of particle = ½ mv2

Where,

m : Mass of particle (kg)

v : Velocity of particle (m/s)

The amount of air passing in unit time, through an area 'A', with velocity 'V' is A x V, and its mass 'm' is equal to its volume multiplied by its density 'ρ' of air.

$$m = \rho AV$$

Where, m is the mass of air traversing the area 'A' swept by the rotating blades of a wind mill type generator.

Substituting Equ. (5.2) in Equ. (5.1),

We get,

$$\text{Kinetic Energy} = \frac{1}{2}\rho AV \times V^2$$

$$= \frac{1}{2}\rho AV^3 \text{ (Watts)} \quad \ldots (5.3)$$

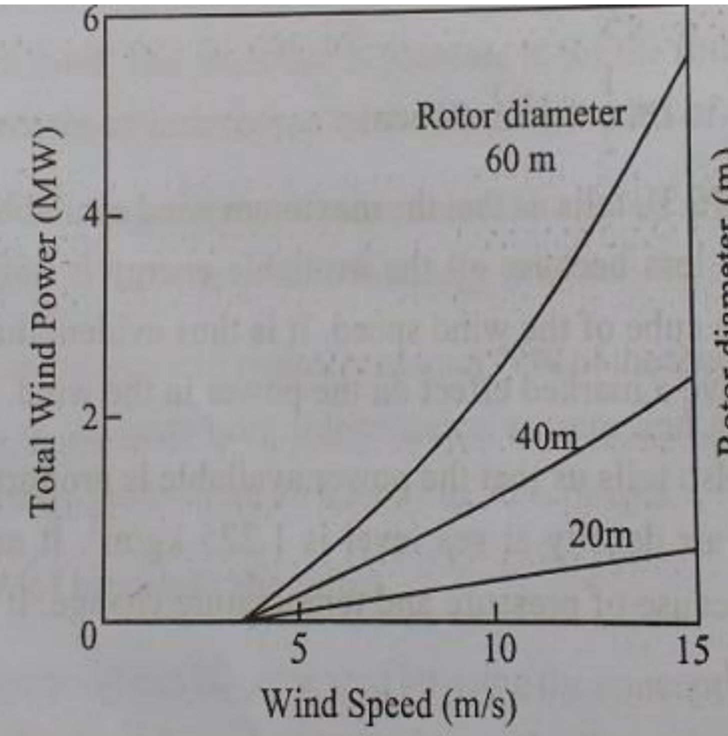

Fig. 5.3 Power variation corresponds to combined effect of rotor diameter and wind speed

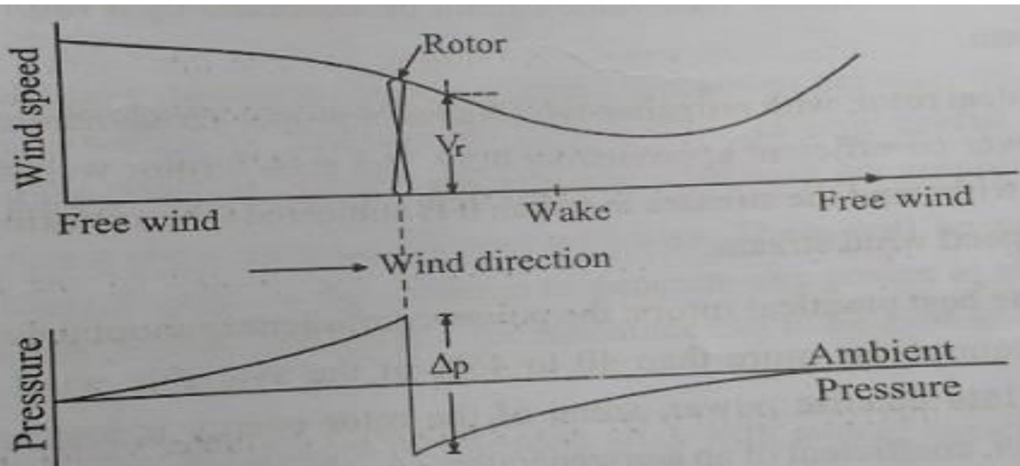

Fig. 5.4 Condition in traversing a wind power.

Power Coefficient

The fraction of the free-flow wind power that can be extracted by the rotor is called the power co-efficient; Thus,

Power Coefficient = Power of wind rotor / Power available in the wind

Where, power available is calculated from the air density, rotor diameter and free wind speed as discussed earlier. The maximum theoretical power coefficient is equal to 16/27 or 0.593. This value cannot be exceeded by a rotor in free-flow wind-stream.An ideal rotor, with propeller-type blades of proper aerodynamic design, would have a power co-efficient approaching 0.59. But such a rotor would not be strong enough to withstand the stresses to which it is subjected when rotating at a high rate in a high-speed wind stream.

Video Content / Details of website for further learning (if any): https://www.youtube.com/watch?v=FAvUxcMbch0 https://www.evwind.es/2009/10/24/wind-energy-or-wind-power-the-basics/1932
Important Books/Journals for further learning including the page nos.: ➢ G.D.Rai, 'Non-Conventional Energy Sources', Khanna Publishers , 2011. (Page No:245-250)

Course Faculty

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L20

LECTURE HANDOUTS

EEE

II/III

Course Name with Code : **19GES20/ Renewable Energy Sources**

Course Faculty : **Mr.C.RAMKUMAR**

Unit :**3-Wind Energy** **Date of Lecture:**

Topic of Lecture: Types of Wind Energy Systems

Introduction :

- Wind result from air in motion. Air in motion arises from a pressure gradient. On a global basis one primary forcing function causing surface winds from the poles towards the equator, and this low this low density heated air is buoyed up.
- At the surface it is displaced by cooler more dense higher pressure air flowing from the poles. In the upper atmosphere near the equator the air thus tend to flow back toward the poles and away from the equator.

Prerequisite knowledge for Complete understanding and learning of Topic:

1.Basics of Civil & Mechanical

2.Engineering Physics

Types of Wind Energy Systems

The fact that the wind is variable and intermittent source of energy is immaterial for some application such as pumbing water for land drainage-provided, of course, that there is a broad match between the energy supplied over any critical period and the energy required. If the wind blows, the job gets done; if it does not, the job waits. However, for many of the uses to which electricity is put, the interruption of supply may be highly inconvenient. Operators or users of wind turbines must ensure that there is some from of back-up can take the form of

(1) Battery storage

(2) Connection with the local electricity distribution systems, or

(3) A stand by generator powered by liquid or gaseous fuels

For utility responsible for public supply, the integration of medium sized and large wind turbines into their distribution network could required some additional plant which is capable of responding quickly to meet fluctuating demand.

1. Small Producers

Private citizens in several countries have won to right to operate wind generator and other renewable energy systems and to export power to the grid. For most small wind generators this requires that the output is conditioned, so that in the frequency and phase of the mains supply. Only few small units are designed to maintain a constant rotational rate, so that can be synchronized to the mains frequency and feed electricity directly into the grid. Most current (DC) or variable output Alternating current (AC).

Power conditioning is readily achieved using an electronic black-box called a “Synchronous Inverter” and although this is an expensive item of equipment, it does eliminate the need for batteries and for conversion of home appliances to run on DC. Where there is no grid connection, electricity that is surplus to immediately requirements must be stored on site using heavy duty batteries. It can be recovered later when the demand exceeds the supply. An alternative is to dump it (by generating and dissipating heat) or better, to convert it into heat that can be stored, for example as hot water in a well insulated tank.

2. Large Producers

Large and medium-sized wind generators are designed to give a stable and constant electrical output over a wide range of wind speeds and to feed current directly into the grid, they operate primarily as fuel savers, reducing the utility’s total fuel burn.

The choice of generator type depends on the size of the local distribution grid and its associated generating capacity.

An induction generator would normally be used where there is a significant amount of other generating capacity (which could provide the necessary reactive power for excitation). Induction generators are robust and reliable and require minimal control equipment.

For isolated networks where other local generating capacity is limited, a synchronous generator is more appropriate. Synchronous generator are more complex and therefore more expensive than induction machines.

Video Content / Details of website for further learning (if any):

https://www.eia.gov/energyexplained/wind/types-of-wind-turbines.php

https://www.awea.org/wind-101/basics-of-wind-energy

Important Books/Journals for further learning including the page nos.:

- G.D.Rai, ‘Non-Conventional Energy Sources’, Khanna Publishers , 2011. (Page No:240-245)

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LECTURE HANDOUTS

EEE **II/III**

Course Name with Code : **19GES20/ Renewable Energy Sources**

Course Faculty : **Mr.C.RAMKUMAR**

Unit : **3-Wind Energy** **Date of Lecture:**

Topic of Lecture : Types of Wind Energy Systems

Introduction :

Wind possesses energy by virtue of its motion. Any device capable of slowing down the mass of moving air, like a sail or propeller, can extract part of the energy and convert is into useful work.

Prerequisite knowledge for Complete understanding and learning of Topic:

1.Basics of Civil & Mechanical

2.Environmental Science

Types of Wind Energy Systems

3. Lift and Drag Force

The extraction of power, and hence energy, from the wind depends on creating certain forces and applying them to rotate (or to translate) a mechanism. There are two primary mechanisms for producing forces from the wind: Lift and Drag. By definition of Lift forces act perpendicular to the air flow, while drag forces act in the direction flow. Lift forces are produced by changing the velocity of the air stream flowing over either side of the lifting surface. Speeding up the air flow causes the pressure to drop, while slowing the air stream down leads to increase in pressure.

In other words, any change in velocity generates a pressure difference across the lifting surface. This pressure difference produces a force that begins to act on the high pressure side and moves towards the low pressure side of the lifting surface which is called an airfoil. A Good airfoil has a high lit/drag ratio, in some cases it can generate lift forces perpendicular to the air stream direction that are 30 times as great as the drag force parallel to the flow. The lift increases as the angle formed at the junction of the airfoil and the air stream (the angle of attack) becomes less and less acute, upon the point where the angle of the airflow on the low pressure side becomes excessive. When this happens, the air flow breaks away from the low pressure side. A lot of turbulence ensues, the lit decreases and the drag increases quite substantially; this phenomenon is known as Stalling.

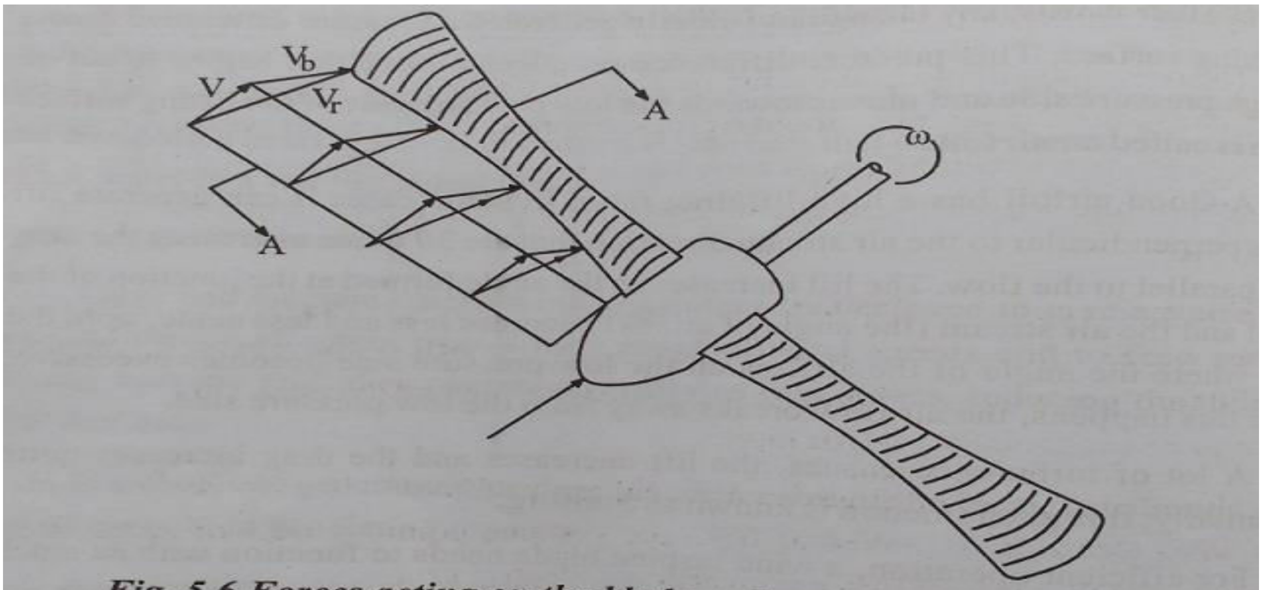

Fig. 5.6 Forces acting on the blade and cross-section across A–A.

For efficient operation, a wind turbine blade needs to function with as much lift and as little drag as possible because drag dissipates energy. As lift does not involves anything more complex than deflecting the air flow, it is usually an efficient process. The design of each wind turbine species the angle at which the air foil should bet set to achieve the maximum lift to drag ratio. In addition to airfoil, there are two other mechanisms for creating lift. One is the so-called Magnus Effect, caused by spinning a cylinder in an air stream at a high-speed of rotation. The spinning's slows down the air speed on the side where the cylinder is moving into wind and increases it on the other side; the result is similar to an airfoil. This principle has been put to practical use in one or two cases but is not generally employed. The second way is to blow air through narrow slots in a cylinder, so that it emerges tangentially; this is known as a Thwaits Slot. Thwaits Slots also creates a rotation (or circulation) of airflow, which in turn generate lift. Because the lift drag ratio of airfoils is generally much better than those of rotating or slotted cylinders, the latter techniques probably have little practical potential. Fig. 5.6 and Fig. 5.7 shows the forces acting on the blade and cross section across A-A. The wind mill blade 'sees' the resultant vector 'Vf'. The blades need to be twisted because 'r' varies in proportion to radius.

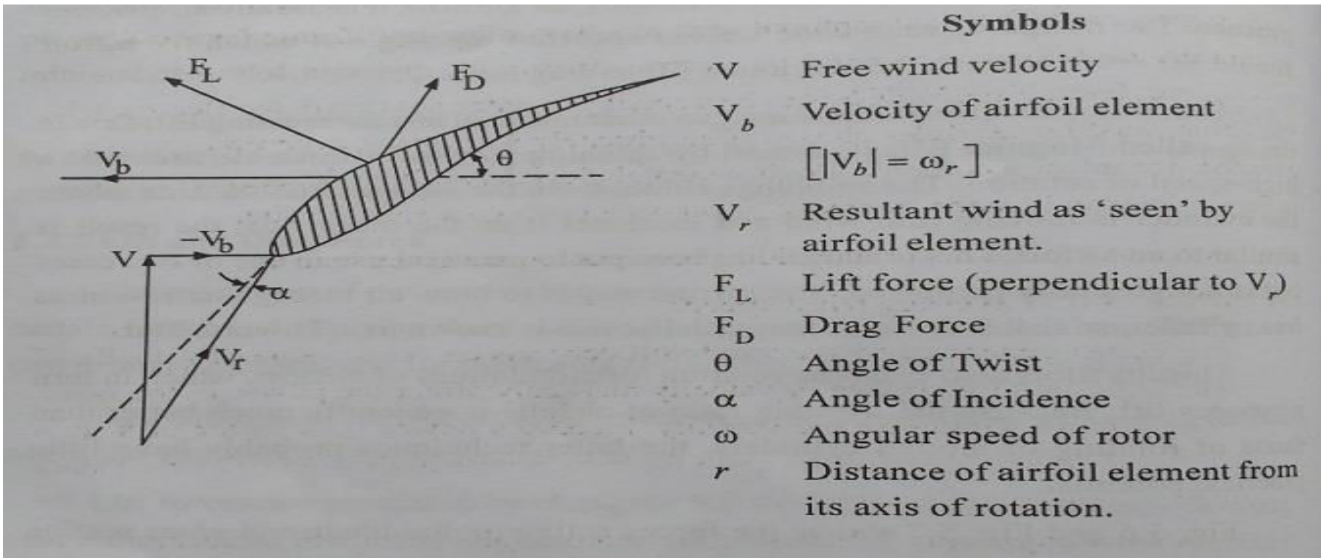

Fig. 5.7 Forces acting on the blade and cross - section across A–A.

Video Content / Details of website for further learning (if any): https://www.eia.gov/energyexplained/wind/types-of-wind-turbines.php https://www.awea.org/wind-101/basics-of-wind-energy
Important Books/Journals for further learning including the page nos.: ➢ G.D.Rai, 'Non-Conventional Energy Sources', Khanna Publishers , 2011. (Page No:240-245)

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LECTURE HANDOUTS **L22**

EEE **II/III**

Course Name with Code : **19GES20/ Renewable Energy Sources**

Course Faculty : **Mr.C.RAMKUMAR**

Unit : **3-Wind Energy** **Date of Lecture:**

Topic of Lecture: Performance of Wind Machines

Introduction :

- In general, during the day the air above the land mass tends to heat up more rapidly than the air over water. In coastal regions this manifests itself in a strong onshore wind.
- At night the process is reversed because the air cools down more rapidly over the land and the breeze therefore blows off shore.

Prerequisite knowledge for Complete understanding and learning of Topic:

1.Basics of Civil & Mechanics

2.Engineering Physics

Performance of Wind Machines

WECS efficiency is of interest to both aerogenerator designers and system engineers. As WECS is a capital intensive technology, it is desirable for the overall wind electric plant to have the highest efficiency possible, thus optimally utilizing capital resources and minimizing the busbar electric energy cost.

The overall conversion efficiency, µoof an aerogenerator of the general type is

$$\eta_0 = \frac{\text{Useful Output Power}}{\text{Wind Power Input}} = \eta_A \cdot \eta_G \cdot \eta_C \cdot \eta_{Gen}$$

Where,

η_A → Efficiency of the aeroturbine,

η_G → Efficiency of gearing,

η_C → Efficiency of the mechanical coupling, and

η_{Gen} → Efficiency of the generator.

Above equation shows an application of cascaded energy conversion, from which overall efficiency will be strongly determined by the lowest efficiency converter in the cascade. For the aerogenerator this is the aeroturbine; the efficiency of the remaining three elements can be made quite high but less than 100 percent. It is now evident why so much emphasis is placed on the efficiency of the aeroturbine in wind literature. Consider an arbitrary aeroturbine (Here Aero turbine is not equal to aerogenerator) of cross-sectional area 'A' driven by the wind. Its efficiency would be:

$$\eta_A = \frac{\text{Useful shaft power output}}{\text{Wind power input}}$$
$$= C_P$$
$$= \text{Co-efficient of performance.}$$

Thus the coefficient of performance of an aero turbine is the fraction of power in the wind through the swept area which is converted into useful mechanical shaft power. The coefficient of performance is widely utilized throughout the recent wind research. We have seen that Cp for horizontal axis wind machine has theoretical maximum value = 0.593.This theoretical efficiency limitation on a wind energy conversion system is loosely analogical similar to the thermodynamic cannot efficiency limitation on a conventional thermal power plant.

We know that the convertible power of energy is proportional to the cube of the wind speed. Thus if the wind speed decreases by 20%, the power output is reduced by almost 50%. The wind speed may very considerable from day to day and from season to season. The efficiency of a wind generator depends on the design of an wind rotor and rotational speed, expressed as the ratio of blade tip speed to wind speed i.e., VT/V (is called as TSR – Tip Speed Ratio), if n is the rotation frequency, ie., rotation per second, if a rotor diameter D meters, the tip speed is π ND m/sec.

The dependence of the power coefficient on the tip speed ratio (TSR) for some common rotor types is indicated in Fig. 5.13. It is seen that the two-bladed propeller type of rotor can attain a much higher power coefficient (i.e., it is more efficient) than the American multi-blade wind mill and the classical Dutch four-bladed windmill. In practice two-bladed propeller (horizontal axis) rotor are around to attain a maximum power coefficient of 0.40 to 0.45 at a tip speed ratio in the range a roughly 6 to 10

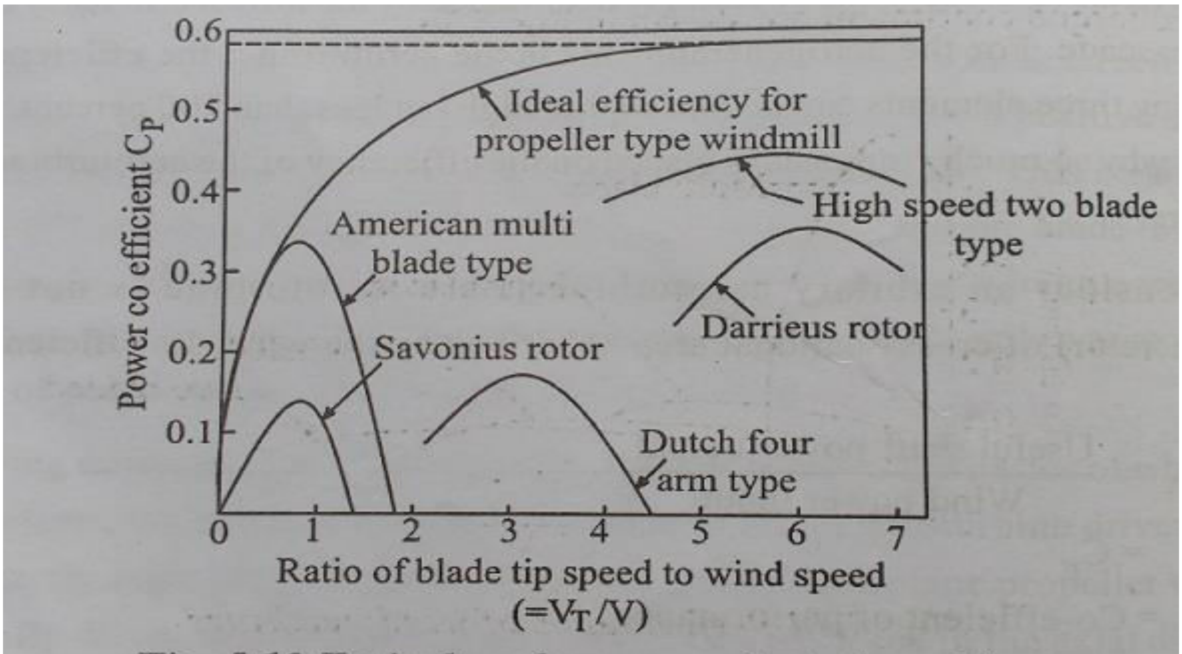

Fig. 5.13 Typical performance of wind machines

expression for aero turbine efficiency as,

$$\eta_A = \frac{1 - K\frac{V_T}{V}}{1 + K\frac{V}{V_T}} = CP \qquad \text{... (5.32)}$$

Where, $K = \frac{F_D}{F_L} = \frac{\text{Drag}}{\text{Lift}}$ ratio

Clearly If there were no drag, i.e., K=0, then efficiency would be unity (μA=1). In actuality K can be made very small, depending on the airfoil chosen and the angle of attack. Also above equation tells us the efficiency would be low if VT/V were very large or again If it were small. One suspicions that there exists an optimum ratio of VT/V (i.e., TSR). If one assembles models of various types of aero turbine blades and puts them in a wind tunnel and runs carefully controlled experiments of their efficiencies as function of their TSR'S, then one obtains a family of curves similar to that shown in Fig.5.14.The various types of windmills performance characteristics with respect to TSR and torque coefficient are shown in Fig. 5.14.

Only at intermediate wind speed does the system efficiency reach its optimum and the power extracted then follows a V3 law. The range of optimum operation depends on the engine which was selected so as to give optimum output over the year.

Considering the range of wind speed is 10-14m/sec, 14m/sec being the rated velocity maintained also at higher wind speeds. Only there depending on the degree of sophistication, could between 70 and 85% of the convertible wind energy by the gear type transmission, which connects the rotor shaft to the electric generator. The energy conversion from wind to utilities with losses in indicated by energy flow diagram shown in Fig. 5.15.

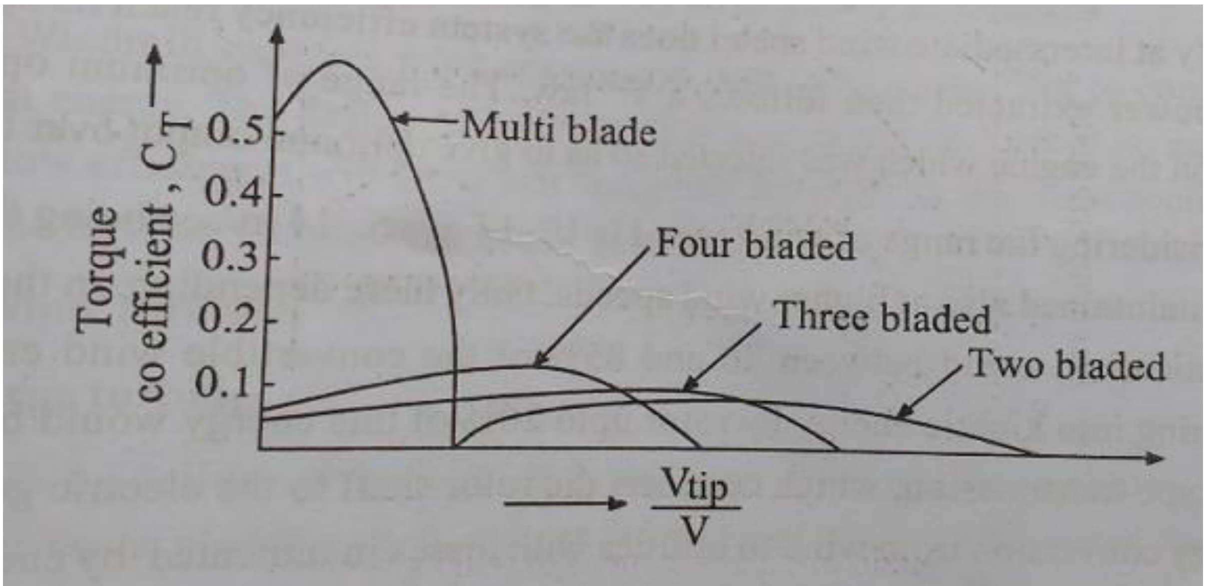

Fig. 5.14 Performance of wind machines

Video Content / Details of website for further learning (if any): https://www.energy.gov/energysaver/save-electricity-and-fuel/buying-and-making-electricity/small-wind-electric-systems https://www.ge.com/renewableenergy/wind-energy/onshore-wind/3mw-platform
Important Books/Journals for further learning including the page nos.: ➢ G.D.Rai, 'Non-Conventional Energy Sources', Khanna Publishers , 2011. (Page No:287-291)

CourseFaculty

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L23

LECTURE HANDOUTS

EEE

II/III

Course Name with Code : **19GES20/ Renewable Energy Sources**

Course Faculty : **Mr.C.RAMKUMAR**

Unit : **3-Wind Energy** **Date of Lecture:**

Topic of Lecture: Site Selection

Introduction :

- The power available in the wind increases rapidly with the speed, hence wind energy conversion machines should be located preferable in areas where the winds are strong and persistent.
- Although daily winds at a given site may be highly variable, the monthly and especially annual average are remarkably constant from year to year.

Prerequisite knowledge for Complete understanding and learning of Topic:

1.Basics of Civil & Mechanics

2.Engineering Physics

Site Selection Consideration For WECS

The power available in the wind increases rapidly with the speed, hence wind energy conversion machines should be located preferable in areas where the winds are strong and persistent. Although daily winds at a given site may be highly variable, the monthly and especially annual average are remarkably constant from year to year.

The major contribution to the wind power available at a given site is actually made by winds with speeds above the average. Nevertheless, the most suitable sites for wind turbines would be found in areas where the annual average wind speeds are known to be moderately high or high. The site choice for a single or a spatial array of WECS is an important matter when wind electrics is looked at from the systemspoint of view of aeroturbine generators feeding power into a conventional electric grid.

If the WECS sites are wrongly or poorly chosen the net wind electrics generated energy per year may be sub optimal with resulting high capital cost for the WECS apparatus, high costs for wind generated electric energy, and low Returns on Investment. Even if the WECS is to be a small generator not tied to the electric grid, the sitting must be carefully chosen if inordinately long break even times are to be avoided. Technical, Economic, Environmental, Social and Other actors are examined before a decision is made to erect a generating plant on a specific site.

1. High annual average wind speed:

The speed generated by the wind mill depends on cubic values of velocity of wind, the small increases in velocity markedly affect the power in the wind. For example, Doubling the velocity, increases power by a factor of 8. It is obviously desirable to select a site for WECS with high wind velocity. Thus a high average wind velocity is the principle fundamental parameter of concern in initially appraising WESCS site. For more detailed estimate value, one would like to have the average of the velocity cubed.

2. Availability of anemometry data:

It is another improvement sitting factor. The aerometry data should be available over some time period at the precise spot where any proposed WECS is to be built and that this should be accomplished before a sitting decision is made.

3. Availability of wind V(t) Curve at the proposed site:

This important curve determines the maximum energy in the wind and hence is the principal initially controlling factor in predicting the electrical output and hence revenue return o the WECS machines.It is desirable to have average wind speed 'V' such that V>=12-16 km/hr (3.5 – 4.5 m/sec) which is about the lower limit at which present large scale WECS generators 'cut in' i.e., start turning. The V(t) Curve also determines the reliability of the delivered WECS generator power, for if the V(t) curve goes to zero there be no generated power during that time.

If there are long periods of calm the WECS reliability will be lower than if the calm periods are short. In making such reliability estimates it is desirable to have measured V(t) Curve over about a 5 year period for the highest confidence level in the reliability estimate.

4. Wind structure at the proposed site:

The ideal case for the WECS would be a site such that the V(t) Curve was flat, i.e., a smooth steady wind that blows all the time; but a typical site is always less than ideal. Wind specially near the ground is turbulent and gusty, and changes rapidly in direction and in velocity. This departure from homogeneous flow is collectively referred to as "the structure of the wind".

5. Altitude of the proposed site:

It affects the air density and thus the power in the wind and hence the useful WECS electric power output. Also, as is well known, the wind tend to have higher velocities at higher altitudes. One must be carefully to distinguish altitude from height above ground. They are not the same except for a sea level WECS site.

6. Terrain and its aerodynamic:

One should know about terrain of the site to be chosen. If the WECS is to be placed near the top but not on the top of a not too blunt hill facing the prevailing wind, then it may be possible to obtain a 'speed-up' of the wind velocity over what it would otherwise be. Also the wind here may not flow horizontal making it necessary to tip the axis of the rotor so that the aero turbine is always perpendicular to the actual wind flow.It may be possible to make use of hills or mountains which channel the prevailing wind into a pass region, thereby obtaining higher wind power.

7. Local Ecology

If the surface is base rock it may mean lower hub height hence lower structure cost. If trees or grass or vegetation are present, all of which tend to destructure the wind, the higher hub heights will be needed resulting in larges system costs that the bare ground case.

8. Distance to road or railways:

This is another factor the system engineer must consider for heavy machinery, structure, materials, blades and other apparatus will have to be moved into any chosen WECS site.

9. Nearness of site to local center/users:

This obvious criterion minimizes transmission line length and hence losses and cost. After applying all the previous string criteria, hopefully as one narrows the proposed WECS sites to one or two they would be relatively near to the user of the generated electric energy.

10. Nature of ground:

Ground condition should be such that the foundation for a WECS are secured. Ground surface should be stable. Erosion problem should not be there, as it could possibly later wash out the foundation of a WECS, destroying the whole system.

11. Favorable land cost:

Land cost should be favorable as this along with other siting costs, enters into the total WECS system cost.

12. Other conditions such as icing problem, salt spray or blowing dust should not present at the site, as they may affect aeroturbine blades or environmental is generally adverse to machinery and electrical apparatus.

Video Content / Details of website for further learning (if any):

https://www.youtube.com/watch?v=k4QlrGISCF4

https://www.youtube.com/watch?v=ZF0iVgiBM6Q

Important Books/Journals for further learning including the page nos.:

- G.D.Rai, 'Non-Conventional Energy Sources', Khanna Publishers , 2011. (Page No:252-255)

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L24

LECTURE HANDOUTS

EEE

II/III

Course Name with Code : **19GES20/ Renewable Energy Sources**

Course Faculty : **Mr.C.RAMKUMAR**

Unit : **3-Wind Energy** **Date of Lecture:**

Topic of Lecture: Details of Wind Turbine Generator

Introduction :

- The circulation of air in the atmosphere is caused by the non-uniform heating of the earth's surface by the sun. The air immediately above a warm area expands, it is forced upward by cool, denser air which flows in from surrounding areas causing wind.
- The nature of the terrain, the degree of cloud and the angle of the sun in the sky are all factors which influences this process.

Prerequisite knowledge for Complete understanding and learning of Topic:

1.Basics of Civil & Mechanics

2.Engineering Physics

Horizontal Axis Wind Turbines (HAWT)

Horizontal axis wind turbines, also shortened to HAWT, are the common style that most of us think of a wind turbine. A HAWT has a similar design to a windmill, it has blades that look like a propeller that spin on the horizontal axis as shown in figure. Horizontal axis wind turbines have the main rotor shaft and electrical generator at the top of a tower, and they must be pointed into the wind. Small turbine are pointed by a simple wind vane placed square with the rotor (blades), while large turbines generally use a wind sensor coupled with a servo motor to turn the turbine into the wind. Most large wind turbines have a gearbox, which turns the slow rotation of the rotor into a faster rotation that is more suitable to drive an electrical generator.

Since a tower produces turbulence behind it, the turbine is usually pointed upwind of the tower. Wind turbine blades are made stiff to prevent the blades from being pushed into the tower by high winds. Additionally, the blades are placed a considerable distance in front of the tower and are sometimes tilted up a small amount.Downwind machines have been built, despite the problem of turbulence, because they don't need an additional mechanism for keeping them in line with the wind. Additionally, in high winds the blades can be allowed to bend which reduces their swept area and thus their wind resistance. Since turbulence leads to fatigue failures, and reliability is so important, most HAWTs are upwind machines.

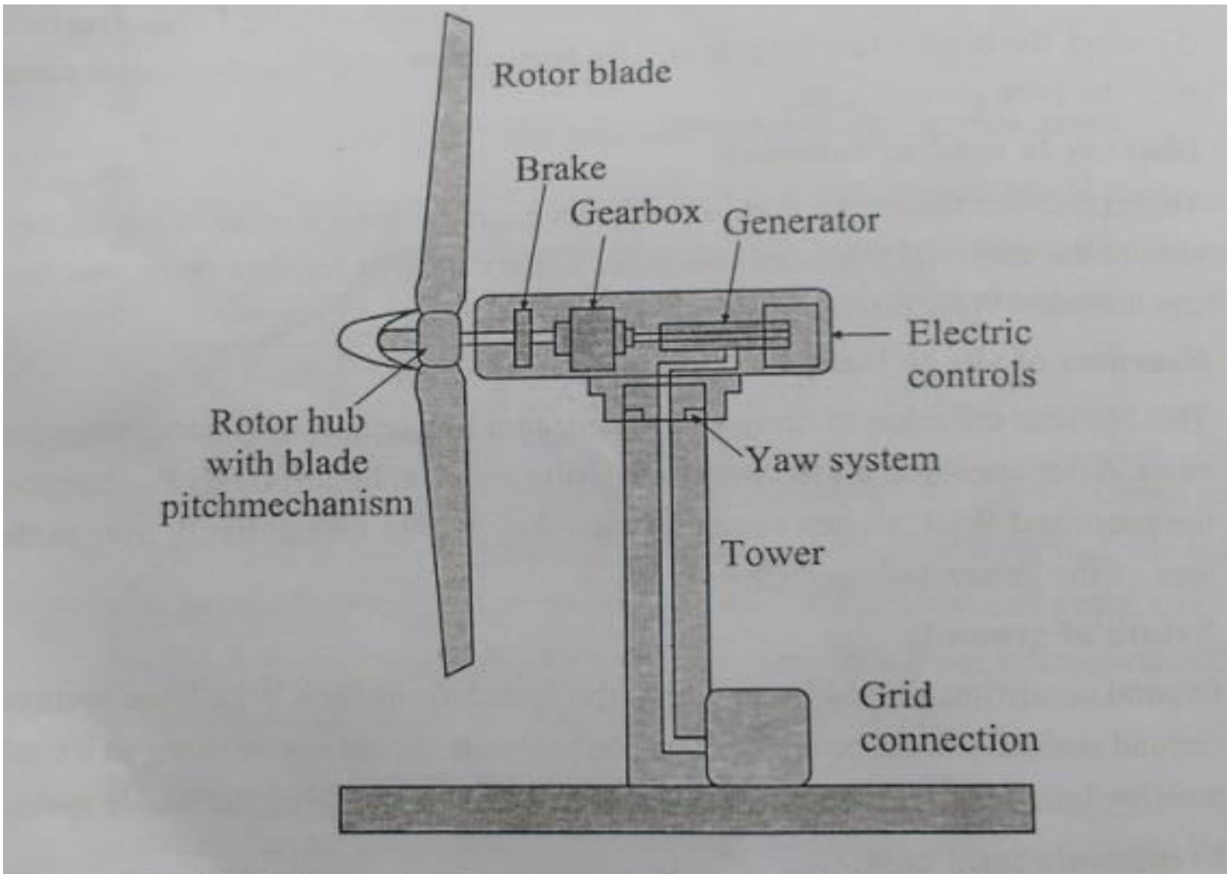

Fig. 5.8 Schematic Structure ofHorizontal Axis Wind Turbines

Important point to remember recording HAWT:

(1) Lift is the main force

(2) Much lower cyclic stress

(3) 95% of the existing turbines are HAWTs

(4) Nacelle is placed at the top of the tower

(5) Yaw mechanism is required

HAWT Advantage

1. The tall tower base allows access to stronger wind in sites with wind shear. In some wind shear sites, every ten meters up the wind speed can increase by 20% and the power output by 34%.

2. High efficiency, since the blades always move perpendicular to the wind, receiving power through the whole rotation. In contrast, all vertical axis wind turbines, and most proposed airborne wind turbine designs, involve various types of reciprocating actions, requiring airfoil surfaces to the wind leads to inherently lower efficiency.

HAWT Disadvantages

1. Massive tower construction is required to support the heavy blades, gearbox, and generator.

2. Components of horizontal axis wind turbine (gearbox, rotor shaft and brake assembly) being lifted into position. 3. Their height makes them obtrusively visible across large areas, disrupting the appearance of the landscape and sometimes creating local opposition. 4. Download variants suffer from fatigue and structural failure caused by turbulence when a blade passes through the tower's wind shadow (for this reason, the majority of HAWTs use an upwind design, with the rotor facing the wind in front of the tower). 5. HAWTs require an additional yaw control mechanism to turn the blades toward the wind. 6. HAWTs generally require a braking or yawing device in high winds to stop the turbine from spinning and destroying or damaging itself.
Video Content / Details of website for further learning (if any): https://solarfeeds.com/types-of-wind-turbine-generators-and-their-functions/
Important Books/Journals for further learning including the page nos.: ➢ G.D.Rai, 'Non-Conventional Energy Sources', Khanna Publishers , 2011. (Page No:256-262)

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L25

LECTURE HANDOUTS

EEE **II/III**

Course Name with Code : **19GES20/ Renewable Energy Sources**

Course Faculty : **Mr.C.RAMKUMAR**

Unit : **3-Wind Energy** **Date of Lecture:**

Topic of Lecture : Details of Wind Turbine Generator

Introduction :

- The circulation of air in the atmosphere is caused by the non-uniform heating of the earth's surface by the sun. The air immediately above a warm area expands, it is forced upward by cool, denser air which flows in from surrounding areas causing wind.
- The nature of the terrain, the degree of cloud and the angle of the sun in the sky are all factors which influences this process.

Prerequisite knowledge for Complete understanding and learning of Topic:

1.Basics of Civil & Mechanics

2.Engineering Physics

Vertical Axis Wind Turbines(VAWT)

Vertical wind turbines, as shortened to VAWTs, have the main rotor shaft arranged vertically as shown in Fig 5.9. The main advantage of this arrangement is that the wind turbine does not need to be pointed into the wind. This is an advantage on site where the wind direction is highly variable or has turbulent winds. With a vertical axis, the generator and other primary components can be placed near the ground, so the tower does not need to support it, also makes maintenance easier. The main drawback of a VAWT generally create drag when rotating into the wind.

It is difficult to mount vertical-axis turbines on towers, meaning they are often installed nearer to the base on which they rest, such as the ground or a building rooftop. The wind speed is slower at a lower altitude, so less wind energy is available for a given size turbine. Air flow near the ground and other objects can create turbulent flow, which can introduce issues of vibration, including noise and bearing wear which may increase the maintenance or shorten its service life. However, when a turbine is mounted on a rooftop, the building generally redirects wind over the roof and this can double the wind speed at the turbine. If the height of the rooftop mounted turbine tower is approximately 50% of the building height, this is near the optimum for maximum wind energy and minimum wind turbulence.

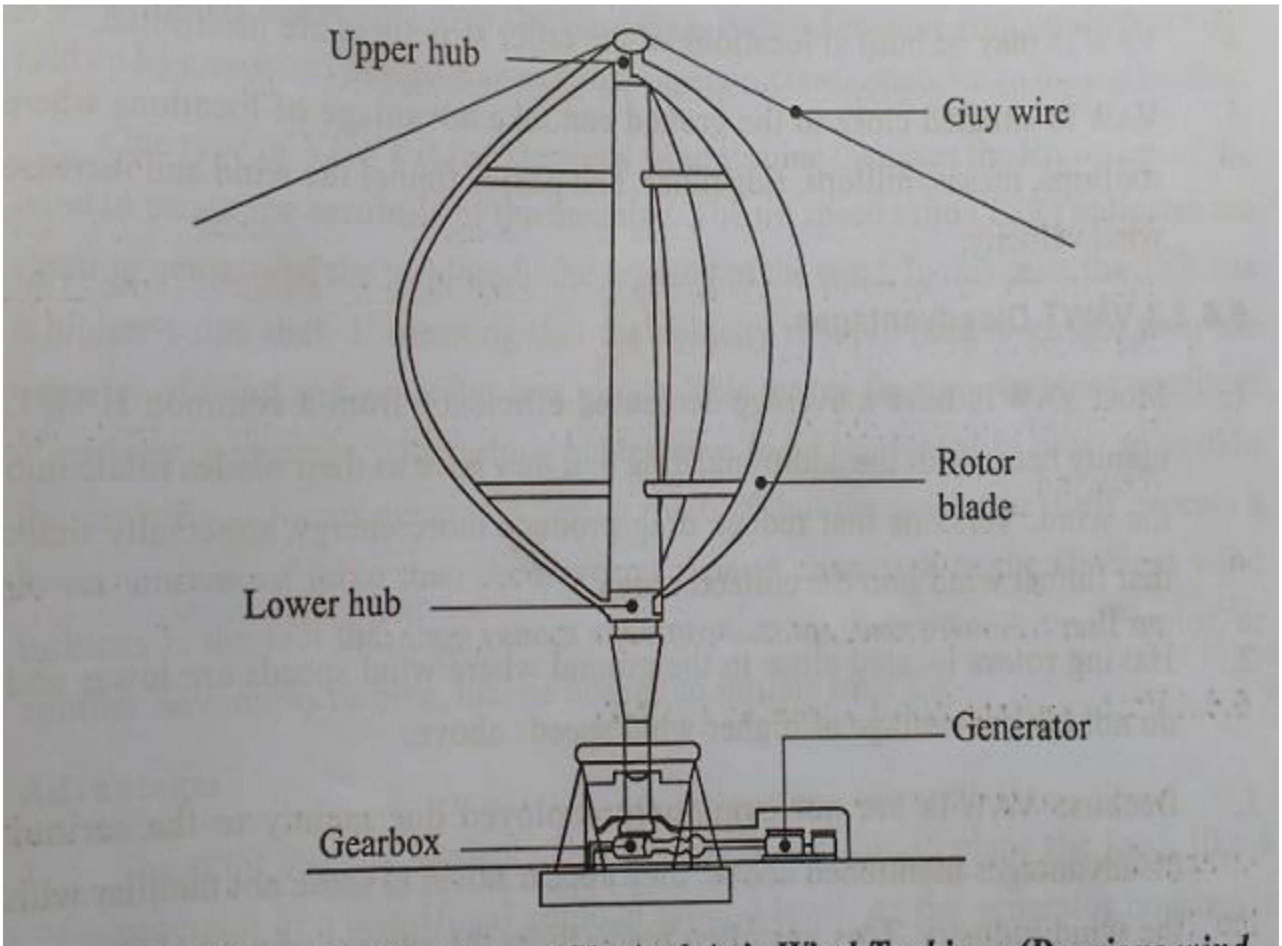

Fig. 5.9 Schematic Structure of Vertical Axis Wind Turbines (Darrieus wind turbine)

Important points to remember recording VAWT:

Nacelle is placed at the bottom.

Drag is the main force

Yaw mechanism is not required

Lower starting torque

Difficulty in mounting the turbine

Unwanted fluctuations in the power output

VAWT Advantages

1. No yaw mechanisms is needed

2. A VAWT can be located nearer the ground, making it easier to maintain the moving parts.

3. VAWTs have lower wind startup speeds than the typical the HAWTs.

4. VAWTs may be built at locations where taller structures are prohibited.

5. VAWTs situated close to the ground can take advantage of locations where rooftops, means hilltops, ridgelines, and passes funnel the wind and increase wind velocity.

VAWT Disadvantage

1. Most VAWTs have a average decreased efficiency from a common HAWT, mainly because o the additional drag that they have as their blades rotate into the wind. Versions that reduce drag produce more energy, especially those that funnel wind into the collector area.

2. Having rotors located close to the ground where wind speeds are lower and do not take advantage of higher wind speeds above.

3. Because VAWTs are not commonly deployed due mainly to the serious disadvantage mentioned above, they appear novel to those not familiar with the wind industry. This has often made them the subject of wild claims and investment scams over the last 50 years.

VAMT Subtypes

Darrius Wind Turbine

Darrius turbine has long, thin blades in the shape of loops connected to the top and bottom of the axle; it is often called an “eggbeater windmill.” It is named after the French engineer Georges Darrius who patented the design in 1931. (It was manufactured by the US company flow Wind which went bankrupt in 1997). The Darrius turbine is characterized by its C-shaped rotor blades which give it its eggbeater appearance. It is normally built with two or three blades.

Darrius wind turbines are commonly called “Eggbeater” turbines, because they look like a giant eggbeater. They have good efficiency, but produce large torque ripple and cyclic stress on the tower, which contributes to poor reliability. Also, they generally require some external power source, or an additional savonius rotor, to start turning, because the starting torque is very low. The torque ripple is reduced by using three or more blades which results in a higher solidity for the rotor. Solidity is measured by blade area over the rotor area. Newer Darrieus type turbines are not help up by guy-wires but have an external superstructure connected to the top bearing.

One type of VAWT is the Darrieus wind turbine that uses the lift forces of the wind to rotate the aerofoils of the machine. The tip speed ratio (TSR) indicates the rotating velocity of the turbines to the velocity of the wind. In this case, the TSR has a higher value than 1, meaning that the velocity rotation here is greater than the velocity of wind and generates less torque. This makes Darrieus turbines excellent electricity generators. The turbine blades have to be reinforced in order to sustain the centrifugal forces generated during rotation, but the generator itself accepts a lower amount of force than the Savorius type. A drawback to the Darrieus wind turbines is the fact that they cannot start rotation on their own. A small motor, or another Savonius turbine, maybe needed to initiate rotation.

Advantages

(1) The rotor shaft is vertical. Therefore it is possible to place the load, like a generator or a centrifugal pump at ground level. As the generator housing is not rotating, the cable to the load is not twisted and no brushes are requires for large twisting angles.

(2) The rotor can take wind from every direction.

(3) The visual acceptation for placing of the windmill on a building might be larger than for an horizontal axis windmill.

(4) Easily integrates into buildings.

Disadvantages

(1) Difficult start unlike the Savonius wind turbine.

(2) Low efficiency.

Savonius wind turbine

The Savonius wind turbine is a type of vertical-axis wind turbine invented by the Finnish engineer Sigurd Savonius in the 1920's. It is one of the simplest wind turbine designs. It consists of two to three "scoops" that employ a drag action to convert wind energy into torque to drive a turbine. When looked at from above in cross-section, a two scoop Savonius turbine looks like an S-shape. Due to the curvature of the scoops, the turbine encounters less drag when moving against the wind than with it, and this causes the spin in any wind regardless of facing. Drag type wind turbines such as the Savonius turbine are less efficient at using the wind's energy than lift-type wind turbines, which are the ones commonly used in wind farms.

A Savonius is a drag type turbine, they are commonly used in cases of high reliability in many things such as ventilation and anemometers. Because they are a drag type turbine they are less efficiency than the common HAWT. Savonius are excellent in areas of turbulent wind and self starting. The schematic diagram of savonius wind turbine as shown in fig.5.10.

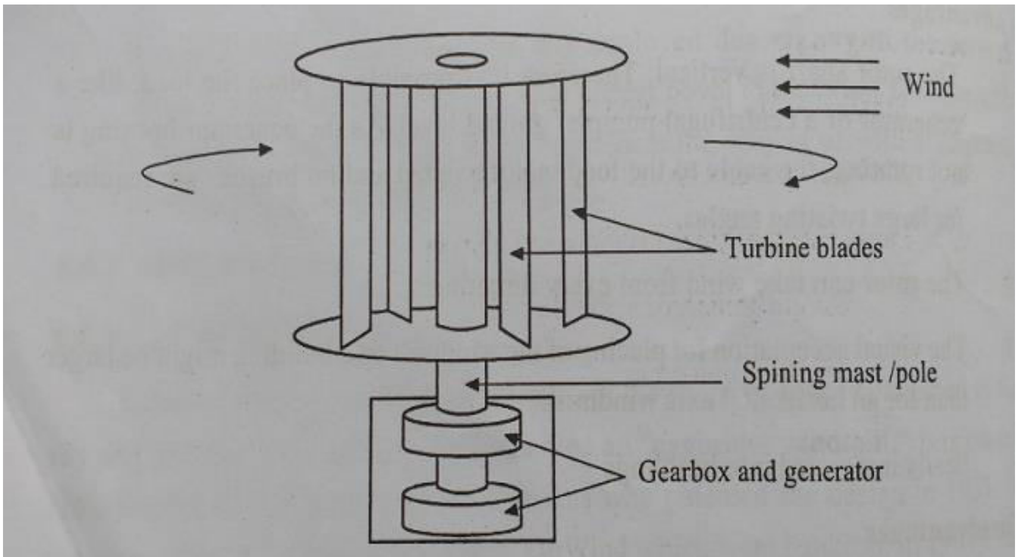

Fig. 5.10 Schematic Structure of Vertical Axis Wind Turbines (Savonius wind turbine)

Advantages

(1) Having a vertical axis, the Savonius turbine continues to work effectively even if the wind changes direction.

(2) Because the Savonius design works well even at low wind speeds, there's no need for a tower or other expensive structure to hold it in place, greatly reducing the initial setup cost.

(3) The device is quiet, easy to build, and relatively small.

(4) Because the turbine is close to the ground, maintenance is easy.

Disadvantages

The scoop system used to capture the wind's energy is half as efficient as a conventional turbine, resulting in less power generation

Video Content / Details of website for further learning (if any):

https://solarfeeds.com/types-of-wind-turbine-generators-and-their-functions/

Important Books/Journals for further learning including the page nos.:

- G.D.Rai, 'Non-Conventional Energy Sources', Khanna Publishers , 2011. (Page No:256-262)

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LECTURE HANDOUTS

L-26

EEE

II/III

Course Name with Code : **19GES20/ Renewable Energy Sources**

Course Faculty : **Mr.C.RAMKUMAR**

Unit : **3-Wind Energy** **Date of Lecture:**

Topic of Lecture: Grid integration issues of Wind Power Plants

Introduction :

- The ideal case for the WECS would be a site such that the V(t) Curve was flat, i.e., a smooth steady wind that blows all the time; but a typical site is always less than ideal.
- Wind specially near the ground is turbulent and gusty, and changes rapidly in direction and in velocity. This departure from homogeneous flow is collectively referred to as "the structure of the wind".

Prerequisite knowledge for Complete understanding and learning of Topic:

1.Basics of Civil & Mechanics

2.Engineering Physics

Grid Integration Issues of Wind Power Plants

The simple structure of horizontal axis wind turbine (wind mill) shown in fig.5.11.

The following components are used in a wind mill.

(1) Anemometer

Measure the wind speed and transmits wind speed data to the controller

(2) Blades

Most turbines have either two or three blades. Wind blowing over the blades causes the blades to "lift" and rotate.

(3) Brake

A disc brake, which can be applied mechanically, electrically, or hydraulically to stop the rotor in emergencies.

(4) Controller

The controller starts up the machine at wind speeds of about 8 to 16 miles per hour (mph) and shuts off the machine at about 55 mph. Turbines do not operate at wind speeds above about 55 mph because they might be damaged by the high winds.

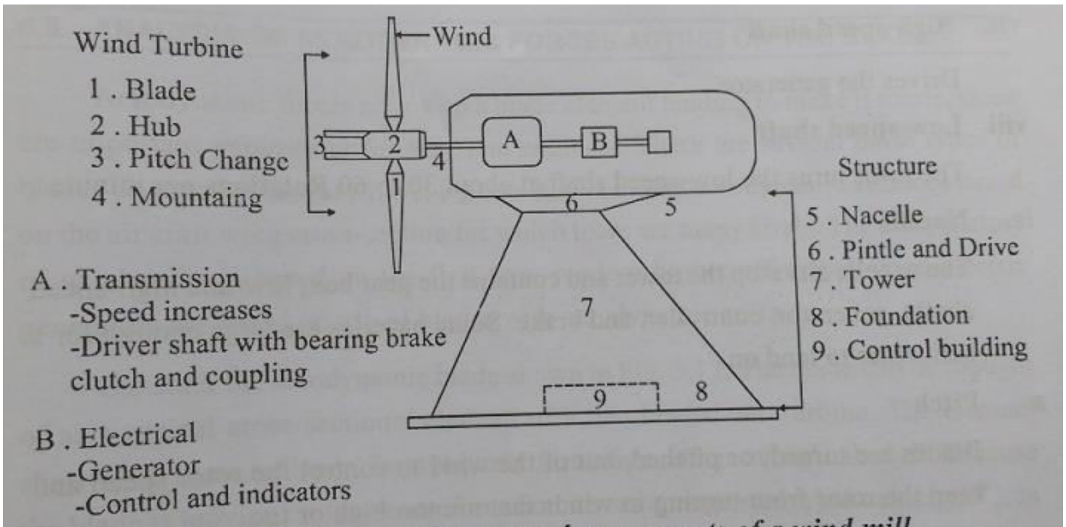

Fig. 5.11 Simple structure and components of a wind mill

(5) Gear box

Gear connect the low-speed shaft to the high speed shaft and increase rotational speeds from about 30 to 60 rotations per minute (rpm) to about 1000 to 1800 rpm, the rotational speed required by most generators to produce electricity. The gear box is a costly (and heavy) part of the wind turbine and engineers are exploiting "direct-drive" generators that operate at lower rotational speeds and don't need gear boxes.

(6) Generator

Usually an off-the-shelf induction generator that produces 60-cyclic AC electricity.

(7) High speed shaft

Drives the generator.

(8) Low-speed shaft

The rotor turns the low-speed shaft 30 to 60 rotations per minute.

(9) Nacelle

The nacelle sits the lower and contains the gear box, low-and high-speed shafts, generator, controller, and brake. Some nacelle are large enough for a helicopter to land on.

(10) Pitch

Blades are turned, or pitched, out of the wind to control the rotor speed and keep the rotor form turning in winds that are too high or too.

(11) Rotor

The blades and the hub together are called the rotor.

(12) Tower

Towers are made from tubular steel (shown here), concrete, or steel lattice. Because wind speed increases with height, taller towers enable turbines to capture more energy and generate more electricity.

(13) Wind direction

This is an "upwind" turbine, so called because it operates facing into the wind. Other turbines are designed to run "downwind", facing away from the wind.

(14) Wind vane

Measure wind direction and communicates with the yaw drive to orient the turbine properly with respect to the wind.

(15) Yaw drive

Upwind turbines face into the wind, the yaw drive is used to keep the rotor facing into the wind as the wind direction changes. Downwind turbines don't require a yaw drive, the wind blows the rotor downwind.

(16) Yaw motor

Powers the yaw drive.

Video Content / Details of website for further learning (if any):

https://www.youtube.com/watch?v=faCu_n2w6PY

Important Books/Journals for further learning including the page nos.:

- G.D.Rai, 'Non-Conventional Energy Sources', Khanna Publishers , 2011. (Page No:306-308)

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LECTURE HANDOUTS

EEE | **II/III**

Course Name with Code : **19GES20/ Renewable Energy Sources**

Course Faculty : **Mr.C.RAMKUMAR**

Unit : **3-Wind Energy** **Date of Lecture:**

Topic of Lecture : Grid Integration Issues of Wind Power Plants.

Introduction :

- The ideal case for the WECS would be a site such that the V(t) Curve was flat, i.e., a smooth steady wind that blows all the time; but a typical site is always less than ideal.
- Wind specially near the ground is turbulent and gusty, and changes rapidly in direction and in velocity. This departure from homogeneous flow is collectively referred to as "the structure of the wind".

Prerequisite knowledge for Complete understanding and learning of Topic:

1.Basics of Civil & Mechanics

2.Engineering Physics

Grid integration issues of Wind Power Plants

The fact that the wind is variable and intermittent source of energy is immaterial for some application such as pumping water for land drainage-provided, of course, that there is a broad match between the energy supplied over any critical period and the energy required. If the wind blows, the job gets done; if it does not, the job waits. However, for many of the uses to which electricity is put, the interruption of supply may be highly inconvenient. Operators or users of wind turbines must ensure that there is some from of back-up can take the form of

(1) Battery storage

(2) Connection with the local electricity distribution systems, or

(3) A stand by generator powered by liquid or gaseous fuels

For utility responsible for public supply, the integration of medium sized and large wind turbines into their distribution network could required some additional plant which is capable of responding quickly to meet fluctuating demand.

1. Small Producers

Private citizens in several countries have won to right to operate wind generator and other renewable energy systems and to export power to the grid. For most small wind generators this requires that the output is conditioned, so that in the frequency and phase of the mains supply. Only few small units are designed to maintain a constant rotational rate, so that can be synchronized to the mains frequency and feed electricity directly into the grid. Most current (DC) or variable output Alternating current (AC).

Power conditioning is readily achieved using an electronic black-box called a "Synchronous Inverter" and although this is an expensive item of equipment, it does eliminate the need for batteries and for conversion of home appliances to run on DC. Where there is no grid connection, electricity that is surplus to immediately requirements must be stored on site using heavy duty batteries. It can be recovered later when the demand exceeds the supply. An alternative is to dump it (by generating and dissipating heat) or better, to convert it into heat that can be stored, for example as hot water in a well insulated tank.

2. Large Producers

Large and medium-sized wind generators are designed to give a stable and constant electrical output over a wide range of wind speeds and to feed current directly into the grid, they operate primarily as fuel savers, reducing the utility's total fuel burn.

The choice of generator type depends on the size of the local distribution grid and its associated generating capacity.An induction generator would normally be used where there is a significant amount of other generating capacity (which could provide the necessary reactive power for excitation). Induction generators are robust and reliable and require minimal control equipment.

For isolated networks where other local generating capacity is limited, a synchronous generator is more appropriate. Synchronous generator are more complex and therefore more expensive than induction machines.

Video Content / Details of website for further learning (if any):

https://www.youtube.com/watch?v=faCu_n2w6PY

Important Books/Journals for further learning including the page nos.:

- G.D.Rai, 'Non-Conventional Energy Sources', Khanna Publishers , 2011. (Page No:306-308)

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Rasipuram - 637 408, Namakkal Dist., Tamil Nadu

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L28

LECTURE HANDOUTS

EEE **II/III**

Course Name with Code : **19GES20/ Renewable Energy Sources**

Course Faculty : **Mr.C.RAMKUMAR**

Unit : **4-Biomass Energy** **Date of Lecture:**

Topic of Lecture : Biomass direct combustion

Introduction :

Combustion is the process by which more than 90% of the world's primary energy supply is realized in order to provide heat and energy services such as materials processing including food preparation; space heating, ventilation and cooling; electricity, and transportation. The non-thermal sources of energy in the primary energy mix are hydro and nuclear power, as well as renewable sources. Only about 11% of the fuels used are biomass resources, and the wide range of fuels used in combustion include: coals ranging from anthracite (an almost pure form of carbon) to lignite or brown coal; peat; natural gas; crude and refined oils including liquid petroleum gas (LPG), gasoline, diesel and kerosene.

Prerequisite knowledge for Complete understanding and learning of Topic:

1.Environmental Science

2.Basics of Civil & Mechanics

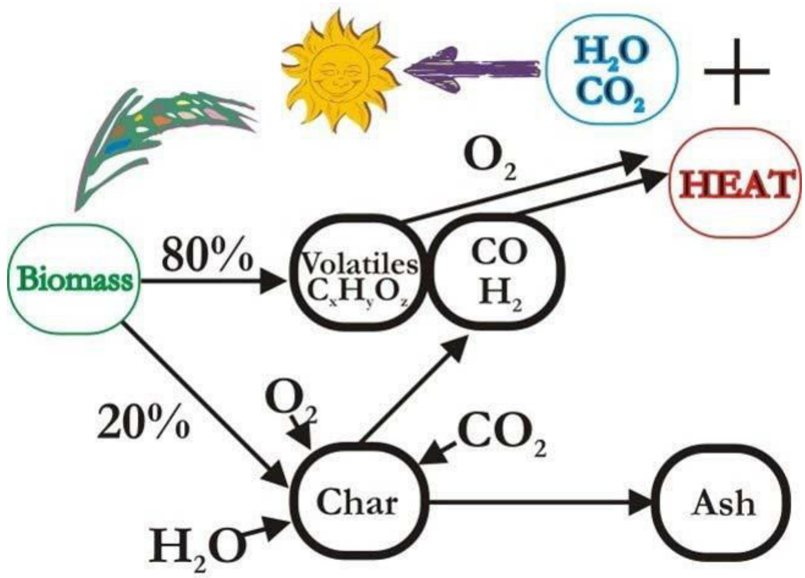
Principles of Bio-Conversion

Fundamentals of Biomass Combustion

Biomass combustion is not only the oldest form of combustion used by humanity, but it is also one of the most complex combustion systems to manage since it involves the use of solid fuels in a multi-phase reaction system with extensive interaction between the thermal and mass fluxes, processes that have only recently been properly analyzed and used in simulations to design efficient combustion systems. The key to understanding solid fuel combustion processes is to recognize that only fuel gases burn and release heat, that liquids and the solids do not burn themselves, but actually consume heat in the drying and volatilization processes needed for them to be chemically converted into fuel gases. The main fuel intermediates are the volatile hydrocarbons and energy rich organic molecules, carbon monoxide (CO) and hydrogen (H2).

The process of gas evolution due to heat is called pyrolysis, and progressively converts the biomass into gases, volatile liquids, and a carbon rich solid residue called char. In the pyrolysis stage, the rate of fuel gas evolution is a function of both the temperature and the intensity of the heat flux supplied to the solid surface and the pyrolysis liquids. When the char combustion stage is reached, after all of the volatiles have been removed, the char combustion rate is controlled by the velocity with which oxidizers namely oxygen, carbon dioxide and water vapor can reach the hot char surface to produce the fuel gases, hydrogen and carbon monoxide.

The action of the hot char on water vapor and carbon dioxide is to convert the fully oxidized carbon and hydrogen forms back to fuel intermediates.



This process of chemical reduction requires energy and is described as an endothermic reaction. The energy comes from the flame in which the carbon monoxide and hydrogen burn with oxygen from the air producing water vapor and carbon dioxide. This reaction is so endothermic that if the rate of heat release to the hot char surface is not sufficient the combustion reaction will come to a halt as the temperature at the surface will fall below 700°C. For this reason simple camp fires glow with only an red-orange color due to the limitation on the rate of diffusion of the gaseous reactants to the surface of the char. If the air flow is forced through the charcoal, the diffusion limitation is overcome and the temperatures become very high with a white incandescent appearance and temperatures greater than 1500°C – sufficient to melt even stainless steels. There are many different materials that are described as biomass ranging from solid wood, to oils, fats and proteins. While the majority of biomass used is a wood biomass or lignocellulosic, there is an increasing number of industrial and processing residues that have different material properties and combustion characteristics that are being used. However, a general and important biomass characteristic is the very high level of volatile material that is released during the pyrolysis stage. This is reported by the proximate analysis (see below) by the measurement of volatiles, which generally exceed 80% in most biomass materials, whereas many coals have volatile fractions less than 50%.

Each of the biomass combustion stages shown in Figure 1has a series of limitations, which limit the overall efficiency of heat generation and the maximum temperature reached. To ensure that combustion is as efficient as possible, it is essential to maximize the three T's simultaneously. The role of turbulence is to ensure full and complete mixing of the fuel gases with oxygen in the process and ensure complete burning without diffusion limitations. Time is required as the processes of drying and pyrolyzing the solids are relatively slow processes, and even the combustion of the fuel gases requires a few seconds to be complete. Finally, maximizing the temperature increases the rate of all of the reactions.

Efficiency Constraints in Combustion

The influence of excess air and the moisture content of the biomass fuel on the efficiency of the combustion process is very strong and this is explored through the use of some approximate models derived by Tillman to describe combustion. In a system with a good separation of the combustion chamber from the heat transfer surfaces, a formula for the efficiency of combustion is established: η= (Efficiency, %) = 96.84 - 0.28 MCg - 0.064Ts - 0.065EA, where MCg, %- is the moisture in the fuel measured on a total weight basis; i.e., 50% moisture would be a typical green wood as harvested with half dry matter and half water. The large effect of this term is due to the 2.8 MJ kg-1 of energy required to produce steam from the water; Ts, o C –is the stack temperature. While lower values increase the efficiency, they may also cause corrosion in the stack due to condensation of water vapor and acid gases such as CO_2 dissolving in the water. To avoid this condensation, both the stack temperature and the excess air (EA) may be maintained at quite high values. Typical values may be Ts = 150 - 200°C and an EA of 25 to 100%. EA is measured as a percentage of the minimum amount of air required to fully consuming all of the oxygen in combusting the fuel to carbon dioxide and water. A related term is the λ, which is the ratio of the actual air used to the stoichiometric amount of air needed to fully combust the fuel. The equivalence ratio, φ, is defined as the actual fuel to air ratio relative to the stoichiometric fuel to air ratio, and is a reciprocal of λ. For a typical biomass with an HHV of 18.6 GJ t^{-1}, the stoichiometric mass of air is 5.7 t. Practical excess air values when burning high moisture biomass result in about 10 t of air per 1 t of biomass at 70% excess air.

Very often combustion emissions data are quoted in terms of the flue gas oxygen content $[O_2]$, %. Typical for boilers $[O_2]$ is 12% , for gas turbines -15%. This can be quickly converted to the excess air factor by the equation:

EA = 21/21-[O2] * 100

The adiabatic temperature of the flame in a furnace or combustor can be calculated as follows: Temperature, °C = 420 - 10.1 MCg + 1734φ + 0.6(A-25) A,°C is the temperature of the preheated combustion air. Many boilers have stages of heat recovery after the boiler has produced steam, namely, the economizer and the air preheater (Figure 2). The pressurized boiler feed-water is passed through the economizer, while the air to the boiler is passed through the preheater and heated to temperatures over 200°C.

Video Content / Details of website for further learning (if any):

1. https://www.youtube.com/watch?v=whSZuAoaTQ0

Important Books/Journals for further learning including the page nos.:

- G.D.Rai, 'Non-Conventional Energy Sources', Khanna Publishers , 2011. (Page No:319-323)

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LECTURE HANDOUTS

EEE

II/III

Course Name with Code : **19GES20/ Renewable Energy Sources**

Course Faculty : **Mr.C.RAMKUMAR**

Unit : **4-Biomass Energy** **Date of Lecture:**

Topic of Lecture : Biomass gasifies

Introduction :

Biomass gasification is a process of converting solid biomass fuel into a gaseous combustible gas (called producer gas) through a sequence of thermo-chemical reactions. The gas is a low-heating value fuel, with a calorific value between 1000- 1200 kcal/Nm3 (kilo calorie per normal cubic meter).

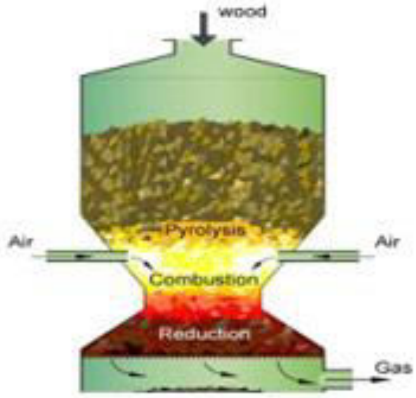
Biomass gasification is a mature technology pathway that uses a controlled process involving heat, steam, and oxygen to convert biomass to hydrogen.

Prerequisite knowledge for Complete understanding and learning of Topic:

1.Environmental Science

2.Basics of Civil & Mechanics

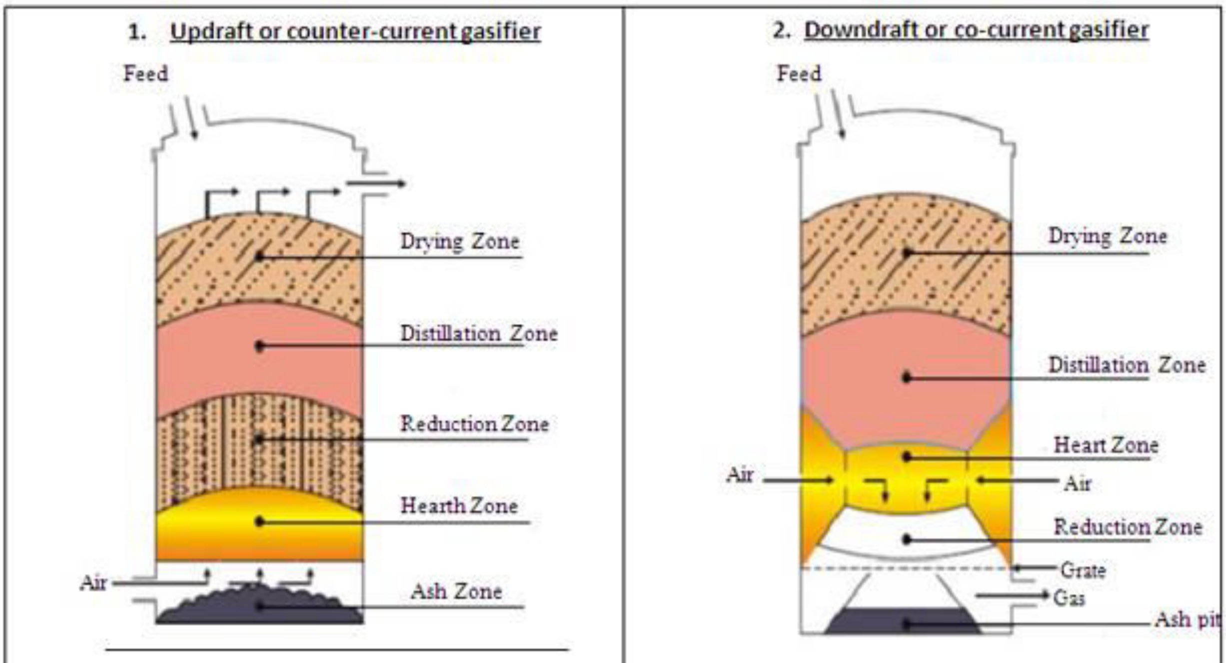
Bio gasifier for thermal and power applications



Biomass gasification is a process of converting solid biomass fuel into a gaseous combustible gas (called producer gas) through a sequence of thermo-chemical reactions. The gas is a low-heating value fuel, with a calorific value between 1000- 1200 kcal/Nm3 (kilo calorie per normal cubic metre). Almost 2.5-3.0 Nm3 of gas can be obtained through gasification of about 1 kg of air-dried biomass. Since the 1980's the research in biomass gasification has significantly increased in developing countries, as they aim to achieve energy security.

TERI independently began research work in gasifier technology in the mid-1980s. Since, the gasifier technology has been customized for a range of direct-heat application and tested successfully in the field. Silk processing, large-cardamom drying and gasifier-based crematoria are a few examples of the applications worked on at TERI. This technology is slowly replacing both traditional biomass use and gas-powered systems, as it provides an excellent de-centralized source of energy at an affordable cost. Apart from rural households, biomass fuels are the main source of energy to a large number of small, rural and cottage industries.

Two Types of Bio Gasifier



Updraft gasifiers are less sensitive to fuel size and moisture content as compared to a downdraft gasifier.

Downdraft gasifiers give relatively cleaner gas (low tar content) and are preferred for engine applications, niche applications demanding clean gas.

Salient Features of TERI's biomass gasifier

- Throat-less patented design
- Multi-fuel capability
- Low initial investment
- Better conversion (solid gas) efficiency (>75%)
- Production of clean gases in the exhaust
- Available in both, downdraft and updraft mode
- Can be customized for a variety of applications
    - Thermal application to meet the process heat requirement
    - Power application for rural electrification and captive use
    - Shaft powder

- Reduced deforestation through fuel wood savings
- Substantial reduction in diesel/kerosene/furnace oil cost (since 3-4 kg of biomass can replace 1 litre of petroleum fuel)
- Use of castable insulation material in the fire box capable of withstanding high temperatures (up to 1860°C)
- Since biomass is a carbon neutral fuel, the net emission of CO2 would amount to zero

The then-applied technologies in brick manufacture such as clamps, downdraught kilns, and BTKs require huge proportions of highly polluting coal (with an ash content as high as 40%), firewood, and biomass as fuel. In fact, the coal consumed by this industry was an astronomical 24 million tonnes.

Video Content / Details of website for further learning (if any):

1. https://www.teriin.org/technology/biomass-gasifier-for-thermal-and-power-applications

Important Books/Journals for further learning including the page nos.:

- G.D.Rai, 'Non-Conventional Energy Sources', Khanna Publishers , 2011. (Page No:331-336)

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MUTHAYAMMAL ENGINEERING COLLEGE

(An Autonomous Institution)

(Approved by AICTE, New Delhi, Accredited by NAAC & Affiliated to Anna University)
Rasipuram - 637 408, Namakkal Dist., Tamil Nadu

L30

LECTURE HANDOUTS

EEE **II/III**

Course Name with Code : **19GES20/ Renewable Energy Sources**

Course Faculty : **Mr.C.RAMKUMAR**

Unit : **4-Biomass Energy** **Date of Lecture:**

Topic of Lecture : Biogas plants

Introduction :

Most organic materials undergo a natural anaerobic digestion in the presence of moisture and absence of oxygen and produce biogas. The biogas so obtained is a mixture of methane (CH_4): 55-65% and Carbon dioxide (CO_2): 30-40%. The biogas contains traces of H_2, H_2S and N_2. The calorific value of biogas ranges from 5000 to 5500 Kcal/Kg (18.8 to 26.4 MJ /m^3). The biogas can be upgraded to synthetic natural gas (SNG) by removing CO_2 and H_2S. The production of biogas is of particular significance in India because of its large scale cattle production. The biogas is used for cooking, domestic lighting and heating, run I.C. Engines and generation of electricity for use in agriculture and rural industry. Family biogas plants usually of 2-3 m^3 capacity.

Prerequisite knowledge for Complete understanding and learning of Topic:

1.Environmental Science

2.Basics of Civil & Mechanics

Types of biogas plants:

Biogas plants basically are two types.

a. Floating dome type

Eg. KVIC-type (KVIC- Khadi Village Industries Commission)

b. Fixed dome type

Eg.Deenabandu model

KVIC type biogas plant

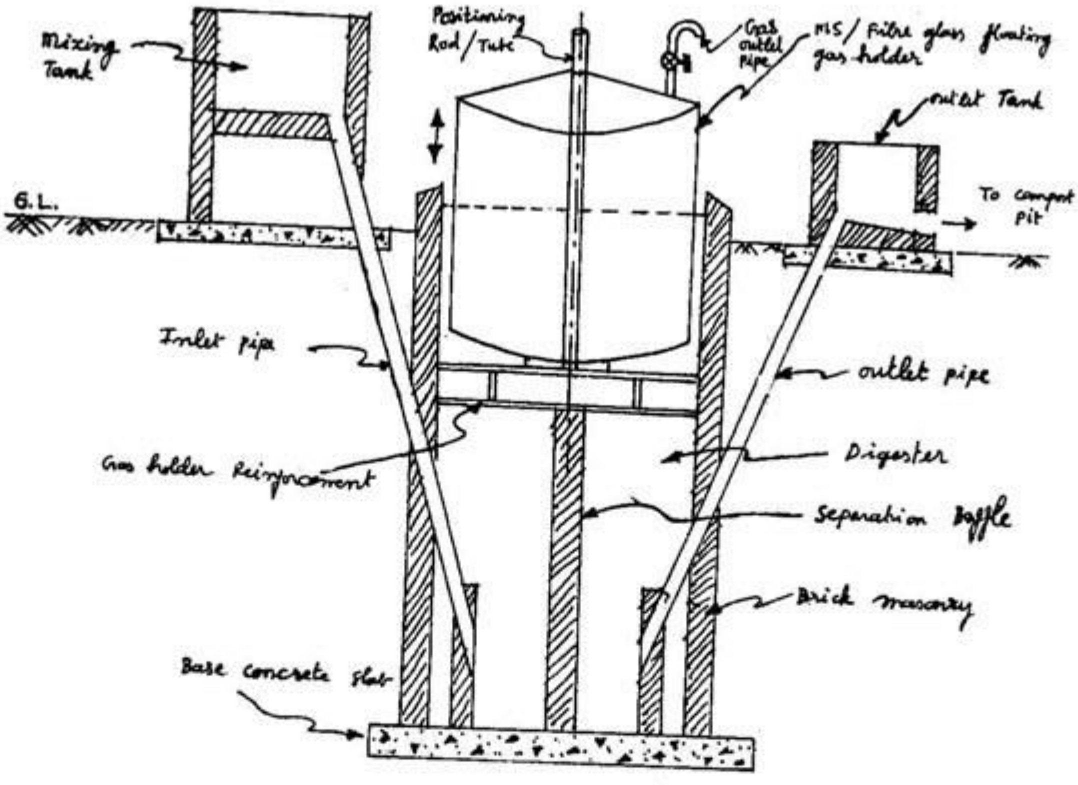
This mainly consists of a digester or pit for fermentation and a floating drum for the collection of gas. Digester is 3.5-6.5 m in depth and 1.2 to 1.6 m in diameter. There is a partition wall in the center, which divides the digester vertically and submerges in the slurry when it is full. The digester is connected to the inlet and outlet by two pipes. Through the inlet, the dung is mixed with water (4:5) and loaded into the digester.

The fermented material will flow out through outlet pipe. The outlet is generally connected to a compost pit. The gas generation takes place slowly and in two stages. In the first stage, the complex, organic substances contained in the waste are acted upon by a certain kind of bacteria, called acid formers and broken up into small-chain simple acids. In the second stage, these acids are acted upon by another kind of bacteria, called methane formers and produce methane and carbon dioxide.

Gas holder

The gas holder is a drum constructed of mild steel sheets. This is cylindrical in shape with concave. The top is supported radically with angular iron. The holder fits into the digester like a stopper. It sinks into the slurry due to its own weight and rests upon the ring constructed for this purpose. When gas is generated the holder rises and floats freely on the surface of slurry.

A central guide pipe is provided to prevent the holder from tilting. The holder also acts as a seal for the gas. The gas pressure varies between 7 and 9 cm of water column. Under shallow water table conditions, the adopted diameter of digester is more and depth is reduced. The cost of drum is about 40% of total cost of plant. It requires periodical maintenance. The unit cost of KVIC model with a capacity of 2 m3/day costs approximately Rs.14, 000 - 00. Fig. 1. Schematic diagram of a KVIC biogas plant



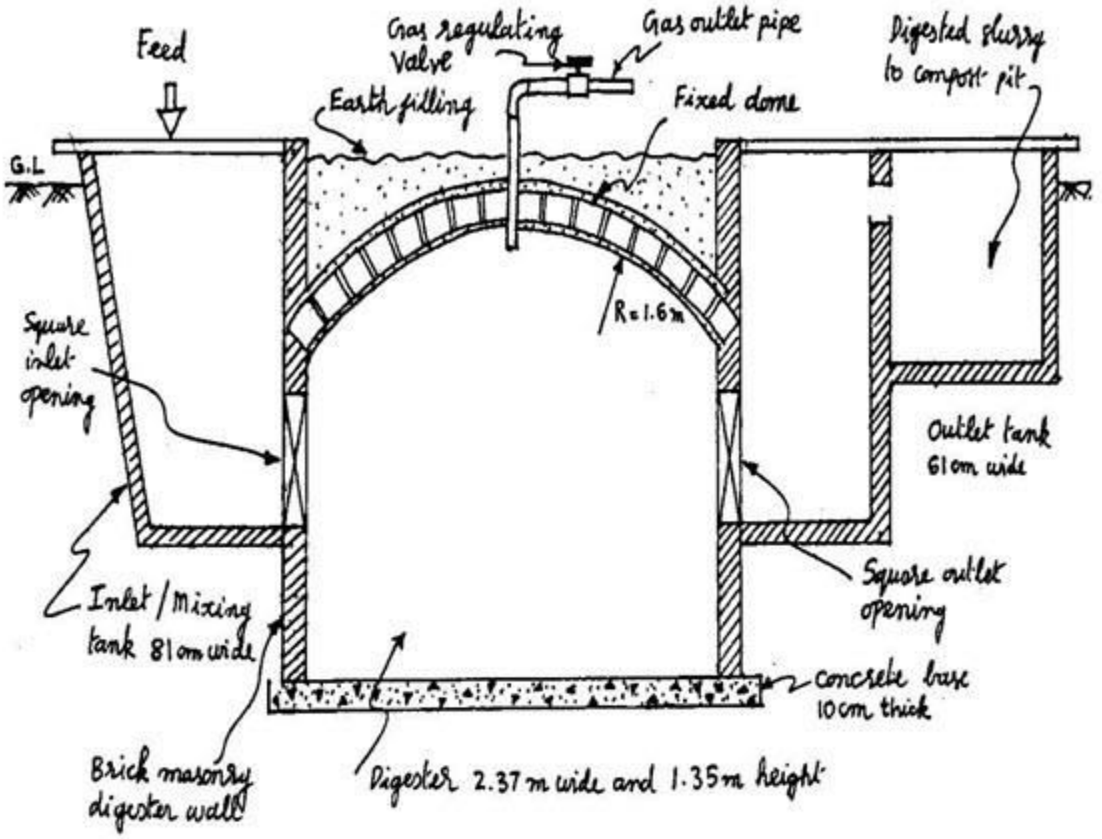
Schematic diagram of a KVIC biogas plant

Janata type biogas plant:

The design of this plant is of Chinese origin but it has been introduced under the name "Janata biogas plant" by Gobar Gas Research Station, Ajitmal in view of its reduced cost. This is a plant where no steel is used, there is no moving part in it and maintenance cost is low. The plant can be constructed by village mason taking some pre-explained precautions and using all the indigenously available building materials. Good quality of bricks and cement should be used to avoid the afterward structural problems like cracking of the dome and leakage of gas.

This model have a higher capacity when compared with KVIC model, hence it can be used as a community biogas plant. This design has longer life than KVIC models. Substrates other than cattle dung such as municipal waste and plant residues can also be used in janata type plants. The plant consists of an underground well sort of digester made of bricks and cement having a dome shaped roof which remains below the ground level is shown in figure. At almost middle of the digester, there are two rectangular openings facing each other and coming up to a little above the ground level, act as an inlet and outlet of the plant.

Dome shaped roof is fitted with a pipe at its top which is the gas outlet of the plant. The principle of gas production is same as that of KVIC model. The biogas is collected in the restricted space of the fixed dome, hence the pressure of gas is much higher, which is around 90 cm of water column.



Video Content / Details of website for further learning (if any):

https://blog.anaerobic-digestion.com/biogas-generator/

Important Books/Journals for further learning including the page nos.:

- G.D.Rai, 'Non-Conventional Energy Sources', Khanna Publishers , 2011. (Page No:342-352)

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L31

LECTURE HANDOUTS

EEE **II/III**

Course Name with Code : **19GES20/ Renewable Energy Sources**

Course Faculty : **Mr.C.RAMKUMAR**

Unit : **4-Biomass Energy** **Date of Lecture:**

Topic of Lecture : Digesters

Introduction :

Most organic materials undergo a natural anaerobic digestion in the presence of moisture and absence of oxygen and produce biogas. The biogas so obtained is a mixture of methane (CH_4): 55-65% and Carbon dioxide (CO_2): 30-40%. The biogas contains traces of H_2, H_2S and N_2. The calorific value of biogas ranges from 5000 to 5500 Kcal/Kg (18.8 to 26.4 MJ /m^3). The biogas can be upgraded to synthetic natural gas (SNG) by removing CO_2 and H_2S. The production of biogas is of particular significance in India because of its large scale cattle production. The biogas is used for cooking, domestic lighting and heating, run I.C. Engines and generation of electricity for use in agriculture and rural industry. Family biogas plants usually of 2-3 m^3 capacity.

Prerequisite knowledge for Complete understanding and learning of Topic:

1.Environmental Science

2.Basics of Civil & Mechanics

Deenbandhu biogas plant :

Deenbandhu model was developed in 1984, by Action for Food Production (AFPRO), a voluntary organization based in New Delhi. Schematic diagram of a Deenabandhu biogas plantentire biogas programme of India as it reduced the cost of the plant half of that of KVIC model and brought biogas technology within the reach of even the poorer sections of the population. The cost reduction has been achieved by minimizing the surface area through joining the segments of two spheres of different diameters at their bases. The cost of a Deenbandhu plant having a capacity of 2 m3/day is about Rs.8000-00.

The Deenbandhu biogas plant has a hemispherical fixed-dome type of gas holder, unlike the floating dome of of the KVIC-design is shown. The dome is made from pre-fabricated ferrocement or reinforced concrete and attached to the digester, which has a curved bottom. The slurry is fed from a mixing tank through an inlet pipe connected to the digester.

After fermentation, the biogas collects in the space under the dome. It is taken out for use through a pipe connected to the top of the dome, while the sludge, which is a by-product, comes out through an opening in the side of the digester. About 90 percent of the biogas plants in India are of the Deenbandhu type.

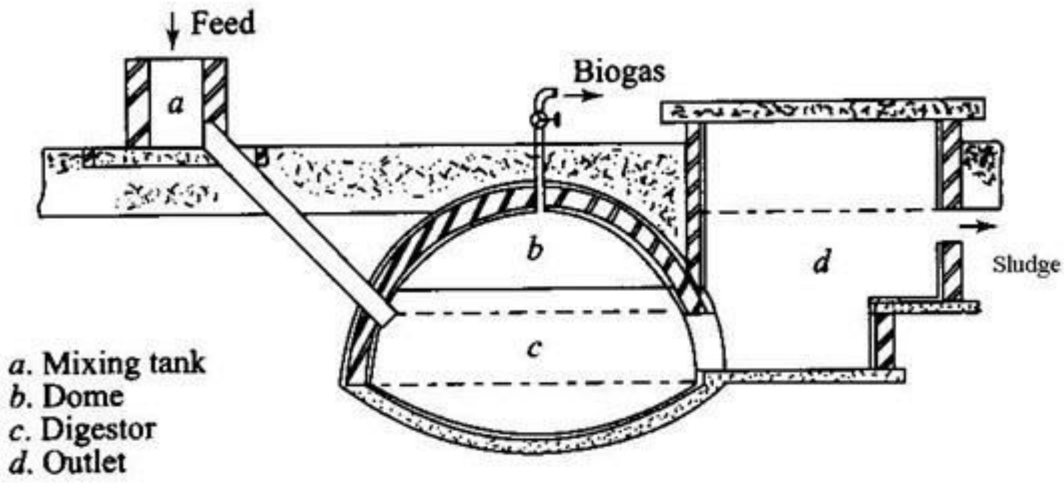

Fig. Schematic diagram of a Deenabandhu biogas plant

Video Content / Details of website for further learning (if any):

https://blog.anaerobic-digestion.com/biogas-generator/

Important Books/Journals for further learning including the page nos.:

- G.D.Rai, 'Non-Conventional Energy Sources', Khanna Publishers , 2011. (Page No:342-352)

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LECTURE HANDOUTS

EEE

II/III

Course Name with Code : **19GES20/ Renewable Energy Sources**

Course Faculty : **Mr.C.RAMKUMAR**

Unit : **4-Biomass Energy** **Date of Lecture:**

Topic of Lecture : Ethanol production

Introduction :

Biogas a mixture of gas produced by the microorganisms during the anaerobic fermentation of biodegradable materials. Anaerobic fermentation is a biochemical process in which particular kinds of bacteria digest biomass in an oxygen-free environment resulting in production of CH_4, CO_2, H_2 and traces of other gases along with decomposed mass.

Prerequisite knowledge for Complete understanding and learning of Topic:

1.Environmental Science

2.Basics of Civil & Mechanics

Ethanol Production

Biogas is a mixture of different components and the composition varies depending upon the characteristics of feed materials, amount of degradation, etc. Biogas predominantly consists of 50 to 70 per cent methane, 30 to 40 per cent carbon dioxide and low amount of other gases. Methane is a combustible gas. The energy content of biogas depends on the amount of methane it contains. Methane content varies from about 50 percent to 70 percent. The composition and the properties of the biogas are given in the following table 1.1 and 1.2.

Table .1 Composition of biogas

Name of the gas	Composition in biogas (%)
Methane (CH_4)	50-70
Carbon dioxide (CO_2)	30-40
Hydrogen (H_2)	5-10
Nitrogen (N_2)	1-2
Water vapour (H_2O)	0.3
Hydrogen sulphide (H_2S)	Traces

Table 1.2 Properties of biogas

Properties	Range
Net calorific value (MJ/m^3)	20
Air required for combustion (m^3/m^3)	5.7
Ignition temperature (^0C)	700
Density (kg/m^3)	0.94

Microbiology of biogas production:

The production of biogas from organic material under anaerobic condition involves sequence of microbial reactions. During the process complex organic molecule present in the biomass are broken down to sugar, alcohols, pesticides and amino acids by acid producing bacteria. The resultant products are then used to produce methane by another category of bacteria. The biogas production process involves three stages namely:

1. Hydrolysis
2. Acid formation and
3. Methane formation

The process of degradation of organic material in every step is done by range of bacteria, which are specialized in reduction of intermediate products formed. The different process involved in production of biogas is given in the figure. The efficiency of the digestion depends how far the digestion happens in these three stages. Better the digestion, shorter the retention time and efficient gas production.

Hydrolysis

The complex organic molecules like fats, starches and proteins which are water insoluble contained in cellulosic biomass are broken down into simple compounds with the help of enzymes secreted by bacteria. This stage is also known as polymer breakdown stage (polymer to monomer). The major end product is glucose which is a simple product.

Acid formation

The resultant product (monomers) obtained in hydrolysis stage serve as input for acid formation stage bacteria. Products produced in previous stage are fermented under anaerobic conditions to form different acids. The major products produced at the end of this stage are acetic acid, propionic acid, butyric acid and ethanol.

Methane formation:

The acetic acid produced in the previous stages is converted into methane and carbon dioxide by a group of microorganism called "*Methanogens*". In other words, it is process of production of methane by methanogens. They are obligatory anaerobic and very sensitive to environmental changes. Methanogens utilise the intermediate products of the preceding stages and convert them into methane, carbon dioxide, and water. It is these components that make up the majority of the biogas emitted from the system. Methanogenesis is sensitive to both high and low pH's and occurs between pH 6.5 and pH 8. Major reactions occurring in this stage is given below:

$$CH_3COOH \text{ (Acetic acid)} \longrightarrow CH_4 \text{ (Methane)} + CO_2 \text{ (Carbon dioxide)}$$

$$2CH_3CH_2OH \text{ (Ethanol)} + CO_2 \text{ (Carbon dioxide)} \longrightarrow CH_4 \text{ (Methane)} + 2CH_3COOH \text{ (Acetic acid)}$$

$$CO_2 \text{ (Carbon dioxide)} + 4H_2 \text{ (Hydrogen)} \longrightarrow CH_4 \text{ (Methane)} + 2H_2O \text{ (Water)}$$

The process of biogas formation through different stages is depicted in figure.

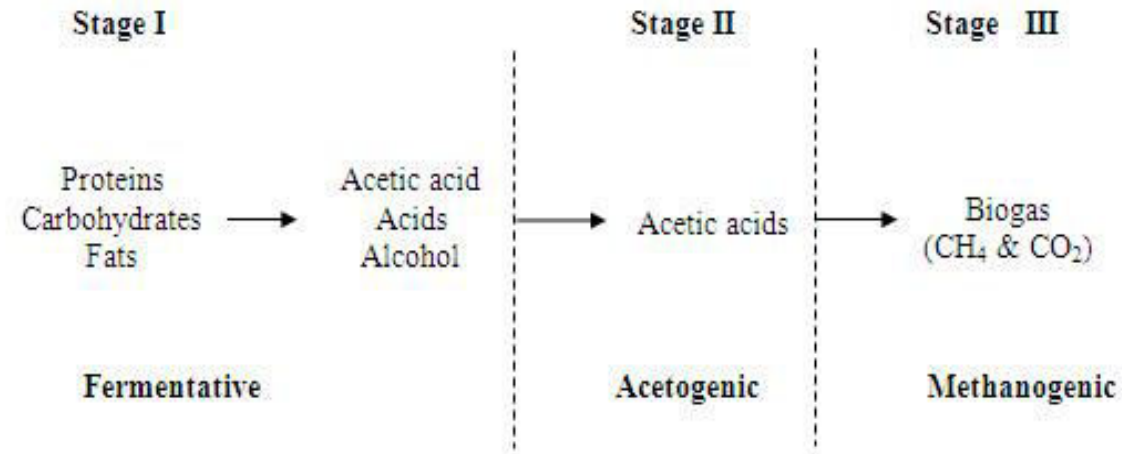

Figure: Stages of biogas formation

Biogas plant and its components:

A physical structure designed to carry out anaerobic digestion of organic materials is called "Biogas plant". Following are the components of biogas plants:

Mixing tank	:	Cow dung is collected from the shed and mixed with the water in equal proportion (1:1) to make a homogenous mixture (slurry) in the mixing tank
Feed inlet pipe/tank	:	The homogenous slurry is let into the digester through this inlet pipe (KVIC biogas plants)/tank (Janatha biogas plants)
Digester	:	The fed slurry is subjected to anaerobic fermentation with the help of microorganisms inside the digester.
Gas holder	:	As a result of anaerobic fermentation, gas produced is stored in gas holder (Drum in the case of KVIC and in dome in the case of fixed dome

		biogas plants)
Slurry outlet tank/pipe	:	The digested slurry is let out from the digester through slurry outlet pipe (KVIC biogas plants)/tank (Janatha biogas plants)
Gas outlet pipe	:	Stored gas is released and conveyed through the gas outlet pipe present at the top of gas holder.

Video Content / Details of website for further learning (if any):

https://www.chemengonline.com/the-biogas-boom/?printmode=1

Important Books/Journals for further learning including the page nos.:

- G.D.Rai, 'Non-Conventional Energy Sources', Khanna Publishers , 2011. (Page No:385-390)

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L33

LECTURE HANDOUTS

EEE

II/III

Course Name with Code : **19GES20/ Renewable Energy Sources**

Course Faculty : **Mr.C.RAMKUMAR**

Unit : **4-Biomass Energy** **Date of Lecture:**

Topic of Lecture : Bio diesel

Introduction :
Biodiesel [1–5] is a liquid biofuel obtained by chemical processes from vegetable oils or animal fats and an alcohol that can be used in diesel engines, alone or blended with diesel oil. ... For instance, "B5" indicates a blend with 5% biodiesel and 95% diesel fuel; in consequence, B100 indicates pure biodiesel.

Prerequisite knowledge for Complete understanding and learning of Topic:
1.Environmental Science

2.Basics of Civil & Mechanics

Biodiesel
It is a liquid biofuel obtained by chemical processes from vegetable oils or animal fats and an alcohol that can be used in diesel engines, alone or blended with diesel oil. ASTM International (originally known as the American Society for Testing and Materials) defines biodiesel as a mixture of long-chain monoallelic esters from fatty acids obtained from renewable resources, to be used in diesel engines.
Blends with diesel fuel are indicated as ''Bx'', where ''x'' is the percentage of biodiesel in the blend. For instance, ''B5'' indicates a blend with 5% biodiesel and 95% diesel fuel; in consequence, B100 indicates pure biodiesel.

Advantages of the Use of Biodiesel
Some of the advantages of using biodiesel as a replacement for diesel fuel are [1–4]:
• Renewable fuel, obtained from vegetable oils or animal fats.
• Low toxicity, in comparison with diesel fuel.
• Degrades more rapidly than diesel fuel, minimizing the environmental consequences of biofuel spills.
• Lower emissions of contaminants: carbon monoxide, particulate matter, polycyclic aromatic hydrocarbons, aldehydes.
• Lower health risk, due to reduced emissions of carcinogenic substances.
• No sulfur dioxide (SO_2) emissions.
• Higher flash point (100C minimum). S. D. Romano and P. A. Sorichetti, Dielectric Spectroscopy in Biodiesel Production and Characterization, Green Energy and Technology, DOI: 10.1007/978-1-84996-519-4_2, Springer-Verlag London Limited 2011 7
• May be blended with diesel fuel at any proportion; both fuels may be mixed during the fuel

supply to vehicles.
• Excellent properties as a lubricant.
• It is the only alternative fuel that can be used in a conventional diesel engine, without modifications. • Used cooking oils and fat residues from meat processing may be used as raw materials.

Disadvantages of the Use of Biodiesel
There are certain disadvantages of using biodiesel as a replacement for diesel fuel that must be taken into consideration:
• Slightly higher fuel consumption due to the lower calorific value of biodiesel.
• Slightly higher nitrous oxide (NOx) emissions than diesel fuel.
• Higher freezing point than diesel fuel. This may be inconvenient in cold climates.
• It is less stable than diesel fuel, and therefore long-term storage (more than six months) of biodiesel is not recommended.
• May degrade plastic and natural rubber gaskets and hoses when used in pure form, in which case replacement with Tefloncomponents is recommended.
• It dissolves the deposits of sediments and other contaminants from diesel fuel in storage tanks and fuel lines, which then are flushed away by the biofuel into the engine, where they can cause problems in the valves and injection systems. In consequence, the cleaning of tanks prior to filling with biodiesel is recommended. It must be noted that these disadvantages are significantly reduced when biodiesel is used in blends with diesel fuel.

Raw Materials for Biodiesel Production
The raw materials for biodiesel production are vegetable oils, animal fats and short chain alcohols. The oils most used for worldwide biodiesel production are rapeseed (mainly in the European Union countries), soybean (Argentina and the United States of America), palm (Asian and Central American countries) and sunflower, although other oils are also used, including peanut, linseed, safflowerused vegetable oils, and also animal fats. Methanol is the most frequently used alcohol although ethanol can also be used. Since cost is the main concern in biodiesel production and trading (mainly due to oil prices), the use of non-edible vegetable oils has been studied for several years with good results.
Introduction to Biodiesel Production Besides its lower cost, another undeniable advantage of non-edible oils for biodiesel production lies in the fact that no foodstuffs are spent to produce fuel.
These and other reasons have led to medium- and large-scale biodiesel production trials in several countries, using non-edible oils such as castor oil, tung, cotton, jojoba and jatropha. Animal fats are also an interesting option, especially in countries with plenty of livestock resources, although it is necessary to carry out preliminary treatment since they are solid; furthermore, highly acidic grease from cattle, pork, poultry, and fish can be used. Microalgae appear to be a very important alternative for future biodiesel production due to their very high oil yield; however, it must be taken into account that only some species are useful for biofuel production. Although the properties of oils and fats used as raw materials may differ, the properties of biodiesel must be the same, complying with the requirements set by international standards.

Typical Oil Crops Useful for Biodiesel Production
The main characteristics of typical oil crops that have been found useful for biodiesel production are summarized in the following paragraphs [6–10]. Rapeseed and Canola Rapeseed adapts well to low fertility soils, but with high sulfur content. With a high oil yield (40–50%), it may be grown as a winter-cover crop, allows double cultivation and crop rotation. It is the most important raw material for biodiesel production in the European Community. However, there were technological limitations for sowing and harvesting in some Central and South American countries, mainly due to the lack of adequate information about fertilization,

seed handling, and storage (the seeds are very small and require specialized agricultural machinery). Moreover, low prices in comparison to wheat (its main competitor for crop rotation) and low production per unit area have limited its use. Rapeseed flour has high nutritional value, in comparison to soybean; it is used as a protein supplement in cattle rations. Sometimes canola and rapeseed are considered to be synonymous; canola (Canadian oil low acid) is the result of the genetic modification of rapeseed in the past 40 years, in Canada, to reduce the content of erucic acid and glycosylates in rapeseed oil, which causes inconvenience when used in animal and human consumption. Canola oil is highly appreciated due to its high quality, and with olive oil, it is considered as one of the best for cooking as it helps to reduce blood cholesterol levels.
Video Content / Details of website for further learning (if any): 1. https://www.youtube.com/watch?v=eGYcZ2UyHMc
Important Books/Journals for further learning including the page nos.: ➢ G.D.Rai, 'Non-Conventional Energy Sources', Khanna Publishers , 2011. (Page No:392-395)

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L34

LECTURE HANDOUTS

EEE **II/III**

Course Name with Code : **19GES20/ Renewable Energy Sources**

Course Faculty : **Mr.C.RAMKUMAR**

Unit : **4-Biomass Energy** **Date of Lecture:**

Topic of Lecture : Cogeneration

Introduction :

Cogeneration or combined heat and power (CHP) is the use of a heat engine or power station to generate electricity and useful heat at the same time.

Cogeneration is a more efficient use of fuel or heat, because otherwise-wasted heat from electricity generation is put to some productive use. Combined heat and power (CHP) plants recover otherwise wasted thermal energy for heating. This is also called combined heat and power district heating. Small CHP plants are an example of decentralized energy. By-product heat at moderate temperatures (100–180 °C, 212–356 °F) can also be used in absorption refrigerators for cooling.

The supply of high-temperature heat first drives a gas or steam turbine-powered generator. The resulting low-temperature waste heat is then used for water or space heating. At smaller scales (typically below 1 MW), a gas engine or diesel engine may be used.

Cogeneration was practiced in some of the earliest installations of electrical generation. Before central stations distributed power, industries generating their own power used exhaust steam for process heating. Large office and apartment buildings, hotels, and stores commonly generated their own power and used waste steam for building heat. Due to the high cost of early purchased power, these CHP operations continued for many years after utility electricity became available.

Prerequisite knowledge for Complete understanding and learning of Topic:

1.Environmental Science

2.Basics of Civil & Mechanics

Cogeneration

Topping cycle plants primarily produce electricity from a steam turbine. Partly expanded steam is then condensed in a heating condenser at a temperature level that is suitable e.g. district heating or water desalination.

Bottoming cycle plants produce high temperature heat for industrial processes, then a waste heat recovery boiler feeds an electrical plant. Bottoming cycle plants are only used in industrial processes that require very high temperatures such as furnaces for glass and metal manufacturing, so they are less common.

Large cogeneration systems provide heating water and power for an industrial site or an entire town. Common CHP plant types are:

- Gas turbine CHP plants using the waste heat in the flue gas of gas turbines. The fuel used is typically natural gas.
- Gas engine CHP plants use a reciprocating gas engine, which is generally more competitive than a gas turbine up to about 5 MW. The gaseous fuel used is normally natural gas. These plants are generally manufactured as fully packaged units that can be installed within a plantroom or external plant compound with simple connections to the site's gas supply, electrical distribution network and heating systems.
- Biofuel engine CHP plants use an adapted reciprocating gas engine or diesel engine, depending upon which biofuel is being used, and are otherwise very similar in design to a Gas engine CHP plant. The advantage of using a biofuel is one of reduced hydrocarbon fuel consumption and thus reduced carbon emissions. These plants are generally manufactured as fully packaged units that can be installed within a plantroom or external plant compound with simple connections to the site's electrical distribution and heating systems. Another variant is the wood gasifier CHP plant whereby a wood pellet or wood chip biofuel is gasified in a zero oxygen high temperature environment; the resulting gas is then used to power the gas engine.
- Combined cycle power plants adapted for CHP
- Molten-carbonate fuel cells and solid oxide fuel cells have a hot exhaust, very suitable for heating.
- Steam turbine CHP plants that use the heating system as the steam condenser for the steam turbine
- Nuclear power plants, similar to other steam turbine power plants, can be fitted with extractions in the turbines to bleed partially expanded steam to a heating system. With a heating system temperature of 95 °C it is possible to extract about 10 MW heat for every MW electricity lost. With a temperature of 130 °C the gain is slightly smaller, about 7 MW for every MWe lost.A review of cogeneration options is in Czech research team proposed a "Template" system where heat from spent fuel rods is recovered for the purpose of residential heating.

Smaller cogeneration units may use a reciprocating engine or Stirling engine. The heat is removed from the exhaust and radiator. The systems are popular in small sizes because small gas and diesel engines are less expensive than small gas- or oil-fired steam-electric plants.

Some cogeneration plants are fired by biomass, or industrial and municipal solid waste (see incineration). Some CHP plants utilize waste gas as the fuel for electricity and heat generation. Waste gases can be gas from animal waste, landfill gas, gas from coal mines, sewage gas, and combustible industrial waste gas.

Some cogeneration plants combine gas and solar photovoltaic generation to further improve technical and environmental performance. Such hybrid systems can be scaled down to the building level and even individual homes.

Cogeneration using biomass

Biomass is emerging as one of the most important sources of renewable energy. Biomass refers to any plant or animal matter in which it is possible to be reused as a source of heat or electricity, such as sugarcane, vegetable oils, wood, organic waste and residues from the food or agricultural industries. Brazil is now considered a world reference in terms of energy generation from biomass.

A growing sector in the use of biomass for power generation is the sugar and alcohol sector, which mainly uses sugarcane bagasse as fuel for thermal and electric power generation.

Power cogeneration in the sugar and alcohol sector

In the sugarcane industry, cogeneration is fueled by the bagasse residue of sugar refining, which is burned to produce steam. Some steam can be sent through a turbine that turns a generator, producing electric power.

Energy cogeneration in sugarcane industries located in Brazil is a practice that has been growing in last years. With the adoption of energy cogeneration in the sugar and alcohol sector, the sugarcane industries are able to supply the electric energy demand needed to operate, and generate a surplus that can be commercialized.

Advantages of the cogeneration using sugarcane bagasse

In comparison with the electric power generation by means of fossil fuel-based thermoelectric plants, such as natural gas, the energy generation using sugarcane bagasse has environmental advantages due to the reduction of CO2 emissions.

In addition to the environmental advantages, cogeneration using sugarcane bagasse presents advantages in terms of efficiency comparing to thermoelectric generation, through the final destination of the energy produced. While in thermoelectric generation, part of the heat produced is lost, in cogeneration this heat has the possibility of being used in the production processes, increasing the overall efficiency of the process.

Video Content / Details of website for further learning (if any):

1. https://global.kawasaki.com/en/energy/equipment/gas_turbines/cogeneration.html

Important Books/Journals for further learning including the page nos.:

- G.D.Rai, 'Non-Conventional Energy Sources', Khanna Publishers , 2011. (Page No:395-406)

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L35

LECTURE HANDOUTS

EEE **II/III**

Course Name with Code : **19GES20/ Renewable Energy Sources**

Course Faculty : **Mr.C.RAMKUMAR**

Unit : **4-Biomass Energy** **Date of Lecture:**

Topic of Lecture : Biomass Applications.

Introduction :
Biomass systems range from small stoves used in homes for heating or cooking to large power plants used by centralized utilities to produce electricity. In residential applications, biomass can be used for space heating or for cooking.

Prerequisite knowledge for Complete understanding and learning of Topic:
1.Environmental Science

2.Basics of Civil & Mechanics

Electricity Generation

For generating electricity, the producer gas from the biomass gasifier is first cleaned and cooled and then used as a fuel in an IC engine. A generator coupled to the engine produces electricity.

Biomass gasifier engine sets are typically available in capacities ranging from 10 kWto 500 kW. Two types of engines are used. Diesel engines are modified and can be run on a mixture of diesel and producer gas. These are called dual-fuel engines. Typically 60 -85% diesel is replaced with producer gas. Now 100% producer gas engines are also available — as the name suggests these can operate on 100% producer gas.

Village Electrification in an off grid mode

In recent years biomass gasifiers have been used for electrification of remote villages. The size of such systems can vary from 10kWe to 500 kW. In India, several of the smaller size (10-20 kW) biomass gasifier systems have been established under two Government of India schemes called Remote Village Electrification (RVE) and Village Energy Security Programmers (VESP). Apart from the Government programmers, several NGOs and corporate have also established such systems.

There have been a few instances like 500 kW biomass gasifier based power plant at Gasaboisland in Sundarbans (India) where large capacity gasifiers have been used.

Video Content / Details of website for further learning (if any):
1. https://www.e-education.psu.edu/eme444/node/405
Important Books/Journals for further learning including the page nos.:
➢ G.D.Rai, 'Non-Conventional Energy Sources', Khanna Publishers , 2011. (Page No:364)

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LECTURE HANDOUTS

EEE

II/III

Course Name with Code : **19GES20/ Renewable Energy Sources**

Course Faculty : **Mr.C.RAMKUMAR**

Unit : **4-Biomass Energy** **Date of Lecture:**

Topic of Lecture : Utilization for cooking

Introduction :

If the materials used in the plant construction such as cement, sand, aggregate etc. are not of good quality, the quality of the plant will be poor even if the design and workmanship are excellent. A brief description regarding the specifications for some of the construction materials is provided below to assist with selection of the best quality materials.

Prerequisite knowledge for Complete understanding and learning of Topic:

1.Environmental Science

2.Basics of Civil & Mechanics

Construction &Utilization for cooking

Cement

Cement should be high quality Portland cement from a brand with a good reputation. It must be fresh, free from lumps and stored in dry place. Bags of cement should not be stacked directly on the floor or against the walls. Wooden planks have to be placed on the floor to protect cement from dampness. Cement bags should be stalked at least 20 cm away from any walls.

Sand

Sand should be clean and not contain soil or other material; dirty sand will have a very early negative effect to the structure. Coarse and granular sand are suitable for concreting work, however fine sand should be used for plastering works. River/lake sand is well graded hence preferred. Avoid dusty sand.

Gravel/Ballast

The size of gravel should neither be very big nor very small and should be clean, hard and angular in shape. If dirty should be cleaned first before use and the maximum size of gravel should be ¾" or ¼ the slab thickness. Gravel should be clean, hard and of angular shape. If it is dirty, it has to be washed properly before use.

Water

Water is mainly required for making the cement mortar for masonry works, concreting works and plastering. It is also used to soak bricks before using. Besides, it is required for cleaning or washing construction materials if they are dirty. The water from ponds or cannel may be dirty so it is better not to use it. Dirty water will have an adverse effect on the strength of structure. Water from water tap or well or any other sources that supply clean water has to be used.

Bricks

Brick plays a very important role in construction of biodigesters. Bricks should be of high quality, usually the best quality available in the local market. The bricks should be well burnt, straight, regular in shape, sizes and should not have cracks or broken parts. High quality bricks make a clear metallic sound when hitting them to each other. Such bricks should be able to bear a pressure of 120 kg per square centimeter. Before use, bricks must be soaked for few minutes in clean water. Wet brick will not absorb water from the mortar which is needed for setting properly.

Mild steel bars

MS bars are used to construct the covers of outlet tank and water drain chamber. It should meet the engineering standard generally adopted. For plants of 4, 6 and 8 cum, MS rods of 8 mm diameter and for plant of 10 cum capacity 10 mm diameter is recommended. MS bar should be free from heavy rust.

Mixing Device

This device is used to prepare good quality water-dung solution in the inlet tank when cattle dung is used as feeding material. Usually for household biogas digesters, vertical mixing devices are installed. The device should be of good quality, as per the design, and the mixing blades have to be well galvanized. The blade should be properly aligned for the effective mixing.

List of materials required for construction of KVIC biogas plants(40 days retention time)

Materials	Plant size (m^3)					
	2	3	4	6	8	10
Bricks- I Class (no)	2460	2770	3210	3730	4430	4650
Cement (50kg) bags (no)	13	17	19	23	26	28
Stone chip(12mm/20mm) (cu.m)	0.60	0.90	0.95	1.25	1.40	1.60
River sand(cu.m)	2.00	2.55	2.90	3.40	4.50	5.00
A.C.Pipe 100 mm dia (m)	3.9	4.6	6.3	6.5	7.7	8.0

List of materials required for construction of deenbandhu biogas plants(40 days retention time)

Materials	Plant size (m^3)				
	1	2	3	4	6
Bricks- I Class (no)	700	1000	1300	1600	2200
Cement (50kg) bags (no)	8	14	16	22	28
Stone chip (12mm/20mm) (cu.m)	0.85	1.14	1.43	1.70	2.40
River sand(cu.m)	0.85	111	1.43	1.70	2.40

GI pipe (cm)	17.78	17.78	17.78	17.78	17.78
A.C pipe 6″ dia (m)	1.80	1.80	1.80	1.80	1.80
Iron rod 6 mm dia (kg)	6.00	7.00	10.00	12.00	15.00
Labours (man hours)					
Excavation	8	10	14	18	24
Masons	8	11	13	16	22
Construction labours	16	22	26	30	44

Plant layout

Construction works of biodigester starts with the process of layout works. This is the activity carried out to mark the dimensions of plant in the ground to start the digging work. For this purpose, first a small peg has to be stuck in the ground at the centre spot of the digester. Then the following steps should be followed:

- Level the ground and determine the centre line of the digester, outlet tank and inlet pit
- Decide the reference level. It is better to assume the leveled ground level as the reference level. The top of the dome (outer) should exactly be in this level.
- Select the outer radius of the pit (digester diameter plus wall thickness plus space for a footing projection of at least 10 cm) and mark it in the rope or chord.
- Insert a stick or wooden peg in the leveled ground at the centre of the proposed digester pit. With the help of this pole and chord prepared earlier, make a circle, which indicates the area to dig.
- From the centre point where the central line meets with the perimeter line, draw a tangent and measure a length equal to half of the breadth of outlet plus wall thickness (for outlet chamber) and half of the size of manhole (30cm) plus wall thickness for manhole, on either side of this tangent. Mark the manhole ensuring that the inner size is 60 cm x 60 cm.
- Draw horizontal parallel lines from the points in either side in the tangent, which will meet the dome. From the centre point where the central line meets with the perimeter line, measure the length of outlet plus wall thickness to decide the outer dimension of outlet.
- Use coloured powder to mark the dimensions.
- Decide the location of slurry pits while laying out plant digester and outlet.

Digging of Pit

After completion of lay-out work, the work for digging of pit has to be started. Tools like, crow-bar, picks, spade, shovel and basket should be available at the site. The following points have to be followed to dig the pit.

- Digging should be done as per the dimensions fixed during layout
- As far as practical the cutting in ground should be vertical
- If the water table is high and digging to the required depth is difficult, a deeper pit has to be constructed near the digester pit. Water accumulated in the digester pit has to be drain to this pit through underground pipes. Water should be pumped from this pit.

- Once the depth of digging is equal to the dimension, the work of leveling and ramming the base has to be done. The pit bottom must be leveled and the earth must be untouched
- Ensure that the excavated earth is deposited at least 2 m away from the pit in each side to ease the construction works.
- Be careful to avoid accident while digging near the sides as soil may collapse.
- Dig the foundation for the manhole (first step of outlet tank) along with the foundation for digester as per the dimensions in the drawing during the layout.

Video Content / Details of website for further learning (if any):

https://www.youtube.com/watch?v=Hj0a6llobbo

Important Books/Journals for further learning including the page nos.:

- G.D.Rai, 'Non-Conventional Energy Sources', Khanna Publishers , 2011. (Page No:381-384)

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LECTURE HANDOUTS

EEE

II/III

Course Name with Code : **19GES20/ Renewable Energy Sources**

Course Faculty : **Mr.C.RAMKUMAR**

Unit : **5- Other Renewable Energy Sources**

Date of Lecture:

Topic of Lecture : Tidal energy

Introduction :

Tidal power or **tidal energy** is harnessed by converting energy from tides into useful forms of power, mainly electricity using various methods.

Although not yet widely used, tidal energy has the potential for future electricity generation. Tides are more predictable than the wind and the sun. Among sources of renewable energy, tidal energy has traditionally suffered from relatively high cost and limited availability of sites with sufficiently high tidal ranges or flow velocities, thus constricting its total availability. However, many recent technological developments and improvements, both in design (e.g. dynamic tidal power, tidal lagoons) and turbine technology (e.g. new axial turbines, cross flow turbines), indicate that the total availability of tidal power may be much higher than previously assumed and that economic and environmental costs may be brought down to competitive levels.

Historically, tide mills have been used both in Europe and on the Atlantic coast of North America. The incoming water was contained in large storage ponds, and as the tide goes out, it turns waterwheels that use the mechanical power to produce mill grain.

The earliest occurrences date from the Middle Ages, or even from Roman times. The process of using falling water and spinning turbines to create electricity was introduced in the U.S. and Europe in the 19th century.

Prerequisite knowledge for Complete understanding and learning of Topic:

1.Environmental Science

2.Basics of Civil & Mechanics

Tidal stream generator

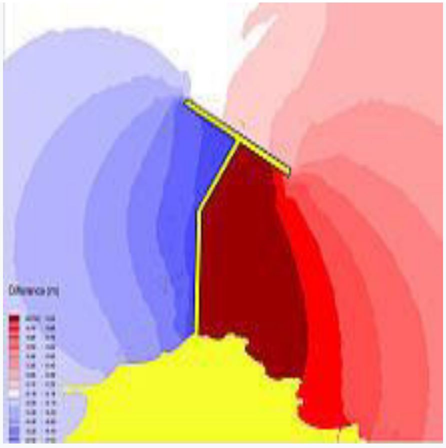
Tidal stream generators make use of the kinetic energy of moving water to power turbines, in a similar way to wind turbines that use the wind to power turbines. Some tidal generators can be built into the structures of existing bridges or are entirely submersed, thus avoiding concerns over the impact on the natural landscape. Land constrictions such as straits or inlets can create high velocities at specific sites, which can be captured with the use of turbines. These turbines can be horizontal, vertical, open, or ducted.

Stream energy can be used at a much higher rate than wind turbines due to water being denser than air. Using similar technology to wind turbines converting the energy in tidal energy is much more efficient. Close to 10 mph (4.5 m/s; 8.7 km; 16 km/h) ocean tidal current would have an energy output equal or greater than a 90 mph (40 m/s; 78 km; 140 km/h) wind speed for the same size of the turbine system.

Tidal barrage

Tidal barrages make use of the potential energy in the difference in height (or hydraulic head) between high and low tides. When using tidal barrages to generate power, the potential energy from a tide is seized through the strategic placement of specialized dams. When the sea level rises and the tide begins to come in, the temporary increase in tidal power is channeled into a large basin behind the dam, holding a large amount of potential energy. With the receding tide, this energy is then converted into mechanical energy as the water is released through large turbines that create electrical power through the use of generators. Barrages are essentially dams across the full width of a tidal estuary.

Dynamic tidal power



Top-down diagram of a DTP dam. Blue and dark red colors indicate low and high tides, respectively.

Dynamic tidal power (or DTP) is a theoretical technology that would exploit an interaction between potential and kinetic energies in tidal flows. It proposes that very long dams (for example: 30–50 km length) be built from coasts straight out into the sea or ocean, without enclosing an area. Tidal phase differences are introduced across the dam, leading to a significant water-level differential in shallow coastal seas – featuring strong coast-parallel oscillating tidal currents such as found in the UK, China, and Korea. Induced tides (TDP) could extend the geographic viability of a new hydro-atmospheric concept 'LPD' (lunar pulse drum) discovered by a Devon innovator in which a tidal 'water piston' pushes or pulls a metered jet of air to a rotary air-actuator & generator. The principle was demonstrated at London Bridge June 2019. Plans for a 30m, 62.5kwh 'pilot' installation on a (Local Authority) tidal estuary shoreline in the Bristol Channel are underway.

Tidal lagoon

A new tidal energy design option is to construct circular retaining walls embedded with turbines that can capture the potential energy of tides. The created reservoirs are similar to those of tidal barrages, except that the location is artificial and does not contain a pre-existing ecosystem.

The lagoons can also be in double (or triple) format without pumping or with pumping that will flatten out the power output. The pumping power could be provided by excess to grid demand renewable energy from for example wind turbines or solar photovoltaic arrays. Excess renewable energy rather than being curtailed could be used and stored for a later period of time.

Geographically dispersed tidal lagoons with a time delay between peak production would also flatten out peak production providing near baseload production though at a higher cost than some other alternatives such as district heating renewable energy storage. The cancelled Tidal Lagoon Swansea Bay in Wales, United Kingdom would have been the first tidal power station of this type once built.

Video Content / Details of website for further learning (if any):

1. https://www.youtube.com/watch?v=2knGB8gK7UY

Important Books/Journals for further learning including the page nos.:

- G.D.Rai, 'Non-Conventional Energy Sources', Khanna Publishers , 2011. (Page No:364)

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LECTURE HANDOUTS

EEE **II/III**

Course Name with Code : **19GES20/ Renewable Energy Sources**

Course Faculty : **Mr.C.RAMKUMAR**

Unit : **5- Other Renewable Energy Sources**

Date of Lecture:

Topic of Lecture : Wave Energy

Introduction :

Wave power is the capture of energy of wind waves to do useful work – for example, electricity generation, water desalination, or pumping water. A machine that exploits wave power is a wave energy converter (WEC).

Wave power is distinct from tidal power, which captures the energy of the current caused by the gravitational pull of the Sun and Moon. Waves and tides are also distinct from ocean currents which are caused by other forces including breaking waves, wind, the Coriolis effect, cobbling, and differences in temperature and salinity.

Wave-power generation is not a widely employed commercial technology compared to other established renewable energy sources such as wind power, hydropower and solar power. However, there have been attempts to use this source of energy since at least 1890mainly due to its high power density. As a comparison, the power density of photovoltaic panels is 1 kW/m^2 at peak solar insolation, and the power density of the wind is 1 kW/m^2 at 12 m/s; the average annual power density of the waves at e.g. San Francisco coast is 25 kW/m^2.

Prerequisite knowledge for Complete understanding and learning of Topic:

1.Environmental Science

2.Basics of Civil & Mechanics

Point absorber buoy

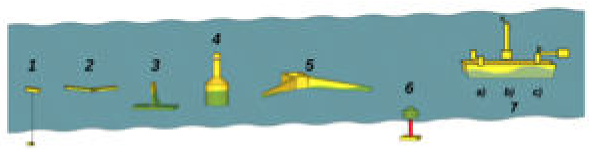
This device floats on the surface of the water, held in place by cables connected to the seabed. The point-absorber is defined as having a device width much smaller than the incoming wavelength λ. A good point absorber has the same characteristics as a good wave-maker. The wave energy is absorbed by radiating a wave with destructive interference to the incoming waves. Buoys use the rise and fall of swells to generate electricity in various ways including directly via linear generators, or via generators driven by mechanical linear-to-rotary converters or hydraulic pumps. Electromagnetic fields generated by electrical transmission cables and acoustics of these devices may be a concern for marine organisms. The presence of the buoys may affect fish, marine mammals, and birds as potential minor collision risk and roosting sites. Potential also exists for entanglement in mooring lines. Energy removed from the waves may also affect the shoreline, resulting in a recommendation that sites remain a considerable distance from the shore.

Surface attenuator

These devices act similarly to the aforementioned point absorber buoys, with multiple floating segments connected to one another and are oriented perpendicular to incoming waves. A flexing motion is created by swells, and that motion drives hydraulic pumps to generate electricity. Environmental effects are similar to those of point absorber buoys, with an additional concern that organisms could be pinched in the joints.

Modern technology

Wave power devices are generally categorized by the method used to capture or harness the energy of the waves, by location and by the power take-off system. Locations are shoreline, nearshore and offshore. Types of power take-off include: hydraulic ram, elastomeric hose pump, pump-to-shore, hydroelectric turbine, air turbine, and linear electrical generator. When evaluating wave energy as a technology type, it is important to distinguish between the four most common approaches: point absorber buoys, surface attenuators, oscillating water columns, and overtopping devices.



Generic wave energy concepts:

1. Point absorber
2. Attenuator
3. Oscillating wave surge converter
4. Oscillating water column
5. Overtopping device
6. Submerged pressure differential
7. Floating in-air converters

Oscillating wave surge converter

These devices typically have one end fixed to a structure or the seabed while the other end is free to move. Energy is collected from the relative motion of the body compared to the fixed point. Oscillating wave surge converters often come in the form of floats, flaps, or membranes. Environmental concerns include minor risk of collision, artificial reefing near the fixed point, electromotive force effects from subsea cables, and energy removal effecting sediment transport. Some of these designs incorporate parabolic reflectors as a means of increasing the wave energy at the point of capture. These capture systems use the rise and fall motion of waves to capture energy. Once the wave energy is captured at a wave source, power must be carried to the point of use or to a connection to the electrical grid by transmission power cables.

Oscillating water column

Oscillating Water Column devices can be located onshore or in deeper waters offshore. With an air chamber integrated into the device, swells compress air in the chambers forcing air through an air turbine to create electricity. Significant noise is produced as air is pushed through the turbines, potentially affecting birds and other marine organisms within the vicinity of the device. There is also concern about marine organisms getting trapped or entangled within the air chambers.

Overtopping device

Overtopping devices are long structures that use wave velocity to fill a reservoir to a greater water level than the surrounding ocean. The potential energy in the reservoir height is then captured with low-head turbines. Devices can be either onshore or floating offshore. Floating devices will have environmental concerns about the mooring system affecting benthic organisms, organisms becoming entangled, or electromotive force effects produced from subsea cables. There is also some concern regarding low levels of turbine noise and wave energy removal affecting the nearfield habitat.

Video Content / Details of website for further learning (if any):

1. https://www.oceanenergycouncil.com/ocean-energy/wave-energy/

Important Books/Journals for further learning including the page nos.:

- G.D.Rai, 'Non-Conventional Energy Sources', Khanna Publishers , 2011. (Page No:319-323)

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LECTURE HANDOUTS

EEE

II/III

Course Name with Code : **19GES20/ Renewable Energy Sources**

Course Faculty : **Mr.C.RAMKUMAR**

Unit : **5- Other Renewable Energy Sources**

Date of Lecture:

Topic of Lecture : OpenOTEC Cycles

Introduction :

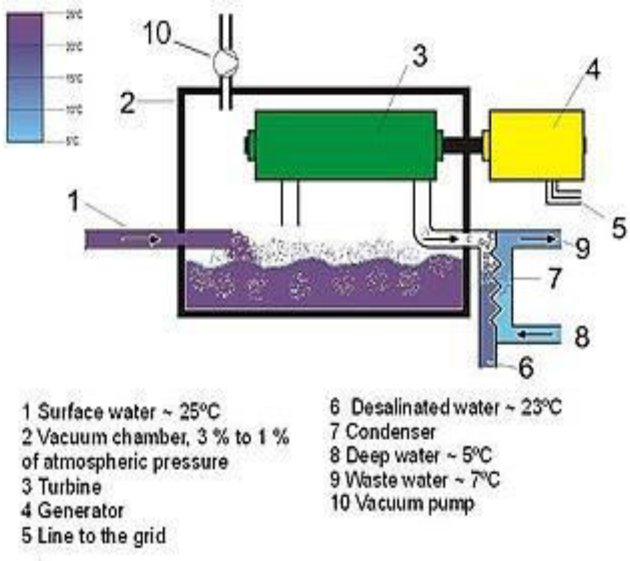
Open-cycle OTEC uses warm surface water directly to make electricity. It is condensed into a liquid by exposure to cold temperatures from deep-ocean water. This method produces desalinized fresh water, suitable for drinking water, irrigation or aquaculture.

Prerequisite knowledge for Complete understanding and learning of Topic:

1.Environmental Science

2.Basics of Civil & Mechanics

Open-cycle OTEC



Open-cycle OTEC uses warm surface water directly to make electricity. The warm seawater is first pumped into a low-pressure container, which causes it to boil. In some schemes, the expanding vapor drives a low-pressure turbine attached to an electrical generator.

The vapor, which has left its salt and other contaminants in the low-pressure container, is pure fresh water. It is condensed into a liquid by exposure to cold temperatures from deep-ocean water. This method produces desalinized fresh water, suitable for drinking water, irrigation or aquaculture.

In other schemes, the rising vapor is used in a gas lift technique of lifting water to significant heights. Depending on the embodiment, such vapor lift pump techniques generate power from a hydroelectric turbine either before or after the pump is used.

In 1984, the Solar Energy Research Institute (now known as the National Renewable Energy Laboratory) developed a vertical-spout evaporator to convert warm seawater into low-pressure steam for open-cycle plants. Conversion efficiencies were as high as 97% for seawater-to-steam conversion (overall steam production would only be a few percent of the incoming water). In May 1993, an open-cycle OTEC plant at Keahole Point, Hawaii, produced close to 80 kW of electricity during a net power-producing experiment. This broke the record of 40 kW set by a Japanese system in 1982.

Working principle

OTEC uses the ocean's warm surface water with a temperature of around 25°C to vaporize a working fluid, which has a low-boiling point, such as ammonia. The vapor expands and spins a turbine coupled to a generator to produce electricity.

Video Content / Details of website for further learning (if any):

1. https://www.youtube.com/watch?v=26e12fepJQs

Important Books/Journals for further learning including the page nos.:

- G.D.Rai, 'Non-Conventional Energy Sources', Khanna Publishers , 2011. (Page No:319-323)

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LECTURE HANDOUTS

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II/III

Course Name with Code : **19GES20/ Renewable Energy Sources**

Course Faculty : **Mr.C.RAMKUMAR**

Unit : **5- Other Renewable Energy Sources**

Date of Lecture:

Topic of Lecture : Closed OTEC Cycles

Introduction :

An OTEC system in which working fluid with a low-boiling point is circulated. Cold, deep seawater is then pumped through a second heat exchanger where the working fluid vapor condenses back into a liquid and is recycled through the system.

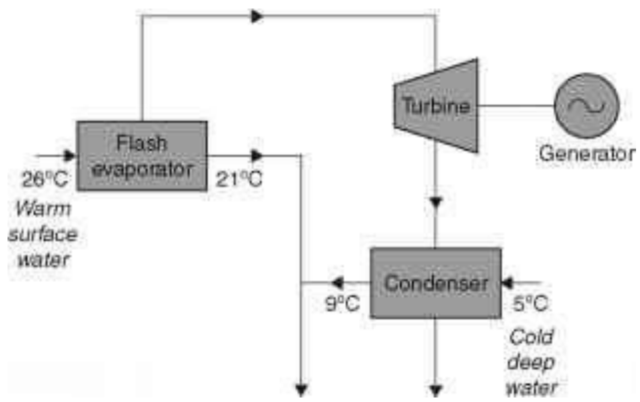
Prerequisite knowledge for Complete understanding and learning of Topic:

1.Environmental Science

2.Basics of Civil & Mechanics

The working principle for closed cycle OTEC

A working fluid such as ammonia vaporizes in an evaporator. The gas is led through a turbine, which drives a generator and in turn generates electrical power. A condenser is used to return the fluid to its original state, and using a pump, the process is repeated. Surface sea water is used to heat the fluid in the evaporator, and deep sea water cools it down to liquid state in the condenser. During the process, the surface sea water returned to sea becomes a few °C cooler, and the deep sea water a few °C warmer than previously. Note that the deep sea water, the surface water, and the working fluid never mix; the deep sea water is typically discharged at minimum 60 m depth not to alter the local environment of the surface water layer.



A closed cycle OTEC plant employs a thermodynamic fluid such as ammonia or a refrigerant like freon. This is contained in a completely closed system including the plant turbine. Hot surface seawater is used to evaporate the fluid and the vapour is then exploited to drive the turbine. The vapour from the turbine exhaust is condensed using the cold, deep ocean water, and returned to the beginning of the cycle where it can be reheated. A 50 kW closed cycle OTEC plant was built in Hawaii in 1979 and operated for a few months. A consortium of Japanese companies has also operated a 100 kW closed cycle OTEC plant in Nauru. Again this plant operated for only a few months to prove the concept. Neither was large enough to be commercially viable. Indeed, closed cycle OTEC is unlikely to be commercially viable in sizes of less than 40 MW.

Advantages of closed cycle gas turbine over open cycle gas turbine:

- (i) It has higher thermal efficiency for the same minimum and maximum temperature limits and for the same pressure ratio.
- **(ii)** Since the heating is external, any kind of fuel even solid fuel having low calorific value may be used.
- **(iii)** There is no corrosion due to circulation of combustion product.
- **(iv)** As the system is a closed one there is no loss of the working fluid.
- **(v)** The size of the turbine will be smaller compared to an open cycle gas turbine of the same output.
- **(vi)** The regulation is more simple.
- **(vii)** The heat transmission coefficient in the exchanger is better due to the increase in suction pressure.
- **(viii)** Loss due to fluid friction is less due to higher Reynolds number.

Video Content / Details of website for further learning (if any):

1. https://www.youtube.com/watch?v=5ngAXPnSmZI

Important Books/Journals for further learning including the page nos.:

- G.D.Rai, 'Non-Conventional Energy Sources', Khanna Publishers , 2011. (Page No:319-323)

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LECTURE HANDOUTS

EEE **II/III**

Course Name with Code : **19GES20/ Renewable Energy Sources**

Course Faculty : **Mr.C.RAMKUMAR**

Unit : **5- Other Renewable Energy Sources**

Date of Lecture:

Topic of Lecture : Small Hydro

Introduction :

Small Hydro is the development of hydroelectric power on a scale serving a small community or industrial plant. The definition of a Small Hydro project varies but a generating capacity of up to 25 megawatts (MW) is generally accepted as the upper limit of what can be termed Small Hydro.

Prerequisite knowledge for Complete understanding and learning of Topic:

1.Environmental Science

2.Basics of Civil & Mechanics

There are three types of hydropower facilities:

Impoundment

Diversion

pumped storage

Some hydropower plants use dams and some do not. Although not all dams were built for hydropower, they have proven useful for pumping tons of renewable energy to the grid.

Small hydro-power

Micro and small hydro-power schemes have little or no environmental impact and can provide a range of valuable energy services especially in rural areas. In regions with hydro-power potential, this form of renewable energy is the most cost-effective opportunity to energize on/off-grid areas. Micro and small hydro-power can be applied to **satisfy low-to-medium voltage electric needs** such as lighting or telecommunication and to **provide motive power for small industry**. UNIDO emphasizes small-scale hydro-power and is currently implementing projects in China, India, Indonesia, Sri Lanka, Zambia, Tanzania, Uganda, Kenya, Nigeria, Ghana, Rwanda and Mali.

UNIDO is developing a large umbrella regional program me with a special focus on South-South cooperation to establish and implement about 100 SHP projects in Africa within the next 3 years, and replicate them in other regions such as Latin America and Asia.

Technical support for UNIDO's SHP projects is provided by the International Centre for Small Hydro-Power (ICSHP) at Hangzhou in China, which facilitates the execution of activities in the field of small hydro-power and fosters cooperation worldwide. UNIDO's Regional Centre for Small Hydro Power in Trivandrum (India) and UNIDO's Regional Centre for Small Hydro Power in Abuja (Nigeria) provide technical assistance at the regional level.
UNIDO has established an energy kiosk (2.5 KW) consisting of Pico hydro and solar PV to energize a remote village in Kenya. The produced energy is used for providing productive, communication and community services.

Video Content / Details of website for further learning (if any):

1. https://www.youtube.com/watch?v=2knGB8gK7UY

Important Books/Journals for further learning including the page nos.:

- G.D.Rai, 'Non-Conventional Energy Sources', Khanna Publishers , 2011. (Page No:364)

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LECTURE HANDOUTS

EEE

II/III

Course Name with Code : **19GES20/ Renewable Energy Sources**

Course Faculty : **Mr.C.RAMKUMAR**

Unit : **5- Other Renewable Energy Sources**

Date of Lecture:

Topic of Lecture : Geothermal Energy Hydrogen

Introduction :

Hydrogen is one of the fuels that has been suggested to help reduce the use of fossil fuels in the United States. Today approximately 9 billion kilograms of hydrogen are produced annually. More than 95% of the merchant hydrogen is used for industrial applications in the chemical, metals, electronics, and space industries. There are several methods used to produce hydrogen. These methods include: natural gas reforming, electrolysis, liquid reforming, nuclear high-temperature electrolysis, hightemperature thermo-chemical water-splitting, photo-biological, and photoelectrochemical. Steam methane reforming accounts for 80% of the hydrogen produced. The remaining 20% is a by-product of chemical processes such as chlor-alkali production. Water electrolysis represents only a niche segment of the merchant hydrogen market. Electrolysis is the process of making a non-spontaneous process occurs by applying an external power supply to the application .

A number of existing and planned demonstration projects are using or will use electrolysis, even though it is one of the more energy intensive processes for producing hydrogen. However, it provides a pathway for producing hydrogen from carbon free renewable energy. Competitive energy costs, reliability of a system and ease of use are the three major factors which determine whether a proposed system is worth implementing. The increased availability of cleaner and inexhaustible energy sources allows a user to seriously consider renewable sources. Stand-alone residential systems utilizing 2 renewable energy are also attracting increasing interest.

This attention is perhaps related to lowered renewable energy costs, increased reliability and desire to be in control of one's energy future. Of the available fuel sources today, hydrogen is suited to become a driving force in each and every energy scenario. This is mainly because hydrogen as a fuel produces high amounts of energy without any relative pollution. Recently, extensive research has explored the methods which can be used to produce hydrogen efficiently.

Prerequisite knowledge for Complete understanding and learning of Topic:

1.Environmental Science

2.Basics of Civil & Mechanics

Hydrogen as a Fuel Source

Finding a sustainable energy source for the future is one of the more urgent tasks of today. With the exhaustion of fossil fuels, the energy economy will have to change from a chemical base to an electrical base. Further action needs to be taken in order to make this transition smooth. This will take years of research in order to provide viable sources of energy. In today's market a low cost energy source is sought after to provide an alternative to fossil fuels. Current energy sources are would be fossil fuels, nuclear fuels, natural gases, hydrogen fuels, sunlight, wind, fuel cells, and hybrid systems. Hydrogen is one of the fuels suggested to help reduce the use of fossil fuels in the United States. Hydrogen is a carrier of energy much like water in a heating system and has the potential, with other sources, to help curb the use of fossil fuels. It has a low molecular weight (it is about 8 times lighter that methane representing natural gas) and has a higher energy content per unit mass. At any given pressure, hydrogen gas contains less energy per unit volume than other substances such as methane, methanol, ethanol, propane, and octane. These other substances require various transformation methods before they can be used.

Hydrogen is a versatile chemical element that can be used to produce, store, move, and use energy. It is abundant but only in compound form and must typically be separated from water or hydrocarbons using a variety of energy-intensive processes. Hydrogen produced from hydrocarbons such as natural gas and coal, creates carbon emissions. *Green hydrogen*, which is produced using a renewable energy source, has no carbon or carbon monoxide emissions.

Since various electrolysis methods exist for hydrogen production and geothermal energy is typically used to make electricity, it is obvious that geothermal energy production can be used in a two-stage process by coupling with electrolysis methods to make hydrogen. Indeed, some companies are pursuing this approach.

However, green hydrogen production is limited by high costs, complicated processes, and safety considerations so a more efficient technology is needed. Most hydrogen production technologies require large amounts of expensive electric power and high heat. Additional power is needed to compress pure hydrogen for storage and transportation. Further, existing methods of producing hydrogen raise safety concerns that further increase the cost of hydrogen production.

GreenFire Energy's GreenLoop technology addresses many of the limitations of existing hydrogen production. See Hydrogen Production Companies to learn more.

Video Content / Details of website for further learning (if any):

1. https://www.nrel.gov/research/re-geothermal.html

Important Books/Journals for further learning including the page nos.:

- G.D.Rai, 'Non-Conventional Energy Sources', Khanna Publishers , 2011. (Page No:319-323)

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LECTURE HANDOUTS

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II/III

Course Name with Code : **19GES20/ Renewable Energy Sources**

Course Faculty : **Mr.C.RAMKUMAR**

Unit : **5- Other Renewable Energy Sources**

Date of Lecture:

Topic of Lecture :Geothermal energy storage

Introduction :

Geothermal energy storage is a form of energy storage using natural underground heat to generate and store energy. It is considered one of the renewable energy alternatives that can act as a substitute for fossil fuels in the present and future.

Prerequisite knowledge for Complete understanding and learning of Topic:

1.Environmental Science

2.Basics of Civil & Mechanics

Geothermal energy storage

It is a form of energy storage using natural underground heat to generate and store energy. It is considered one of the renewable energy alternatives that can act as a substitute for fossil fuels in the present and future.

How Does Geothermal Energy Work!!

Normally, geothermal energy is stored in hot water underground. It is difficult to take advantage of this energy source unless hot water makes it through the Earth's crust in the form of hot springs or steam. However, with geothermal technology, we can finally make use of this energy. According to the U.S. Department of Energy, there are three main types of geothermal energy plants.

3 Types of Geothermal Energy Plants

The most common type used today is a dry steam geothermal power plant. The plant directs underground steam to flow through a turbine. As the steam goes through, it drives a generator that produces electricity.

The second type is a flash steam power plant. This is a little more complicated. Instead of using steam, a pump pushes hot fluid up to a tank on the surface. Then, the fluid cools and quickly turns into vapor. Similar to steam, this vapor will drive a generator that produces power.
The last type is a binary cycle geothermal plant. This plant also uses underground hot fluid. It pumps the hot fluid to the surface, then use it to heat a cooler fluid.

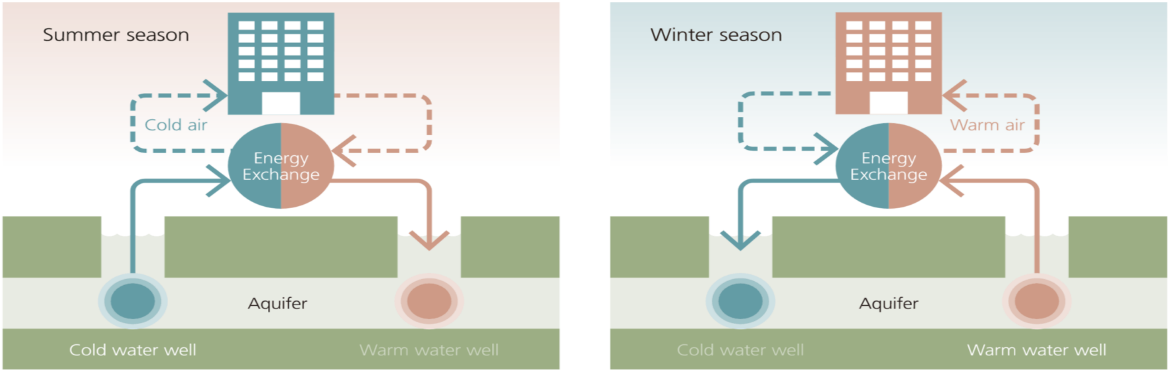
This process is called heat transfer. When the cooler fluid is heated up to its boiling point, it will transfer to vapor. The vapor then spins a turbine that drives a generator to produce energy.

How Does Geothermal Energy Storage Work?

Technology can transfer heat energy from underground water to electricity, then it can also store the extra energy into underground water. Unlike other widely used energy storage such as battery, thermal energy storage, and solar storage, geothermal energy storage stores energy in subsurface groundwater.

According to the Environmental Department of Canon Global, a geothermal energy storage system consists of two separate groundwater wells–one for cold water and the other for warm water. Both of them are connected to an aquifer. It operates differently in the summer and winter. When the weather is hot in the summer, cold groundwater from the cold aquifer is used to cool the building.

As heat transfers from the building to the water, the warmed-up water will be taken to the well that stores warm water. In the winter, the warm water is used to warm up the building, and as the warm water transfers the heat to the building, it cools down and is taken to the cold water well.



How Does Geothermal Energy Storage Benefit Us!!

1. Less emissions of CO_2
2. Recycle wastewater
3. Preserve the minerals in the soil
4. Lower utility costs for your facility

According to the U.S. Department of Energy, the U.S. Geological Survey estimates once geothermal energy storage is developed successfully, it can support "10% of today's energy needs."

Geothermal energy also has been catching the attention of the U.S.

Video Content / Details of website for further learning (if any):

1. https://www.enbridge.com/energy-matters/energy-school/geothermal

Important Books/Journals for further learning including the page nos.:

- G.D.Rai, 'Non-Conventional Energy Sources', Khanna Publishers , 2011. (Page No:319-323)

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LECTURE HANDOUTS

EEE **II/III**

Course Name with Code : **19GES20/ Renewable Energy Sources**

Course Faculty : **Mr.C.RAMKUMAR**

Unit : **5- Other Renewable Energy Sources**

Date of Lecture:

Topic of Lecture : Fuel Cell Systems

Introduction :

A fuel cell is an electrochemical cell that converts the chemical energy of a fuel (often hydrogen) and an oxidizing agent (often oxygen) into electricity through a pair of redox reactions. Fuel cells are different from most batteries in requiring a continuous source of fuel and oxygen (usually from air) to sustain the chemical reaction, whereas in a battery the chemical energy usually comes from metals and their ions or oxidesthat are commonly already present in the battery, except in flow batteries. Fuel cells can produce electricity continuously for as long as fuel and oxygen are supplied.

The first fuel cells were invented by Sir William Grove in 1838. The first commercial use of fuel cells came more than a century later following the invention of the hydrogen–oxygen fuel cell by Francis Thomas Bacon in 1932. The alkaline fuel cell, also known as the Bacon fuel cell after its inventor, has been used in NASA space programs since the mid-1960s to generate power for satellites and space capsules. Since then, fuel cells have been used in many other applications. Fuel cells are used for primary and backup power for commercial, industrial and residential buildings and in remote or inaccessible areas. They are also used to power fuel cell vehicles, including forklifts, automobiles, buses, boats, motorcycles and submarines.

There are many types of fuel cells, but they all consist of an anode, a cathode, and an electrolyte that allows ions, often positively charged hydrogen ions (protons), to move between the two sides of the fuel cell. At the anode a catalyst causes the fuel to undergo oxidation reactions that generate ions (often positively charged hydrogen ions) and electrons. The ions move from the anode to the cathode through the electrolyte. At the same time, electrons flow from the anode to the cathode through an external circuit, producing direct current electricity. At the cathode, another catalyst causes ions, electrons, and oxygen to react, forming water and possibly other products. Fuel cells are classified by the type of electrolyte they use and by the difference in startup time ranging from 1 second for proton-exchange membrane fuel cells (PEM fuel cells, or PEMFC) to 10 minutes for solid oxide fuel cells (SOFC).

Prerequisite knowledge for Complete understanding and learning of Topic:

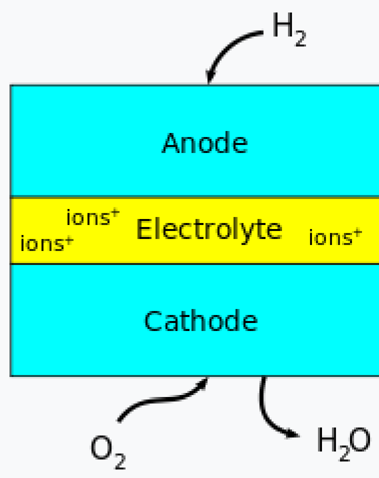
1.Environmental Science

2.Basics of Civil & Mechanics

Types of fuel cells

Fuel cells come in many varieties; however, they all work in the same general manner. They are made up of three adjacent segments: the anode, the electrolyte, and the cathode. Two chemical reactions occur at the interfaces of the three different segments. The net result of the two reactions is that fuel is consumed, water or carbon dioxide is created, and an electric current is created, which can be used to power electrical devices, normally referred to as the load.

At the anode a catalyst oxidizes the fuel, usually hydrogen, turning the fuel into a positively charged ion and a negatively charged electron. The electrolyte is a substance specifically designed so ions can pass through it, but the electrons cannot. The freed electrons travel through a wire creating the electric current. The ions travel through the electrolyte to the cathode. Once reaching the cathode, the ions are reunited with the electrons and the two react with a third chemical, usually oxygen, to create water or carbon dioxide.



Design features in a fuel cell include:

- The electrolyte substance, which usually defines the type of fuel cell, and can be made from a number of substances like potassium hydroxide, salt carbonates, and phosphoric acid.
- The fuel that is used. The most common fuel is hydrogen.
- The anode catalyst, usually fine platinum powder, breaks down the fuel into electrons and ions.
- The cathode catalyst, often nickel, converts ions into waste chemicals, with water being the most common type of waste.
- Gas diffusion layers that are designed to resist oxidization.

A typical fuel cell produces a voltage from 0.6 to 0.7 V at full rated load. Voltage decreases as current increases, due to several factors:

- Activation loss
- Ohmic loss (voltage drop due to resistance of the cell components and interconnections)
- Mass transport loss (depletion of reactants at catalyst sites under high loads, causing rapid loss of voltage).

To deliver the desired amount of energy, the fuel cells can be combined in series to yield higher voltage, and in parallel to allow a higher current to be supplied. Such a design is called a fuel cell stack. The cell surface area can also be increased, to allow higher current from each cell.

Phosphoric acid fuel cell (PAFC)

Phosphoric acid fuel cells (PAFC) were first designed and introduced in 1961 by G. V. Elmore and H. A. Tanner. In these cells phosphoric acid is used as a non-conductive electrolyte to pass positive hydrogen ions from the anode to the cathode. These cells commonly work in temperatures of 150 to 200 degrees Celsius. This high temperature will cause heat and energy loss if the heat is not removed and used properly. This heat can be used to produce steam for air conditioning systems or any other thermal energy consuming system. Using this heat in cogeneration can enhance the efficiency of phosphoric acid fuel cells from 40 to 50% to about 80%. Phosphoric acid, the electrolyte used in PAFCs, is a non-conductive liquid acid which forces electrons to travel from anode to cathode through an external electrical circuit. Since the hydrogen ion production rate on the anode is small, platinum is used as catalyst to increase this ionization rate. A key disadvantage of these cells is the use of an acidic electrolyte. This increases the corrosion or oxidation of components exposed to phosphoric acid.

Solid acid fuel cell (SAFC)

Solid acid fuel cells (SAFCs) are characterized by the use of a solid acid material as the electrolyte. At low temperatures, solid acids have an ordered molecular structure like most salts. At warmer temperatures (between 140 and 150 °C for $CsHSO_4$), some solid acids undergo a phase transition to become highly disordered "super protonic" structures, which increases conductivity by several orders of magnitude. The first proof-of-concept SAFCs were developed in 2000 using cesium hydrogen sulfate ($CsHSO_4$).Current SAFC systems use cesium dihydrogen phosphate (CsH_2PO_4) and have demonstrated lifetimes in the thousands of hours.

Alkaline fuel cell (AFC)

The alkaline fuel cell or hydrogen-oxygen fuel cell was designed and first demonstrated publicly by Francis Thomas Bacon in 1959. It was used as a primary source of electrical energy in the Apollo space program.The cell consists of two porous carbon electrodes impregnated with a suitable catalyst such as Pt, Ag, Co, etc. The space between the two electrodes is filled with a concentrated solution of KOH or NaOH which serves as an electrolyte. H_2 gas and O_2 gas are bubbled into the electrolyte through the porous carbon electrodes. Thus the overall reaction involves the combination of hydrogen gas and oxygen gas to form water. The cell runs continuously until the reactant's supply is exhausted. This type of cell operates efficiently in the temperature range 343–413 K and provides a potential of about 0.9 V. AAEMFC is a type of AFC which employs a solid polymer electrolyte instead of aqueous potassium hydroxide (KOH) and it is superior to aqueous AFC.

High-temperature fuel cells

Solid oxide fuel cells (SOFCs) use a solid material, most commonly a ceramic material called yttria-stabilized zirconia (YSZ), as the electrolyte. Because SOFCs are made entirely of solid materials, they are not limited to the flat plane configuration of other types of fuel cells and are often designed as rolled tubes. They require high operating temperatures (800–1000 °C) and can be run on a variety of fuels including natural gas.

SOFCs are unique since in those, negatively charged oxygen ions travel from the cathode (positive side of the fuel cell) to the anode (negative side of the fuel cell) instead of positively charged hydrogen ions travelling from the anode to the cathode, as is the case in all other types of fuel cells. Oxygen gas is fed through the cathode, where it absorbs electrons to create oxygen ions. The oxygen ions then travel through the electrolyte to react with hydrogen gas at the anode. The reaction at the anode produces electricity and water as by-products. Carbon dioxide may also be a by-product depending on the fuel, but the carbon emissions from an SOFC system are less than those from a fossil fuel combustion plant.

The chemical reactions for the SOFC system can be expressed as follows:

Anode reaction: $2H_2 + 2O^{2-} \rightarrow 2H_2O + 4e^-$
Cathode reaction: $O_2 + 4e^- \rightarrow 2O^{2-}$
Overall cell reaction: $2H_2 + O_2 \rightarrow 2H_2O$

SOFC systems can run on fuels other than pure hydrogen gas. However, since hydrogen is necessary for the reactions listed above, the fuel selected must contain hydrogen atoms. For the fuel cell to operate, the fuel must be converted into pure hydrogen gas. SOFCs are capable of internally reforming light hydrocarbons such as methane (natural gas), propane and butane. These fuel cells are at an early stage of development.

Challenges exist in SOFC systems due to their high operating temperatures. One such challenge is the potential for carbon dust to build up on the anode, which slows down the internal reforming process. Research to address this "carbon coking" issue at the University of Pennsylvania has shown that the use of copper-based cermet (heat-resistant materials made of ceramic and metal) can reduce coking and the loss of performance. Another disadvantage of SOFC systems is slow start-up time, making SOFCs less useful for mobile applications. Despite these disadvantages, a high operating temperature provides an advantage by removing the need for a precious metal catalyst like platinum, thereby reducing cost. Additionally, waste heat from SOFC systems may be captured and reused, increasing the theoretical overall efficiency to as high as 80–85%.

The high operating temperature is largely due to the physical properties of the YSZ electrolyte. As temperature decreases, so does the ionic conductivity of YSZ. Therefore, to obtain optimum performance of the fuel cell, a high operating temperature is required. According to their website, Ceres Power, a UK SOFC fuel cell manufacturer, has developed a method of reducing the operating temperature of their SOFC system to 500–600 degrees Celsius. They replaced the commonly used YSZ electrolyte with a CGO (cerium gadolinium oxide) electrolyte. The lower operating temperature allows them to use stainless steel instead of ceramic as the cell substrate, which reduces cost and start-up time of the system.

Video Content / Details of website for further learning (if any):

1. https://www.energy.gov/eere/fuelcells/fuel-cell-basics

Important Books/Journals for further learning including the page nos.:

- G.D.Rai, 'Non-Conventional Energy Sources', Khanna Publishers , 2011. (Page No:319-323)

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LECTURE HANDOUTS

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II/III

Course Name with Code : **19GES20/ Renewable Energy Sources**

Course Faculty : **Mr.C.RAMKUMAR**

Unit : **5- Other Renewable Energy Sources**

Date of Lecture:

Topic of Lecture : Hybrid Systems

Introduction :

A hybrid system is a dynamical system that exhibits both continuous and discrete dynamic behavior – a system that can both *flow* (described by a differential equation) and *jump* (described by a state machine or automaton). Often, the term "hybrid dynamical system" is used, to distinguish over hybrid systems such as those that combine neural nets and fuzzy logic, or electrical and mechanical drivelines. A hybrid system has the benefit of encompassing a larger class of systems within its structure, allowing for more flexibility in modeling dynamic phenomena.

Prerequisite knowledge for Complete understanding and learning of Topic:

1.Environmental Science

2.Basics of Civil & Mechanics

Bouncing ball

A canonical example of a hybrid system is the bouncing ball, a physical system with impact. Here, the ball (thought of as a point-mass) is dropped from an initial height and bounces off the ground, dissipating its energy with each bounce. The ball exhibits continuous dynamics between each bounce; however, as the ball impacts the ground, its velocity undergoes a discrete change modeled after an inelastic collision.

The bouncing ball is an especially interesting hybrid system, as it exhibits Zeno behavior. Zeno behavior has a strict mathematical definition, but can be described informally as the system making an *infinite* number of jumps in a *finite* amount of time. In this example, each time the ball bounces it loses energy, making the subsequent jumps (impacts with the ground) closer and closer together in time.

It is noteworthy that the dynamical model is complete if and only if one adds the contact force between the ground and the ball. Indeed, without forces, one cannot properly define the bouncing ball and the model is, from a mechanical point of view, meaningless. The simplest contact model that represents the interactions between the ball and the ground, is the complementarity relation between the force and the distance (the gap) between the ball and the ground. This is written as Such a contact model does not incorporate magnetic forces, nor gluing effects. When the complementarity relations are in, one can continue to integrate the system after the impacts have accumulated and vanished: the equilibrium of the system is well-defined as the static equilibrium of the ball on the ground, under the action of gravity compensated by the contact force . One also notices from basic convex analysis that the complementarity relation can equivalently be rewritten as the inclusion into a normal cone, so that the bouncing ball dynamics is a differential inclusion into a normal cone to a convex set. See Chapters 1, 2 and 3 in Acary-Brogliato's book cited below (Springer LNACM 35, 2008). See also the other references on non-smooth mechanics.

The hybrid solar energy systems have various advantages. Let's have a look at few of them.

1. Continuous power supply – The hybrid solar systems provide power continuously, without any interruption, as the batteries connected to them store the energy. So, when there is an electricity outage, the batteries work as inverter to provide you backup. This is also the case during the evening or night time when there is no sun and energy is not being generated; batteries provide the back-up and life goes on without any interruption.

2. Utilize the renewable sources in best way – Because the batteries are connected to the system to store the energy, there is no waste of the excess energy generated on bright sunny days. So, these systems make use of the renewable energy in best way, storing energy on a good day and utilize the stored power on a bad day. The balance is maintained.

3. Low maintenance cost – The maintenance cost of the hybrid solar energy systems is low as compared to the traditional generators which use diesel as fuel. No fuel is used and they do not require frequent servicing.

4. High efficiency – The hybrid solar energy systems work more efficiently than your traditional generators which waste the fuel under certain conditions. Hybrid solar systems work efficiently in all types of conditions without wasting the fuel.

5. Load management – Unlike traditional generators, which provide high power as soon as they turned on, most of hybrid solar power systems manage load accordingly. A hybrid solar system may have technology that adjusts the energy supply according to the devices they are connected to, whether it's an air conditioner requiring high power or a fan which requires less.

Like all things, hybrid solar energy systems also have few disadvantages. Let's have a look at them:

1. Complicated controlling process – With different types of energy sources in use, the systems require some knowledge. The operation of different energy sources, their interaction and co-ordination must be controlled and it can become complicated.

2. High installation cost – Although the maintenance cost is low, the initial investment for the installation of a hybrid solar energy systems is high as compared to a solar systems.

3. Less battery life – The batteries connected to the system may have a lower life as they are often exposed to natural elements like heat, rain, etc.

4. The number of instruments connectable is limited – The number of devices you can connect to a hybrid solar energy system is limited and vary from system to system.

Video Content / Details of website for further learning (if any):

1. https://www.youtube.com/watch?v=5ngAXPnSmZI

Important Books/Journals for further learning including the page nos.:

- G.D.Rai, 'Non-Conventional Energy Sources', Khanna Publishers , 2011. (Page No:319-323)

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