Green Energy Technology

LECTURE NOTES

B TECH (VI SEM)

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Green Energy Technology

Module: 1 Introduction

Basics of energy, Conventional energy sources, Fossil fuels limitation, Renewable energy sources, Advantage & limitation, Global energy scenario of india, New technology (Hydrogen energy, Fuel cell, Bio cell)

Module: 2 Solar energy

Types of solar cells, Solar cell materials, I V characteristics of solar cell, PV module, PV array, MPPT, PV system, Stand alone and grid connected PV system, Storage, PV based water pumping, Solar radiation and its measurement, Flat plate collector and its material, Application and performance, Solar thermal power plant and its limitation.

Module: 3 Wind energy

Wind power and its sources, Site selection, Power in the wind, Impact of tower height, Classification of wind turbine and rotor, Wind energy extraction, betz's limit, Wind characteristics, Performance and limitation of wind energy conversion system.

Module: 4 Biomass and Geothermal energy

Availability of biomass and its conversion theory, Types of biomass , Gasification, Biogas plant, Biomass cogeneration, Resources of geothermal energy, Thermodynamics of geothermal energy conversion , Geothermal power generation, Environmental consideration.

Module: 5 Tidal, Wave and Ocean energy

Introduction to tidal energy, Tidal characteristics, Tidal power plant, Tidal power development in india, Introduction to wave energy, Factors affecting wave energy, Principle of wave energy plant, OTEC, Application OTEC.

Module: 6 Emerging technologies for power generation

Fuel cells, Principle of working of various types of fuel cell and their working, Performance and limitation, Future potential of fuel cells, Emergence of hydrogen, Cost analysis of hydrogen production, Hydrogen storage.

Suggested Text book

Non conventional energy resources by D. S. chauhan , NAI PVT LTD

Renewable energy sources and emerging technology by D P Kothari, PHI

Course Outcomes

Indentify different non conventional energy system and realize their important in today's scenario.

Analyze the performance and limitation of solar energy and wind energy conversion system.

Understand the concept behind the biomass, geothermal, tidal, ocean thermal and wave energy system.

Outline the basis of fuel cell and hydrogen production and storage.

Module: 1 Introduction

Basics of energy

Energy is involved in all life cycles, and it is essential in agriculture as much as in all other productive activities. An elementary food chain already shows the need for energy: crops need energy from solar radiation to grow, harvesting needs energy from the human body in work, and cooking needs energy from biomass in a fire. The food, in its turn, provides the human body with energy.

Intensifying food production for higher output per hectare, and any other advancement in agricultural production, implies additional operations which all require energy. For instance: land preparation and cultivation, fertilising, irrigation, transport, and processing of crops. In order to support these operations, tools and equipment are used, the production of which also requires energy (in sawmills, metallurgical processes, workshops and factories, etc.).

Major changes in agriculture, like mechanisation and what is called the "green revolution", imply major changes with respect to energy. Mechanisation means a change of energy sources, and often a net increase of the use of energy. The green revolution has provided us with high yield varieties. But these could also be called low residue varieties (i.e. per unit of crop). And it is exactly the residue which matters as an energy source for large groups of rural populations.

Other sectors of rural life require energy as well. The provision of shelter, space heating, water lifting, and the construction of roads, schools and hospitals, are examples. Furthermore, social life needs energy for lighting, entertainment, communication, etc. We observe that development often implies additional energy, and also different forms of energy, like electricity.

Energy is a scarce resource, at least for some groups of people in some places and, maybe, for the world as a whole. A rational use of energy is then necessary for economic and environmental reasons. This applies to agriculture as much as to any other sector of the economy. A key to the rational use of energy is the understanding of the role of energy. The following sections aim to help understand energy in agriculture and rural development. It should help communication between agricultural planners and energy specialist

Forms of energy

Energy can exist in various forms. Examples are:

- Radiation energy: the radiation from the sun contains energy, and also the radiation from a light or a fire. More solar energy is available when the radiation is more intense and when it is collected over a larger area. Light is the visible part of radiation;

- Chemical energy: wood and oil contain energy in a chemical form. The same is true for all other material that can burn. The content of chemical energy is larger the larger the heating value (calorific value) of the material is and, of course, the more material we have. Also animate energy (delivered by bodies of human beings and animals) is, in essence, chemical energy. Furthermore, batteries contain chemical energy;

- Potential energy: this is, for example, the energy of a water reservoir at a certain height. The water has the potential to fall, and therefore contains a certain amount of energy. More potential energy is available when there is more water and when it is at a higher height;

- Kinetic energy: this is energy of movement, as in wind or in a water stream. The faster the stream flows and the more water it has the more energy it can deliver. Similarly, more wind energy is available at higher wind speeds, and more of it can be tapped by bigger windmill rotors;

- Thermal energy or heat: this is indicated by temperature. The higher the temperature, the more energy is present in the form of heat. Also, a larger body contains more heat;

- Mechanical energy, or rotational energy, also called shaft power: this is the energy of *a* rotating shaft. The amount of energy available depends on the flywheel of the shaft, i.e.:. on the power which makes the shaft rotate;

- Electrical energy: a dynamo or generator and a battery can deliver electrical energy. The higher the voltage and the current, the more electrical energy is made available.

Conventional energy sources

When we cannot reuse a source of energy after using it once we call them "conventional sources of energy" or **"**non-renewable energy resources**"**. They are the most important conventional sources of energy. These include coal, petroleum, natural gas and nuclear energy. Oil is the most widely used source of energy. Coal, petroleum and natural gas account for about 90% of world's production of commercial energy and hydroelectric and nuclear power account for about 10%.

Fossil fuels limitation

1. The burning of coal and petroleum produces a lot of pollutants, causing air pollution.
2. Fossil fuels release oxides of carbon, nitrogen, sulphur, etc., that cause acid rain, affecting soil fertility and potable water.
3. The burning of fossil fuels produce gases such as carbon dioxide that causes global warming.

Renewable energy sources

The major types of renewable energy sources are:

Biomass

- Wood and wood waste

  - Municipal solid waste
  - Landfill gas and biogas
  - Ethanol
  - Biodiesel
- Hydropower
- Geothermal
- Wind
- Solar

Advantage of renewable energy sources

1. Renewable Energy is Eco-friendly
2. It’s a Renewable Resource
3. Renewable Energy is a Reliable Source of Energy
4. Leads to Job Creation
5. Renewable Energy has Stabilized Global Energy Prices
6. Less Maintenance of Facilities
7. Boosts Public Health
8. Empowering of People in the Countryside
9. Renewable Save Money and Profitable

Limitation of renewable energy sources

1. The Electricity Generation Capacity is Still Not Large Enough
2. Renewable Energy can be Unreliable
3. Low-efficiency Levels
4. Requires a Huge Upfront Capital Outlay
5. Takes a Lot of Space to Install
6. Expensive Storage Costs
7. Not Always a Commercially-viable Option
8. It Still Generates Pollution

Energy scenario of india

Electricity Generation (Conventional and Renewable Sources)								
Jan-2020			Jan-2019			% Growth		
Generation from Conventional Sources*	Generation from Renewable Sources*	Total*	Generation from Conventional Sources	Generation from Renewable Sources	Total	Growth in Conventional Generation	Growth in Renewable Generation	Growth in Total Generation
(BU)	(BU)	(BU)	(BU)	(BU)	(BU)	(%)	(%)	(%)
102.88	10.325	113.20	100.85	9.433	110.280	2.01	9.46	2.65

Note: * Tentative

All India Generation From Renewables		(All Figures are in MU)			
Sl.No.	Source-Wise All India Generation from Renewables	For the Month of		Cummulative for the period	
		Dec-2019	Dec-2018	Apr-19 to Dec-19	Apr-18 to Dec-18
1	Wind	3943.01	2789.24	54396.21	53124.09
2	Solar	3932.61	3182.12	34798.64	27794.92
3	Biomass	238.09	247.01	2072.84	2035.81
4	Bagasse	1801.17	2311.49	5778.21	7451.18
5	Small Hydro	702.83	516.72	7694.14	7410.48
6	Others	29.61	36.69	276.31	318.58
	Total :	**10647.32**	**9083.27**	**105016.35**	**98135.06**

1) All figures are provisional

Module: 2 Solar energy

Types of solar cells

There are four types of solar cells, which is given below

- Crystalline silicon cells
- Monocrystalline cells
- Polycrystalline cells
- Thin film solar cells

Monocrystalline cells

Monocrystalline solar cells are made from single crystalline silicon. They are very distinctive in their appearance as they are often coloured, and the cells hold a cylindrical shape. In order to keep the costs low and performance at optimal levels, manufacturers cut out the four sides of the monocrystalline cells. This gives them their recognisable appearance.

Advantages

- Here are some of the advantages of monocrystalline solar cells:
- They have the highest level of efficiency at 15-20%
- They require less space compared to other types due to their high efficiency
- Manufacturers state that this form of solar cell lasts the longest, with most giving them a 25-year warranty
- They perform better in low levels of sunlight, making them ideal for cloudy areas

Disadvantages

- Here are some of the disadvantages to monocrystalline solar cells:
- They are the most expensive solar cells on the market, and so not in everyone's price range
- The performance levels tend to suffer from an increase in temperature. However, it is a small loss when compared to other forms of solar cell
- There is a lot of waste material when the silicon is cut during manufacture

Polycrystalline Solar Cells

The polycrystalline solar panels were first introduced to the public in 1981. Unlike the monocrystalline cells, polycrystalline ones do not require each of the four sides to be cut. Instead, the silicon is melted and poured into square moulds. These then form perfectly shaped square cells.

Advantages

Here are some of the advantages of polycrystalline solar cells:

- The manufacturing process is cheaper and easier than the monocrystalline cells
- It avoids silicon waste
- High temperatures have less negative effects on efficiency compared with monocrystalline cells. This makes the polycrystalline cells more attractive to people in warmer areas as the price is lower

Disadvantages

Here are some of the disadvantages to polycrystalline solar cells:

- Efficiency is only around 13-16% due to low levels of silicon purity. So they are not the most efficient on the market
- They have lower output rates which make them less space efficient. So more roof space is needed for installation

Thin Film Solar Cells

Thin film solar cells are manufactured by placing several thin layers of photovoltaic on top of each other to create the module. There are actually a few different types of thin film solar cell, and the way in which they differ from each other comes down to the material used for the PV layers. The types are as follows:

- Amorphous silicon
- Cadmium telluride
- Copper indium gallium selenide
- Organic PV cells

Depending on the technology that has been used, the efficiency rates for thin film solar cells tends to vary from 7% to 13%. Since 2002, the knowledge levels and popularity for thin film solar cells has risen dramatically, which also means that research and development have been increased. Due to this, we can expect future models to hold efficiency rates of 10-16%.

Advantages

Here are some of the advantages of thin film solar cells:

- They can be manufactured to be flexible, making them widely applicable to a range of situations and building types
- Mass production is easy to achieve, making them potentially cheaper to produce than crystalline solar cells
- Shading has a similar effect on their efficiency

Disadvantages

Here are some of the disadvantages of thin film solar cells:

- They are not ideal for domestic use as thy take up a lot of space

- Low space efficiency means that they will cause further expenses in the form of enhancers, like cables of support structures
- They have a shorter lifespan and so shorter warranty periods

Solar cell materials

The basic component of a solar cell is pure silicon, which is not pure in its natural state. Pure silicon is derived from such silicon dioxides as quartzite gravel (the purest silica) or crushed quartz. The resulting pure silicon is then doped (treated with) with phosphorous and boron to produce an excess of electrons and a deficiency of electrons respectively to make a semiconductor capable of conducting electricity. The silicon disks are shiny and require an anti-reflective coating, usually titanium dioxide.

- Amorphous silicon
- Cadmium telluride
- Copper indium gallium selenide
- Organic PV cells

I V characteristics of solar cell

Solar Cell I-V Characteristic Curves show the current and voltage (I-V) characteristics of a particular photovoltaic (PV) cell, module or array giving a detailed description of its solar energy conversion ability and efficiency. Knowing the electrical I-V characteristics (more importantly P_{max}) of a solar cell, or panel is critical in determining the device's output performance and solar efficiency.

Photovoltaic solar cells convert the suns radiant light directly into electricity. With increasing demand for a clean energy source and the sun's potential as a free energy source, has made solar energy conversion as part of a mixture of renewable energy sources increasingly important. As a result, the demand for efficient solar cells, which convert sunlight directly into electricity, is growing faster than ever before.

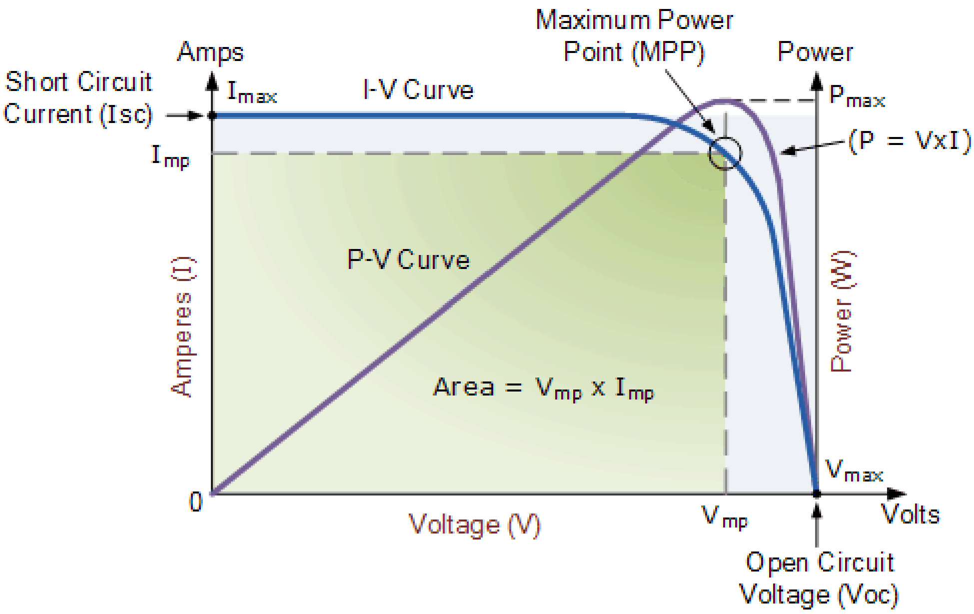
Photovoltaic (PV) cells are made made almost entirely from silicon that has been processed into an extremely pure crystalline form that absorbs the photons from sunlight and then releases them as electrons, causing an electric current to flow when the photoconductive cell is connected to an external load. There are a variety of different measurements we can make to determine the solar cell's performance, such as its power output and its conversion efficiency.

The main electrical characteristics of a PV cell or module are summarized in the relationship between the current and voltage produced on a typical solar cell I-V characteristics curve. The intensity of the solar radiation (insolation) that hits the cell controls the current (I), while the increases in the temperature of the solar cell reduces its voltage (V).

Solar cells produce direct current (DC) electricity and current times voltage equals power, so we can create solar cell I-V curves representing the current versus the voltage for a photovoltaic device.

Solar Cell I-V Characteristics Curves are basically a graphical representation of the operation of a solar cell or module summarising the relationship between the current and voltage at the existing conditions of irradiance and temperature. I-V curves provide the information required to configure a solar system so that it can operate as close to its optimal peak power point (MPP) as possible.

Solar Cell I-V Characteristic Curve



The above graph shows the current-voltage (I-V) characteristics of a typical silicon PV cell operating under normal conditions. The power delivered by a single solar cell or panel is the product of its output current and voltage (I x V). If the multiplication is done, point for point, for all voltages from short-circuit to open-circuit conditions, the power curve above is obtained for a given radiation level.

With the solar cell open-circuited that is not connected to any load the current will be at its minimum (zero) and the voltage across the cell is at its maximum, known as the solar cells **open circuit voltage**, or Voc. At the other extreme, when the solar cell is short circuited, that is the positive and negative leads connected together, the voltage across the cell is at its minimum (zero) but the current flowing out of the cell reaches its maximum, known as the solar cells **short circuit current**, or Isc.

Then the span of the solar cell I-V characteristics curve ranges from the short circuit current (Isc) at zero output volts, to zero current at the full open circuit voltage (Voc). In other words, the maximum voltage available from a cell is at open circuit, and the maximum current at closed circuit. Of course, neither of these two conditions generates any electrical power, but there must be a point somewhere in between was the solar cell generates maximum power.

However, there is one particular combination of current and voltage for which the power reaches its maximum value, at Imp and Vmp. In other words, the point at which the cell generates maximum electrical power and this is shown at the top right area of the green rectangle. This is the "maximum power point" or MPP. Therefore the ideal operation of a photovoltaic cell (or panel) is defined to be at the maximum power point.

The maximum power point (MPP) of a solar cell is positioned near the bend in the I-V characteristics curve. The corresponding values of Vmp and Imp can be estimated from the open circuit voltage and the short circuit current: Vmp ≅ (0.8–0.90)Voc and Imp ≅ (0.85–0.95)Isc. Since solar cell output voltage and current both depend on temperature, the actual output power will vary with changes in ambient temperature.

PV module

PV Module or Solar PV Module is an assembly of photovoltaic (PV) cells, also known as solar cells. To achieve a required voltage and current, a group of PV module**s** (also called PV panels) are wired into large array that called PV array. A PV module is the essential component of any PV system that converts sunlight directly into direct current (DC) electricity. PV modules can be wired together in series and/or parallel to deliver voltage and current in a particular s

Types of PV Module

Crystalline Silicon PV Module

Two types of crystalline silicon (c-Si) are used to produce PV module: single crystalline silicon or known as monocrystalline silicon and multi-crystalline silicon, also called polycrystalline silicon. The polycrystalline silicon PV module has lower conversion efficiency than single crystalline silicon PV module but both of them have high conversion efficiencies that average about 10-12%

Amorphous Silicon PV Module

Amorphous silicon (a-Si) PV module or thin-film silicon PV module absorbs light more effectively than crystalline silicon PV module, so it can be made thinner. It suits for any applications that high efficiency is not required and low cost is important. The typical efficiency of amorphous silicon PV module is around 6%.

PV array

An interconnected system of PV modules that function as a single electricity-producing unit is called PV array.

PV system

A stand alone system the solar panels are not connected to a grid but instead are used to charge a bank of batteries. These batteries store the power produced by the solar panels and then your electrical loads draw their electricity from these batteries. Stand alone solar power systems have been used for a long time in areas where no public grid is available. However, the real growth in solar power systems in the last 5 years has been in grid connects systems. Why is this? Because most people live in areas that are connected to a public grid and stand-alone systems are much, much more expensive than grid connect systems because batteries are very expensive. It is my hope that in the future we will see a fall in battery prices and that stand alone systems will be used more. However, batteries will need to become a lot cheaper for this to happen.

A grid connect system is one that works in with the local utility grid so that when your solar panels produce more solar electricity than your house is using the surplus power is fed into the grid. With a grid connect solar power system when your house requires more power than what your solar panels are producing then the balance of your electricity is supplied by the utility grid. So for example if your electrical loads in your house were consuming 20 amps of power and your solar power was only generating 12 amps then you would be drawing 8 amps from the grid. Obviously at night all of your electrical needs are supplied by the grid because with a grid connect system you do not store the power you generate during the day.

With a standalone solar system the solar panels are not connected to a grid but instead are used to charge a bank of batteries. These batteries store the power produced by the solar panels and then your electrical loads draw their electricity from these batteries. Stand alone solar power systems have been used for a long time in areas where no public grid is available. However, the real growth in solar power systems in the last 5 years has been in grid connects systems. Why is this? Because most people live in areas that are connected to a public grid and stand-alone systems are much, much more expensive than grid connect systems because batteries are very expensive. It is my hope that in the future we will see a fall in battery prices and that stand alone systems will be used more. However, batteries will need to become a lot cheaper for this to happen.

PV based water pumping

Photovoltaic water pumping systems convert solar energy into electrical energy to power the water pump. Solar water pumping technology can be considered a promising alternative to electricity, diesel, or gasoline-based pumping systems as they are cost-effective and environment friendly.

Solar pumping systems make it possible to collect water from a source (river, basin, well …) even if no energy source is present on the site. Often used to provide drinking water, irrigation or to fill reservoirs, these systems allow access to water in the most remote areas.

How does it work?

Photovoltaic water pumping systems convert solar radiation into electricity via PV panels with the mission to power the electric pumps. The electrical energy produced by the PV modules is used to supply DC motors or to be converted into alternating current by the inverter. Depending on the installation, it is possible to store energy in batteries. However, it is not always necessary to store the energy produced because the installation of a reservoir at the pump outlet makes it possible to store water and thus obtain a usable reserve even without the sun. Another option is the thermodynamic conversion which converts solar energy into mechanical energy to run the solar pump.

 PV water pumping systems have long-term lower costs when compared to diesel or gasoline-based pumping systems.
 They are reliable and low maintenance as they don’t require an attendant to be present during operations.
 No energy storage is needed as the water can be stored by itself.
 High modularity, photovoltaic water pumping systems can adapt to the eventual needs of growth.
 Environment friendly, PV water pumping technology does not cause air, water, or noise pollution.

Flat plate collector and its material, Application and performance

The flat-plate solar collectors are probably the most fundamental and most studied technology for solar-powered domestic hot water systems. The overall idea behind this technology is pretty simple. The Sun heats a dark flat surface, which collects as much energy as possible, and then the energy is transferred to water, air, or other fluid for further use.

These are the main components of a typical flat-plate solar collector:

- Black surface - absorbent of the incident solar energy
- Glazing cover - a transparent layer that transmits radiation to the absorber, but prevents radiative and convective heat loss from the surface
- Tubes containing heating fluid to transfer the heat from the collector
- Support structure to protect the components and hold them in place
- Insulation covering sides and bottom of the collector to reduce heat losses

The flat-plate systems normally operate and reach the maximum efficiency within the temperature range from 30 to 80 ^oC (Kalogirou, 2009), however, some new types of collectors that employ vacuum insulation can achieve higher temperatures (up to 100 ^oC). Due to the introduction of selective coatings, the stagnant fluid temperature in flat-plate collectors has been shown to reach 200 ^oC.

ome advantages of the flat-plate collectors are that they are:

- Easy to manufacture
- Low cost
- Collect both beam and diffuse radiation
- Permanently fixed (no sophisticated positioning or tracking equipment is required)
- Little maintenance

Flat-plate collectors are installed facing the equator (i.e. South oriented in the Northern hemisphere and North oriented in the Southern hemisphere). The optimal tilt of the collector plate is close to the latitude of the location (+/- 15^o). If the application is solar cooling, the optimum installation angle is Latitude - 10^o, so that the solar beam is perpendicular to the collector during summertime. If the application is solar heating, the optimum installation angle is Latitude + 10^o. It was found however, that for year-round hot water application, the optimum angle is Latitude + 5^o, which provides somewhat better performance during winter, when the hot water is more needed (Kalogirou, 2009)

Transport fluid options

The flat plate collectors can involve liquid or air heat transport.

Water is one of the common options as liquid fluid due to its accessibility and good thermal properties:

- It has a relatively high volumetric heat capacity
- It is incompressible (or almost incompressible)
- It has a high mass density (which allows using small tubes and pipes for transport)

One disadvantage of water is that it freezes during winter, which can damage the collector or piping system. This can be managed by draining down the collector at low solar inputs (below a critical insolation threshold). Drain down sensors are often employed to monitor the system and to ensure complete draining, as pocket water freezing can cause damage. Refilling the system with water on the next morning also is not perfect. Possible air pockets in the collector can be a problem, blocking water flow and decreasing system efficiency .

Antifreeze mixtures can be used instead of pure water to alleviate the above-said problems. The common antifreeze components are ethylene glycol or propylene glycol. Those chemicals are mixed with water require closed-loop systems and proper disposal due to toxicity. Nominal antifreeze service like is about 5 years, after which it needs to be replaced. Air can be used as transport fluid in some designs of flat -plate collectors. This option is better suited to space heating applications or crop drying. A fan is usually required to facilitate air flow in the system and efficient heat transport. Certain designs can provide passive (no fan) movement of air due to thermal buoyancy.

Phase-change liquids can also be used with flat-plate collectors. Some refrigerants are included in this group of fluids. They do not freeze, which eliminates troubles explained above for water, and, due to their low boiling point can change from liquid to gas as temperature increases. Those fluids can be practical in settings where quick response to rapid temperature fluctuation is needed.
Collector construction

The key considerations in flat plate collector design are maximizing absorption, minimizing reflection and radiation losses, and effective heat transfer from the collector plate to the fluids. One of the important issues is obtaining a good thermal bond between the absorber plate and changes (tubes or ducts containing the heat-transfer fluids)

The plate - channel assembly may use a variety of methods of component attachment - thermal cement, solder, clips, clamps, brazing, mechanical pressure applicators. One of the considerations in choosing the assembly method is cost of labor and materials.

Module: 3 Wind energy

Wind power and its sources

Wind is the movement of air from an area of high pressure to an area of low pressure. In fact, wind exists because the sun unevenly heats the surface of the Earth. As hot air rises, cooler air moves in to fill the void. As long as the sun shines, the wind will blow. And wind has long served as a power source to humans.

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 systems point of view of aero turbine 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.

Some of the main site selection consideration is given below:

1. High annual average wind speed:
2. Availability of anemometry data:
3. Availability of wind V(t) Curve at the proposed site:
4. Wind structure at the proposed site:
5. Altitude of the proposed site:
6. Terrain and its aerodynamic:
7. Local Ecology

8. Distance to road or railways:

9. Nearness of site to local centre/users:

10. Nature of ground:

11. Favourable land cost:

Power in the wind

Wind energy is the kinetic energy of air in motion, also called wind. Total wind energy flowing through an imaginary surface with area *A* during the time *t* is:

$E= mv^2 / 2 = (Avt\rho)\, v^2 / 2 = At\rho\, v^3 / 2$

Where ρ is the density of air; v is the wind speed; Avt is the volume of air passing through A (which is considered perpendicular to the direction of the wind); Avtρ is therefore the mass m passing through "A". $½ \rho v^2$ is the kinetic energy of the moving air per unit volume.

Power is energy per unit time, so the wind power incident on *A* (e.g. equal to the rotor area of a wind turbine) is:

$P = E / t = A\rho\, v^3 / 2$

Wind power in an open air stream is thus proportional to the third power of the wind speed;

Classification of wind turbine and rotor

There are two basic types of wind turbines: those with a horizontal axis, and those with a a vertical axis.

The majority of wind turbines have a horizontal axis: a propeller-style design with blades that rotate around a horizontal axis. Horizontal axis turbines are either upwind (the wind hits the blades before the tower) or downwind (the wind hits the tower before the blades). Upwind turbines also include a yaw drive and motor -- components that turns the nacelle to keep the rotor facing the wind when its direction changes.

While there are several manufacturers of vertical axis wind turbines, they have not penetrated the utility scale market (100 kW capacity and larger) to the same degree as horizontal access turbines. Vertical axis turbines fall into two main designs:

- Drag-based, or Savonius, turbines generally have rotors with solid vanes that rotate about a vertical axis.
- Lift-based, or Darrieus, turbines have a tall, vertical airfoil style (some appear to have an eggbeater shape)

Types of wind rotors

Starting from classical horizontal axis rotors (old windmills), a lot of types of wind rotors were developed as time went on, some of them were excellent. Indeed the first windmills developed in Mesopotamia were built with vertical axis, mounting, radially, some vertical flags. After some centuries and thanks to the deep experience gained, man optimized the rotor reaching excellent results such as the Dutch and Greek windmills.

Wind rotors can be divided into three main groups:

- With horizontal axis
- With vertical axis
- Hybrid

Moreover, wind rotors can be classified into:

RESISTANCE SYSTEMS**:** where the blade offers resistance to the wind which presses on it making it move and generating mechanical energy.

LIFT SYSTEMS**:** where the blade, of aerodynamic form, exploits the lift principle, i.e. the air flow (wind) which allows it to move generating mechanical energy

SYSTEM WITH HORIZONTAL AXIS

In this case the axis is perpendicular to the wind direction and the blades move to the direction of the air flux. The SAVONIUS rotor (from the name of the Finlander J. Savonius who invented it in 1929) is the simplest type. It can be built opposing two half cylinders hinged on the axis of the rotor itself. In this type of rotor a system of orientation of the blades is not necessary; however not all the surface is exposed to the wind. In fact, while a blade collects the air flux and it is pushed, the other one turns to the opposite side, reducing the performance.

The main characteristics of this wind rotor are the following ones:

- front area totally used
- high speed of rotation
- high coefficient of lift
- high power obtainable

Thanks to the high speed of rotation granted by this rotor, the complete system is very simple to be built and to be joined to the electrical generators. However, the propeller demands a refined technology as it has to grant lightness and strength. Moreover, the propeller generator could create some problems: small mistakes in its construction can destroy the whole system, tower included. This is why it is better to keep the turns number low and constant through brakes or aerodynamic solutions of different types.

SYSTEM WITH VERTICAL AXIS

In this case the axis is perpendicular to the wind direction and the blades move to the direction of the air flux. The SAVONIUS rotor (from the name of the Finlander J. Savonius who invented it in 1929) is the simplest type. It can be built opposing two half cylinders hinged on the axis of the rotor itself. In this type of rotor a system of orientation of the blades is not necessary; however not all the surface is exposed to the wind. In fact, while a blade collects the air flux and it is pushed, the other one turns to the opposite side, reducing the performance.

The main characteristics of this wind rotor are the following ones:

- low speed of rotation
- high mechanical torque
- modest performance

There is also an aerodynamic limit which prevents to improve, beyond a certain level, the efficiency of the Savonius rotors. They are proper to mechanical uses as the water pumps. Indeed they are mostly used in rural area.

HYBRID SYSTEMS
They are the youngest and they combine the advantageous characteristics of both the systems with horizontal and vertical axis. In general they are with vertical axis with propellers or blades derived from the previous ones. Here are some examples: the Darrieous rotor, the Cycloturbine, the Ropatec rotor, the rotor with delta flange (see the photo), ext.

The main characteristics of this wind rotor are the following ones:

- **easiness** of construction
- high speed of rotation
- no orientation system
- power coefficients close to the theoretical value

Wind energy extraction, betz's limit

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

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

Assumptions

1. The rotor does not possess a hub and is ideal, with an infinite number of blades, which have no drag. Any resulting drag would only lower this idealized value.
2. The flow into and out of the rotor is axial. This is a control-volume analysis, and to construct a solution, the control volume must contain all flow going in and out, failure to account for that flow would violate the conservation equations.
3. The flow is non-compressible. Density remains constant, and there is no heat transfer.
4. Uniform thrust is exerted on the disc or rotor.

Wind characteristics

As the wind power is proportional to the cubic wind speed, it is crucial to have detailed knowledge of the site-specific wind characteristics. Even small errors in estimation of wind speed can have large effects on the energy yield, but also lead to poor choices for turbine and site. An average wind speed is not sufficient. Site-specific wind characteristics pertinent to wind turbines include:

- Mean wind speed: Only interesting as a headline figure, but does not tell how often high wind speeds occur.
- wind speed distribution : diurnal, seasonal, annual patterns
- turbulence: short-term fluctuations
- long-term fluctuations
- distribution of wind direction
- wind shear

Wind speed patterns can be depicted as a **wind speed spectrum**. A high value indicates a significant change in wind speed over the corresponding time period.

Performance and limitation of wind energy conversion system

- The wind is inconsistent.
- Wind turbines involve high upfront capital investment.
- Wind turbines have a visual impact.
- May reduce the local bird population.
- Wind turbines are prone to noise disturbances.
- Installation can take up a significant portion of land.

Module: 4 Biomass and Geothermal energy

Availability of biomass and its conversion theory

Biomass is plant or animal material used as fuel to produce electricity or heat. Examples are wood, energy crops and waste from forests, yards, or farms. Since biomass technically can be used as a fuel directly (e.g. wood logs), some people use the terms biomass and biofuel interchangeably. More often than not, the word biomass simply denotes the biological raw material the fuel is made of. The word biofuel is usually reserved for *liquid* or *gaseous* fuels, used for transportation. Wood and wood residues is the largest biomass energy source today. Wood can be used as a fuel directly or processed into pellet fuel or other forms of fuels. Other plants can also be used as fuel, for instance corn, switchgrass, miscanthus and bamboo.

Biomass conversion theory

Thermal conversions

Thermal conversion processes use heat as the dominant mechanism to upgrade biomass into a better and more practical fuel. The basic alternatives are torrefaction, pyrolysis, and gasification, these are separated principally by the extent to which the chemical reactions involved are allowed to proceed (mainly controlled by the availability of oxygen and conversion temperature). There are other less common, more experimental or proprietary thermal processes that may offer benefits, such as hydrothermal upgrading. Some have been developed for use on high moisture content biomass, including aqueous slurries, and allow them to be converted into more convenient forms.

Chemical conversion

A range of chemical processes may be used to convert biomass into other forms, such as to produce a fuel that is more practical to store, transport and use, or to exploit some property of the process itself. Many of these processes are based in large part on similar coal-based processes, such as the Fischer-Tropsch synthesis. Biomass can be converted into multiple commodity chemicals

Biochemical conversion

As biomass is a natural material, many highly efficient biochemical processes have developed in nature to break down the molecules of which biomass is composed, and many of these biochemical conversion processes can be harnessed. In most cases, microorganisms are used to perform the conversion process: anaerobic digestion, fermentation, and composting. Glycoside hydrolases are the enzymes involved in the degradation of the major fraction of biomass, such as polysaccharides present in starch and lignocellulose. Thermostable variants are gaining increasing roles as catalysts in biorefining applications, since recalcitrant biomass often needs thermal treatment for more efficient degradation

Electrochemical conversions

Biomass can be directly converted to electrical energy via electrochemical (electrocatalytic) oxidation of the material. This can be performed directly in a direct carbon fuel cell. irect liquid fuel cells such as direct ethanol fuel cell, a direct methanol fuel cell, a direct formic acid fuel cell, a L-ascorbic Acid Fuel Cell (vitamin C fuel cell). The fuel can also be consumed indirectly via a fuel cell system containing a reformer which converts the biomass into a mixture of CO and H_2 before it is consumed in the fuel cell.

Types of biomass

Biomass can be split into two distinct categories:

- Waste biomass
- Energy Crops

  Forestry residues include biomass not harvested or removed from logging sites in commercial forests, as well as material resulting from forest management operations such as pre-commercial thinning and removal of dead and dying trees.

  Wood is the most commonly used biomass fuel for heat and power, and unwanted woody waste is a by-product of many forestry operations. Using these materials for electricity generation recovers their energy value while avoiding landfill disposal.

Forestry waste includes logging residues, imperfect commercial trees, dead wood, and other non-commercial trees that need to be thinned from crowded, unhealthy, fire-prone forests. Forest thinning is necessary to help some forests regain their natural health, but for smaller woodlands the cost of removing the wood cannot be recovered through timber sales due to their poor quality.

About 12% of UK land is covered by trees, with about 47% of this area in Scotland. Commercial amounts of wood for fuel can be produced as a by-product of forestry management. Wood has a relatively low calorific value of around 19GJ/dry tonne. When harvested, wood has moisture content of around 55% by weight.

Resources of geothermal energy

Geothermal resources are reservoirs of hot water that exist at varying temperatures and depths below the Earth's surface. Mile-or-more-deep wells can be drilled into underground reservoirs to tap steam and very hot water that can be brought to the surface for use in a variety of applications, including electricity generation, direct use, and heating and cooling. In the United States, most geothermal reservoirs are located in the western states.

Thermodynamics of geothermal energy conversion

Laws of Thermodynamics

The Zeroth Law of Thermodynamics: If two systems are in thermal equilibrium with a third, then they are in thermal equilibrium with each other. This law is the basis of temperature measurement.

First Law of Thermodynamics: The change in internal energy of a closed system is equals to the heat added to the system (or absorbed from the environment) minus the work done by the system (or on the environment). This law is a consequence of conservation of energy. While attempting to transform heat into work with full efficacy, we quickly learned that always some heat would escape into the surrounding environment as wasted energy (recall that energy cannot be destroyed). This wasted energy can never be fully converted into anything useful.

Second Law of Thermodynamics: It is impossible to construct an engine which, operating in a cycle, will produce no other effect than the extraction of heat from a single heat reservoir and the performance of an equal amount of work. It imposes a limitation on energy transformations other than that imposed by the first law.

The second law states that heat flows naturally from regions of higher temperature to regions of lower temperature, but that it will not flow naturally the other way. Heat can be made to flow from a colder region to a hotter region, which is exactly what happens in an air conditioner, but heat only does this when it is forced. On the other hand, heat flows from hot to cold spontaneously. Entropy is an indicator of the temperature of energy. A given amount of thermal energy has low entropy when it is at high temperature, and the same amount of energy has higher entropy when it is at lower temperature. Heat is energy, and with energy, size matters. With temperature, it does not. The radiant energy that arrives at Earth from the Sun at a temperature of 6000 K is a very lowentropy form of heat.

A power cycle receives heat at a high temperature, converts some of this energy into mechanical work, and rejects reminder at a lower temperature. By virtue of second law of thermodynamics, no power cycle can convert more heat into work than the Carnot cycle. The theoretical maximum efficiency of any heat engine is defined by the Carnot Cycle. The Carnot cycle is a hypothetical engine involving four processes: an adiabatic reversible compression and expansion and a constant temperature heat addition and rejection. The Carnot heat engine (the ideal heat engine) has an efficiency equal to (TH - TC)/TH where TH is the temperature of the hot source and TC is the temperature of the cold sink.

Reversible isothermal expansion of the gas at the "hot" temperature, TH. During this step, the expanding gas causes the piston to do work on the surroundings. The gas expansion is driven by absorption of heat from the high temperature reservoir. 2. Reversible adiabatic expansion of the gas. For this step we assume the piston and cylinder are thermally insulated, so that no heat is gained or lost. The gas continues to expand, doing work on the surroundings. The gas expansion causes it to cool to the "cold" temperature, TC. 3. Reversible isothermal compression of the gas at the "cold" temperature, TC. Now the surroundings do work on the gas, causing heat to flow out of the gas to the low temperature reservoir. 4. Reversible adiabatic compression of the gas. Once again we assume the piston and cylinder are thermally insulated. During this step, the surroundings do work on the gas, compressing it and causing the temperature to rise to TH. At this point the gas is in the same state as at the start of step 1.

Carnot's theorem states that No engine operating between two heat reservoirs can be more efficient than a Carnot engine operating between the same reservoirs. Thus, Equation 3 gives the maximum efficiency possible for any engine using the corresponding temperatures. A corollary to Carnot's theorem states that: All reversible engines operating between the same heat reservoirs are equally efficient. So Equation 3 gives the efficiency of any reversible engine. In reality it is not practical to build a thermodynamically reversible engine, so real heat engines are less efficient than indicated by Equation 3. Nevertheless, Equation 3 is extremely useful for determining the maximum efficiency that could ever be expected for a given set of thermal reservoirs. A more useful question to ask is : what is the efficiency when the engine is working at maximum power? A simple analysis will give the output.

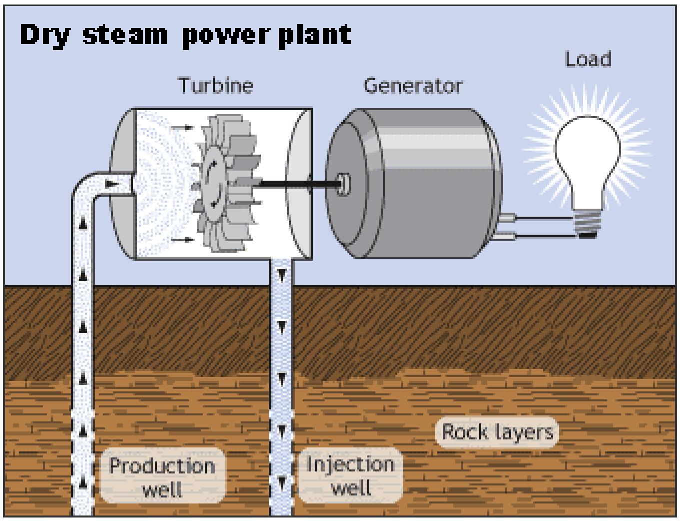
Geothermal power generation

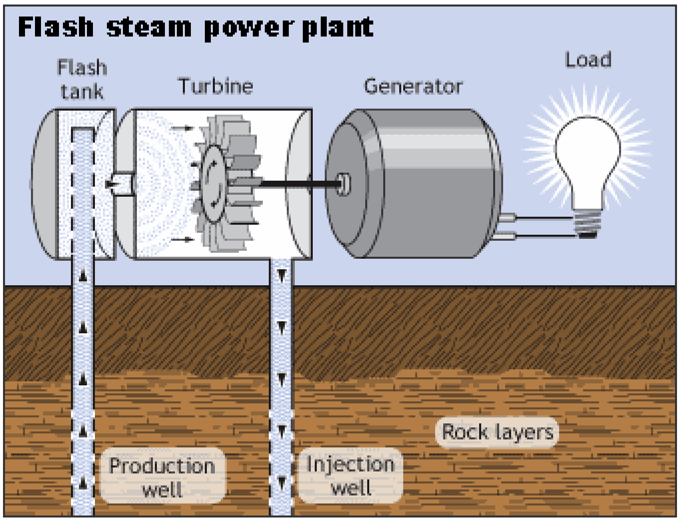
Geothermal power plants use hydrothermal resources that have both water (hydro) and heat (thermal). Geothermal power plants require high-temperature (300°F to 700°F) hydrothermal resources that come from either dry steam wells or from hot water wells. People use these resources by drilling wells into the earth and then piping steam or hot water to the surface. The hot water or steam powers a turbine that generates electricity. Some geothermal wells are as much as two miles deep.

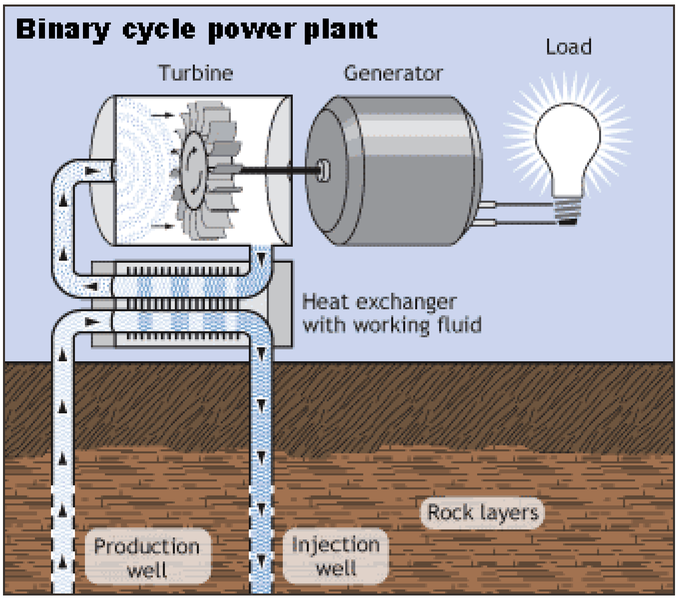
Types of geothermal power plants

There are three basic types of geothermal power plants:

- **Dry steam plants** use steam directly from a geothermal reservoir to turn generator turbines. The first geothermal power plant was built in 1904 in Tuscany, Italy, where natural steam erupted from the earth.
- **Flash steam plants** take high-pressure hot water from deep inside the earth and convert it to steam to drive generator turbines. When the steam cools, it condenses to water and is injected back into the ground to be used again. Most geothermal power plants are flash steam plants.
- **Binary cycle power plants** transfer the heat from geothermal hot water to another liquid. The heat causes the second liquid to turn to steam, which is used to drive a generator turbine.


Dry steam power plant
Load
Turbine
Generator
Rock layers
Production well
Injection well


Flash steam power plant
Load
Flash tank
Turbine
Generator
Rock layers
Production well
Injection well


Binary cycle power plant
Load
Turbine
Generator
Heat exchanger with working fluid
Rock layers
Production well
Injection well

Module: 5 Tidal, Wave and Ocean energy

Introduction to tidal energy

Tidal energy is produced by the surge of ocean waters during the rise and fall of tides. Tidal energy is a renewable source of energy.

During the 20th century, engineers developed ways to use tidal movement to generate electricity in areas where there is a significant tidal range—the difference in area between high tide and low tide. All methods use special generators to convert tidal energy into electricity.

Tidal energy production is still in its infancy. The amount of power produced so far has been small. There are very few commercial-sized tidal power plants operating in the world. The first was located in La Rance, France. The largest facility is the Sihwa Lake Tidal Power Station in South Korea. The United States has no tidal plants and only a few sites where tidal energy could be produced at a reasonable price. China, France, England, Canada, and Russia have much more potential to use this type of energy.

In the United States, there are legal concerns about underwater land ownership and environmental impact. Investors are not enthusiastic about tidal energy because there is not a strong guarantee that it will make money or benefit consumers. Engineers are working to improve the technology of tidal energy generators to increase the amount of energy they produce, to decrease their impact on the environment, and to find a way to earn a profit for energy companies.

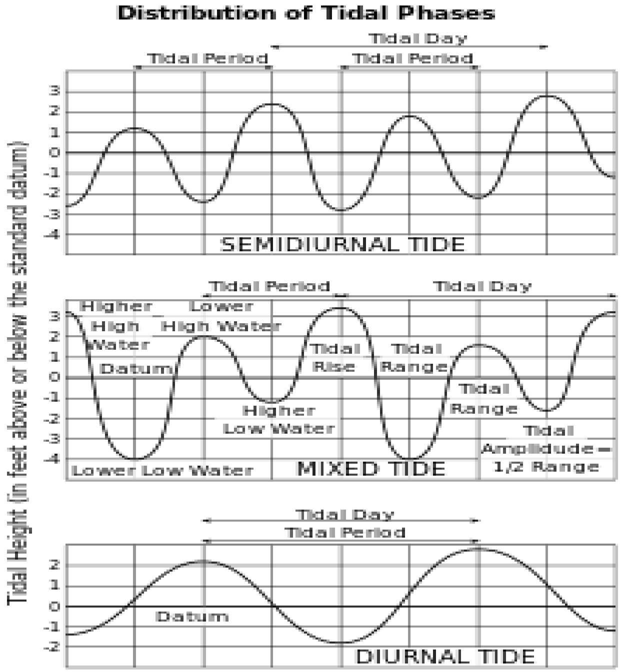
Tidal characteristics

Tide changes proceed via the following stages:

- Sea level rises over several hours, covering the intertidal zone; flood tide.
- The water rises to its highest level, reaching high tide.
- Sea level falls over several hours, revealing the intertidal zone; ebb tide.
- The water stops falling, reaching low tide.

Oscillating currents produced by tides are known as tidal streams. The moment that the tidal current ceases is called slack water or slack tide. The tide then reverses direction and is said to be turning. Slack water usually occurs near high water and low water. But there are locations where the moments of slack tide differ significantly from those of high and low water.

Tides are commonly semi-diurnal (two high waters and two low waters each day), or diurnal (one tidal cycle per day). The two high waters on a given day are typically not the same height (the daily inequality); these are the higher high water and the lower high water in tide tables. Similarly, the two low waters each day are the higher low water and the lower low water. The daily inequality is not consistent and is generally small when the Moon is over the Equator.



Tidal power plant

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Tidal Energy Generators

There are currently three different ways to get tidal energy: tidal streams, barrages, and tidal lagoons.

For most tidal energy generators, turbines are placed in tidal streams. A tidal stream is a fast-flowing body of water created by tides. A turbine is a machine that takes energy from a flow of fluid. That fluid can be air (wind) or liquid (water). Because water is much more dense than air, tidal energy is more powerful than wind energy. Unlike wind, tides are predictable and stable. Where tidal generators are used, they produce a steady, reliable stream of electricity.

Placing turbines in tidal streams is complex, because the machines are large and disrupt the tide they are trying to harness. The environmental impact could be severe, depending on the size of the turbine and the site of the tidal stream. Turbines are most effective in shallow water. This produces more energy and allows ships to navigate around the turbines. A tidal generator's turbine blades also turn slowly, which helps marine life avoid getting caught in the system.

The world's first tidal power station was constructed in 2007 at Strangford Lough in Northern Ireland. The turbines are placed in a narrow strait between the Strangford Lough inlet and the Irish Sea. The tide can move at 4 meters (13 feet) per second across the strait.

Barrage

Another type of tidal energy generator uses a large dam called a barrage. With a barrage, water can spill over the top or through turbines in the dam because the dam is low. Barrages can be constructed across tidal rivers, bays, and estuaries.

Turbines inside the barrage harness the power of tides the same way a river dam harnesses the power of a river. The barrage gates are open as the tide rises. At high tide, the barrage gates close, creating a pool, or tidal lagoon. The water is then released through the barrage's turbines, creating energy at a rate that can be controlled by engineers.

The environmental impact of a barrage system can be quite significant. The land in the tidal range is completely disrupted. The change in water level in the tidal lagoon might harm plant and animal life. The salinity inside the tidal lagoon lowers, which changes the organisms that are able to live there. As with dams across rivers, fish are blocked into or out of the tidal lagoon. Turbines move quickly in barrages, and marine animals can be caught in the blades. With their food source limited, birds might find different places to migrate.

A barrage is a much more expensive tidal energy generator than a single turbine. Although there are no fuel costs, barrages involve more construction and more machines. Unlike single turbines, barrages also require constant supervision to adjust power output.

The tidal power plant at the Rance River estuary in Brittany, France, uses a barrage. It was built in 1966 and is still functioning. The plant uses two sources of energy: tidal energy from the English Channel and river current energy from the Rance River. The barrage has led to an increased level of silt in the habitat. Native aquatic plants suffocate in silt, and a flatfish called plaice is now extinct in the area. Other organisms, such as cuttlefish, a relative of squids, now thrive in the Rance estuary. Cuttlefish prefer cloudy, silty ecosystems.

Tidal Lagoon
The final type of tidal energy generator involves the construction of tidal lagoons. A tidal lagoon is a body of ocean water that is partly enclosed by a natural or manmade barrier. Tidal lagoons might also be estuaries and have freshwater emptying into them.

A tidal energy generator using tidal lagoons would function much like a barrage. Unlike barrages, however, tidal lagoons can be constructed along the natural coastline. A tidal lagoon power plant could also generate continuous power. The turbines work as the lagoon is filling and emptying.

The environmental impact of tidal lagoons is minimal. The lagoons can be constructed with natural materials like rock. They would appear as a low breakwater (sea wall) at low tide, and be submerged at high tide. Animals could swim around the structure, and smaller organisms could swim inside it. Large predators like sharks would not be able to penetrate the lagoon, so smaller fish would probably thrive. Birds would likely flock to the area.

But the energy output from generators using tidal lagoons is likely to be low. There are no functioning examples yet. China is constructing a tidal lagoon power plant at the Yalu River, near its border with North Korea. A private company is also planning a small tidal lagoon power plant in Swansea Bay, Wales.

Introduction to wave energy

Wave energy is a form of renewable energy that can be harnessed from the motion of the waves. There are several methods of harnessing wave energy that involve placing electricity generators on the surface of the ocean.

Depending on the lunar cycles, tides, winds, and weather, waves can vary in size and strength. As waves roll through the ocean, they create kinetic energy, or movement. This movement can be used to power turbines, which, in turn, create energy that can be converted into electricity and power. There are also several ways of harnessing wave energy that utilize the up and down motion of the waves to power pistons/turn generators.

Factors affecting wave energy

Wave height is affected by wind speed, wind duration (or how long the wind blows), and fetch, which is the distance over water that the wind blows in a single direction. If wind speed is slow, only small waves result, regardless of wind duration or fetch.

Principle of wave energy plant

The Wave energy hitting the shore is converted into electricity using a wave energy converter (WEC), essentially, a power station. The operating principle of this power station is both simple and ingenious. It's an enclosed chamber with an opening under the sea, which allows strong sea waves to flow into the chamber and back.

The water level in the chamber rises and falls with the rhythm of the wave, and so air is forced forwards and backward via the turbines joined to an upper opening in the chamber. The compressed and decompressed air has enough power to propel the turbines. The turbine is propelled in the same direction by the back and forth airflow through the turbine. The propelling turbine turns a shaft connected to a generator.

The generator produces electricity, which is transported to electrical grids and later supplied to demand centers and distribution lines that connect individual homes and industries. The advantage of this wave energy converter is that even considerably low wave motions can produce sufficient airflow to maintain the movement of the turbine to generate energy.

Advantages of Wave Energy

It's highly predictable

The wave arrival pattern is highly predictable. They arrive day and night and harbor more energy than other renewable sources like wind and solar. Wind energy and solar energy, on the other hand, are highly unpredictable.

Wind speeds die down unexpectedly, which affects the generation of electricity. Solar energy depends upon exposure from the sun, which means cloud coverage and night hours significantly reduce this exposure leading to less efficiency.

It's a renewable form of energy

renewable means it's an endless resource. It does not need man's intervention to continue existing. No one has dared to suggest that the oceans and seas will disappear someday. Humans will continue harnessing it to the very end. This aspect makes wave energy a reliable and efficient energy resource.

Creation of green jobs

Communities living in remote areas and declining industries like the shipbuilding industry bear the biggest brunt of unemployment and economic unsustainability due to lack of electricity.

The wave energy sector has the potential to create numerous green opportunities to remote and urban populations alike because remote areas that are not able to be reached by conventional electricity supply are well catered by wave power

The exponential growth of remote area

The wave energy harnessed can to channeled to remote locations, and this means springing up of industries and businesses. These remote areas will witness strong economic growth moving forward

Security of energy supply

Setting up a strong wave energy infrastructure can enormously help a country from overdependence on fossil fuels. The fossil fuel market is largely volatile and could hurt a country's economy if a shortage occurs. Wave energy is the surefire way to bridge this volatility gap since it's cheap, reliable and efficient.

Land remains undamaged

Wave energy plants can be situated offshore alleviating any risk that comes along with these plants situated onshore like soil pollution. Also, the land remains in its natural state unlike fossil fuel extraction, which requires high levels of excavation that leaves land heavily damaged.

Disadvantages of Wave Energy

High upfront capital costs

Construction of wave energy plants requires huge capital outlay. Energy plant maintenance, connection to the power grid, wave resources, expected drop in energy costs once the infrastructure is up and running and shelf life of the technology are just some of the variables driving up the cost of wave energy. Determination of actual cost is also difficult since wave energy is in its early stage of development

Variability in wave magnitude can damage equipment

The wave magnitude is so unpredictable in the seas. Sometimes it comes with a vengeance and could cause heavy wear and tear to the wave energy generation turbines. Damage to this equipment can be costly in terms of repair. It would also mean the stalling of electricity supply.

Damage to sea life ecosystem

Offshore wave energy projects are a lot more sophisticated than onshore ones. The projects include platforms, cables, turbines, interconnections, dredging and much more. From an ecological standpoint, shallow waters are fertile breeding and resting grounds for most marine life.

So, activities from construction and operation of the wave energy plant greatly affect the marine ecosystem. Accidental leaks or spills emanating from hydraulic fluids in the plants could potentially pollute the water resulting in marine life deaths.

OTEC

Ocean thermal energy conversion (OTEC) generates electricity indirectly from solar energy by harnessing the temperature difference between the sun-warmed surface of tropical oceans and the colder deep waters. A significant fraction of solar radiation incident on the ocean is retained by seawater in tropical regions, resulting in average year-round surface temperatures of about 283C. Deep, cold water, meanwhile, forms at higher latitudes and descends to Sow along the seashore toward the equator. The warm surface layer, which extends to depths of about 100}200m, is separated from the deep cold water by a thermo cline. The temperature difference, T, between the surface and thousand-meter depth ranges from 10 to 253C, with larger differences occurring in equatorial and tropical waters. OTEC power systems operate as cyclic heat engines. They receive thermal energy through heat transfer from surface sea water warmed by the sun, and transform a portion of this energy to electrical power. The Second Law of Thermodynamics precludes the complete conversion of thermal energy in to electricity. A portion of the heat extracted from the warm sea water must be rejected to a colder thermal sink. The thermal sink employed by OTEC systems is sea water drawn from the ocean depths by means of a submerged pipeline. A steady-state control volume energy analysis yields the result that net electrical power produced by the engine must equal the difference between the rates of heat transfer from the warm surface water and to the cold deep water. The limiting (i.e., maximum) theoretical Carnot energy conversion efficiency of a cyclic heat engine scales with the difference between the temperatures at which these heat transfers occur. For OTEC, this difference is determined by T and is very small; hence, OTEC efRciency is low. Although viable OTEC systems are characterized by Carnot efRciencies in the range of 6}8%, state-of-the-art combustion steam power cycles, which tap much higher temperature energy sources, are theoretically capable of converting more than 60% of the extracted thermal energy into electricity. The low energy conversion efRciency of OTEC means that more than 90% of the thermal energy extracted from the ocean's surface is 'wasted' and must be rejected to the cold, deep sea water. This necessitates large heat exchangers and seawater Sow rates to produce relatively small amounts of electricity.

Closed Cycle OTEC

D'Arsonval's original concept employed a pure working Suid that would evaporate at the temperature of warm sea water. The vapor would subsequently expand and do work before being condensed by the cold sea water. This series of steps would be repeated continuously with the same working Suid, whose Sow path and thermodynamic process representation constituted closed loops } hence, the name 'closed cycle.' The speciRc process adopted for closed cycle OTEC is the Rankine, or vapor power, cycle. The principal components are the heat exchangers, turbogenerator, and seawater supply system, which, although not shown, accounts for most of the parasitic power consumption and a signiRcant fraction of the capital expense. Also not included are ancillary devices such as separators to remove residual liquid downstream of the evaporator and subsystems to hold and supply working Suid lost through leaks or contamination. In this system, heat transfer from warm surface sea water occurs in the evaporator, producing a saturated vapor from the working fluid. Electricity is generated when this gas expands to lower pressure through the turbine. Latent heat is transferred from the vapor to the cold sea water in the condenser and the resulting liquid is pressurized with a pump to repeat the cycle. The success of the Rankine cycle is a consequence of more energy being recovered when the vapor expands through the turbine than is consumed in re-pressurizing the liquid. In conventional (e.g., combustion) Rankine systems, this yields net electrical power. For OTEC, however, the remaining balance may be reduced substantially by an amount needed to pump large volumes of sea water through the heat exchangers. (One misconception about OTEC is that tremendous energy must be expended to bring cold sea water up from depths approaching 1000 meters. In reality, the natural hydrostatic pressure gradient provides for most of the increase in the gravitational potential energy of a Suid particle moving with the gradient from the ocean depths to the surface.

Open Cycle OTEC

Claude's concern about the cost and potential biofouling of closed cycle heat exchangers led him to propose using steam generated directly from the warm sea water as the OTEC working Suid. The steps of the Claude, or open, cycle are: (1) Sash evaporation of warm sea water in a partial vacuum; (2) expansion of the steam through a turbine to generate power; (3) condensation of the vapor by direct contact heat transfer to cold sea water; and (4) compression and discharge of the condensate and any residual noncondensable gases. Unless fresh water is a desired by-product, open cycle OTEC eliminates the need for surface heat exchangers. The name 'open cycle' comes from the fact that the working Suid (steam) is discharged after a single pass and has different initial and Rnal thermodynamic states; hence, the Sow path and process are 'open.

The entire system, from evaporator to condenser, operates at partial vacuum, typically at pressures of 1}3% of atmospheric. Initial evacuation of the system and removal of noncondensable gases during operation are performed by the vacuum compressor, which, along with the sea water and discharge pumps, accounts for the bulk of the open cycle OTEC parasitic power consumption. The low system pressures of open cycle OTEC are necessary to induce boiling of the warm sea water. Flash evaporation is accomplished by exposing the sea water to pressures below the saturation pressure corresponding to its temperature. This is usually accomplished by pumping it into an evacuated chamber through spouts designed to maximize heat and mass transfer surface area. Removal of gases dissolved in the sea water, which will come out of solution in the low-pressure evaporator and compromise operation, may be performed at an intermediate pressure prior to evaporation. Vapor produced in the Sash evaporator is relatively pure steam. The heat of vaporization is extracted from the liquid phase, lowering its temperature and preventing any further boiling. Flash evaporation may be perceived, then, as a transfer of thermal energy from the bulk of the warm sea water of the small fraction of mass that is vaporized. Less than 0.5% of the mass of warm sea water entering the evaporator is converted into steam. The pressure drop across the turbine is established by the cold seawater temperature. At 43C, steam condenses at 813 Pa. The turbine (or turbine diffuser) exit pressure cannot fall below this value. Hence, the maximum turbine pressure drop is only about 3000Pa, corresponding to about a 3:1 pressure ratio. This will be further reduced to account for other pressure drops along the steam path and differences in the temperatures of the steam and seawater streams needed to facilitate heat transfer in the evaporator and condenser. Condensation of the low-pressure steam leaving the turbine may employ a direct contact condenser (DCC), in which cold sea water is sprayed over the vapour, or a conventional surface condenser that physically separates the coolant and the condensate. DCCs are inexpensive and have good heat transfer characteristics because they lack a solid thermal boundary between the warm and cool fluids. Surface condensers are expensive and more difficult to maintain than DCCs; however, they produce a marketable freshwater by-product. Effluents from the condenser must be discharged to the environment. Liquids are pressurized to ambient levels at the point of release by means of a pump, or, if the elevation of the condenser is suitably high, can be compressed hydrostatically. As noted previously, noncondensable gases, which include any residual water vapour, dissolved gases that have come out of solution, and air that may have leaked into the system, are removed by the vacuum compressor.

Module: 6 Emerging technologies for power generation

Fuel cells

A fuel cell uses the chemical energy of hydrogen or other fuels to cleanly and efficiently produce electricity. If hydrogen is the fuel, the only products are electricity, water, and heat. Fuel cells are unique in terms of the variety of their potential applications; they can use a wide range of fuels and feedstock's and can provide power for systems as large as a utility power station and as small as a laptop computer.

Fuel cells have several benefits over conventional combustion-based technologies currently used in many power plants and vehicles. Fuel cells can operate at higher efficiencies than combustion engines and can convert the chemical energy in the fuel directly to electrical energy with efficiencies capable of exceeding 60%. Fuel cells have lower or zero emissions compared to combustion engines. Hydrogen fuel cells emit only water, addressing critical climate challenges as there are no carbon dioxide emissions. There also are no air pollutants that create smog and cause health problems at the point of operation. Fuel cells are quiet during operation as they have few moving part.

Fuel cells work like batteries, but they do not run down or need recharging. They produce electricity and heat as long as fuel is supplied. A fuel cell consists of two electrodes—a negative electrode (or anode) and a positive electrode (or cathode)—sandwiched around an electrolyte. A fuel, such as hydrogen, is fed to the anode, and air is fed to the cathode. In a hydrogen fuel cell, a catalyst at the anode separates hydrogen molecules into protons and electrons, which take different paths to the cathode. The electrons go through an external circuit, creating a flow of electricity. The protons migrate through the electrolyte to the cathode, where they unite with oxygen and the electrons to produce water and heat.

Principle of working of various types of fuel cell

The reaction between hydrogen and oxygen can be used to generate electricity via a fuel cell. Such a cell was used in the Apollo space programme and it served two different purposes – It was used as a fuel source as well as a source of drinking water (the water vapour produced from the cell, when condensed, was fit for human consumption).

The working of this fuel cell involved the passing of hydrogen and oxygen into a concentrated solution of sodium hydroxide via carbon electrodes. The cell reaction can be written as follows:

Cathode Reaction: $\mathbf{O_2 + 2H_2O + 4e^- \rightarrow 4OH^-}$

Anode Reaction: $\mathbf{2H_2 + 4OH^- \rightarrow 4H_2O + 4e^-}$

Net Cell Reaction: $\mathbf{2H_2 + O_2 \rightarrow 2H_2O}$

However, the reaction rate of this electrochemical reaction is quite low. This issue is overcome with the help of a catalyst such as platinum or palladium. In order to increase the effective surface area, the catalyst is finely divided before being incorporated into the electrodes.

The efficiency of the fuel cell described above in the generation of electricity generally approximates to 70% whereas thermal power plants have an efficiency of 40%. This substantial difference in efficiency is because the generation of electric current in a thermal power plant involves the conversion of water into steam, and the usage of this steam to rotate a turbine. Fuel cells, however, offer a platform for the direct conversion of chemical energy into electrical energy.

Types of Fuel Cells

Despite working similarly, there exist many varieties of fuel cells. Some of these types of fuel cells are discussed in this subsection.

The Polymer Electrolyte Membrane (PEM) Fuel Cell

- These cells are also known as proton exchange membrane fuel cells (or PEMFCs).
- The temperature range that these cells operate in is between 50^oC to 100^o
- The electrolyte used in PEMFCs is a polymer which has the ability to conduct protons.
- A typical PEM fuel cell consists of bipolar plates, a catalyst, electrodes, and the polymer membrane.

- Despite having eco-friendly applications in transportation, PEMFCs can also be used for the stationary and portable generation of power.

Phosphoric Acid Fuel Cell

- These fuel cells involve the use of phosphoric acid as an electrolyte in order to channel the H^+
- The working temperatures of these cells lie in the range of 150°C – 200°
- Electrons are forced to travel to the cathode via an external circuit because of the non-conductive nature of phosphoric acid.
- Due to the acidic nature of the electrolyte, the components of these cells tend to corrode or oxidize over time.

Solid Acid Fuel Cell

- A solid acid material is used as the electrolyte in these fuel cells.
- The molecular structures of these solid acids are ordered at low temperatures.
- At higher temperatures, a phase transition can occur which leads to a huge increase in conductivity.
- Examples of solid acids include $CsHSO_4$ and CsH_2PO_4 (cesium hydrogen sulfate and cesium dihydrogen phosphate respectively)

Alkaline Fuel Cell

- This was the fuel cell which was used as the primary source of electricity in the Apollo space program.
- In these cells, an aqueous alkaline solution is used to saturate a porous matrix, which is in turn used to separate the electrodes.
- The operating temperatures of these cells are quite low (approximately 90°C).
- These cells are highly efficient. They also produce heat and water along with electricity.

Solid Oxide Fuel Cell

- These cells involve the use of a solid oxide or a ceramic electrolyte (such as yttria-stabilized zirconia).
- These fuel cells are highly efficient and have a relatively low cost (theoretical efficiency can even approach 85%).
- The operating temperatures of these cells are very high (lower limit of 600°C, standard operating temperatures lie between 800 and 1000°C).
- Solid oxide fuel cells are limited to stationary applications due to their high operating temperatures.

Molten Carbonate Fuel Cell

- The electrolyte used in these cells is lithium potassium carbonate salt. This salt becomes liquid at high temperatures, enabling the movement of carbonate ions.
- Similar to SOFCs, these fuel cells also have a relatively high operating temperature of 650^o
- The anode and the cathode of this cell are vulnerable to corrosion due to the high operating temperature and the presence of the carbonate electrolyte.
- These cells can be powered by carbon-based fuels such as natural gas and biogas.

Limitation of fuel cells

- Expensive to manufacture due the high cost of catalysts (platinum)
- Lack of infrastructure to support the distribution of hydrogen
- A lot of the currently available fuel cell technology is in the prototype stage and not yet validated.
- Hydrogen is expensive to produce and not widely available.

Future potential of fuel cells

In the future, fuel cells could power our cars, with hydrogen replacing the petroleum fuel that is used in most vehicles today. Many vehicle manufacturers are actively researching and developing transportation fuel cell technology.

Stationary fuel cells are the largest, most powerful fuel cells. They are designed to provide a clean, reliable source of on-site power to hospitals, banks, airports, military bases, schools, and homes.

Fuel cells can power almost any portable device or machine that uses batteries. Unlike a typical battery, which eventually goes dead, a fuel cell continues to produce energy as long as fuel and oxidant are supplied. Laptop computers, cellular phones, video recorders, and hearing aids could be powered by portable fuel cells.

Fuel cells have strong benefits over conventional combustion-based technologies currently used in many power plants and cars. They produce much smaller quantities of greenhouse gases and none of the air pollutants that create smog and cause health problems. If pure hydrogen is used as a fuel, fuel cells emit only heat and water as a by-product. Hydrogen-powered fuel cells are also far more energy efficient than traditional combustion technologies.

Emergence of hydrogen

Water is an essential compound that can be formed as a by-product of the combustion of hydrogen unlike other compounds like carbon, which generates harmful by-products such as sooth and carbon monoxide. This is one of the reasons why hydrogen has an edge over carbon for decades. Although, when hydrogen is produced through the exposition of fossil fuels to steam, it contains some carbon.
This technique of extraction of hydrogen from fossil fuels (beneath the bedrock layer of the soil) by subjecting the fossils to high temperature and pressure in the form of steam is referred to as gray hydrogen extraction, and the hydrogen produced is called gray hydrogen; on the other hand, if the CO2 is trapped and isolated, the hydrogen produced is known as blue hydrogen.

Electrolysis of Green Hydrogen

The green hydrogen is usually produced entirely differently. Water is taken as the aqueous solution and an electric charge is passed through the cell to liberate hydrogen and oxygen as the only by-product. This method of producing green hydrogen was less practiced in the past since a high amount of electricity was required to satisfy the conditions of electrolysis (chemical decomposition of water to liberate hydrogen and oxygen).
The production of green hydrogen by electrolysis has grown significantly since there is more electricity from renewable energy sources which can be passed into the electrolytic cell to produce green hydrogen. An electrolyser is another device that can be used to generate hydrogen by breaking water into hydrogen and oxygen.

Cost analysis of hydrogen production

NREL analyzed the cost of hydrogen production via wind-based water electrolysis at 42 potential sites in 11 states across the nation. This analysis included centralized plants producing the Department of Energy (DOE) target of 50,000 kg of hydrogen per day, using both wind and grid electricity. The use of wind and grid electricity can be balanced either by power or cost, including or excluding the purchase of peak summer electricity. Current wind incentives—such as the Production Tax Credit (PTC), Investment Tax Credit (ITC), and Treasury Grant—can reduce hydrogen costs approximately $1/kg and are crucial to meeting DOE cost targets.

Hydrogen storage

Hydrogen storage is a key enabling technology for the advancement of hydrogen and fuel cell technologies in applications including stationary power, portable power, and transportation. Hydrogen has the highest energy per mass of any fuel; however, its low ambient temperature density results in a low energy per unit volume, therefore requiring the development of advanced storage methods that have potential for higher energy density.

Hydrogen can be stored physically as either a gas or a liquid. Storage of hydrogen as a gas typically requires high-pressure tanks (350–700 bar [5,000–10,000 psi] tank pressure). Storage of hydrogen as a liquid requires cryogenic temperatures because the boiling point of hydrogen at one atmosphere pressure is −252.8°C. Hydrogen can also be stored on the surfaces of solids (by adsorption) or within solids (by absorption).

THANK YOU