LESSON 2

I. Lesson Title: GENERATION OF ELECTRICAL POWER

II. Overview:

Electricity is most often generated at a power plant by generators, primarily driven by heat engines using nuclear and fossil fuels such as coal, oil, and natural gas. It can also be generated using water and wind turbines, photovoltaics and geothermal power.

This lesson discusses technologies that can be used to produce electricity – chemical, solar panels for homes, fuel-driven generators, steam turbines, hydroelectric, wind and thermal energy.

III. Specific Objectives: At the end of this lesson, the students can

1. identify the most common sources of power used to generate electricity;
2. differentiate ac and dc generators;
3. discuss the conversion processes of solar energy to electricity;
4. classify the different types of wind turbine; and
5. explain the conversion process of hydropower, geothermal energy, and biomass to electricity

IV. Materials Needed: Handouts, blackboard, chalks, books, LCD/LED monitor or smart tv, computer/laptop, internet service

V. Duration: 2 weeks

VI. Lesson Proper:

SOURCES OF ELECTRICITY

Chemical Action

A voltaic chemical cell is a combination of materials which are used for converting chemical energy into electric energy. A battery is formed when two or more cells are connected. A chemical reaction produces on two dissimilar metals, which serve as the negative and positive terminals. The metals are in contact with an electrolyte.

Thermal Energy

The production of most electric energy begins with the formation of heat energy. Coal, oil, or natural gas can be burned to release large quantitates of heat. Once the heat energy is available, conversion to mechanical energy is next step. Water is heated to produce steam, which is then used to turn the turbines that drive the electric generators. A direct conversion from heat energy to electric energy will increase efficiency and reduce thermal pollution of water resources and the atmosphere.

Solar Cells (Photoelectricity)

Solar cells convert light energy directly into electric energy. They consist of semiconductor material like silicon and are used in large arrays in spacecraft to recharge batteries. Solar cells are also used in home heating.

Piezoelectric Effect (Piezoelectricity)

Certain crystals, such as quartz and Rochelle salts, generate a voltage when they are vibrated mechanically. This action is known as the *piezoelectric* *effect*. One example is the crystal phonograph cartridge, which contains a Rochelle salt crystal to which a needle is fastened. As the needle moves in the grooves of a record, it swings from side to side. This mechanical motion is applied to the crystal, and a voltage is then generated.

Thermocouples (Thermoelectrcity)

If wire of two different metals, such as iron and copper, are welded together and the joint is heated, the difference in electron activity in the two metals produces an emf across the joint. Thermocouple junction can be used to measure the amount of current because current acts to heat the junction.

Friction

Voltage can be produced by rubbing two non-metallic materials together. Static electricity is often the undesired product of friction between moving objects. For example, clouds driven by strong winds can gather huge electrostatic charges and release to earth in the form of lightning.

Magnetism

Magnetism is a phenomenon that occurs naturally in some metallic materials. It can also be produced by electrical currents (*electromagnetism*). A magnetic field can be used to produce a voltage through the principle of *induction*. Most electricity produced today is created through the use of alternators or generators. Both machines use magnetism to induce voltages.

Generator

The generator is a machine in which electromagnetic inductance is used to produce a voltage by rotating coils of wire through a stationary magnetic field or by rotating a magnetic field through stationary coils of wire. Today, more than 95% of the world's energy is produced by generators.

1. CONVENTIONAL ENERGY – GENERATING SET

AC GENERATOR

Alternators

Alternating-current generators are also called alternators. Almost all electric power for homes and industry is supplied by alternators in power plants.

Composition of alternator:

(1) a strong, constant magnetic field;
(2) conductors that rotate across the magnetic field; and
(3) some means of making a continuous connection to the conductors as they are rotating.

The amount of generated voltage of an ac generator depends on the field strength and speed of the rotor. Since most generators are operated at constant speed, the amount of emf depends on field excitation. Fig 2.1 shows the ac generator operates and the induced voltage of ac generator is shown in Fig 2.2 .

Three important facts about the ac generator are:

1. The induced voltage in the loop reverses in orientation twice each revolution.
2. An alternating current present in the external circuit reverses direction twice each revolution.

3. The voltage and resulting current are sine waves in nature.

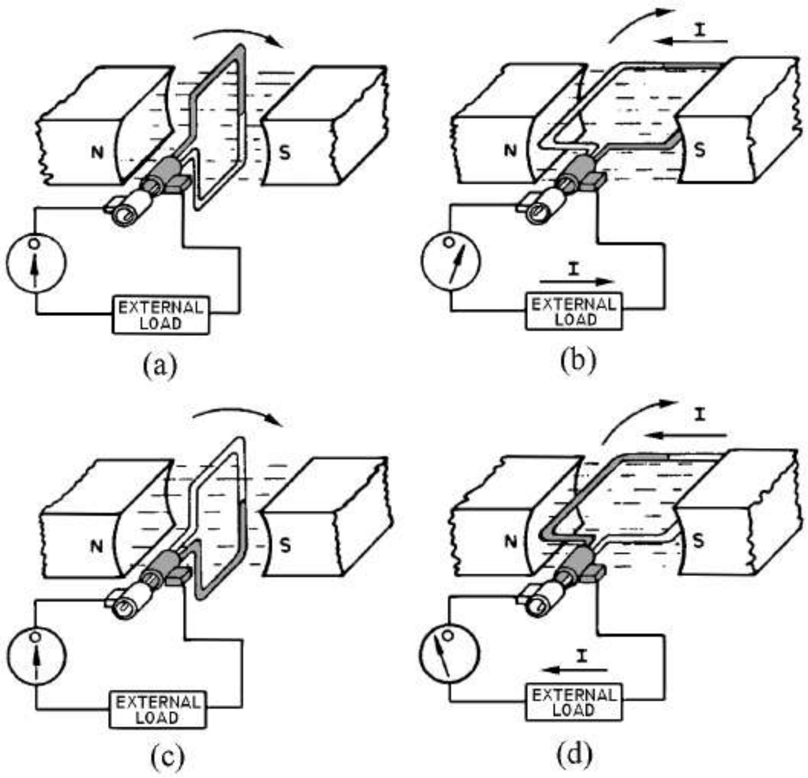

Fig. 2.1 Operation of an ac generator

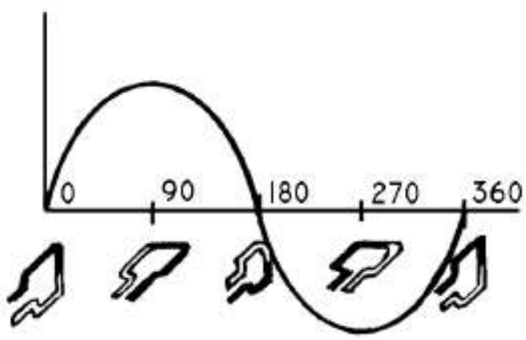

Fig. 2.2 Induced voltage from an alternator (ac generator)

Frequency

The frequency of the generated emf depends on the number of field poles and on the speed at which the generator is operated, or

$$f = \frac{pn}{120} \qquad\qquad f = \frac{1}{T}$$

where f = frequency in Hertz
p = number of poles
n = speed in rev/min
T = time in second

Example 2.1

What is the frequency of a four-pole alternator operating at a speed of 1500rpm?

Solution:

$$f = \frac{pn}{120}$$
$$= [4\ (1500)] \div 120 = 50 \text{ Hz}$$

Regulation of an ac generator is the percentage rise in terminal voltage as load is reduced from the rated full-load current to zero, with the speed and excitation being constant, or

$$Voltage\ regulation = \frac{no\ load\ voltage - full\ load\ voltage}{full\ load\ voltage}$$

When the output voltage is not steady, there would be a constant flickering of electric lights, and TV sets would not operate properly. Automatic voltage-regulator devices are used to make up for the drop in output voltage by increasing the field current. Voltage regulation is usually a function external to the alternator.

Example 2.2
An alternator is operating at 120V with no load. A load is now applied to the generator. The voltage output drops (the field current remains the same) to I10 V. What is the regulation?

Solution:

$$\text{Voltage regulation} = \frac{no\ load\ voltage - full\ load\ voltage}{full\ load\ voltage}$$
$$= (120 - 110) \div 110 = 0.091 = 9.1\%$$

DC GENERATOR

Now a days, the ac is generated first and then is converted into dc by the rectifiers. Thus, dc generators has generally been suppressed by a rectified ac supply for many applications.

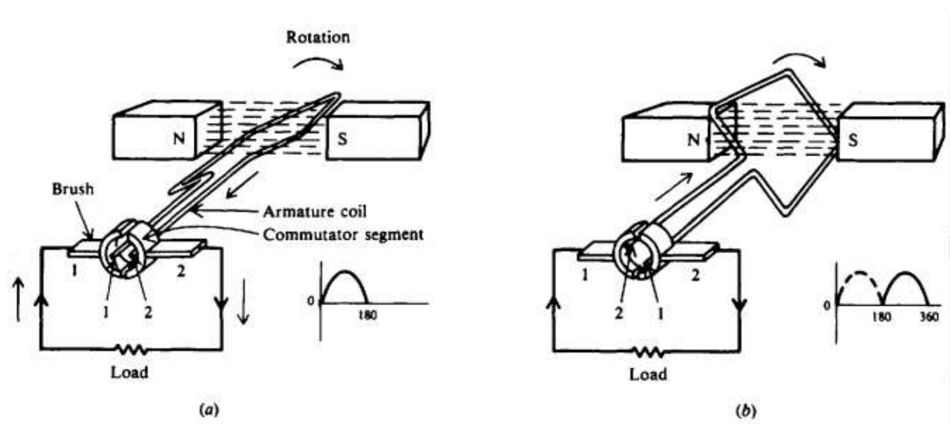

Fig. 2.3 Operation of a dc generator

Components

Generator Armature – delivers current to an external circuit (the load) and is rotated by an external mechanical force.

Commutator – converts the alternating current flowing in its armature into the direct current at its terminals (in the case of the generator). The commutator consists of copper segments with one pair of segments for each armature coil. Each commutator segment is insulated from the others by mica. The segments are mounted around the armature shaft and are insulated from the shaft and armature iron. Two stationary brushes are mounted on the frame of the machine so that they contact opposite segments of the commutator.

Brushes – are stationary and spring-mounted to slide or "brush" against the commutator on the armature shaft. Thus, brushes provide a connection between the armature coils and the external load.

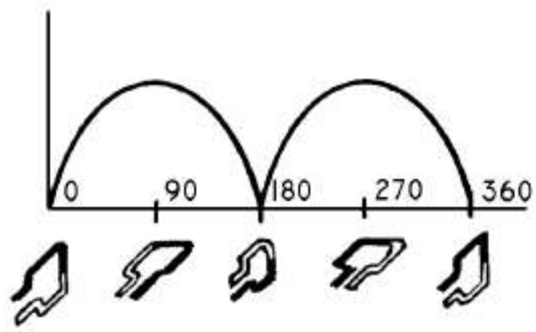

Fig. 2.4 Induced voltage from a dc generator

Two important facts about the dc generator are:

1. The induced voltage in the loop reverses itself twice each revolution.
2. The induced voltage and resulting current at the load are pulsating and sinusoidal in shape but always of one polarity.

2. RENEWABLE ENERGY

Renewable Energy – is also called alternative, sustainable, or green energy source. An energy source is called renewable if it can be renewed and sustained without any depletion and significant effect on the environment.

Renewable energy system – converts the energy found in sunlight, wind, falling-water, sea-waves, geothermal heat, or biomass into a form, we can use such as heat or electricity.

2.1 SOLAR ENERGY

Solar energy – is the energy received by the earth from the sun. It is the main source energy of the earth since its creation directly or indirectly. The cost of solar energy system is high compared to other renewable energy. There are many methods to convert solar energy to electricity as shown below.

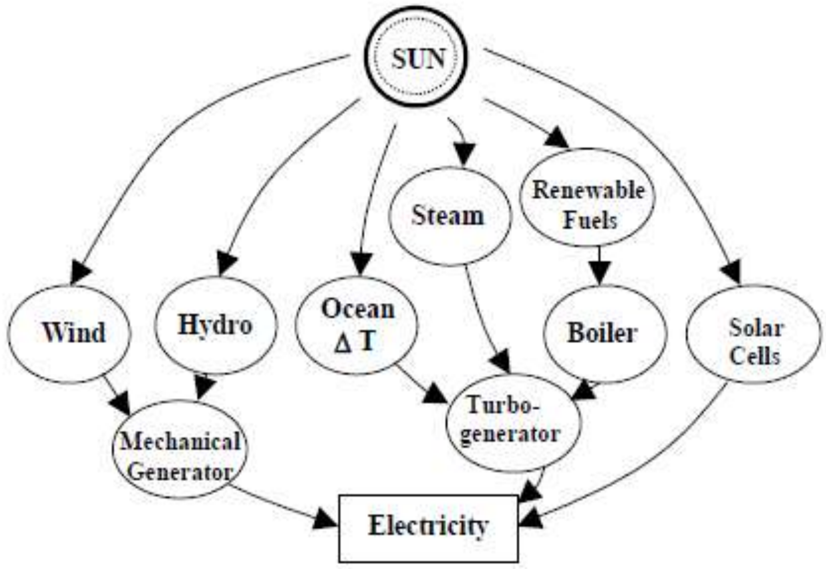

Fig 2.5 Methods for conversion of solar energy to electricity

Three conversion processes of solar energy to useful form of energy:

> **Heliochemical process** – is basically photosynthesis process, and it is responsible for the production of fossil fuel and biomass.
>
> **Heliothermal process –** is the collection and conversion of solar energy to thermal energy or heat.
>
> **Helioelectrical process** The production of electricity by photovoltaic or solar cells is accomplished by a helioelectrical process. This process is different from heliostats in that solar energy is converted to electricity directly in solar cells while it is first converted to thermal energy in heliostats.

Solar Radiation – is the energy coming off the sun in the form of electromagnetic waves.

Total solar irradiance or **solar constant** – is the solar energy reaching the earth's atmosphere ranging from 1373 – 1418 W/m^2. But due to attenuation of the solar radiation, the solar energy reaching the earth's surface is reduced to about 950 – 1,000 W/m^2.

Photovoltaic cell system – is a system that convert directly the solar radiation into electricity and consists of an array of *solar cells*. The conversion does not involve moving parts and specific thermal stresses. A photovoltaic system operate quietly, can offer extremely high reliability, low maintenance requirements, and a long lifetime.

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Solar Cell – is the smallest independent operational unit of PV systems. It consists of a specific semiconductor diode, in most cases silicon, with a large aperture area for light absorption. A single solar cell produces only 1 to 2 W of power. Multiple cells should be connected to form lessons and lessons should be connected into arrays so that reasonable amounts of power can be generated.

Photovoltaic Generator – is the combination of solar lessons interconnected in series and in parallel. The size of PV generators may range from single cells with sub-milliwatt levels (e.g., in consumer products such as calculators) to lessons and up to lesson arrays with many megawatts.

Components of Photovoltaic System

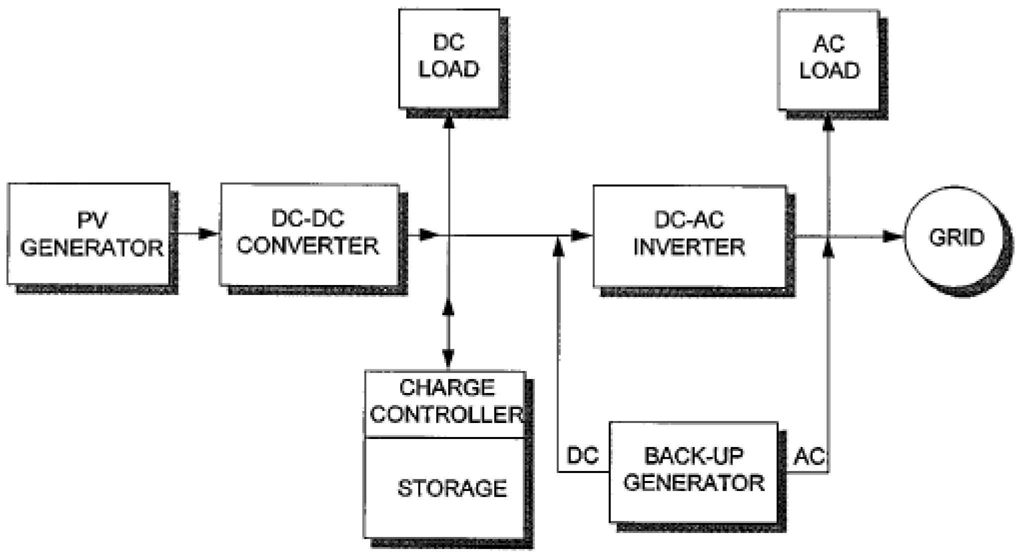

Fig. 2.6 General PV system

- PV Generator – consists of a number of lessons
- Direct Current to Direct Current Converter – the output voltage of the PV generator will be matched with good accuracy to the battery or load voltage.
- Inverter – converts the dc and the voltage produced by the PV generator into an ac with appropriate voltage and frequency levels, is always required in order for PV systems connected to the public electricity grid
- Storage – for stand-alone systems, in most cases a storage battery or a backup generator (e.g., diesel) is required for providing power during cloudy and dark periods.
- Charge Controller – protects the battery storage from overcharging which accelerate battery deterioration.

Electrical Energy Supply for Rural Households

- Central Power Station
- Battery-Charging Station
- Solar Home System (SHS)
- Pump Systems - one of the most promising fields of PV application. A wide range of application for autonomous PVP systems exists: village drinking-water supply, drinking-water supply for livestock, or small-scale irrigation

Flat-plate collectors - consist of an absorber, a transparent cover, and backward insulation in collecting the solar radiation.

Types:

- *Solar water heater* – is operated as a closed-loop system. It has medium of high density and specific heat capacity.
- *Solar air heater* – is operated in the open-loop mode. It is fixed without any tracking device. The performance is is mainly influenced by meteorological parameters (direct and diffuse radiation, ambient temperature, wind speed), design parameters (type of collector, collector materials), and flow parameters (air flow rate, mode of flow).

Useful formula in solar energy

Home Systems (SHS), Solar Battery Charging Stations (BCS) and Solar Dryers:

1. Power Output

$$P_o = 1000AE, \quad \textit{solar irradiance of 1000 watts/}\text{m}^2 \text{ assumed}$$

where: P_o = power output, watts
A = collector area, m^2
E = efficiency, ratio typically 0.1-0.12 for photovoltaic systems like solar home systems and 0.08 for solar thermal systems like dryers

2. Solar Insolation or Energy Output

$$I = P_oT$$

Where: I = daily solar insolation or energy output, kw
P_o = power output, watts
T = hours of daily sensible sunlight, about 5 hrs for Phils. and most of southeast Asia

3. Solar Collector Tilt Angle

The tilt angle of the solar collector or solar lesson should be equal to the latitude of the site but should not be less than 10° for self-cleaning purposes. This makes the collector perpendicular with sunlight at 12:00 noon, the time with the brightest illumination.

4. Solar Collector Orientation

The solar collector or solar lesson should be facing the opposite hemisphere. For installations in the northern hemisphere like Philippines, it must face south. Similarly, for installations in the southern hemisphere like Australia, it must face north.

Example 2.3:
Design a solar car with a total roof area for solar cells of 6.4 m^2. Calculate the electrical power available, assuming total cell efficiency of 17% and a constant light intensity of 980 W/m^2.

Solution:
Power input = (light intensity) x (roof area)
= (980)(6.4)
= 6.3×10^3 W

= 6.3 kW

Efficiency = (power output) / (power input)
Power output = (efficiency) x (power input)
= 0.17 x 6.3 kW
= 1.1 kW of electrical power is available for the operation of the solar car.

Example 2.4:
A solar hot water system receives solar energy at the rate of 10.5 MJ/m^2 per day. If the collector area is 4.8 m^2, collector efficiency is 0.7 and the water volume is 325 dm^3,

a) Calculate the total water energy gain per day;
b) Estimate the temperature rise of the water in the tank during the day.

Solution:

Water energy gain per day = (rate at which the system receives solar energy) x (collector area)
= (10.5 MJ/m^2) x (4.8 m^2)
= 50 MJ or 50,000 kJ

$$Q = m\ C\ \Delta T$$

where: Q = heat gained by the system
m = mass of water = density x volume = 1.0 kg dm^3 x 325 dm^3
= 325 kg
T = temperature

ΔT = Q/(mc) = 50,000 kJ / (325 kg x 4.18 kJ/°C-kg)
= 37°C (temperature of the water increases by 37°C during the day)

Example 2.5:
Flat, selective solar collector (SC) will be installed at optimal orientation in the city having annual global solar irradiation 1000 kWh/m^2. SC will be used for domestic tap water heating in one family building. Useful area of building is 120 m^2. If 65% of tap water should be prepared by solar system, what will be the required SC area?

Solution:

Average heat demand for tap water heating is 12 kWh to 16 kWh per year per 1 m^2 of house useful area:

Q_{tap} = (15 kWh/m^2-y) x (120 m^2) = 1800 kWh/y
A_{sc} = (0.65) x (Q_{tap}) / (500 x 1000/1200) = 2.81 ≈ 3 m^2

Note: 1000/1200 is correction factor of solar irradiation on the site

WIND ENERGY

Wind – is an atmospheric air in motion. it is generated as the fluid and gaseous parts of the atmosphere move across the surface of the earth due to the ever changing temperatures of the oceans, land masses and other features heated by the rays of the sun.

A wind energy system usually requires an average annual wind speed of at least 15 km/h. The following table represents a guideline of different wind speeds and their potential in producing electricity.

Average Wind Speed km/h (mph)	Suitability
Up to 15 (9.5)	No good
18 (11.25)	Poor
22 (13.75)	Moderate
25 (15.5)	Good
29 (18)	Excellent

Wind power – is the conversion of wind energy into a useful form of energy, such as using wind turbines to make electricity, windmills and wind turbines

Wind farm – is a group of wind turbines in the same location used for production of electric power. The land between the turbines may be used for agricultural or other purposes. A wind farm may also be located offshore. It consists of several hundred individual wind turbines which are connected to the electric power transmission network.

Windmill – is a device used for mechanical power generation such as grinding grain, milling, pumping water, etc.

Wind turbine – is a device used for electrical power generation

Components:

1. Aerodynamic blades
2. Mechanical transmission
3. Various controls

Common configurations for wind turbines:

1. Horizontal type – the most common for electrical power generation using 2 to 4 blades.

2. Vertical axis type – less commonly used, its blade rotate around a vertical axis.

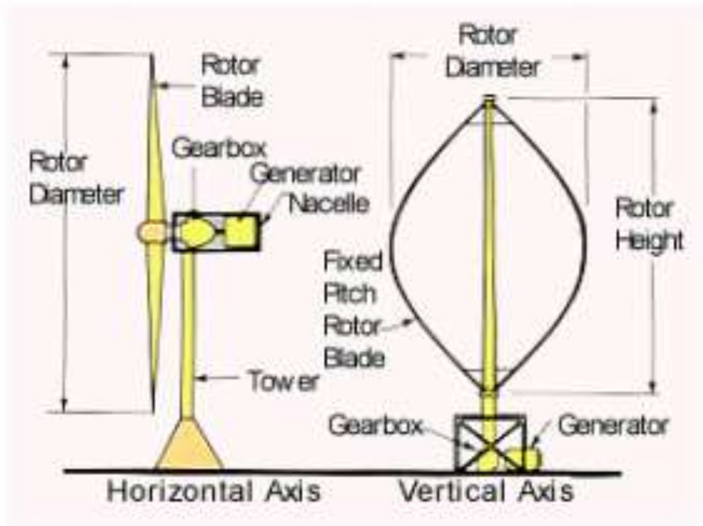

Fig 2.7 Common configuration of wind turbine

Wind pumps – contributed to the expansion of rail transport systems throughout the world, by pumping water from water wells for the steam locomotives.

Wind generator or **Wind charger -** a wind turbine that used the mechanical energy to produce electricity

Offshore wind power – refers to the construction of wind farms in bodies of water to generate electricity from wind. Better wind speeds are available offshore compared to on land, so offshore wind power's contribution in terms of electricity supplied is higher.

(a) Onshore

(b) Offshore

Fig. 2.8 Wind farms

Capacity factor – the ratio of actual productivity in a year to this theoretical maximum. Typical capacity factors are 20–40%, with values at the upper end of the range in particularly favorable sites. For example, a 1 MW turbine with a capacity factor of 35% will not produce 8,760 MW·h in a year (1 × 24 × 365), but only 1 × 0.35 × 24 × 365 = 3,066 MW·h, averaging to 0.35 MW.

Wind energy "penetration" – refers to the fraction of energy produced by wind compared with the total available generation capacity. There is no generally accepted "maximum" level of wind penetration. The limit for a particular grid will depend on the existing generating plants, pricing mechanisms, capacity for storage or demand management, and other factors

Wind Power Density (WPD) – is a quantitative measure of the wind energy available at any location. It is a calculation of the mean annual power available per square meter of swept area of a turbine, and is tabulated for different heights above ground. The calculations includes the effect of wind velocity and air density

Three key locations on the wind-speed scale:

1. **Cut-in speed** is the minimum wind speed at which useful power can be generated.

2. **Rated speed** is the wind speed that delivers the rated power, usually the maximum power.

3. **Cut-out speed** is the maximum wind speed at which the wind turbine is designed to produce power. At wind speeds greater than the cut-out speed, the turbine blades are stopped by some type of braking mechanism to avoid damage and for safety issues. The short section of dashed blue line indicates the power that *would* be produced if cut-out were not implemented.

Steps for evaluating the feasibility of wind energy/electrical system:

1. Evaluate Potential Legal and Environmental Problems
2. Evaluate Wind Resources
3. Evaluate the Application
4. Select Size of System and Components
5. Evaluate the Costs and Returns of the Systems

Useful formula in wind energy

- The **wind power potential** is given by,

$$P = \frac{1}{2} \rho \, A \, V^3$$

Where P = power
ρ = air density, 123 kg/m^3
A = swept area of blades given by A = ∏ r^2 where r is the radius of the blade
V = velocity of the wind

- **Wind power density:**

$$\frac{P}{A} = \frac{1}{2} \rho \, V^3$$

- **Wind turbine efficiency:**

$$\eta_{wt} = \frac{P_{output}}{\frac{1}{2} \rho \, A \, V^3}$$ where P_{output} = electrical power output

- **Actual power shaft output from wind turbine:**

$$W_{shaft} = \frac{1}{2}\, \eta_{wt}\, \rho\, A\, V^3$$

- **Multi-Bladed Wind Pumps**

$$P_h = 9.8QH$$

where
P_h = hydraulic power requirement, watts
Q = net pumping discharge, li/s
H = dynamic pumping head (drawdown and headloss excluded), m

Example 2.6:
Calculate the power in the wind if the wind speed is 15m/s and blade length is 60m.

Solution:

$$A = \pi\, r^2 = \pi \times 60^2 = 11{,}309.7\, m^2$$

P = ½ x 123 kg/m^3 x 11309.7 m^2 x (15 m/s)^2 = 23.47 MW

HYDROPOWER

Hydropower – or hydroelectricity refers to the conversion of energy from flowing water into electricity. It is the largest contributor of all renewable energy sources.

hydraulic turbines or **hydroturbines** – is used to convert flowing water into mechanical energy which is created when moving water spins rotors on a turbine. Its rotating part is called runner.

Hydroelectric power plant or hydro plant– is a group of turbines connected to an electromagnetic generator, which produce electricity when the turbine spins.

Three main types of hydro plants:

1. Impoundment facilities – the most common technology which uses a dam to create a large reservoir of water. Electricity is made when water passes through turbines in the dam.

2. Pumped storage facilities – are similar to impounded facilities but have a second reservoir below the dam. Water is pumped from the lower reservoir to the upper reservoir, storing energy for use at a later time.

3. Run-of-river facilities – rely more on natural water flow rates, diverting just a portion of river water through turbines, sometimes without the use of a dam. It is subjected to natural water variability.

The hydroelectric power plants have large dynamic turbines that are used to produce electricity. There are two basic types of dynamic turbine:

Impulse turbine - require a higher head, but can operate with a smaller volume flow rate. The fluid is sent through a nozzle so that most of its available mechanical energy is converted into kinetic energy. This turbines converts the 90% available mechanical energy of the water to rotating shaft energy.

Reaction turbine - can operate with much less head, but require a higher volume flow rate. It consists *stay vanes* (fixed guide vanes), *wicket gates* (adjustable guide vanes) and *runner blades* (rotating blades). It produces more power than an impulse turbine.

Two main types of reaction turbine:

1. *Francis turbine* is somewhat similar in geometry to a centrifugal or mixed-flow pump, but with the flow in the opposite direction.
2. *Kaplan turbine* is somewhat like an *axial-flow* fan running backward.

Useful formula in Microhydro Power Plants (100 kw and below)

$$P_o = 9.8QHE$$

Where: P_o = power output, kw
Q = design flow, m^3/s
H = gross head, m (microhydro usually operates between 5-17 m of head)
E = system efficiency, ratio, typically 0.55-0.65

GEOTHERMAL ENERGY

Geothermal energy is the thermal energy within the earth's interior. The origin of geothermal energy is earth's core, and it is about 6500 km deep.

Uses of Geothermal Energy

- Electricity production
- Space Heating
- Cogeneration
- Cooling
- Heat pump

Geothermal Power Plant

Types:

- Direct steam - Steam from the geothermal well is passed through a turbine and exhausted to the atmosphere or to a condenser.
- Flash type - are used to generate power from liquid-dominated resources that are hot enough to flash a significant proportion of the water to steam in surface equipment
    - Single-flash.

    - Double-flash
- Binary cycle - use the geothermal brine from liquid-dominated resources at relatively low temperatures.
- Combined flash/binary plant - incorporates a binary unit and a flashing unit to exploit the advantages associated with both systems. The liquid portion of the geothermal mixture serves as the input heat for the binary cycle while the steam portion drives a steam turbine to produce power. Power is obtained from both the steam turbine and the binary turbine.

BIOMASS ENERGY

Biomass is a renewable resource so far as its production is continued in a sustainable way. It is mostly produced from agriculture and forest products and residues, energy crops, and algae. Organic component of municipal and industrial wastes and the fuel produced from food processing waste such as used cooking oil are also considered biomass. Fuels from biomass can take various forms such as liquid, gas, and solid. They are used for electric or mechanical power generation and heat according to their properties and economy.

Biopower – is the production of electricity and heat from biomass

Biomass Resources:

- ***Dedicated Energy Crops:*** These *herbaceous energy crops* are perennials that are harvested after reaching maturity. These include such grasses as switchgrass, miscanthus, bamboo, sweet sorghum, tall fescue, kochia, wheatgrass, and others.

- ***Agricultural Crops:*** These include cornstarch and corn oil, soybean oil and meal, wheat starch, and vegetable oils. They generally yield sugars, oils, and extractives.

- ***Agriculture Crop Residues:*** Biomass materials consisting primarily of stalks and leaves not used for commercial use such as corn stover (stalks, leaves, husks, and cobs), wheat straw, and rice straw are included in this resource. Approximately, 80 million acres of corn is planted annually.

- ***Forestry Residues:*** These are biomass not harvested or used in commercial forest processes including materials from dead and dying trees.

- ***Aquatic Crops:*** Aquatic biomass resources include algae, giant kelp, other seaweed, and marine microflora.

- ***Biomass Processing Residues:*** Byproducts and waste streams produced by biomass processing are called residues, and they represent an additional biomass resource.

- ***Municipal Waste:*** Plant based organic material generated from industrial, residential, and commercial waste represents an important biomass source. Some examples include waste paper, wood waste, yard waste, and cooking oil.

- ***Animal Waste:*** Animal wastes consist of organic materials and are generated from farms and animal-processing operations. Animal waste is used as a heating fuel in some parts of the world.

Conversion of Biomass to Biofuel

- **Biochemical conversion processes** – is the conversion biomass or biomass-derived compounds into desirable products with the aid of biocatalysts.

- **Hydrolysis** – is the process of breaking down of cellulose and hemicelluloses enzymes of the carbohydrate fractions of biomass to five- and six-carbon sugars using yeast and bacteria which ferment the sugars into products such as ethanol

- **Thermochemical conversion processes** – is the breaking down of biomass into intermediate compounds or products by heat energy and chemical catalysts.

- **Gasification** – is the heating of biomass an oxygen-starved environment to produce a gas composed primarily of hydrogen (H2) and carbon monoxide (CO).

- **Pyrolysis** – is the process of exposing the biomass high temperatures without the presence of air, causing it to decompose.

- **Photobiological conversion processes** – use the natural photosynthetic activity of organisms to produce biofuels directly from sunlight. For example, the photosynthetic activities of bacteria and green algae have been used to produce hydrogen from water and sunlight.

Biomass Products

Liquid Fuel

- **Ethanol** – or ethyl alcohol is from the starch in corn grain, sugar beets, sugar cane, and even cellulose (wood and paper). Gasohol is a gasoline-ethanol mixture with 10 percent ethanol while E85 contains 85 percent ethanol.

- **Biodiesel** - is ethyl or methyl ester that is produced through a process that combines organically-derived oils with ethanol or methanol in the presence of a catalyst. Common sources of biodiesel include new and used vegetable oils, animal fats, and recycled restaurant greases.

- **Methanol** – or methyl alcohol can be produced from fossil sources or biomass. Coal, oil and natural gas represent fossil sources.

- **Pyrolysis oil** – is produced when biomass is exposed to high temperatures without the presence of air, causing it to decompose. Pyrolysis oil is not suitable as a replacement to conventional fuels such as gasoline or diesel. A chemical called phenol can be extracted from pyrolysis oil, and it is used to make wood adhesives, molded plastic, and foam insulation.

Gas fuel

- **Methane** – can be produced through fermentation of biomass with a high moisture content. CH_4 can be used for heat and stationary power without an emission problem.

- **Pyrolysis gas** – or pygas is a naphtha-range products with a high aromatics content. It is usually obtained through the reduction process of CO_2 and consists of CO and H_2 from a biomass gasifier. It is a by-product of high temperature naphtha cracking during ethylene and propylene production.

- **Biogas** – is also called swamp gas, landfill gas, or digester gas, usually consists of 50 to 80 percent methane (CH4) and 20 to 50 percent carbon dioxide (CO2) by volume. It can be produced from biological waste such as animal manure, food waste, and agricultural waste. The process is called *anaerobic digestion* which is the decomposition of organic waste into a gaseous fuel by bacteria action without the presence of oxygen.

- **Producer gas** – is produced by thermal gasification which is the partial oxidation of a solid biomass at high temperatures into a gaseous fuel. Producer gas can be used as a feedstock for liquid fuels or it can be burned directly in a furnace.

- **Synthesis gas** – is also called biosynthesis gas or syngas, is a fuel gas mixture consisting primarily of hydrogen, carbon monoxide and carbon dioxide. It is produced by thermal gasification using oxygen. It is commonly produced from natural gas, coal, and heavy diesel. The name comes fron its use as intermediates in creating synthetic natural gas (SNG) and for producing ammonia or methanol.

Solid Fuel

- **Fuel wood and charcoal** – are common biomass solid fuels in many countries, but heat efficiency of a wood furnace is generally low. Energy loss in charcoal production is also considerably large.

- **Agricultural wastes** - can be used for heat or electric generation. Rice husks, for example, could generate more electricity and heat than a country elevator consumes.

- **Forestry wastes** – are often used for power generation by the Rankine cycle with turbine in wood-processing factories.

- **Solid municipal wastes** - can run a power plant from a city with a large population. Fluctuation of the heat value of the waste must be adjusted somehow.

- **Energy plantation** – is the cultivation of short-rotation intensive culture of fast growing trees or grasses. It can run a small power plant. Planting these grasses and frees around the power plant area can reduce transportation cost

.

Useful Formulas in Biomass Energy

Biogas Plant Design

1. Biogas Production

$$P = NMG$$

Where: P = biogas production, m^3/day
N = number of animal heads
G = specific biogas production, m^3/kg of the manure for the entire retention period; for 30-day retention period, 0.034 for cow/carabao, 0.065 for chicken, 0.063 for hog

2. Biogas Consumption

$$C = N_1B_1T_1 + N_2B_2T_2 + N_nB_nT_n$$

Where: C = biogas consumption, m^3/day
N_n = quantity of biogas-consuming device n
B_n = biogas consumption of device n, m^3/day; 0.28 for 4-inch burner, 0.1 for 25-watt mantle lamp, 0.57/kw output gasoline engine
T_n = time of use of device n, hours/day

3. Number of Animal Heads Required Relative to Biogas Consumption

$$Nr = C/(GM)$$

Where: N_r = number of animal heads required for biogas production
C = biogas consumption, m^3/day
G = specific biogas production of the manure for the entire retention period, m^3/kg
M = daily manure production of the animal, kg/head: 2.2 for mix-age porker, 13 for breeding cattle, 0.075 for layer, 0.025 for broiler

4. Digester Volume

$$V_d = I_sR\ , \quad I_s = 1.6C/(GD_m)$$

Where: V_d = volume of digester, m^3
I_s = slurry (manure and water at 1:1 ratio by volume) input rate, m^3/day
R = retention period of manure inside the digester, days
D_m= manure bulk density, approx. 950-970 kg/ m^3

5. Gasholder Volume (with 30% safety factor for gas expansion)

$$V_g = 1.3UE$$

Where: $E = C/24$ if there is no continuous biogas-consuming device like refrigerator
V_g = volume of gasholder, m^3
U = longest device idle time for non-continuous devices, 10-13 hours/day for households
E = biogas excess or accumulation rate, m^3/hr

Heating/Calorific Values of Biomass

Biomass	Approx. heating value kcal/kg	
	Natural State	Dry state
Wood	1500	3500
Cattle dung	1000	3700
Bagasse	2200	4400
Wheat and rice straw	2400	2500
Cane trash, rice husk, leaves and vegetable wastes	3000	3000
Dry grass and crop residue	3500	3500
Groundnut shells	4000	4000
Coffee and oil palm husks	4200	4200
Cotton husks	4400	4400
Peat	6500	6500
Coconut shell		5500
Coconut husks		4000
Coconut charcoal		7200
Wood charcoal		7000
Bio gas (12 kg of dung produces 1 m^3 gas)		4700-6000 kcal/m^3
Softwood		10–15,000,000 Btu/cord
Hardwood		18–24,000,000 Btu/cord
Sawdust – green		8-10,000,000 Btu/ton
Sawdust – kiln dry		14-18,000,000 Btu/ton
Chips – 45% moisture		7,600,000 Btu/ton
Hog dung		16-20,000,000 Btu/ton
Bark		9-10,500,000 Btu/ton
Wood pellets – 10% moisture		16,000,000 Btu/ton
Corn – shelled		15-17,000,000 Btu/ton
Corn – cobs		16-17,000,000 Btu/ton