20EE604/JO65

Hall Ticket Number:

III/IV B.Tech (Regular) DEGREE EXAMINATION

July/August, 2023 **Electrical & Electronics Engineering**

Sixth Semester **Solar PV and Wind Plant Design**

Time: Three Hours **Maximum:**70 Marks

Answer question 1 compulsory. **(14X1 = 14Marks)**

Answer one question from each unit. **(4X14=56 Marks)**

			CO	BL	M
1	a)	What are the land requirements of solar PV system?	CO1	L1	1 M
	b)	Define solar module.	CO1	L1	1 M
	c)	What is a power condition unit?	CO1	L1	1 M
	d)	What are various sources of losses in solar system?	CO1	L1	1 M
	e)	Define Fill factor.	CO2	L1	1 M
	f)	What are different types of solar radiations?	CO2	L1	1 M
	g)	Define tilt angle.	CO2	L1	1 M
	h)	What are the different types of wind energy converters?	CO3	L1	1 M
	i)	Write the different components in wind energy converters.	CO3	L1	1 M
	j)	What are the obstacles to wind flow?	CO3	L1	1 M
	k)	What is meant by micro wind turbine?	CO4	L1	1 M
	l)	Write the safety aspects of wind turbines.	CO4	L1	1 M
	m)	Write Aerodynamics of wind turbine.	CO4	L1	1 M
	n)	What is the formula for wind turbine efficiency?	CO4	L1	1 M
		Unit-I			
2	a)	What are different types of solar cells and explain them clearly.	CO1	L2	7M
	b)	Explain how solar photovoltaic cell generates electricity in detail.	CO1	L2	7M
		(OR)			
3	a)	Construct Single line diagram of Net Metering solar power system and explain various stages.	CO1	L3	7M
	b)	Explain the concept of battery storage in solar PV systems.	CO1	L2	7M
		Unit-II			
4	a)	Explain the factors to be considered to select the site for solar power plant.	CO2	L2	7M
	b)	Explain with a neat sketch, the working principle of a grid connected solar system	CO2	L2	7M
		(OR)			
5	a)	Interpret the PV module structure inter row spacing calculation.	CO2	L2	7M
	b)	Explain Off-Grid solar power plant with neat sketch.	CO2	L2	7M
		Unit-III			
6	a)	What are the advantages and disadvantages of wind energy systems.	CO3	L2	7M
	b)	Explain in detail the need and functioning of Pitch angle control and Yaw Control in Horizontal Axis Wind Turbine.	CO3	L2	7M
		(OR)			
7	a)	With the help of a diagram, explain the working of a wind energy conversion system.	CO3	L2	7M
	b)	Compare Horizontal axis and vertical axis wind turbines.	CO3	L4	7M
		Unit-IV			
8	a)	Explain the operation and challenge of offshore wind farms.	CO4	L2	7M
	b)	Explain components of small hydro power plant.	CO4	L2	7M
		(OR)			
9	a)	Interpret the blade elemental theory.	CO4	L2	7M
	b)	Develop the expression for Betz limit.	CO4	L3	7M

Scheme of Valuation

1.a A 1kw Solar System Requires A Shade-Free Area Of 6 Square Meters. Accordingly, To Set up Solar Panels of 1 Megawatt, need 6000 Square Meters Of Land.

b. A Solar Module Is A Single Photovoltaic Panel That Is An Assembly Of Connected Solar Cells.

c. A Power Conditioning Unit Is Required To Convert Fuel Cell Generated DC Power To Usable AC Power. A Power Conditioning Unit Typically Consists Of DC–DC Converter And DC–AC Inverter. DC–DC Converter Is Used To Step Up The Low-Magnitude DC Voltage To Higher Voltage (At Least 400 V) To Produce Usable 120 V/240 V AC.

d. Shading loss, Dust loss, Thermal Loss, Solar Inverter Losses, Solar Panel Mismatch Losses, Low radiation loss, DC Cable Losses, AC Cable Losses.

e. Fill factor (solar cell), the ratio of maximum obtainable power to the product of the open-circuit voltage and short-circuit current. Fill factor (image sensor), the ratio of light-sensitive area of a pixel to total pixel area in an image sensor.

f. 1.Direct solar radiation. 2. Diffuse solar radiation.3. Reflected solar radiation.

g. The Space between Two Lines or Planes That Intersect; the Inclination of One Line to another; Measured In Degrees or Radians.

h. 1.Horizontal Axis wind turbine, 2.Vertical Axis Turbine

i.1.Tower, 2.Rotor, 3.Gear box, 4.Generator, 5.Sensors and Yaw drive, 6.High speed and low speed shaft, 7.Saftey System.

j. Obstacles to the wind such as buildings, trees, rock formations etc. can decrease wind speeds significantly, and they often create turbulence in their neighbourhood.

k. wind turbines with a power of less than 100 kW. Wind turbines of greater power would not be considered to be for self-consumption. Micro wind turbines are also smaller in size than the usual wind turbines, which means that they can be installed in smaller spaces.

L.First Aid personnel should always be on-site. At least one person qualified to administer first aid should be on-site whenever work on wind turbines is carried out, ongoing risk management and assessments, Provision of personal protective equipment. Tool and equipment testing. Active weather monitoring.

m. There are two important aerodynamic forces: drag and lift. Drag applies a force on the body in the direction of the relative flow, while lift applies a force perpendicular to the relative flow.

n. $P = 0.5\ Cp\ \rho\ \pi\ R^2\ V^3$

Unit-I

2. a) **{Types-2M,Theory-5M}**

1. Crystalline silicon cells
2. Monocrystalline cells
3. Polycrystalline cells
4. Thin film solar cells

Presently, around 90% of the world's photovoltaic are based on some variation of silicon, and around the same percentage of the domestic solar panel, systems use the crystalline silicon cells. Crystalline silicon cells also form the basis for mono and polycrystalline cells.

The silicon that is in solar cells can take many different forms. However, the thing that matters most is the purity of the silicon. This is because it directly affects its efficiency. What purity means, in this case, is the way in which the silicon molecules have been aligned. The better the alignment, the purer the resulting silicon is. This, ultimately, leads to better conversion rates of sunlight into electricity.

As previously mentioned, the levels of efficiency work alongside the purity of the silicon molecules – and purity can be quite a costly aspect to upgrade. However, it may come as a surprise to learn that efficiency is not the driving force for people who want to invest in solar energy. The cost and the amount of space it takes up tend to be the most important aspects to potential buyers.

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 creates 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.

2.b) **{Figure-2M,Theory-5M}**

a solar panel works by allowing photons, or particles of light, to knock electrons free from atoms, generating a flow of electricity. Solar panels actually comprise many, smaller units called photovoltaic cells. (Photovoltaic simply means they convert sunlight into electricity.) Many cells linked together make up a solar panel.

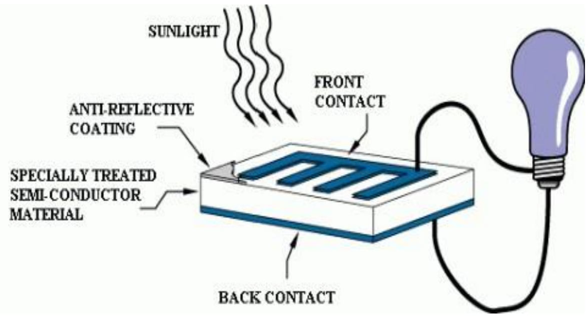
Each photovoltaic cell is basically a sandwich made up of two slices of semi-conducting material, usually silicon — the same stuff used in microelectronics.

To work, photovoltaic cells need to establish an electric field. Much like a magnetic field, which occurs due to opposite poles, an electric field occurs when opposite charges are separated. To get this field, manufacturers "dope" silicon with other materials, giving each slice of the sandwich a positive or negative electrical charge.

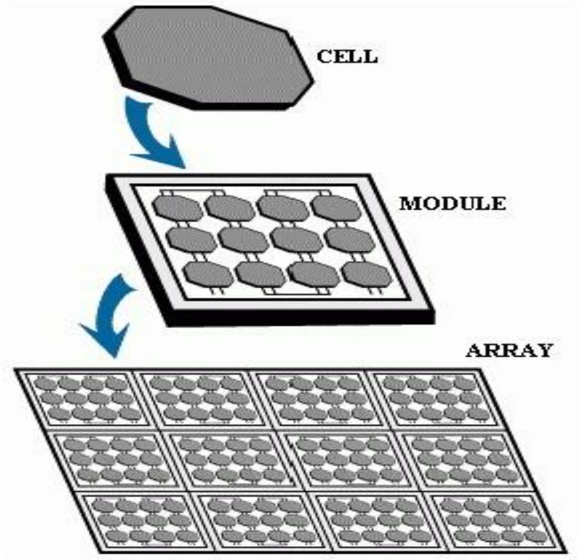
Specifically, they seed phosphorous into the top layer of silicon, which adds extra electrons, with a negative charge, to that layer. Meanwhile, the bottom layer gets a dose of boron, which results in fewer electrons, or a positive charge. This all adds up to an electric field at the junction between the silicon layers. Then, when a photon of sunlight knocks an electron free, the electric field will push that electron out of the silicon junction.

A couple of other components of the cell turn these electrons into usable power. Metal conductive plates on the sides of the cell collect the electrons and transfer them to wires. At that point, the electrons can flow like any other source of electricity.

Photovoltaics is the direct conversion of light into electricity at the atomic level. Some materials exhibit a property known as the photoelectric effect that causes them to absorb photons of light and release electrons. When these free electrons are captured, an electric current results that can be used aselectricity.



The diagram above illustrates the operation of a basic photovoltaic cell, also called a solar cell. Solarcells are made of the same kinds of semiconductor materials, such as silicon, used in the microelectronics industry. For solar cells, a thin semiconductor wafer is specially treated to form an electric field, positive on one side and negative on the other. When light energy strikes the solar cell,electrons are knocked loose



from the atoms in the semiconductor material. If electrical conductors areattached to the positive and negative sides, forming an electrical circuit, the electrons can be capturedin the form of an electric current -- that is, electricity. This electricity can then be used to power a load, such as a light or a tool.A number of solar cells electrically connected to each other and mounted in a support structure or frame is called a photovoltaic module. Modules are designed to supply electricity at a certain voltage,such as a common 12 volts system. The current produced is directly dependent on how much light strikes the module.

Multiple modules can be wired together to form an array. In general, the larger the area of a module orarray, the more electricity that will be produced. Photovoltaic modules and arrays produce direct- current (dc) electricity. They can be connected in both series and parallel electrical arrangements to produce any required voltage and current combination.

Photovoltaic cells, through the photovoltaic effect, absorb sunlight and generate flowing electricity.This process varies depending on the type of solar technology, but there are a few steps common across all solar photovoltaic cells.

Step 1: Light is absorbed by the PV cell and knocks electrons loose

First, light strikes a photovoltaic cell and is absorbed by the semiconducting material it is made from (usually silicon). This incoming light energy causes electrons in the silicon to be knocked loose, which will eventually become the solar electricity you can use in your home.

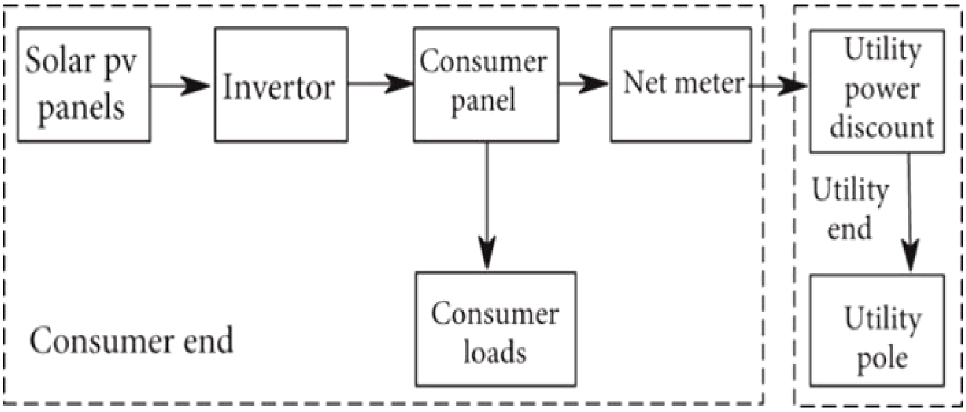
Step 2: Electrons begin to flow, creating an electrical current

There are two layers of silicon used in photovoltaic cells, and each one is specially treated, or "doped", to create an electric field, meaning one side has a net positive charge and one has a net negative charge. This electric field causes loose electrons to flow in one direction through the solar cell, generating an electrical current.

Step 3: The electrical current is captured and combined with other solar cells

Once an electrical current is generated by loose electrons, metal plates on the sides of each solar cell collect those electrons and transfer them to wires. At this point, electrons can flow as electricity through the wiring to a solar inverter and then throughout your home.

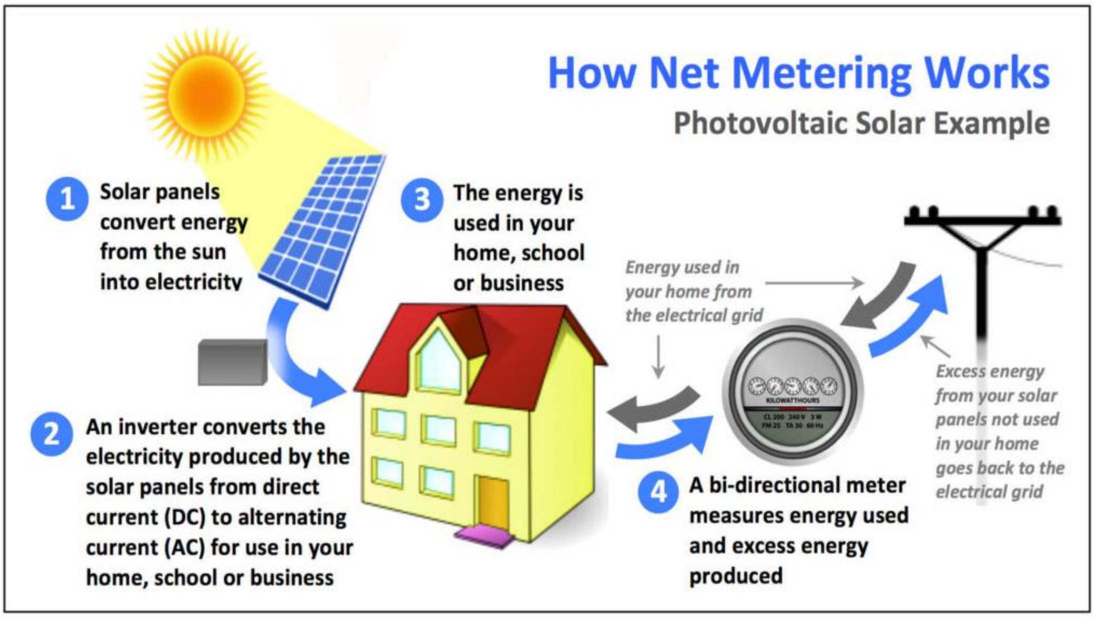
3.a) **{Figure-2M,Theory-5M}**



Net Metering in simple terms is a mechanism that allows for accounting of units exchanged with grid (Imported as well as exported) by a solar powered consumer. Net-Metering is facilitated by a bi-directional meter that records both imported and exported units through a electricity-line. Net-metering facilitates accounting of the electricity units exchanged with grids. For enabling net-metering, the conventional electricity meter (that measures only electricity units supplied to consumer) is replaced by appropriate bi-directional meter (that measures both supplied and exported units). This meter is called as Net-Meter and such accounting method as Net-metering.

Process of Net-Metering

The two-parties, electricity consumer and distribution company, enter into an agreement, called as Net-Metering agreement, which defines the broad terms, conditions and governing norms for such facility.



Net metering (or **net energy metering**, **NEM**) is an electricity billing mechanism that allows consumers who generate some or all of their own electricity to use that electricity anytime, instead of when it is generated. This is particularly important with renewable energy sources like wind and solar, which are non-dispatchable (when not coupled to storage). Monthly net metering allows consumers to use solar power generated during the day at night, or wind from a windy day later in the month. Annual net metering rolls over a net kilowatt-hour (kWh) credit to the following month, allowing solar power that was generated in July to be used in December, or wind power from March in August.

Net metering policies can vary significantly by country and by state or province: if net metering is available, if and how long banked credits can be retained, and how much the credits are worth (retail/wholesale). Most net metering laws involve monthly rollover of kWh credits, a small monthly connection fee,[require a monthly payment of deficits (i.e. normal electric bill), and annual settlement of any residual credit. Net metering uses a single, bi-directional meter and can measure the current flowing in two directions. Net metering can be implemented solely as an accounting procedure, and requires no special metering, or even any prior arrangement or notification.

3.b) **{Purpose-2M,Theory-5M}**

Batteries, which are commonly required for most off-grid applications except water pumping, are currently the "weak-link" in the PV system and will typically need replacement every five years or so. It is essential that storage batteries, and indeed all system components are of an acceptable quality. Where PV systems have failed in the past for technical reasons, it has generally been due to bad system design and/or poor selection of BOS components, rather than to failure of a PV module. As a result, considerable international research efforts are presently directed towards improving performance of BOS components.

Batteries are often used in PV systems for the purpose of storing energy produced by the PV array during the day, and to supply it to electrical loads as needed (during the night and periods of cloudy weather). Other reasons because batteries are used in PV systems are to operate the PV array near its maximum power point, to power electrical loads at stable voltages, and to supply surge currents to electrical loads and inverters. In most cases, a battery charge controller is used in these systems to protect the battery from overcharge and overdischarge. In stand-alone systems, the power generated by the solar panels is usually used to charge a lead-acid battery. Other types of battery such as nickel-cadmium batteries may be used, but the advantages of the lead-acid battery ensure that it is still the most popular choice. A battery is composed of individual cells; each cell in a lead-acid battery produces a voltage of about

2 Volts DC, so a 12 Volt battery needs 6 cells. The capacity of a battery is measured in Ampere-hours or Amp-hours (Ah). To properly select batteries for use in stand-alone PV systems, it is important that system designers have a good understanding of their design features, performance characteristics and operational requirements. The information in the following sections is intended as a review of basic battery characteristics and terminology as is commonly used in the design and application of batteries in PV systems.

Battery manufacturing is an intensive, heavy industrial process involving the use of hazardous and toxic materials. Batteries are generally mass produced, combining several sequential and parallel processes to construct a complete battery unit. After production, initial charge and discharge cycles are conducted on batteries before they are shipped to distributors and consumers.

Unit-II

4.a) **{1-3M,2-2M,3-1M,4-1M}**

1. Latitude and Longitude of area

For installing 1MW PV plant 5 acres of land is required. Here we have selected a land located 5 km away from the Bhongir town, Hyderabad Telangana which comes under Deccan plateau. It has an average elevation 329 m / 1079 ft above sea level. • Area 5 acres Location Bhongir Latitude of Area :17.5°N Longitude of Area :78.89°E

Tilt Angle: To maximize the output of the solar power system, especially in PV Solar Array applications, the optimal tilt angle is typically specified for non-tracking systems, and remains fixed. Structurally, higher tilt angles result in an increased wind load on the solar module which would require a larger ballasted footing. In addition, higher tilt angles may require an increase in distance between rows to eliminate adjacent-row over-shading.

A lower tilt angle is often desired to minimize the wind forces and reduce the ballasted footing size. This may not be feasible in areas of substantial snowfall where an increased tilt angle may be required to shed snow off of the solar module effectively. A lower tilt angle also results in reduced adjacent-row over-shading potential which allows the module rows to be spaced closer together. • A cost comparison could be done to compare the tilt angle versus the adjacent-row over-shading versus the ballasted footing size. In addition, lower tilt angles allow for more compact utilization of the land available by minimizing the unusable area that is in shade thus offering an opportunity for more solar modules.

2. Quality of soil:

This area comprises or consists of red soil/loamy to clayey deep reddish brown soil. In this area the soil strength is moderate and light weighed. The moisture content is low to moderate level during pre monsoon and medium during post monsoon. • In average the soil is a bit dusty on the upper most layer all over the year.

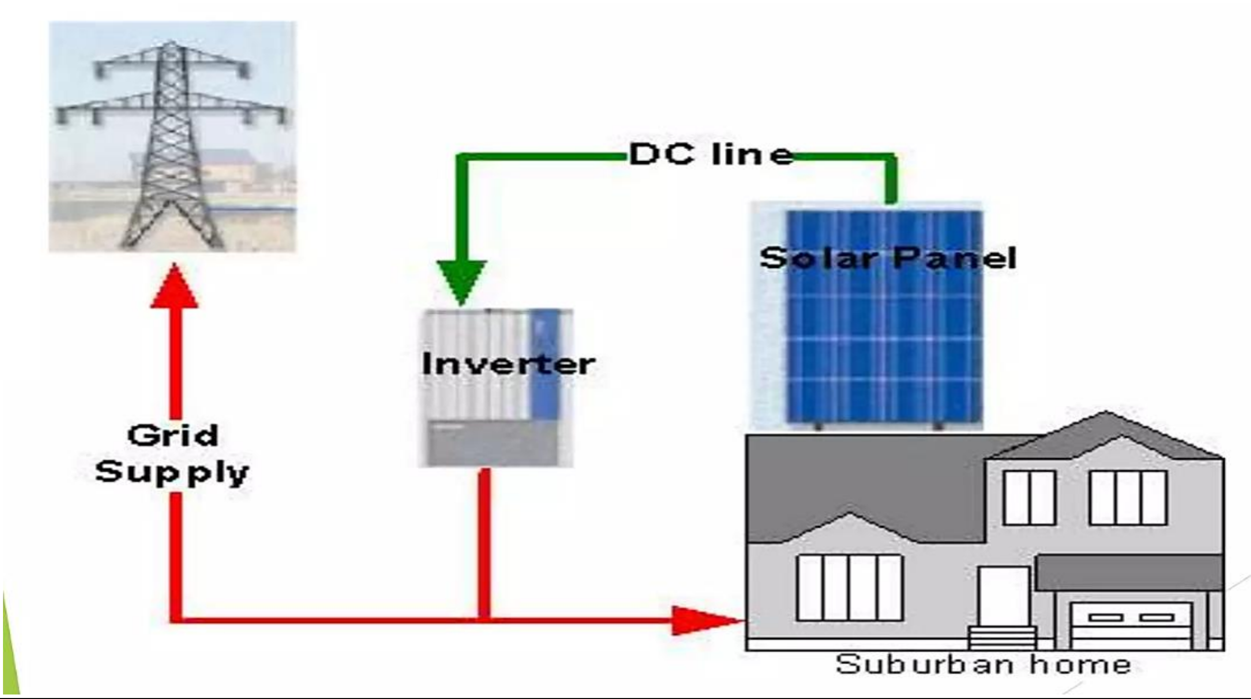
3. Soil Test Report:

Colour of land - Yellowish/ Ash colour • Land characteristics type - light weight land • Ph of land - +6.98 medium • Salinity of land - 0.40 • Availability of minerals in land • Nitrogen - 95kg/ Acre • Phosphorus - 36.75kg/ Acre • Potash - 40.88kg/ Acre.

4.Terrain and contours of Land:

As we have already mentioned that this area comes under Deccan plateau so, the level of the land is neither flat nor sloppy. It is a rocky land. The surface is covered with small sized rocks which occupies 0.5 to 1sqm area in average.

4.b) **{Figure-2M,Theory-3M,Advantages-1M,Disadvantages-1M}**



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.

Advantages

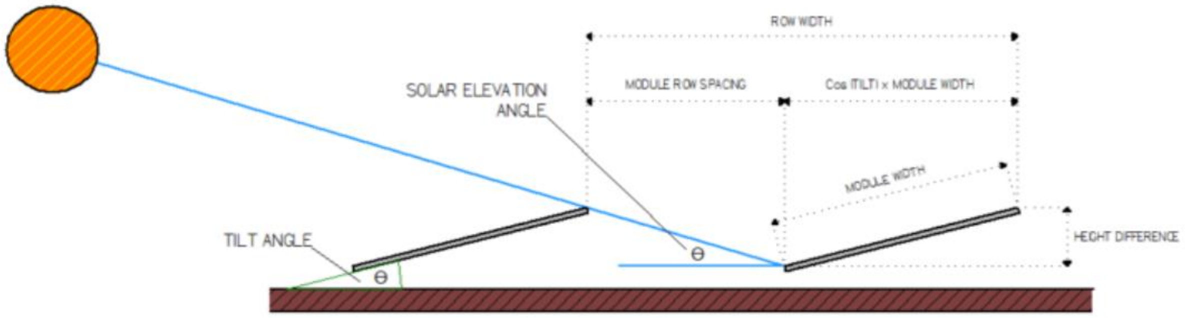
- Solar energy is a clean and renewable energy source.
- Once a solar panel is installed, solar energy can be produced free of charge.
- Solar energy will last forever whereas it is estimated that the world's oil reserves will last for 30 to 40 years.
- Solar energy causes no pollution.
- Solar cells make absolutely no noise at all. On the other hand, the giant machines utilized for pumping oil are extremely noisy and therefore very impractical.
- Very little maintenance is needed to keep solar cells running. There are no moving parts in a solar cell which makes it impossible to really damage them.
- In the long term, there can be a high return on investment due to the amount of free energy a solar panel can produce, it is estimated that the average household will see 50% of their energy coming in from solar panels

Disadvantages

- Solar panels can be expensive to install resulting in a time-lag of many years for savings on energy bills to match initial investments.
- Electricity generation depends entirely on a countries exposure to sunlight; this could be limited by a countries climate.
- Solar power stations do not match the power output of similar sized conventional power stations; they can also be very expensive to build.
- Solar power is used to charge batteries so that solar powered devices can be used at night. The batteries can often be large and heavy, taking up space and needing to be replaced from time to time.

5.a) **{Figure-1M, Theory-6M}**

When designing a PV system that is tilted or ground mounted, determining the appropriate spacing between each row can be troublesome or a downright migraine in the making. However, it is important to do it right the first time to avoid accidental shading from the modules that are ahead of each row. This can lead to under-performing systems and angry customers. No one wants to have that. The same can be said about overcompensation too. Think of how many more kW's you could have had. This article will get you started off on the right foot with a simple and fast process to get you out in the field faster with great results.



The first step in calculating the inter-row spacing for your modules is to calculate the height difference from the back of the module to the surface. To do that, follow this calculation below:

Height Difference = Sin (Tilt Angle) x Module Width

*****Make sure you're calculating in degrees, not radians*****

In this case, I am using a Solar World module that has a width of 39.41 inches at a tilt angle of 15º.

Height Difference = Sin (15) x 39.41

Height Difference = 10.2" rounded down to 10"

In this example, I picked a 9 AM to 3 PM window during the winter solstice for the worst case scenario. You may opt for a less stringent case to suit your needs. I chose this example because some utilities require the 9am-3pm window when offering rebates for customer owned PV systems.

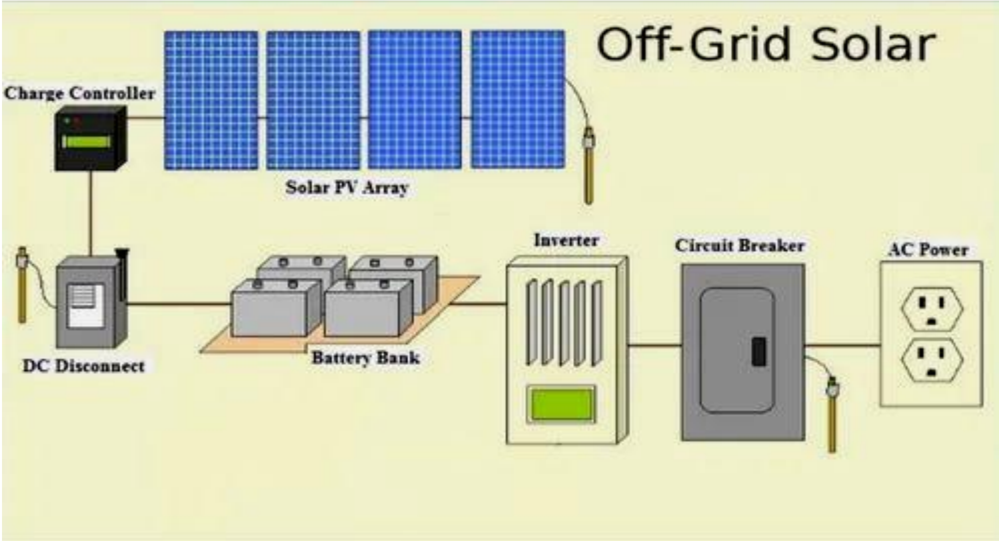
From the chart, you see that I have highlighted this window and drawn a horizontal line out to the left of the chart to narrow in on the Solar Elevation Angle at those times. I estimate a 17º angle which I will use next to determine the Module Row Spacing using the formula below.

- Module Row Spacing = Height Difference / Tan (17)
- Module Row Spacing = 10 / Tan (17)
- Module Row Spacing = 32.7" rounded up to 33"
- Minimum Module Row Spacing = Module Row Spacing x Cos (Azimuth Correction Angle)
- Minimum Module Row Spacing = 33 x Cos (44)
- Minimum Module Row Spacing = 23.7" rounded up to 24"

The following formula gives you the distance from the trailing edge of one row to the trailing edge of the subsequent row or your Row Width.

- Row Width = Minimum Module Row Spacing + Cos (Tilt Angle) x Module Width
- Row Width = 24 + Cos (15) x 39.41
- Row Width = 62"

5.b) **{Figure-2M,Theory-3M,Advantages-1M,Applications-1M}**



A **stand alone 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 connect 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.

off-grid systems work independently of the grid but have batteries which can store the solar power generated by the system. The system usually consists of solar panels, battery, charge controller, grid box, inverter, mounting structure and balance of systems. The panels store enough sunlight during the day and use the excess power generated in the night.

These systems are self-sustaining and can provide power for critical loads in areas where a power grid is not available. However, these systems require specialized equipment to function and can be costly to install. These are ideal for businesses which can sustain for a short period of time with no electricity.

Applications

- **Electricity supply in rural and remote areas -** Off-grid solar systems can facilitate independent, long-term and sustainable electricity generation in rural and remote areas.
  Power back up in areas with frequent electricity cuts - A number of places in India face frequent power cuts due to power transmission malfunctions, which can hamper operations of companies and public institutions. Off-grid solar systems can provide an economical and viable long-term backup solution to overcome the problems occurring during frequent power cuts.

Advantages:

- These self-sustainable systems can work independently and do not rely on the grid.
- They generate enough power that can be stored and used at night or when the power grid is down.
- These are ideal for remote areas where there is no power access from the grid.
- Grid failures and shutdowns will not affect your power supply.

Unit-III

6.a) **{ Advantages of Wind Energy-4M, Disadvantages of Wind Energy-3M }**

Advantages of Wind Energy

1) Wind Energy is an inexhaustible source of energy and is virtually a limitless resource.

2) Energy is generated without polluting environment.

3) This source of energy has tremendous potential to generate energy on large scale.

4) Like solar energy and hydropower, wind power taps a natural physical resource.

5) Windmill generators don't emit any emissions that can lead to acid rain or greenhouse effect.

6) Wind Energy can be used directly as mechanical energy.

7) In remote areas, wind turbines can be used as great resource to generate energy.

8) In combination with Solar Energy they can be used to provide reliable as well as steady supply of electricity.

9) Land around wind turbines can be used for other uses, e.g. Farming.

Disadvantages of Wind Energy

1) Wind energy requires expensive storage during peak production time.

2) It is unreliable energy source as winds are uncertain and unpredictable.

3) There is visual and aesthetic impact on region.

4) Requires large open areas for setting up wind farms.

5) Noise pollution problem is usually associated with wind mills.

6) Wind energy can be harnessed only in those areas where wind is strong enough and weather is windy for most parts of the year.

7) Usually places, where wind power set-up is situated, are away from the places where demand of electricity is there. Transmission from such places increases cost of electricity.

8) The average efficiency of wind turbine is very less as compared to fossil fuel power plants. We might require many wind turbines to produce similar impact.

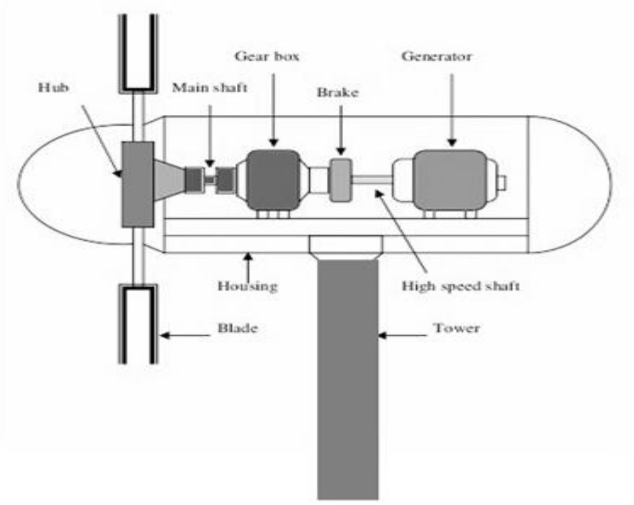
9) It can be a threat to wildlife. Birds do get killed or injured when they fly into turbines.

10) Maintenance cost of wind turbines is high as they have mechanical parts which undergo wear and tear over the time.

6.b) **{Figure-3M,Theory-4M}**

Horizontal axis wind turbines. Most of the technology described on these pages is related to horizontal axis wind turbines. The reason is simple: All grid connected commercial wind turbines today are built with a propeller-type rotor on a horizontal axis (i.e. a horizontal main shaft). The purpose of the rotor, of course, is to convert the linear motion of the wind into rotational energy that can be used to drive a generator. The same basic principle is used in a modern water turbine, where the flow of water is parallel to the rotational axis of the turbine blades.

Current horizontal axis wind turbines utilize the aerodynamic lift force to rotate every rotor blade similar to an airplane flies. Generally, the aerodynamic lift force works once they exposed to winds around both the higher and lower segments of a blade. The pressure difference which is formed between the top & bottom faces of the blade generates a force in the top direction of the blade. The horizontal axis wind turbine line diagram is shown below.



Construction of HAWT

The construction of a horizontal axis wind turbine can be done with different components. So the **horizontal axis wind turbine components** mainly include foundation, nacelle, generator, tower, and rotor blades.

Horizontal axis wind turbines include the rotor shaft & electric generator which are arranged at the top of the tower. Small wind turbines use a simple wind vane, whereas larger wind turbines use wind sensors that are connected through an auxiliary motor. Most wind turbines contain a gearbox, which is used to change the blade rotation from slow to fast, so used to operate an electric generator.

Once the wind blows, a wind turbine changes the kinetic energy from the motion of the wind into mechanical through the revolution of the rotor. After that, this converted energy can be transmitted through the shaft & the gear train toward the generator. Further, this generator converts the energy from mechanical to electrical to generate electricity.

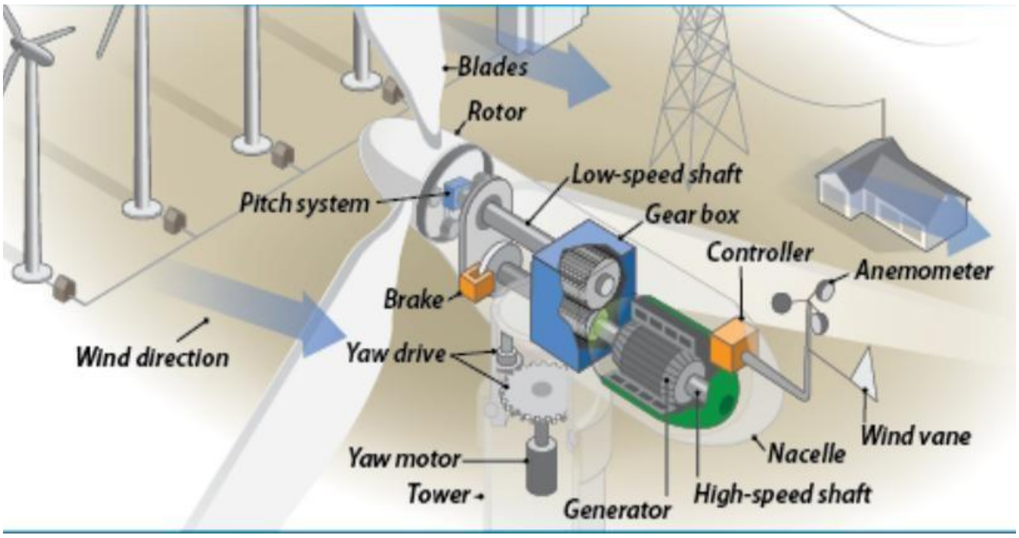
The wind flows on both faces of the airfoil-shaped blade although flows faster on the upper face of the airfoil to create a low-pressure region on the airfoil. The pressure difference between both the top & bottom surfaces results within the aerodynamic lift.

As the blades of a wind turbine are constrained to move in a plane with the hub as the center, the lift force causes rotation about the hub. In addition to the lift force, a drag force perpendicular to the lift force prevents rotor rotation.

The horizontal axis wind turbine design mainly includes a high lift to drag ratio, especially for the blades. So this ratio can change through the blade's length to optimize the output energy for the wind turbine at different speeds of wind. The generator & rotor shaft are arranged within the box at the top of the array.

7.a) **{Figure-3M,Theory-4M}**

Wind turbines harness the power of the wind and use it to generate electricity. Simply stated, wind turbines work the opposite of a fan. Instead of using electricity to make wind—like a fan—wind turbines use wind to make electricity. The wind turns the blades, which in turn spins a generator to create electricity. This illustration provides a detailed view of the inside of a wind turbine, its components, andtheir functionality.



Anemometer:

Measures the wind speed and transmits wind speed data to thecontroller.

Blades:

Lifts and rotates when wind is blown over them, causing therotor to spin. Most turbines have either two or three blades.

Brake:

Stops the rotor mechanically, electrically, or hydraulically, inemergencies.

Controller:

Starts up the machine at wind speeds of about 8 to 16 milesper hour (mph) and shuts off the machine at about 55 mph.Turbines do not operate at wind speeds above about 55 mph because they may be damaged by the high winds.

Gear box:

Connects the low-speed shaft to the high-speed shaft and increases the rotational speeds from about 30-60 rotations perminute (rpm), to about 1,000-1,800 rpm; this is the rotationalspeed required by most generators to produce electricity. The gear box is a costly (and heavy) part of the wind turbine and engineers are exploring "direct-drive" generators that operate at lower rotational speeds and don't need gear boxes.

Generator:

Produces 60-cycle AC electricity; it is usually an off-the-shelfinduction generator.

High-speed shaft:

Drives the generator.

Low-speed shaft:

Turns the low-speed shaft at about 30-60 rpm.

Nacelle:

Sits atop the tower and contains the gear box, low- and high- speed shafts, generator, controller, and brake. Some nacellesare large enough for a helicopter to land on.

Pitch:

Turns (or pitches) blades out of the wind to control the rotor speed, and to keep the rotor from turning in winds that are toohigh or too low to produce electricity.

Rotor:

Blades and hub together form the rotor.

Tower:

Made from tubular steel (shown here), concrete, or steel lattice. Supports the structure of the turbine. Because wind speed increases with height, taller towers enable turbines to capture more energy and generate more electricity.

Wind direction:

Determines the design of the turbine. Upwind turbines—like the one shown here—face into the wind while downwind turbines face away.

Wind vane:

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

Yaw drive:

Orients upwind turbines to keep them facing the wind when the direction changes. Downwind turbines don't require a yaw drive because the wind manually blows the rotor away from it.

Yaw motor:

Powers the yaw drive.

7.b) **{Horizontal Axis wind turbine-3M,Vertical axis turbine-4M}**

Difference between Horizontal Axis Wind Turbine and Vertical Axis Wind Turbine

The various difference between horizontal axis and vertical axis types of wind turbines in tabular form are given below:

S.no	Horizontal Axis Wind Turbine	Vertical Axis Wind Turbine
1.	In HAWTs, the axis of rotation of the rotor is Horizontal to the ground.	In VAWTs the axis of rotation of the rotor is perpendicular to the ground.
2.	Yaw mechanism is present.	Absence of Yaw mechanism.
3.	It has high initial installation cost.	It has low initial installation cost.
4.	They are big in size.	They are small in size.
5.	Its efficiency is high.	It has low efficiency.
6.	It requires large ground area for installation.	It requires less ground area for installation.
7.	High maintenance cost.	Low maintenance cost as compared with HAWT.
8.	They are self-starting.	They are not self-starting.
9.	They are unable to work in low wind speed condition.	They are capable of working in low wind speed condition.
10.	Difficult in transportation.	Easy in transportation.
11.	They are mostly used commercially.	They are mostly used for private purpose only.
12.	It cannot be installed near human population.	It can be installed near human population.
13.	It is not good for the bird's population.	It is good for the bird's population.

Unit-IV

8.a) {Offshore wind plant Definition-1M, Technological/Operational Challenges-6M}

In the race to find viable forms of renewable energy, offshore wind energy presents an attractive option that has been implemented with some success in Europe but remains in the early stages of development in the United States. Offshore wind's appeal stems from the fact that it uses essentially the same technology as onshore wind power, which is already considerably developed and widely deployed around the world, but with some notable advantages. For instance, unlike their onshore counterparts, offshore wind farms generally enjoy stronger and more constant breezes that can generate greater amounts of electricity than is available with onshore wind farms. In addition, since offshore wind turbines are not subject to the same constraints in terms of space, transport of components for assembly, and aesthetics as those onshore, they tend to be larger and more efficient. Another major advantage is that electricity generated by offshore wind is transmitted directly to the coast, where most large population centers are located, and thus does not have to be carried indirectly across long distances from remote areas, as is often the case with onshore wind. The United States Department of Energy has estimated that more than 900,000 megawatts (MW) of potential wind energy exists off the coasts of the United States.

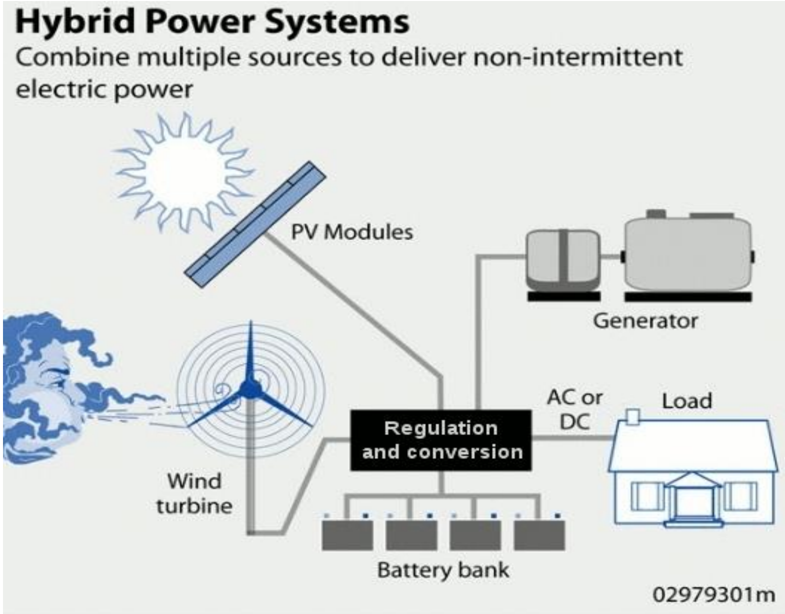
1.Technological/Operational Challenges:

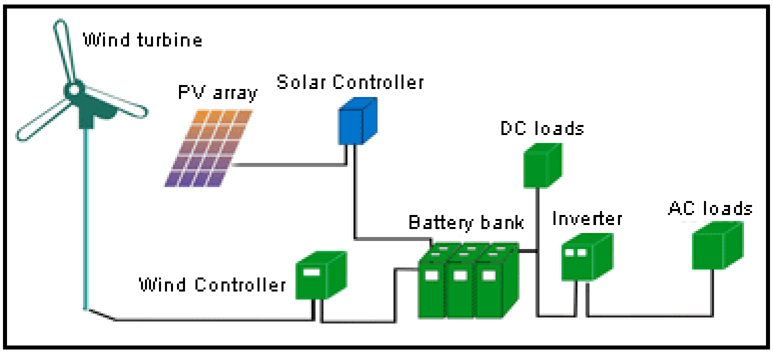
Offshore wind turbines use the same basic technology as their onshore counterparts and are built by the same manufacturers as well. The majority of turbines installed offshore have the capacity to generate between 2.0-3.6 MW of electricity, more than typical onshore wind turbines. 4 While the capacity of an offshore machine is greater, the cost is higher on both an overall and per kWh basis. The additional cost for offshore turbines is due in part to specialized components, such as reinforced foundations to anchor the machines to the seafloor, as well as anti-corrosive features to help them withstand the damaging effects of the sea air and saltwater. 5 Given the greater demand for onshore units, and the resulting unavailability of needed raw materials and components, lead times for offshore turbines can be up to 2-3 years, 6 thus making turbine supply a significant challenge to offshore wind energy development. This supply problem is exacerbated by the fact that there are currently only a handful of turbine manufacturers with extensive track records in offshore technology. Among these, the most widely employed are Vestas and Siemens Wind Power. The difficulties posed by this lack of experienced offshore turbine manufacturers were made apparent in 2007, when developers suffered a serious turbine supply shortage since Vestas decided to place a moratorium on the sale and delivery of its offshore unit, the V90-3 MW, due to gearbox problems. Turbine installation and maintenance also presents a formidable challenge to offshore wind development. With all the specialized equipment, vessels (such as crane and jack-up ships), and personnel required to erect and maintain wind turbines in the harsh conditions offshore, the initial construction and long term operating costs of offshore wind farms far exceed those of onshore wind farms. These costs increase substantially the farther offshore the turbines are placed and the deeper the water in which their foundations are laid. As with offshore turbines themselves, there is also currently a supply shortage of suitable vessels and trained personnel for turbine, foundation, and undersea electrical cable installation and maintenance that further delays the completion of offshore wind projects, and prevents them from keeping pace with onshore wind project development. Part of this shortage is due to the fact that many of the vessels and personnel are also currently being used by the offshore oil and gas industry, which receives somewhat more preferential treatment by offshore marine construction companies largely because it is a more established industry.

8.b) **{Figure-3M,Theory-4M}**

Hybrid systems, as the name implies, combine two or more modes of electricity generation together, usually using renewable technologies such as solar photovoltaic (PV) and wind turbines. Hybrid systems provide a high level of energy security through the mix of generation methods, and often will incorporate a storage system (battery, fuel cell) or small fossil fueled generator to ensure maximum supply reliability and security.

Hybrid renewable energy systems are becoming popular as stand-alone power systems for providing electricity in remote areas due to advances in renewable energy technologies and subsequent rise in prices of petroleum products. A hybrid energy system, or hybrid power, usually consists of two or more renewable energy sources used together to provide increased system efficiency as well as greater balance in energy supply.





hybrid energy system is a photovoltaic array coupled with a wind turbine.This would create more output from the wind turbine during the winter, whereas during the summer, the solar panels would produce their peak output. Hybrid energy systems often yield greater economic and environmental returns than wind, solar, geothermal or tri generation stand-alone systems by themselves.

Horizontal axis wind-turbine, combined with a solar panel on a lighting pylon at Weihai, Shandong province, China

A combine use of wind-solar systems results, in many places, to a smoother power output since the resources are anti-correlated. Therefore, the combined use of wind and solar systems is crucial for a large-scale grid integration.[9]

In 2019 in western Minnesota, a $5m hybrid system was installed. It runs 500 kW of solar power through the inverter of a 2 MW wind turbine, increasing the capacity factor and reducing costs by $150,000 per year. Purchase contracts limits the local distributor to a 5% maximum of self-generation.

The Pearl River Tower in Guangzhou, China, will mix solar panel on its windows and several wind turbines at different stories of its structure, allowing this tower to be energy positive.

In several parts of China & India, there are lighting pylons with combinations of solar panels and wind-turbines at their top. This allows space already used for lighting to be used more efficiently with two complementary energy productions units. Most common models use horizontal axis wind-turbines, but now models are appearing with vertical axis wind-turbines, using a helicoidal shaped, twisted-Savonius system.

Solar panels on the already existing wind turbines has been tested, but produced blinding rays of light that posed a threat to airplanes. A solution was to produce tinted solar panels that do not reflect as much light. Another proposed design was to have a vertical axis wind turbine coated in solar cells that are able to absorb sunlight from any angle.[12]

Other solar hybrids include solar-wind systems. The combination of wind and solar has the advantage that the two sources complement each other because the peak operating times for each system occur at different times of the day and year. The power generation of such a hybrid system is more constant and fluctuates less than each of the two component subsystems.

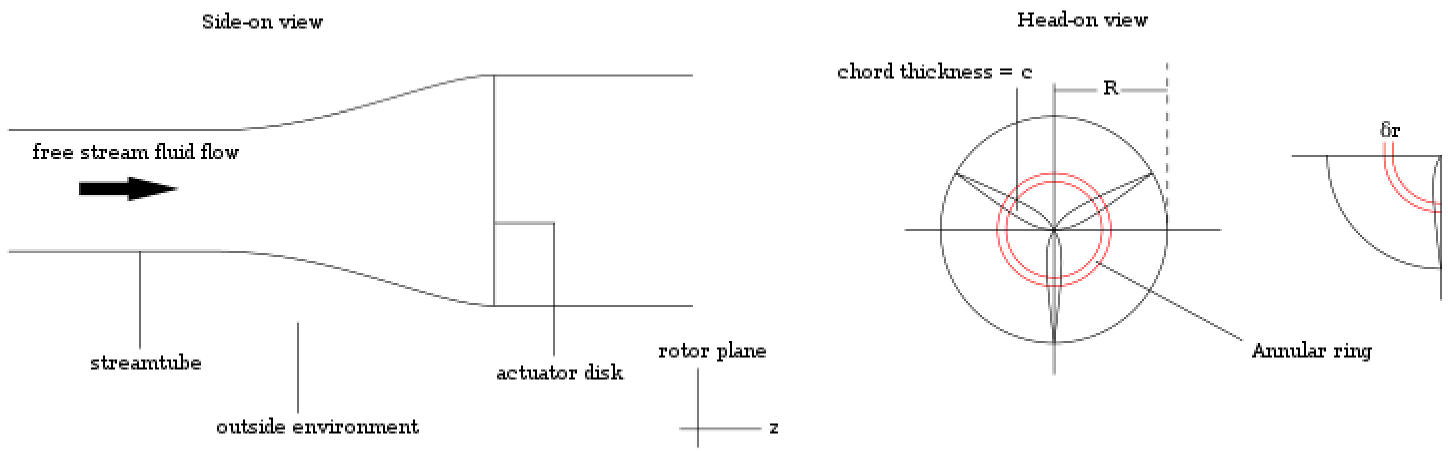
9.a) **{Definition-1M,Figure-1M,Theory-5M}**

Blade element momentum theory is a theory that combines both blade element theory and momentum theory. It is used to calculate the local forces on a propeller or wind-turbine blade. Blade element theory is combined with momentum theory to alleviate some of the difficulties in calculating the induced velocities at the rotor.

This article emphasizes application of BEM to ground-based wind turbines, but the principles apply as well to propellers. Whereas the stream tube area is reduced by a propeller, it is expanded by a wind turbine. For either application, a highly simplified but useful approximation is the Rankine–Froude "momentum" or "actuator disk" model (1865,1889). This article explains the application of the "Betz limit" to the efficiency of a ground-based wind turbine.

A development came in the form of Froude's blade element momentum theory (1878), later refined by Glauert (1926). Betz (1921) provided an approximate correction to momentum "Rankine–Froude actuator-disk" theory [1] to account for the sudden rotation imparted to the flow by the actuator disk (NACA TN 83, "The Theory of the Screw Propeller" and NACA TM 491, "Propeller Problems"). In blade element momentum theory, angular momentum is included in the model, meaning that the wake (the air after interaction with the rotor) has angular momentum. That is, the air begins to rotate about the z-axis immediately upon interaction with the rotor (see diagram below). Angular momentum must be taken into account since the rotor, which is the device that extracts the energy from the wind, is rotating as a result of the interaction with the wind.

Compared to the Rankine–Froude model, Blade element momentum theory accounts for the angular momentum of the rotor. Consider the left hand side of the figure below. We have a stream tube, in which there is the fluid and the rotor. We will assume that there is no interaction between the contents of the stream tube and everything outside of it. That is, we are dealing with an isolated system. In physics, isolated systems must obey conservation laws. An example of such is the conservation of angular momentum. Thus, the angular momentum within the stream tube must be conserved. Consequently, if the rotor acquires angular momentum through its interaction with the fluid, something else must acquire equal and opposite angular momentum. As already mentioned, the system consists of just the fluid and the rotor, the fluid must acquire angular momentum in the wake.



9.b) **{Betz law-1M,Theory-3M,derivation-3M}**

In aerodynamics, **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. It was published in 1919 by the German physicist Albert Betz.[1] The law is derived from the principles of conservation of mass and momentum of the air stream flowing through an idealized "actuator disk" that extracts energy from the wind stream. According to Betz's law, no turbine can capture more than 16/27 (59.3%) of the kinetic energy in wind. The factor 16/27 (0.593) is known as **Betz's coefficient**. Practical utility-scale wind turbines achieve at peak 75–80% of the Betz limit.

The Betz limit is based on an open-disk actuator. If a diffuser is used to collect additional wind flow and direct it through the turbine, more energy can be extracted, but the limit still applies to the cross-section of the entire structure.

$$
\begin{aligned}
P &= \tfrac{1}{2}\dot{m}(v_1^2 - v_2^2) \\
&= \tfrac{1}{2}\rho S v(v_1^2 - v_2^2) \\
&= \tfrac{1}{4}\rho S(v_1 + v_2)(v_1^2 - v_2^2) \\
&= \tfrac{1}{4}\rho S v_1^3 \left(1 - \left(\frac{v_2}{v_1}\right)^2 + \left(\frac{v_2}{v_1}\right) - \left(\frac{v_2}{v_1}\right)^3\right).
\end{aligned}
$$

By differentiating P with respect to $\frac{v_2}{v_1}$ for a given fluid speed v_1 and a given area S, one finds the *maximum* or *minimum* value for P. The result is that P reaches maximum value when $\frac{v_2}{v_1} = \frac{1}{3}$.

Substituting this value results in

$$P_{\max} = \frac{16}{27} \cdot \frac{1}{2}\rho S v_1^3.$$

$$P = C_{\mathrm{p}} \cdot \frac{1}{2}\rho S v_1^3.$$

The reference power for the Betz efficiency calculation is the power in a moving fluid in a cylinder with cross-sectional area S and velocity v_1:

$$P_{\text{wind}} = \frac{1}{2}\rho S v_1^3.$$

Signature of H.O.D

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