Course code	Course Name	L-T-P - Credits	Year of Introduction
EE367	New and Renewable Sources of Energy	3-0-0-3	2016

Prerequisite: Nil

Course Objectives:

- To give sufficient knowledge about the promising new and renewable sources of energy
- To equip students in working with projects and to take up research work in connected areas.

Syllabus:

Solar energy - Solar radiation measurements - Applications of solar energy - Energy from oceans- Tidal energy - Wind energy -Small Hydro Power (SHP) Stations- Biomass and bio-fuels - geothermal energy -Power from satellite stations - Hydrogen energy.

Expected Outcome:

- The students will be able to design and analyse the performance of small isolated renewable energy sources.

References:

1. A.A.M. Saigh (Ed): Solar Energy Engineering, Academic Press, 1977
2. Abbasi S. A. and N. Abbasi, Renewable Energy Sources and Their Environmental Impact, Prentice Hall of India, 2001..
3. Boyle G. (ed.), Renewable Energy - Power for Sustainable Future, Oxford University Press, 1996
4. Earnest J. and T. Wizelius, Wind Power Plants and Project Development, PHI Learning, 2011.
5. F. Kreith and J.F. Kreider: Principles of Solar Engineering, McGraw Hill, 1978
6. G.N. Tiwari: Solar Energy-Fundamentals, Design, Modelling and Applications, Narosa Publishers, 2002
7. J.A. Duffie and W.A. Beckman: Solar Energy Thermal Processes, J. Wiley, 1994
8. Johansson T. B., H. Kelly, A. K. N. Reddy and R. H. Williams, Renewable Energy – Sources for Fuel and Electricity, Earth scan Publications, London, 1993.
9. Khan B. H., Non-Conventional Energy Resources, Tata McGraw Hill, 2009.
10. Rao S. and B. B. Parulekar, Energy Technology, Khanna Publishers, 1999.
11. Sab S. L., Renewable and Novel Energy Sources, MI. Publications, 1995.
12. Sawhney G. S., Non-Conventional Energy Resources, PHI Learning, 2012.
13. Tiwari G. N., Solar Energy- Fundamentals, Design, Modelling and Applications, CRC Press, 2002.

Course Plan

Module	Contents	Hours	Sem. Exam Marks
I	Introduction, Classification of Energy Resources; Conventional Energy Resources - Availability and their limitations; Non-Conventional Energy Resources – Classification, Advantages, Limitations; Comparison of Conventional and Non-Conventional Energy Resources; World Energy Scenario; Indian Energy Scenario. ENERGY STORAGE: Sizing and Necessity of Energy Storage.	5	15%
II	SOLAR THERMAL SYSTEMS: Introduction, Solar Constant, Basic Sun-Earth Angles, Measurement of Solar Radiation Data – Pyranometer and Pyrheliometer .Principle of Conversion of Solar Radiation into Heat, – Solar thermal collectors – General description	11	15%

	and characteristics – Flat plate collectors – Heat transfer processes – Solar concentrators (parabolic trough, parabolic dish, Central Tower Collector) –performance evaluation..		
FIRST INTERNAL EXAMINATION			
III	SOLAR ELECTRIC SYSTEMS: Solar Thermal Electric Power Generation –; Solar Photovoltaic – Solar Cell fundamentals, characteristics, classification, construction of module, panel and array. Solar PV Systems – stand-alone and grid connected; Applications – Street lighting, Domestic lighting and Solar Water pumping systems..	5	15%
IV	ENERGY FROM OCEAN: Tidal Energy – Principle of Tidal Power, Components of Tidal Power Plant (TPP), Classification of Tidal Power Plants, Advantages and Limitations of TPP. Ocean Thermal Energy Conversion (OTEC): Principle of OTEC system, Methods of OTEC power generation – Open Cycle (Claude cycle), Closed Cycle (Anderson cycle) and Hybrid cycle (block diagram description of OTEC); Site-selection criteria, Biofouling, Advantages & Limitations of OTEC.	7	15%
SECOND INTERNAL EXAMINATION			
V	WIND ENERGY: Introduction, Wind and its Properties, History of Wind Energy, Wind Energy Scenario – World and India. Basic principles of Wind Energy Conversion Systems (WECS), Classification of WECS, Parts of WECS, Derivation for Power in the wind, Electrical Power Output and Capacity Factor of WECS, Advantages and Disadvantages of WECS	7	20%
VI	BIOMASS ENERGY: Introduction, Photosynthesis process, Biomass fuels, Biomass conversion technologies, Urban waste to Energy Conversion, Biomass Gasification, Biomass to Ethanol Production, Biogas production from waste biomass, factors affecting biogas generation, types of biogas plants – KVIC and Janata model; Biomass program in India. Small hydro power: Classification as micro, mini and small hydro projects - Basic concepts and types of turbines - Design and selection considerations. EMERGING TECHNOLOGIES: Fuel Cell, Small Hydro Resources, Hydrogen Energy, alcohol energy, nuclear fusion and power from satellite stations.	7	20%
END SEMESTER EXAM			

QUESTION PAPER PATTERN:

Maximum Marks: 100 Exam Duration: 3Hourrs.

Part A: 8 compulsory questions. One question from each module of Module I - IV; and two each from Module V & VI. Student has to answer all questions. (8 x5)=40

Part B: 3 questions uniformly covering Modules I & II. Student has to answer any 2 from the 3 questions: (2 x 10) =20. Each question can have maximum of 4 sub questions (a,b,c,d), if needed.

Part C: 3 questions uniformly covering Modules III & IV. Student has to answer any 2 from the 3 questions: (2 x 10) =20. Each question can have maximum of 4 sub questions (a,b,c,d), if needed.

Part D: 3 questions uniformly covering Modules V & VI. Student has to answer any 2 from the 3 questions: (2 x 10) =20. Each question can have maximum of 4 sub questions (a,b,c,d), if needed.

NEHRU COLLEGE OF ENGINEERING AND RESEARCH CENTRE
(NAAC Accredited)
(Approved by AICTE, Affiliated to APJ Abdul Kalam Technological University, Kerala)

DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

COURSE MATERIALS

EE367 NEWAND RENEWABLE ENERGY SOURCES

VISION OF THE INSTITUTION

To mould true citizens who are millennium leaders and catalysts of change through excellence in education.

MISSION OF THE INSTITUTION

NCERC is committed to transform itself into a center of excellence in Learning and Research in Engineering and Frontier Technology and to impart quality education to mould technically competent citizens with moral integrity, social commitment and ethical values.

We intend to facilitate our students to assimilate the latest technological know-how and to imbibe discipline, culture and spiritually, and to mould them in to technological giants, dedicated research scientists and intellectual leaders of the country who can spread the beams of light and happiness among the poor and the underprivileged.

COURSE OBJECTIVES

Course Name: EE367 NEW AND RENEWABLE SOURCES OF ENERGY

YEAR of Study: THIRD YEAR

C367.1	To give sufficient knowledge about the promising new and renewable sources of energy
C367.2	To understand about solar thermal systems and the various collectors involved.
C367.3	To understand about solar PV systems and its various applications
C367.4	To gain knowledge about TPP, OTEC and its methods
C367.5	To understand about wind energy and its types
C367.6	To gain knowledge about biomass energy and emerging technologies in renewable energy sources

PROGRAM OUTCOMES (POs)

Engineering Graduates will be able to:

1. **Engineering knowledge**: Apply the knowledge of mathematics, science, engineering fundamentals, and an engineering specialization to the solution of complex engineering problems.
2. **Problem analysis**: Identify, formulate, review research literature, and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences, and engineering sciences.
3. **Design/development of solutions**: Design solutions for complex engineering problems and design system components or processes

that meet the specified needs with appropriate consideration for the public health and safety, and the cultural, societal, and environmental considerations.

4. **Conduct investigations of complex problems**: Use research-based knowledge and research methods including design of experiments, analysis and interpretation of data, and synthesis of the information to provide valid conclusions.
5. **Modern tool usage**: Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools including prediction and modeling to complex engineering activities with an understanding of the limitations.
6. **The engineer and society**: Apply reasoning informed by the contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to the professional engineering practice.
7. **Environment and sustainability**: Understand the impact of the professional engineering solutions in societal and environmental contexts, and demonstrate the knowledge of, and need for sustainable development.
8. **Ethics**: Apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice.
9. **Individual and team work**: Function effectively as an individual, and as a member or leader in diverse teams, and in multidisciplinary settings.
10. **Communication**: Communicate effectively on complex engineering activities with the engineering community and with society at large, such as, being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clearinstructions.
11. **Project management and finance**: Demonstrate knowledge and understanding of the engineering and management

principles and apply these to one’s own work, as a member and leader in a team, to manage projects and in multidisciplinary environments.

12. **Life-long learning**: Recognize the need for, and have the preparation and ability to engage in independent and life-long learning in the broadest context of technologicalchange.

CO-PO matrices of courses

CO	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
C367.1	3	2	3	2	3	2	2	1	1	-	-	3
C367.2	3	3	3	3	3	2	2	1	1	-	-	3
C367.3	3	3	3	3	3	2	2	1	1	-	-	3
C367.4	3	2	3	2	3	2	2	1	1	-	-	3
C367.5	3	3	3	3	3	2	2	1	1	-	-	3
C367.6	3	2	3	2	3	2	2	1	1	-	-	3
C367	3	2.5	3	2.5	3	2	2	1	1	-	-	3

CO AND PSO MAPING

PSO

1. Apply Science, Engineering, Mathematics through differential and Integral Calculus, Complex Variables to solve Electrical Engineering Problems.

2. Demonstrate proficiency in the use of software and hardware to be required to practice electrical engineering profession.

3. Able to apply the knowledge of Ethical and Management principles required to work in

CO/PSO	PSO1	PSO2	PSO3
C367.1	2	3	2
C367.2	3	3	1
C367.3	3	3	1
C367.4	3	3	1
C367.5	3	3	1
C367.6	3	3	1
C367	2.83	3	1.16

EE367-NEW AND RENEWABLE SOURCES OF ENERGY

MODULE-I

1. What do you understand by energy resources?
2. How the energy resources can be classified?
3. Discuss the conventional and non-conventional energy sources. Also describe the future of non-conventional resources in India.
4. What is Thermal energy? How are fossil fuels classified?
5. What is hydel energy? Describe briefly a hydro electrical plant.
6. Explain the process of nuclear fission in nuclear energy.
7. Discuss about photovoltaic conversion with their advantages and disadvantages.
8. Explain in detail about wind energy generation.
9. With a neat sketch explain the working of tidal energy.
10. Explain the working principle of geothermal plant.
11. Explain Ocean Temperature Energy Conversion with its working.
12. Discuss a) Energy Intensity b)Energy Elasticity.
13. What is the present situation of India in Energy resources?
14. What is the present situation of World in Energy resources?
15. List the characteristics of energy storage system. Brief about them
16. Classify the means of energy storage available and explain about them in detail.
17. How is a battery used to store electrical energy?
18. Differentiate between pumped hydro and compressed air storage systems.

19. **Explain i) extraterrestrial radiation. ii) solar constant and iii) terrestrial radiation.**
20. **Explain following angles used in solar radiation analysis:**
    a) **Latitude of location**
    b) **Hour angle**
    c) **Solar azimuth angle**
    d) **Zenith angle**
    e) **Declination angle.**
21. **What is the expression for the angle of incidence for an inclined surface?**
22. **Explain Local apparent time. How it Is calculated.**
23. **Derive an expression for solar day length.**
24. **What do you understand by solar radiation data? What is the need of it?**
25. **Explain the working of the following with neat sketch**
    a. **Pyranometer**
    b. **Pyrheliomenter.**
26. **Why solar collectors are needed?**
27. **How the solar collectors are classified? What are its salient features?**
28. **Explain the principle of conversion of solar energy to heat with flat plate solar collector.**
29. **Describe about concentrators.**

1. **With a neat sketch explain the process of solar thermal power generation.**
2. **Explain how a PV cell operates and how it gets varied from a normal pn junction diode with its characteristics.**
3. **Explain with necessary diagrams:**
    a. **Solar cell**
    b. **Solar Module**
    c. **Solar Panel**
    d. **Solar Array**
4. **With a example explain about stand alone PV system and list its advantages and disadvantages.**
5. **With a example explain about Grid connected PV system and list its advantages and disadvantages.**
6. **With a neat sketch explain Solar street lighting.**
7. **With a neat sketch explain Solar domestic lighting.**
8. **With a neat sketch explain Solar water pumping system.**

9. What are the various Tidal power plants ? Explain them.
10. Explain the operation of tidal power plant list it’s advantages and limitations.
11. Explain the principle of OLTC.
12. Explain i) Claude Cycle, ii) Anderson Cycle.
13. Explain Hybrid cycle with a neat diagram.
14. What is Biofouling What are the impacts on OLTC?
15. What is the site selection criteria for OLTC?

16. With a neat diagram explain the various part of wind turbine.
17. Differentiate HAWT and VAWT.
18. Explain the classifications of VAWT.
19. Derive the power Equation for WECS and also the maximum power obtaining point.
20. List the advantages and disadvantages of WECS.
21. Explain how the wind is produced and enlist its properties.

22. Explain the process of photosynthesis.
23. Explain the various available biomass based on its classification.
24. How the biogas can be produced from biomass explain with an example.
25. Explain the list of factors affecting the biogas power generation.
26. Explain the difference between KVIC and Janata model.
27. Describe the characteristics of small hydro power generation.
28. List the various turbine used for small hydro power plant.
29. How the fuel cell works explain with a neat diagram.
30. What is hydrogen energy?
31. How the power can be generated from nuclear fusion.
32. Explain the process of harvesting power from satellite stations..
33. Explain the necessity of producer gas and how it can be obtained from biomass.

MODULE III

SOLAR ELECTRIC SYSTEMS: Solar thermal electric power generation ,Solar photovoltaic- solar cell fundamentals, characteristics, classification, construction of module, panel and array. Solar PV systems- stand alone and grid connected; Applications- street lighting, domestic lighting and solar water pumping systems.

SOLAR THERMAL ELECTRIC CONVERSION

- Heat can be converted directly into electrical energy by solar cell or thermoelectric methods, but these techniques may not be suitable for use with the sun-generated heat.
- The most practical thermal electric procedure for solar energy is to utilize the energy to heat a working fluid.
- The heat energy is then converted into mechanical energy in a turbine and finally into electrical energy by means of conventional generator coupled to the turbine.

- **Power cycles**

  - Low temperature cycle (<=100deg)
  - Medium temperature cycle (150deg-300deg)
  - High temperature cycle (>300deg)

- **Arrangements**

  Central Receiver Collector : large scale generation
  Distributed collector : smaller capacity (2kW)

THERMO ELECTRIC CONVERSION SYSTEMS

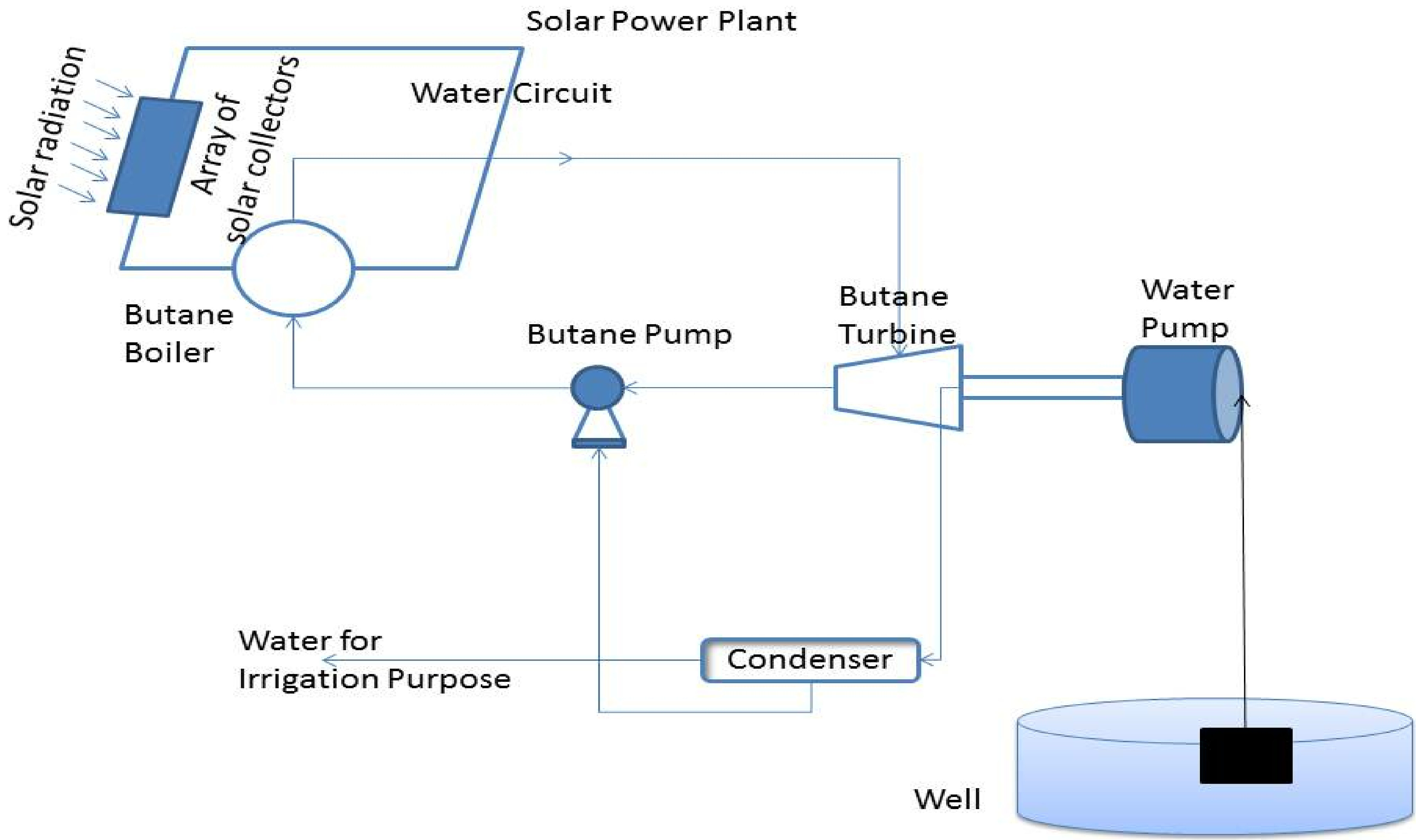
- The following four systems are described in the following section:

1. Low temperature using flat plate collectors or solar pond.
2. Concentrating collectors for medium and high temperature.
3. Power tower concept or central receiver system.
4. Distributed collector system.

Low temperature systems

- Temperature range of 60-100 degree Celsius
- *Rankine cycle* is used
- Organic fluid is Freon or butane
- Flat plate collectors or solar pond arrangement

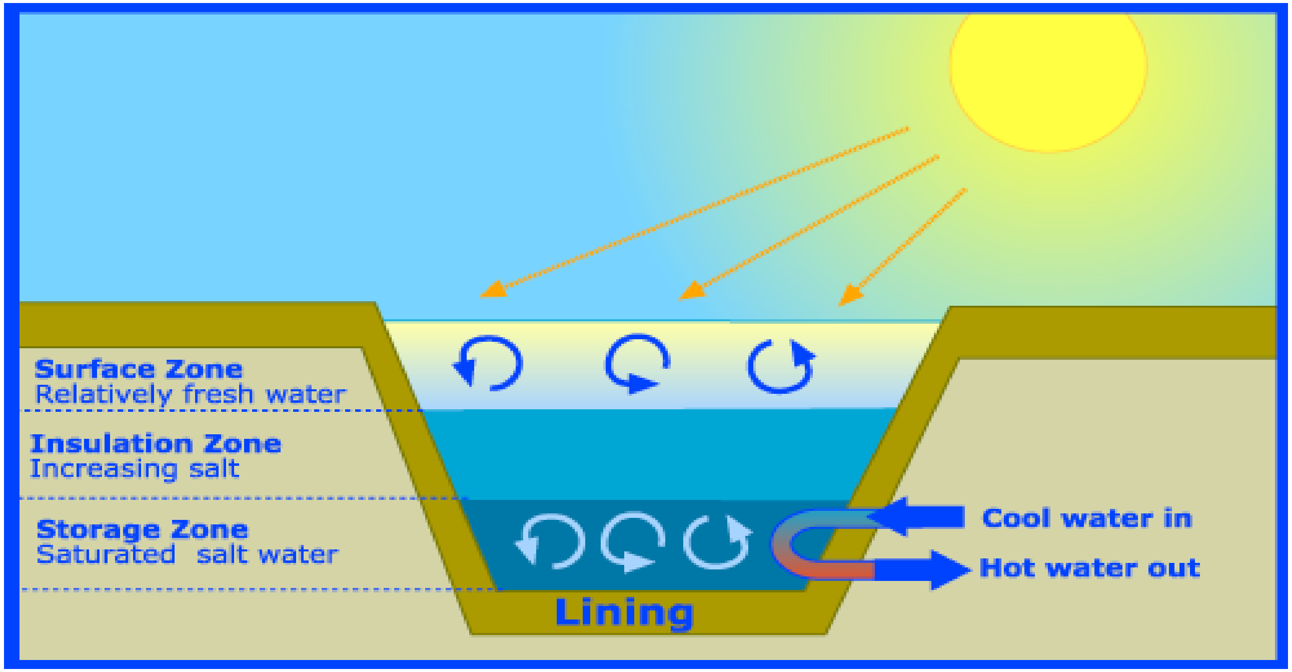
Flat plate collector



Solar pond

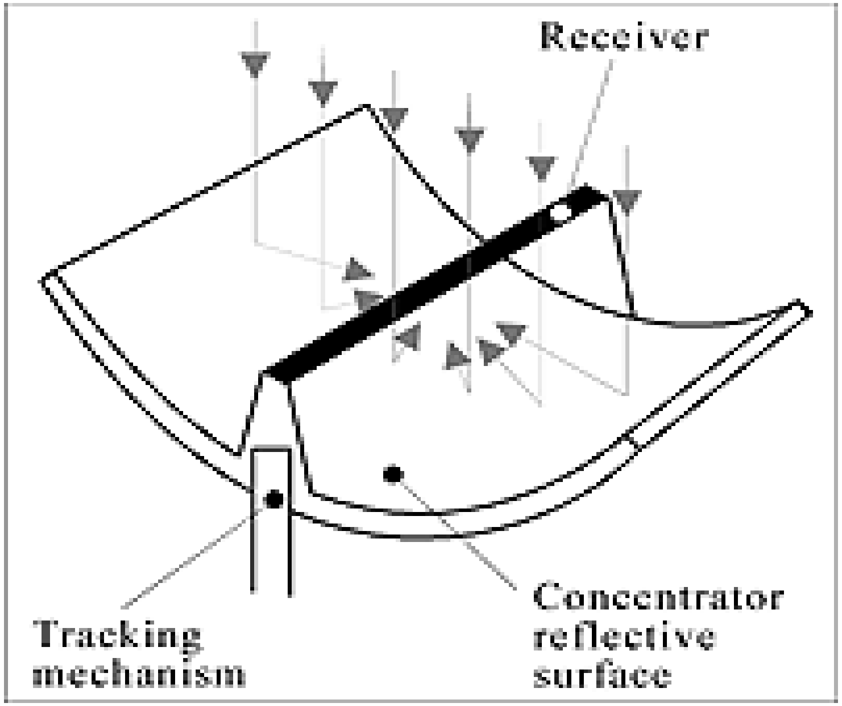
- A natural or artificial body of water for collecting and absorbing solar radiation and storing it as heat.

- Dissolved salts to create stable density gradient.



Medium temperature systems

- Temperature above 100 degree Celsius
- 250-500 degrees Celsius
- Parabolic cylindrical collector is used

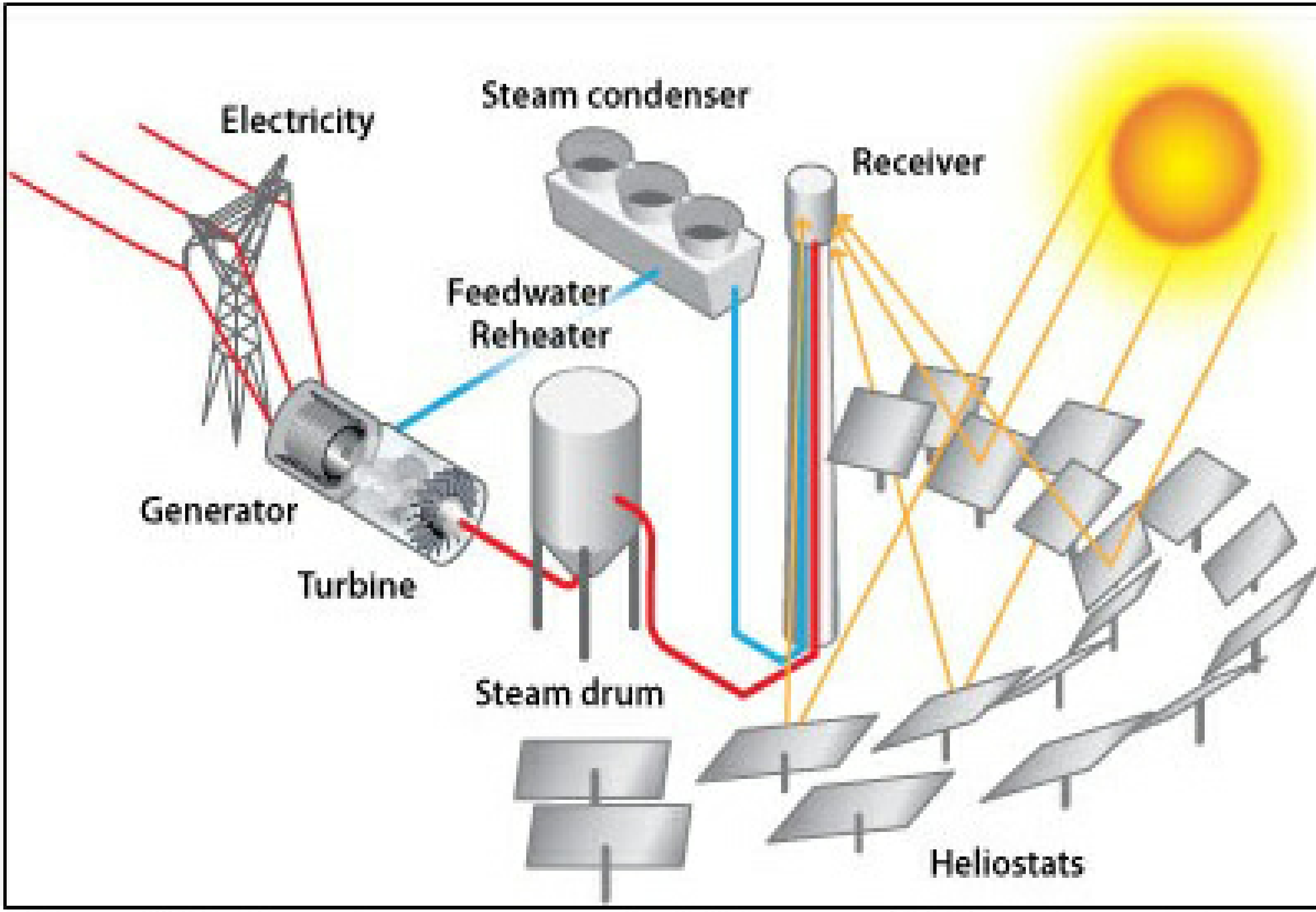


High temperature Systems

- Central Receiver Collector
- Distributed collector systems (solar farms)

Central receiver systems (Tower Power plant)

- A large field of mirrors, called heliostats, track the sun.
- A tower collects light concentrated by the heliostats onto a central receiver on top of a tower. Tower heights range from approximately 300 to 650 feet.
- HTF, composed of either water or molten nitrate salt, moves through the receiver and is heated to temperature over 500 °C.
- The heated HTF is then sent to a heat exchanger where water is turned into steam, which then drives a turbine generator.


Steam condenser
Electricity
Receiver
Feedwater
Reheater
Generator
Turbine
Steam drum
Heliostats

- Description of the system :

1. Tower with the central receiver on top
2. Heat conversion subsystem
3. Heat storage device
4. Field of oriented mirrors

Distributed Collector system (Solar farms)

PV CELLS

PHOTOVOLTAIC EFFECT

- Direct conversion of solar energy into electrical energy.
- Generation of an electromotive force as a result of the absorption of ionizing radiation.
- Solar cells or photovoltaic(PV) cells.
- To increase the electric power output: solar module or solar array.

- Photovoltaic cells are made of semiconductors that generate electricity when they absorb light.

- Application of PV cells: electric power generation in spacecraft(silicon solar cell).

- Other applications are to operate
  - irrigation pumps
  - navigational signals
  - highway emergency call system
  - rail road crossing warnings
  - automatic meteorological stations etc.

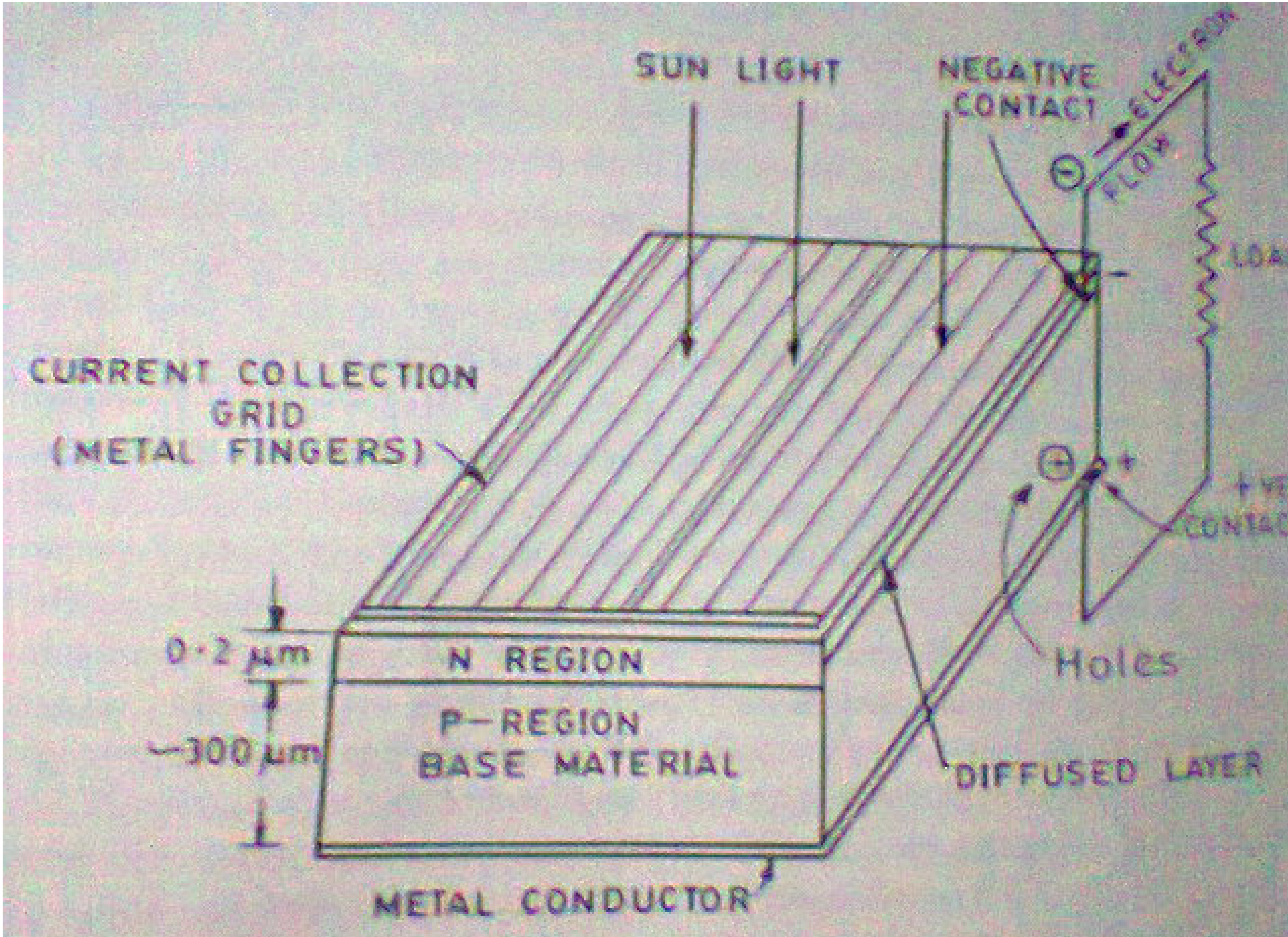
SOLAR CELL PRINCIPLES

- Combination of *n* type and *p* type semiconductors constitute a PV cell.

- Semiconductor with one side of *p type* and the other of *n type* is called a **p-n junction**.

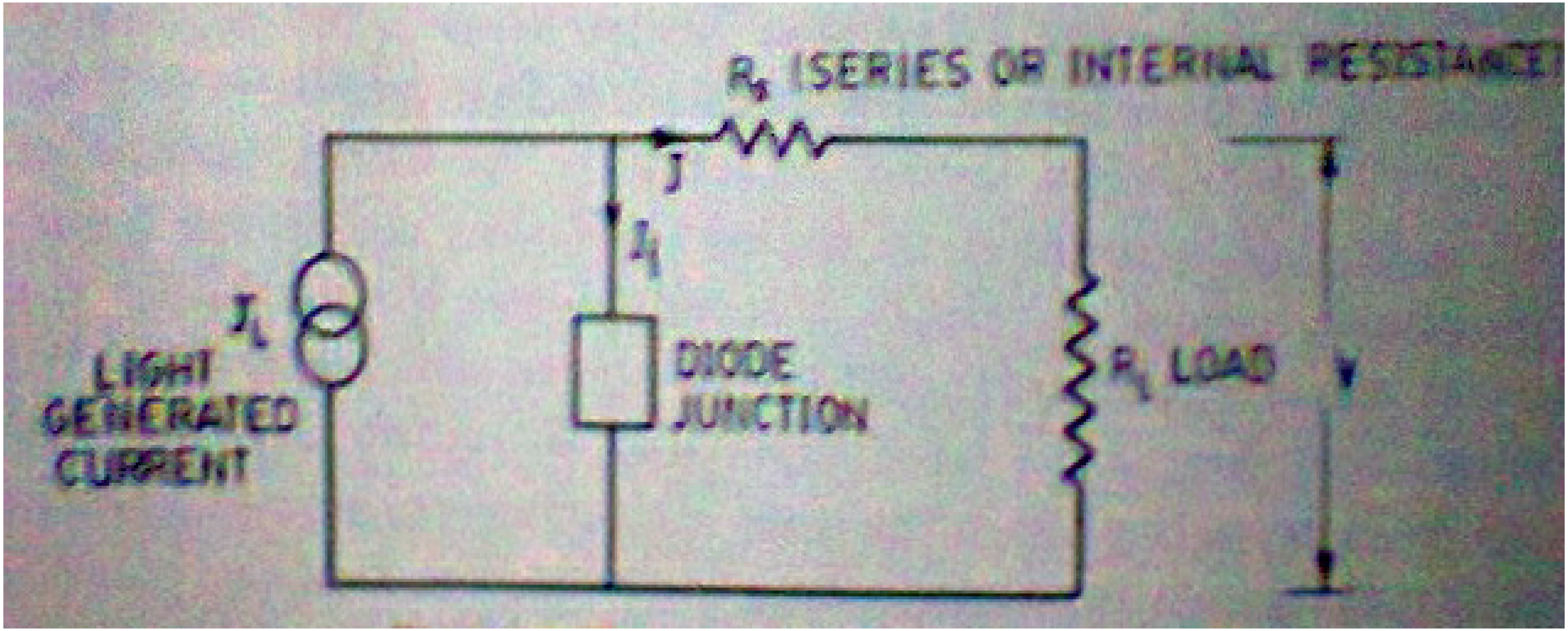
- When photons are absorbed free electrons of the *n* side will tend to flow to the *p* side, and the holes of the *p* side will tend to flow to the *n* region to compensate for their respective deficiencies.

- Requires charge collecting front and back electrodes.


SUN LIGHT
NEGATIVE CONTACT
ELECTRON FLOW
LOAD
CURRENT COLLECTION GRID (METAL FINGERS)
+VE CONTACT
Holes
0·2 μm
N REGION
P-REGION BASE MATERIAL
~300 μm
DIFFUSED LAYER
METAL CONDUCTOR

ELECTRIC CHARACTERISTICS OF PV CELLS

- The equivalent circuit of a solar cell,



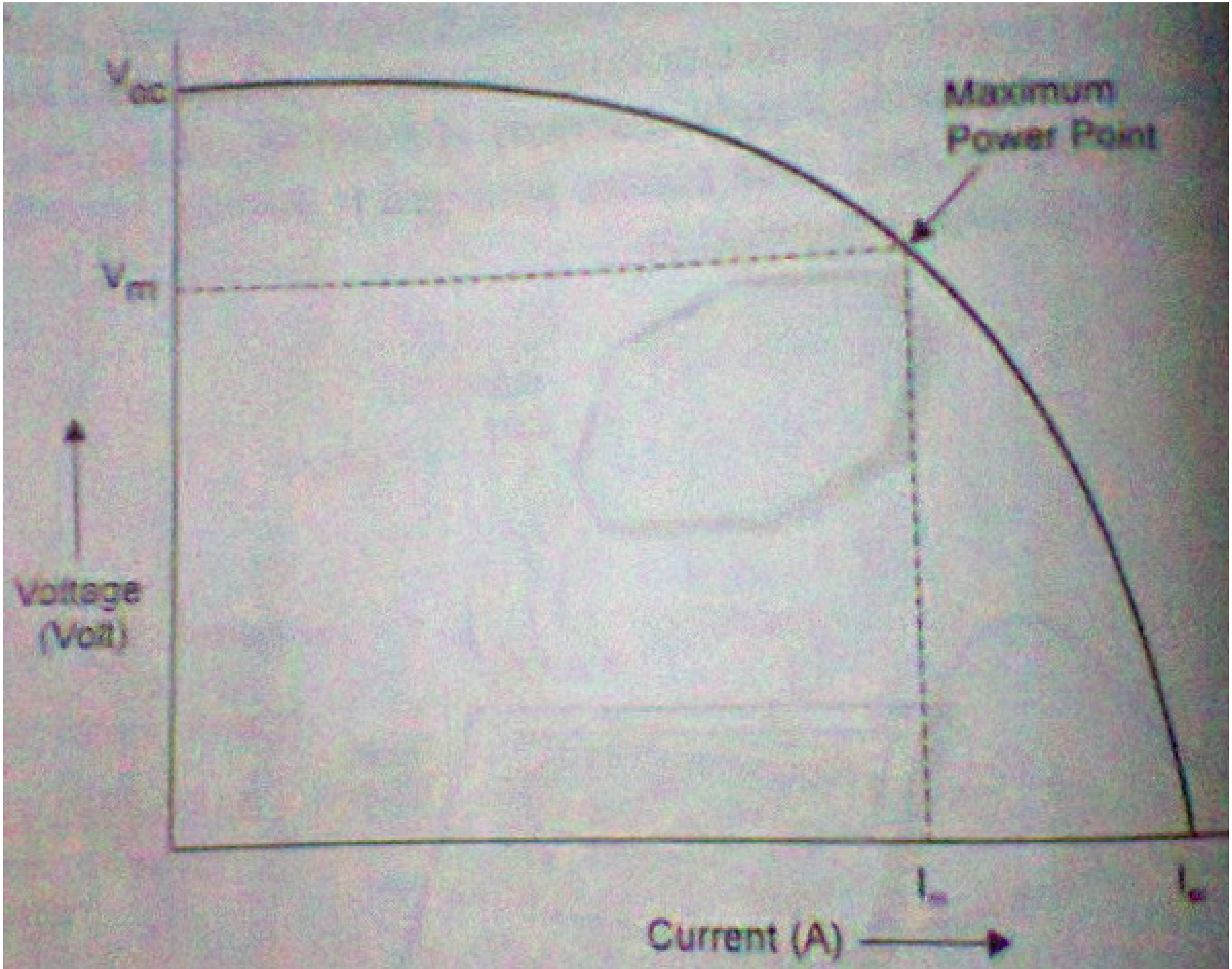
- When light falls on the junction, electron-hole pairs are created at a constant rate providing an electric current flow across the junction.

- Net current is the difference between the normal diode current and light generated current J_L .

$$J= J_L - J_i$$

where

$$j_i = jo[\exp(\frac{Ve}{KT})\text{-}1]$$



Voc
Vm
Maximum
Power Point
Voltage
(Volt)
Current (A)

- *Fill factor*: Ratio of two areas $V_m I_m$ and $V_{oc} I_{sc}$.(<1)

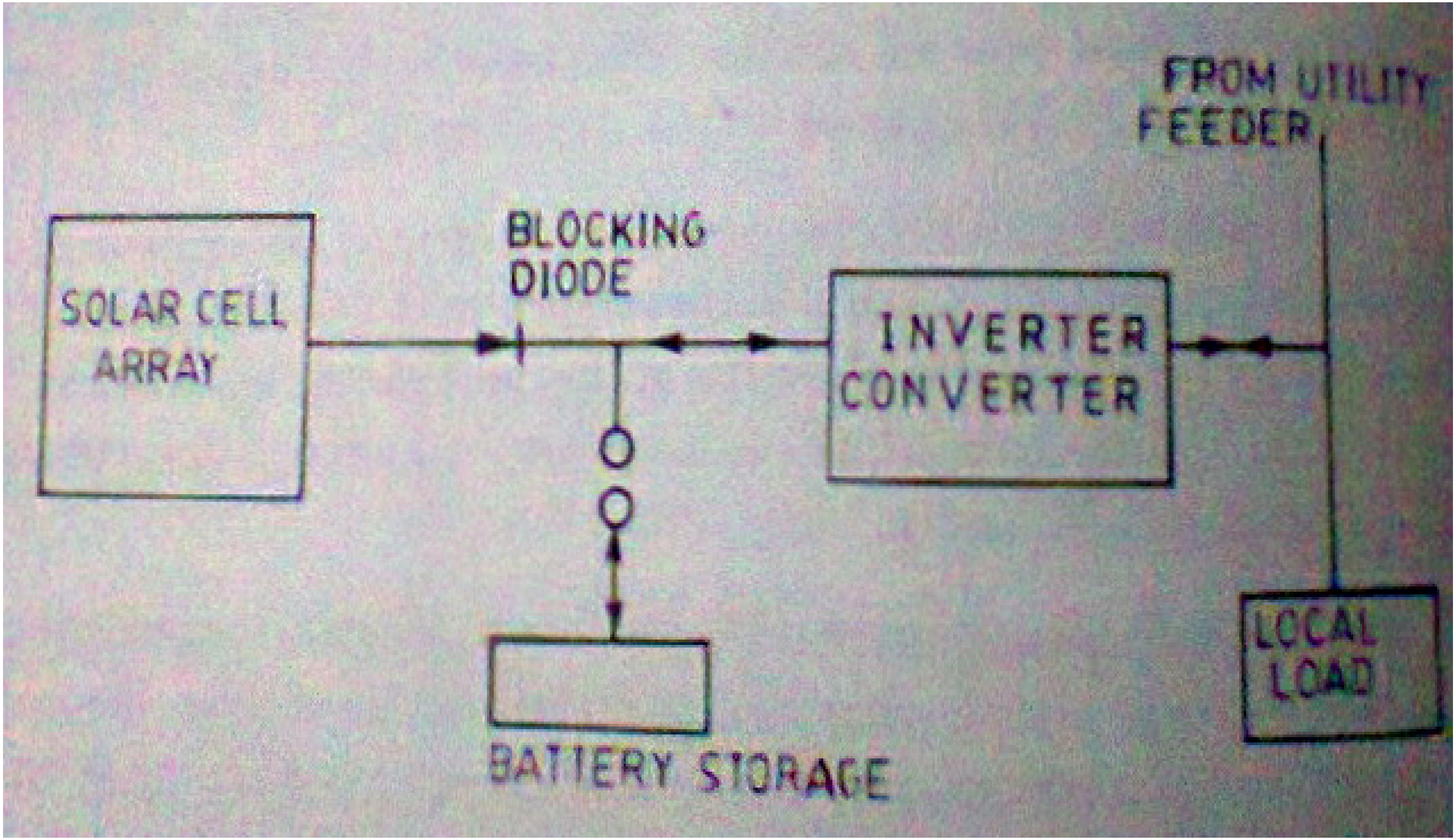
- *Maximum conversion efficiency*: It is defined as the ratio of maximum useful power to the incident solar radiation.

$$\eta_{max} = \frac{V_m I_m}{\varphi_s A_s}$$

φ_s is the incident solar flux

A_s is the area of PV cell

PV SYSTEM FOR POWER GENERATION



MODULE 4

Ocean Energy Utilization

- As you all know, especially in light of last year's Tsunami, the ocean is extremely powerful
- This power is not good or bad, it just is…
- It can be harnessed for constructive uses.
    - This is the attempt with utilizing ocean power

- Types of Ocean Energy?
    - Tides, Waves, Temperature Gradients, Salt Gradients, Marine Biomass

Ocean Energies

- High Energies total, but spread over large areas
  - Low Energy densities
  - Increased costs to collect the energy
    - Large physical equipment
    - Long construction times
      - Low interest rates needed
    - Much of the potential is offshore, at areas far from the energy use point
  - Low pollution
  - High possible environmental impact
    - Large physical equipment again
  - Financial risks perceived high

Financial Aspects

- Large areas and large construction projects
  - Require long construction time
  - Requires low interest rates in order to not pay exorbitant total interest
- High perceived risk
  - Ocean systems not “accepted” yet as common, investors see a high risk of failure, due to natural elements, government regulation changes, unproven technology
  - Drives interests rates up – investors don’t want to lose their money
- Contradictory elements here – low interest rates required, but high risk drives up interest rates

- Maybe more attention needs to be put on small size, scalable technologies

Tides

- Forces acting are the sun and moon
- Cycles caused by the interaction of the sun, earth, and moon
  - Half day cycle – (actually 12 h, 25 m) due to the rotation of the earth within the gravitation field of the moon
  - 14 day cycle – interactions of the sun and moon combine to make min and max tides – or “spring” and “neap” tides.
    - When sun and moon aligned, either on the same side of the earth, or on opposites of the earth, the gravitational pull will be maximized and the tidal range – the distance between the half-daily high and low tides – will be larger
    - When sun and moon are perpendicular to each other (with the earth at the pivot point) the tidal range will be smaller

More cycles

- Half year cycle – due to the inclination of the moon’s orbit – 178 days between the highest “spring” tides in March and September
- 19 Year cycles
- 1600 Year cycles

- Range of “spring” tides is about 2X the “neap” tides – equivalent to +- 50% for 14 day cycle
- +- 11% for ½ year cycle
- +- 4% for 19 year cycle

Tidal Energy Extraction

- Amount of tidal energy available changes with the square of the range of tides (between high and low tides)
- Tidal energy is very predictable
  - Unlike many other renewable energy sources
  - Allows for proper load scheduling
- Tides need to be large and suitable locations need to be determined

Method of Energy Extraction

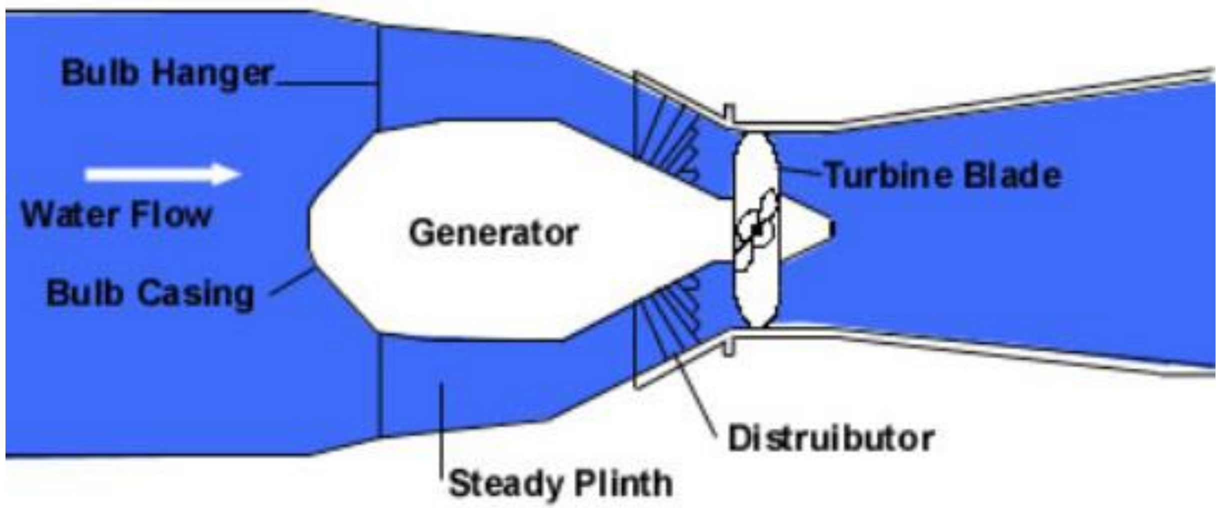
- A wall is built between the estuary (bay) and the ocean – forming a basin
- During high tide, water is allowed to enter behind the wall – filling the basin normally
- The gates are closed and water is trapped in the basin
- During low tide, there is a net height difference between the basin and the sea – this creates water pressure – or a “head”
- The water in the basin is then allowed to return to the sea through turbines
  - This creates electricity

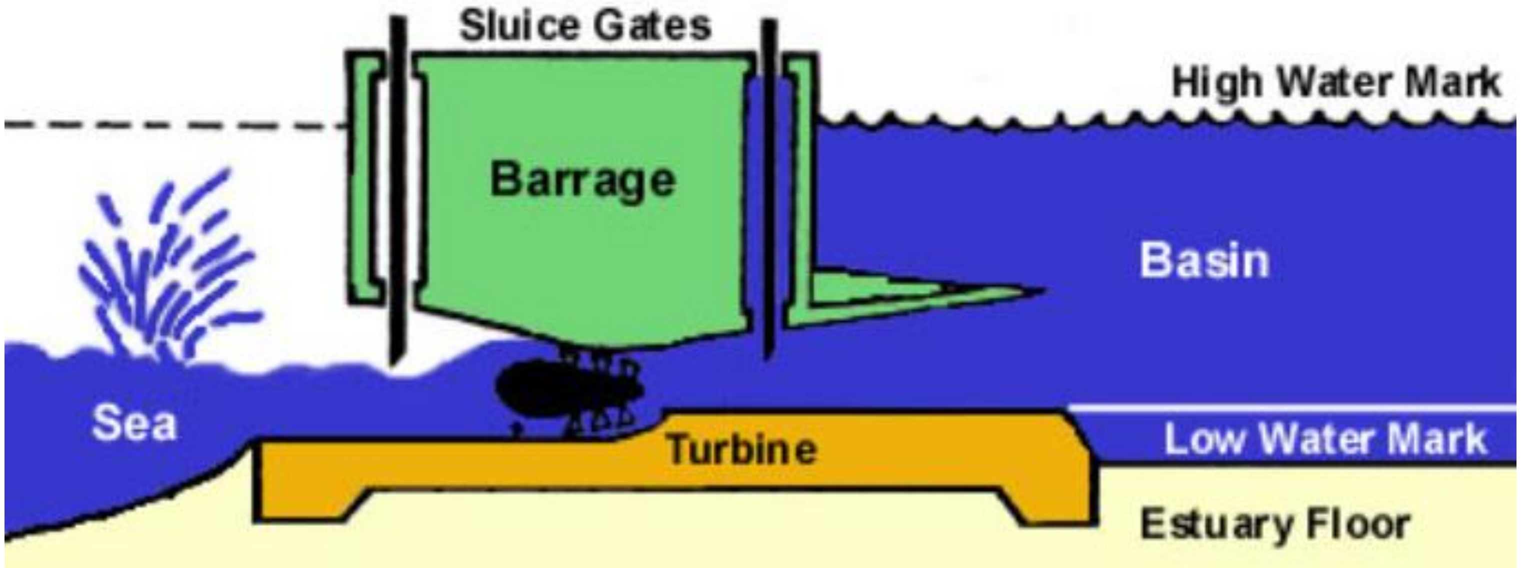
Options

- Other scenarios generate energy on both the inflow and outflow of water
  - Don’t want to limit the amount of water into the basin, as this is your power source

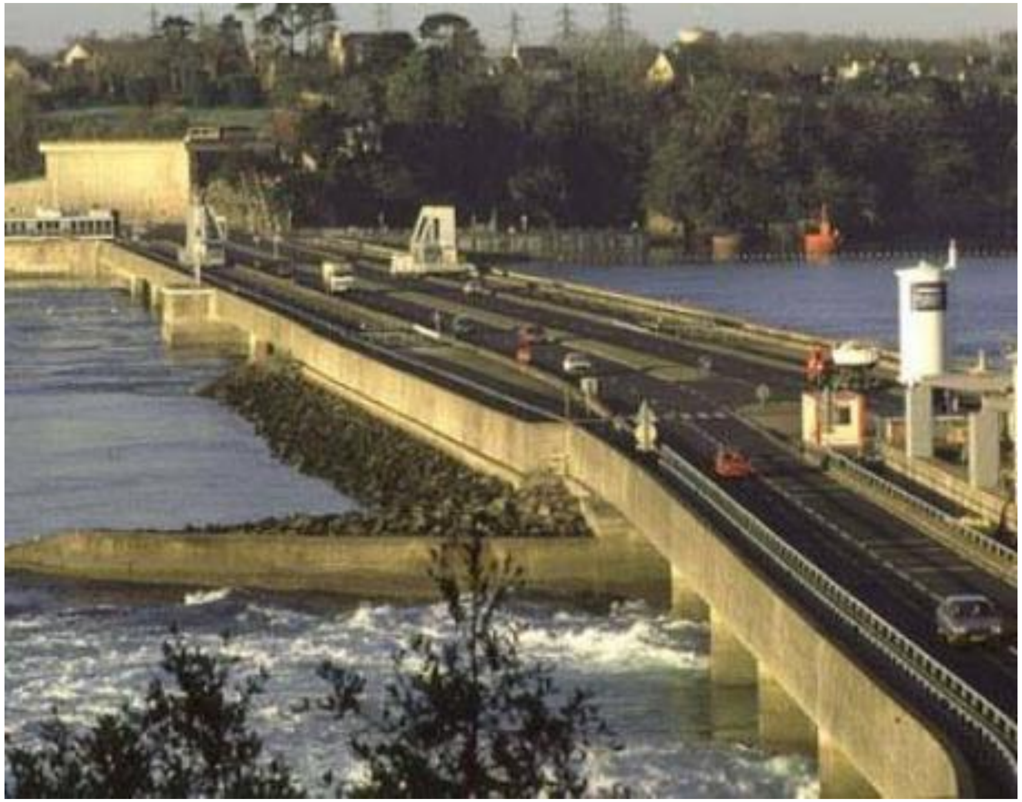
- Another final scenario uses the turbines as pumps and pumps extra water into the basin as the tide is coming in. This raises the basin height and provides more water for power regeneration
  - Extra energy is created because the power generation is at a higher water head (pressure) than when the extra water is pumped in

Tidal Energy Components





Various Installations are in Place around the World



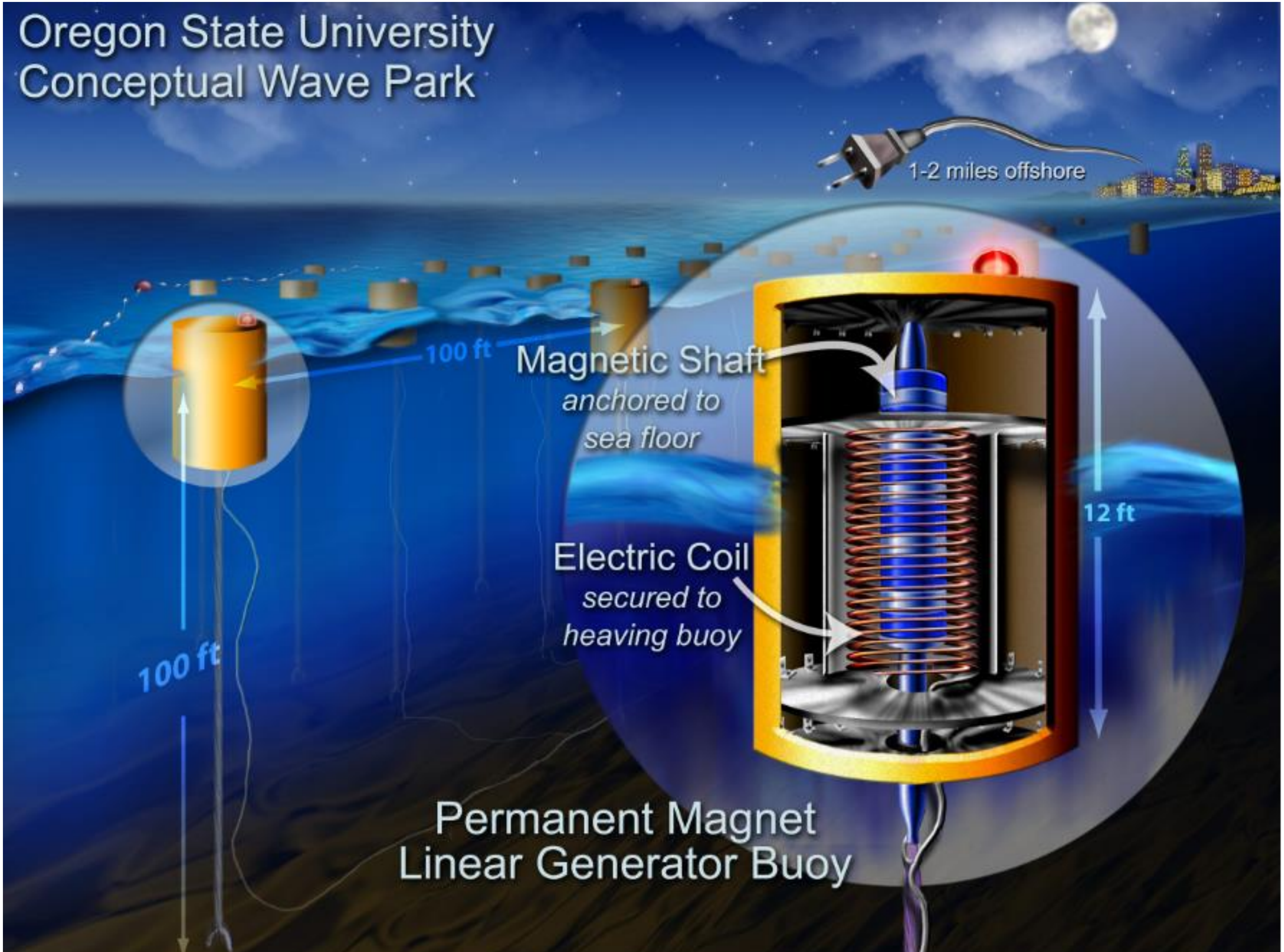
Tidal Stream

- Similar to wind power, but in the ocean

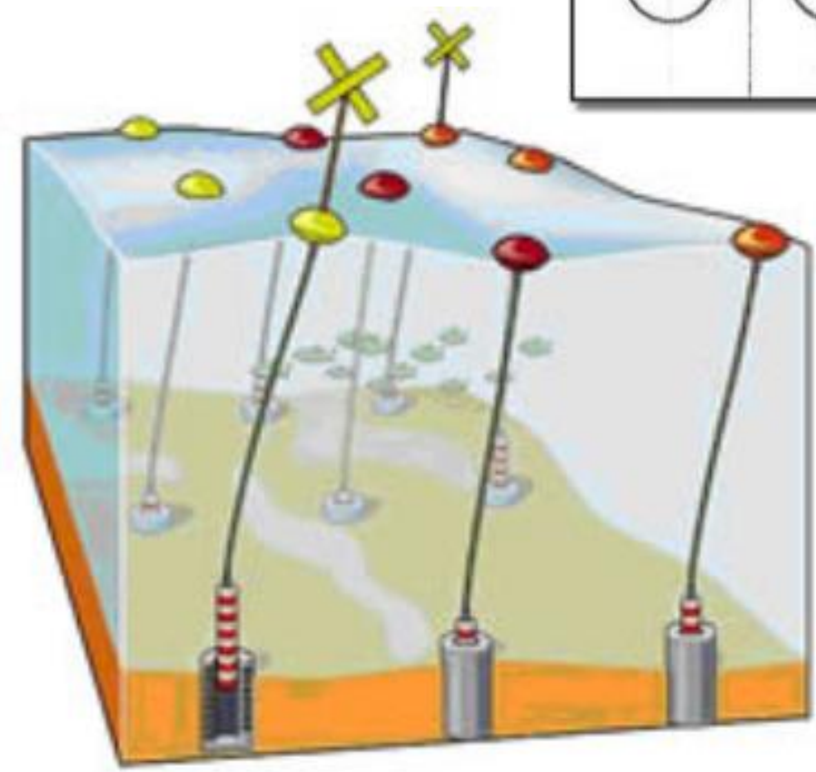
- 11 Meter blade diameter
- Water has 4X Power density over air

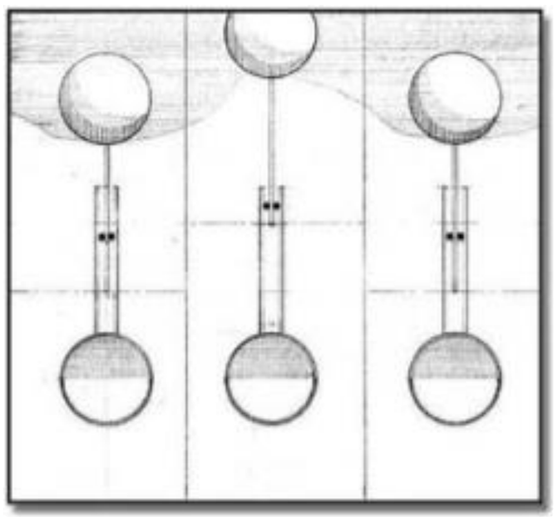
Wave Energy

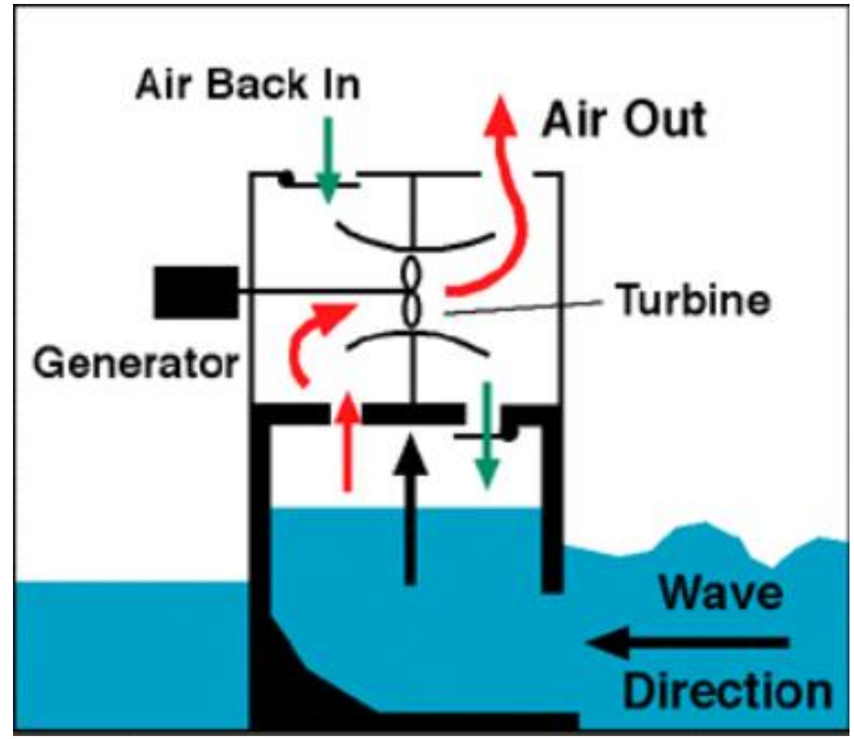
- Generates energy from the mechanical motion of individual waves
- Mostly used offshore – to capture up and down motion of waves
    - Not the foreward and backwards motion of waves
- Difficult because the low frequency of the waves must be increased to 1500 rpm – to use with conventional generating equipment


Oregon State University
Conceptual Wave Park
1-2 miles offshore
100 ft
Magnetic Shaft
anchored to
sea floor
Electric Coil
secured to
heaving buoy
12 ft
100 ft
Permanent Magnet
Linear Generator Buoy

Various Types of Wave Energy Generation

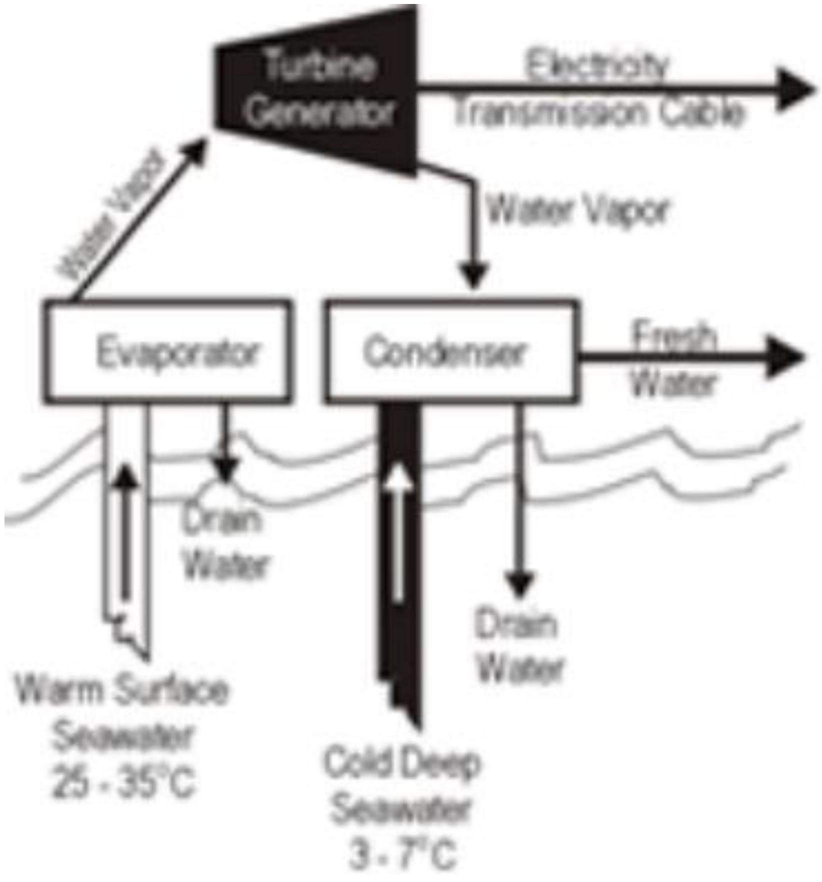






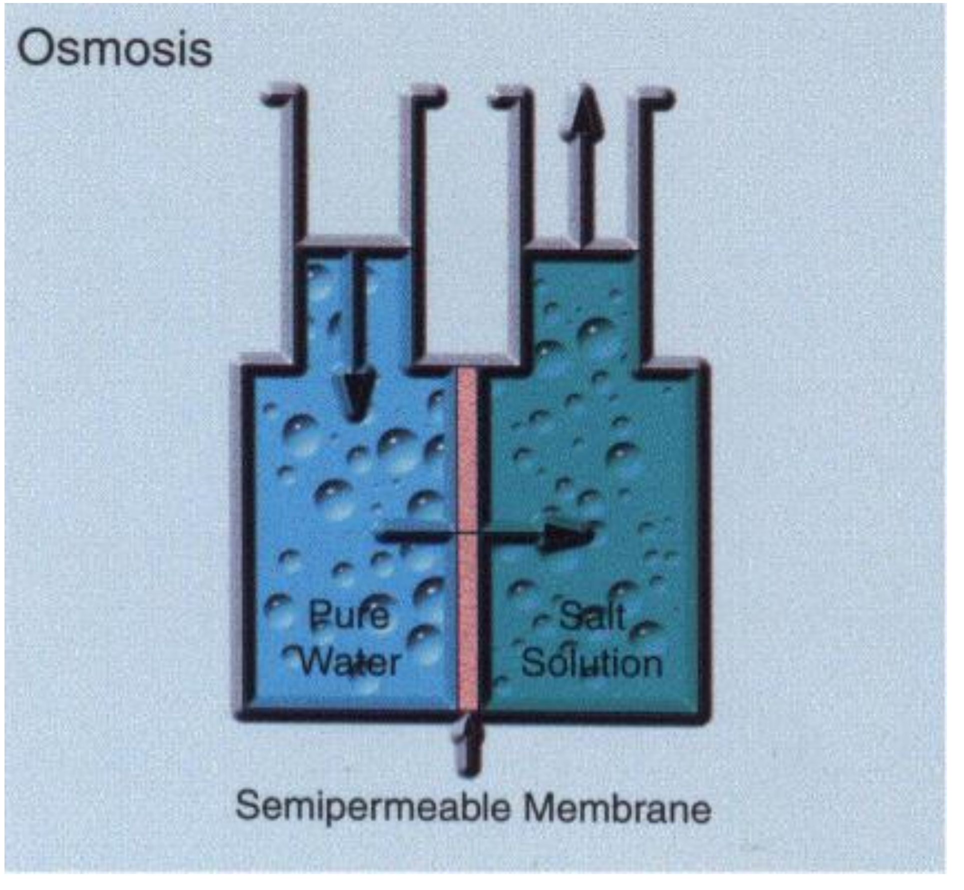
Ocean Thermal Gradient Energy

- Generates energy from the difference in temperature between different parts of the water
  - Top and bottom



Ocean Salt Gradient

- Generates energy from the difference in salinity between different parts of the ocean



Wind Generation

1. History of Wind-Mills

The wind is a by-product of solar energy. Approximately 2% of the sun's energy reaching the earth is converted into wind energy. The surface of the earth heats and cools unevenly, creating atmospheric pressure zones that make air flow from high- to low-pressure areas.

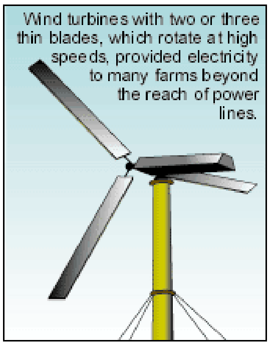
The wind has played an important role in the history of human civilization. The first known use of wind dates back 5,000 years to Egypt, where boats used sails to travel from shore to shore. The first true windmill, a machine with vanes attached to an axis to produce circular motion, may have been built as early as 2000 B.C. in ancient Babylon. By the 10th century A.D., windmills with wind-catching surfaces having 16 feet length and 30 feet height were grinding grain in the areas in eastern Iran and Afghanistan.

The earliest written references to working wind machines in western world date from the 12th century. These too were used for milling grain. It was not until a few hundred years later that windmills were modified to pump water and reclaim much of Holland from the sea.

The multi-vane "farm windmill" of the American Midwest and West was invented in the United States during the latter half of the l9th century. In 1889 there were 77 windmill factories in the United States, and by the turn of the century, windmills had become a major American export. Until the diesel engine came along, many transcontinental rail routes in the U.S. depended on large multi-vane windmills to pump water for steam locomotives.

Farm windmills are still being produced and used, though in reduced numbers. They are best suited for pumping ground water in small quantities to livestock water tanks. In the 1930s and 1940s, hundreds of thousands of electricity producing wind turbines were built in the U.S. They had two or three thin blades which rotated at high speeds to drive electrical generators. These wind turbines provided electricity to farms beyond the reach of power lines and were typically used to charge storage batteries, operate radio receivers and power a light bulb. By the early 1950s, however, the extension of the central power grid to nearly every American household, via the Rural Electrification Administration, eliminated the market for these machines. Wind turbine development lay nearly dormant for the next 20 years.

A typical modern windmill looks as shown in the following figure. The wind-mill contains three blades about a horizontal axis installed on a tower. A turbine connected to a generator is fixed about the horizontal axis.



Like the weather in general, the wind can be unpredictable. It varies from place to place, and from moment to moment. Because it is invisible, it is not easily measured without special instruments. Wind velocity is affected by the trees, buildings, hills and valleys around us. Wind is a diffuse energy source that cannot be contained or stored for use elsewhere or at another time.

2. Classification of Wind-mills

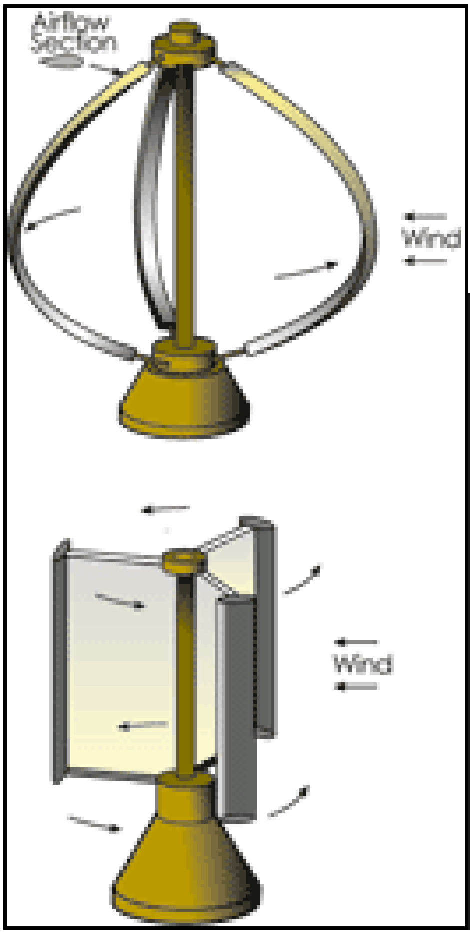
Wind turbines are classified into two general types: Horizontal axis and Vertical axis. A horizontal axis machine has its blades rotating on an axis parallel to the ground as shown in the above figure. A vertical axis machine has its blades rotating on an axis perpendicular to the ground. There are a number of available designs for both and each type has certain advantages and disadvantages. However, compared with the horizontal axis type, very few vertical axis machines are available commercially.

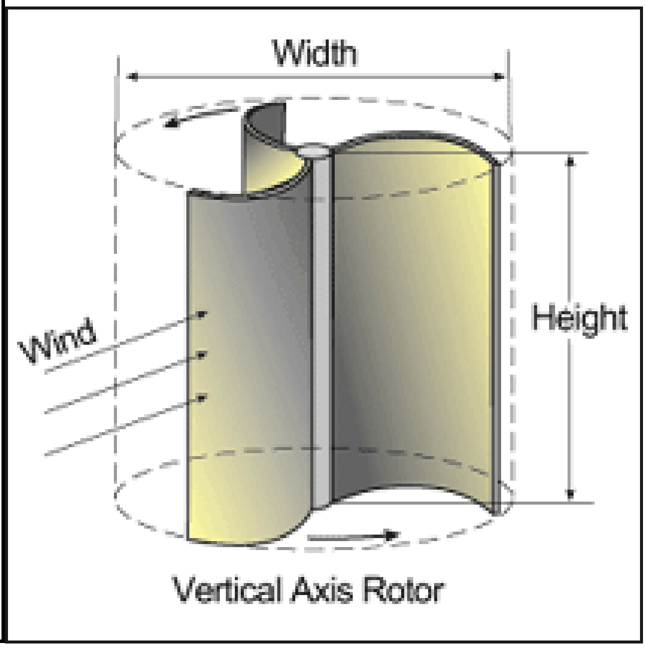
Horizontal Axis

This is the most common wind turbine design. In addition to being parallel to the ground, the axis of blade rotation is parallel to the wind flow. Some machines are designed to operate in an upwind mode, with the blades upwind of the tower. In this case, a tail vane is usually used to keep the blades facing into the wind. Other designs operate in a downwind mode so that the wind passes the tower before striking the blades. Without a tail vane, the machine rotor naturally tracks the wind in a downwind mode. Some very large wind turbines use a motor-driven mechanism that turns the machine in response to a wind direction sensor mounted on the tower. Commonly found horizontal axis wind mills are aero-turbine mill with 35% efficiency and farm mills with 15% efficiency.

Vertical Axis

Although vertical axis wind turbines have existed for centuries, they are not as common as their horizontal counterparts. The main reason for this is that they do not take advantage of the higher wind speeds at higher elevations above the ground as well as horizontal axis turbines. The basic vertical axis designs are the Darrieus, which has curved blades and efficiency of 35%, the Giromill, which has straight blades, and efficiency of 35%, and the Savonius, which uses scoops to catch the wind and the efficiency of 30%. A vertical axis machine need not be oriented with respect to wind direction. Because the shaft is vertical, the transmission and generator can be mounted at ground level allowing easier servicing and a lighter weight, lower cost tower. Although vertical axis wind turbines have these advantages, their designs are not as efficient at collecting energy from the wind as are the horizontal machine designs. The following figures show all the above mentioned mills.

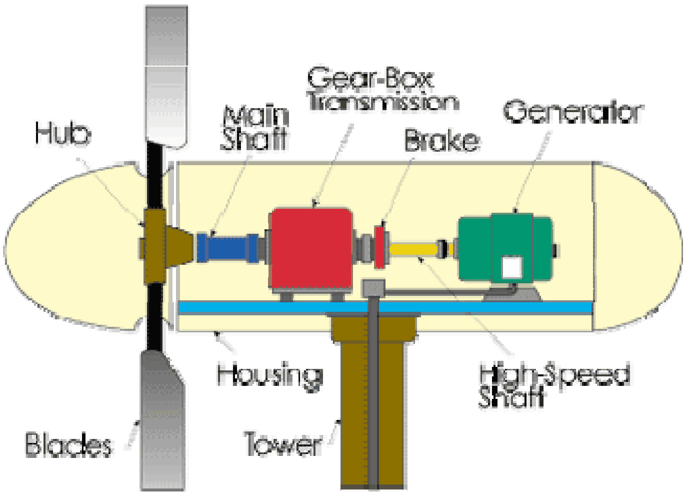




There is one more type of wind-mill called Cyclo-gyro wind-mill with very high efficiency of about 60%. However, it is not very stable and is very sensitive to wind direction. It is also very complex to build.

Main Components of a wind-mill

Following figure shows typical components of a horizontal axis wind mill.



Rotor

The portion of the wind turbine that collects energy from the wind is called the rotor. The rotor usually consists of two or more wooden, fiberglass or metal blades which rotate about an axis (horizontal or vertical) at a rate determined by the wind speed and the shape of the blades. The blades are attached to the hub, which in turn is attached to the main shaft.

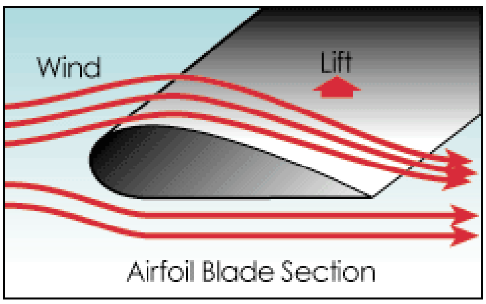
Drag Design

Blade designs operate on either the principle of drag or lift. For the drag design, the wind literally pushes the blades out of the way. Drag powered wind turbines are characterized by slower rotational speeds and high torque capabilities. They are useful for the pumping, sawing or grinding work. For example, a farm-type windmill must develop high torque at start-up in order to pump, or lift, water from a deep well.

Lift Design

The lift blade design employs the same principle that enables airplanes, kites and birds to fly. The blade is essentially an airfoil, or wing. When air flows past the blade, a wind speed and pressure differential is created between the upper and lower blade surfaces. The pressure at the lower surface is greater and thus acts to "lift" the blade. When blades are attached to a central axis, like a wind turbine rotor, the lift is translated into rotational motion. Lift-powered wind turbines have much higher rotational speeds than drag types and therefore well suited for electricity generation.

Following figure gives an idea about the drag and lift principle.



Tip Speed Ratio

The tip-speed is the ratio of the rotational speed of the blade to the wind speed. The larger this ratio, the faster the rotation of the wind turbine rotor at a given wind speed. Electricity generation requires high rotational speeds. Lift-type wind turbines have maximum tip-speed ratios of around 10, while drag-type ratios are approximately 1. Given the high rotational speed requirements of electrical generators, it is clear that the lift-type wind turbine is most practical for this application.

The number of blades that make up a rotor and the total area they cover affect wind turbine performance. For a lift-type rotor to function effectively, the wind must flow smoothly over the blades. To avoid turbulence, spacing between blades should be great enough so that one blade will not encounter the disturbed, weaker air flow caused by the blade which passed before it. It is because of this requirement that most wind turbines have only two or three blades on their rotors.

Generator

The generator is what converts the turning motion of a wind turbine's blades into electricity. Inside this component, coils of wire are rotated in a magnetic field to produce electricity. Different generator designs produce either alternating current (AC) or direct current (DC), and they are available in a large range of output power ratings. The generator's rating, or size, is dependent on the length of the wind turbine's blades because more energy is captured by longer blades.

It is important to select the right type of generator to match intended use. Most home and office appliances operate on 240 volt, 50 cycles AC. Some appliances can operate on either AC or DC, such as light bulbs and resistance heaters, and many others can be adapted to run on DC. Storage systems using batteries store DC and usually are configured at voltages of between 12 volts and 120 volts.

Generators that produce AC are generally equipped with features to produce the correct voltage of 240 V and constant frequency 50 cycles of electricity, even when the wind speed is fluctuating.

DC generators are normally used in battery charging applications and for operating DC appliances and machinery. They also can be used to produce AC electricity with the use of an inverter, which converts DC to AC.

Transmission

The number of revolutions per minute (rpm) of a wind turbine rotor can range between 40 rpm and 400 rpm, depending on the model and the wind speed. Generators typically require rpm's of 1,200 to 1,800. As a result, most wind turbines require a gear-box transmission to increase the rotation of the generator to the speeds necessary for efficient electricity production. Some DC-type wind turbines do not use transmissions. Instead, they have a direct link between the rotor and generator. These are known as direct drive systems. Without a transmission, wind turbine complexity and maintenance requirements are reduced, but a much larger generator is required to deliver the same power output as the AC-type wind turbines.

Tower

The tower on which a wind turbine is mounted is not just a support structure. It also raises the wind turbine so that its blades safely clear the ground and so it can reach the stronger winds at higher elevations. Maximum tower height is optional in most cases, except where zoning restrictions apply. The decision of what height tower to use will be based on the cost of taller towers versus the value of the increase in energy production resulting from their use. Studies have shown that the added cost of increasing tower height is often justified by the added power generated from the stronger winds. Larger wind turbines are usually mounted on towers ranging from 40 to 70 meters tall.

Towers for small wind systems are generally "guyed" designs. This means that there are guy wires anchored to the ground on three or four sides of the tower to hold it erect. These towers cost less than freestanding towers, but require more land area to anchor the guy wires. Some of these guyed towers are erected by tilting them up. This operation can be quickly accomplished using only a winch, with the turbine already mounted to the tower top. This simplifies not only installation, but maintenance as well. Towers can be constructed of a simple tube, a wooden pole or a lattice of tubes, rods, and angle iron. Large wind turbines may be mounted on lattice towers, tube towers or guyed tilt-up towers.

Towers must be strong enough to support the wind turbine and to sustain vibration, wind loading and the overall weather elements for the lifetime of the wind turbine. Their costs will vary widely as a function of design and height.

3. Operating Characteristics of wind mills

All wind machines share certain operating characteristics, such as cut-in, rated and cut-out wind speeds.

Cut-in Speed

Cut-in speed is the minimum wind speed at which the blades will turn and generate usable power. This wind speed is typically between 10 and 16 kmph.

Rated Speed

The rated speed is the minimum wind speed at which the wind turbine will generate its designated rated power. For example, a "10 kilowatt" wind turbine may not generate 10 kilowatts until wind speeds reach 40 kmph. Rated speed for most machines is in the range of 40 to 55 kmph. At wind speeds between cut-in and rated, the power output from a wind turbine increases as the wind increases. The output of most machines levels off above the rated speed. Most manufacturers provide graphs, called "power curves," showing how their wind turbine output varies with wind speed.

Cut-out Speed

At very high wind speeds, typically between 72 and 128 kmph, most wind turbines cease power generation and shut down. The wind speed at which shut down occurs is called the cut-out speed. Having a cut-out speed is a safety feature which protects the wind turbine from damage. Shut down may occur in one of several ways. In some machines an automatic brake is activated by a wind speed sensor. Some machines twist or "pitch" the blades to spill the wind. Still others use "spoilers," drag flaps mounted on the blades or the hub which are automatically activated by high rotor rpm's, or mechanically activated by a spring loaded device which turns the machine sideways to the wind stream. Normal wind turbine operation usually resumes when the wind drops back to a safe level.

Betz Limit

It is the flow of air over the blades and through the rotor area that makes a wind turbine function. The wind turbine extracts energy by slowing the wind down. The theoretical maximum amount of energy in the wind that can be collected by a wind turbine's rotor is approximately 59%. This value is known as the Betz limit. If the blades were 100% efficient, a wind turbine would not work because the air, having given up all its energy, would entirely stop. In practice, the collection efficiency of a rotor is not as high as 59%. A more typical efficiency is 35% to 45%. A complete wind energy system, including rotor, transmission, generator, storage and other devices, which all have less than perfect efficiencies, will deliver between 10% and 30% of the original energy available in the wind.

Mathematical Expression Governing Wind Power

The wind power is generated due to the movement of wind. The energy associated with such movement is the kinetic energy and is given by the following expression:

$Energy = KE = \frac{1}{2} \cdot m \cdot v^2$ Where

m = Air mass in Kg = Volume (m^3) x Density (Kg/m^3) = Q x ρ

Q = Discharge

v = Velocity of air mass in m/s

Hence, the expression for power can be derived as follows:

$$Power = \frac{dE}{dt}$$

$$= \frac{1}{2} \cdot \frac{d}{dt}\left\{m \cdot v^2\right\}$$

$$= \frac{1}{2} \cdot \frac{d}{dt}\left\{\rho \cdot Q \cdot v^2\right\}$$

$$= \frac{1}{2} \cdot \rho \cdot \frac{dQ}{dt} \cdot v^2$$

Here, $\frac{dQ}{dt}$ = Rate of discharge (m^3/s) = A (m^2) • v (m/s)

Where, A = Area of cross section of blade movement.

$$Power = \frac{1}{2} \cdot \rho \cdot A \cdot v^3$$

We know that for given length of blades, A is constant and so is the air mass density ρ. Hence we can say that wind power is directly proportional to (wind speed) ^{3}.

At sea level, ρ = 1.2 Kg/m^3. Therefore,

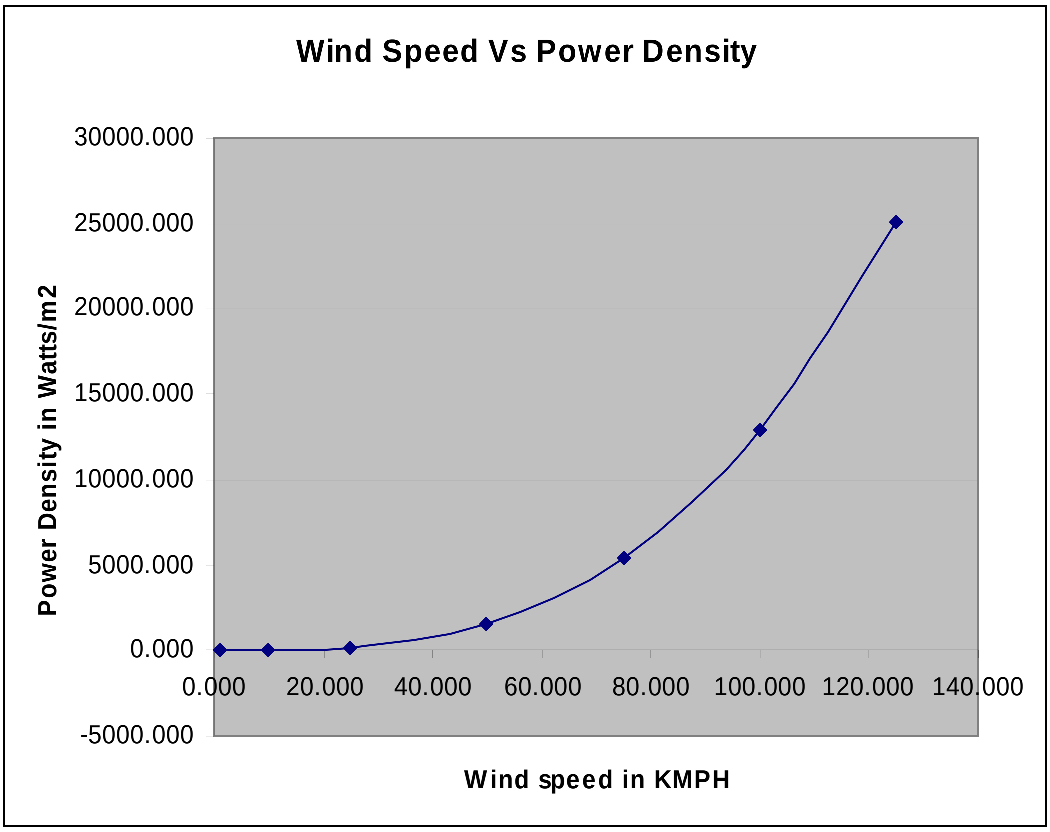
$$Power = \frac{1}{2} \cdot (1.2) \cdot A \cdot v^3$$

$$\frac{Power}{Area} = (0.6) \cdot v^3 \text{ = Power Density in watts/m}^2$$

Let us construct a chart relating the wind speed to the power density and the output of the wind turbine assuming 30% efficiency of the turbine as shown in the following table.

Wind Speed kmph	Wind speed m/s	Power Density Watts/m^2	Turbine Output 30% efficiency
1	0.278	0.013	0.004
Wind Speed kmph	Wind speed m/s	Power Density Watts/m^2	Turbine Output 30% efficiency
10	2.778	12.860	3.858
25	6.944	200.939	60.282
50	13.889	1607.510	482.253
75	20.833	5425.347	1627.604
100	27.778	12860.082	3858.025
125	34.722	25117.348	7535.204

The following plot gives the relationship between wind speed in KMPH and the power density.



In the last column of the table, we have calculated the output of the turbine assuming that the efficiency of the turbine is 30%. However, we need to remember that the efficiency of the turbine is a function of wind speed. *It varies with wind speed.*

Now, let us try to calculate the wind speed required to generate power equivalent to 1 square meter PV panel with 12% efficiency. We know that solar insolation available at the PV panel is 1000 watts/m^2 at standard condition. Hence the output of the PV panel with 12% efficiency would be 120 watts. Now the speed required to generate this power by the turbine with 30% efficiency can be calculated as follows:

Turbine output required = 120 Watts/m^2

Power Density at the blades = 120/ (0.3) = 400 watts/m^2

Therefore, the wind speed required to generate equivalent power in m/s = $\left(\frac{400}{0.6}\right)^{1/3}$ = 8.735805 m/s = 31.4489 kmph.

We have seen that the theoretical power is given by the following expression:

$$P_{theoretical} = \frac{1}{2}\cdot\rho\cdot A\cdot v^3$$

However, there would be losses due to friction and hence, the actual power generated would be smaller. The co-efficient of power is defined as the ratio of actual power to the theoretical power. That is,

$$C_p = \frac{P_{actual}}{P_{theoretical}}$$

Another important ratio we need to know is the tip speed ratio. It is defined as the ratio of tip speed of blade to wind speed. That is,

$$T_R = \frac{Tip\_Speed\_of\_Blade}{Wind\_Speed} = \frac{\omega \cdot radius}{velocity} = \frac{(radians/\sec ond) \cdot meters}{(meters/\sec ond)}$$

In general, C_p is of the order of 0.4 to 0.6 and T_R is of the order of 0.8. Performance measure of a wind mill is given by a plot of T_R Vs C_p as shown in the following figure:

Example:

A small stream has a head of 60 meters and a flow of 10 liters/second. Calculate

a. The hydraulic power
b. The net head and net hydraulic power
c. The useful mechanical power
d. The useful electrical power

Solution:

Hydraulic power in watts = 9.81 x Head (meters) x Flow (liters/second)

= 9.81 x 60 x 10

= 5886 watts = 5.886 kW

Net head = Actual head – loss of head due to friction

Assuming 25% loss due to friction, loss of head due to friction = 0.25 x 60 m = 15 m

Hence, Net head = 60 m – 15 m = 45 m

Net hydraulic power = 9.81 x Net head (meters) x Flow (liters/sec)

= 9.81 x 45 x 10

= 4414 watts = 4.414 kW

Useful mechanical power = net hydraulic power x turbine efficiency

Assuming turbine efficiency of 65%, we get

Useful mechanical power = 4414 x 0.65

= 2870 watts = 2.87 kW

Useful electrical power = useful mechanical power x generator efficiency

Assuming generator efficiency of 80%, we get

Useful electrical power = 2870 x 0.8

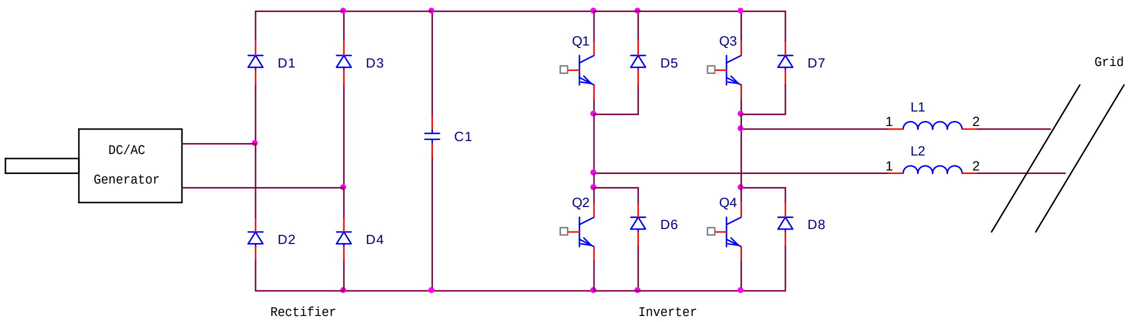
= 2295 watts = 2.295 kW

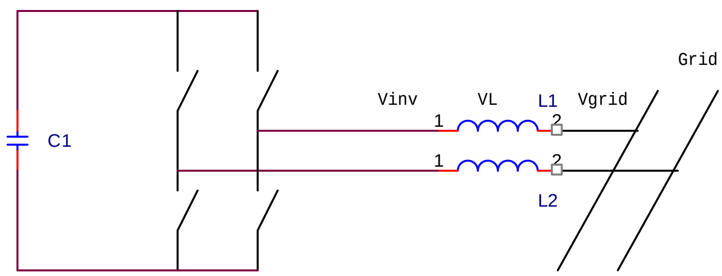
4. Grid Connection

We have seen in the previous section the generation of electrical power by the flow of water through turbines. The generated electrical power could be dc or ac depending on the type of generator. After the power is generated, it needs to be transmitted and distributed to consumers by connecting it to the grid. Following figure shows how the grid connection is done. It has the following sections:

1. The rectifier
2. The capacitor
3. Switches
4. Inductor

The rectifier is required if the generated power is ac by alternator or induction generator. The capacitor is required to smooth the generated power. Switches are required to convert the power to ac to match the grid frequency and inductors are required to develop the voltage.





In the above figure,

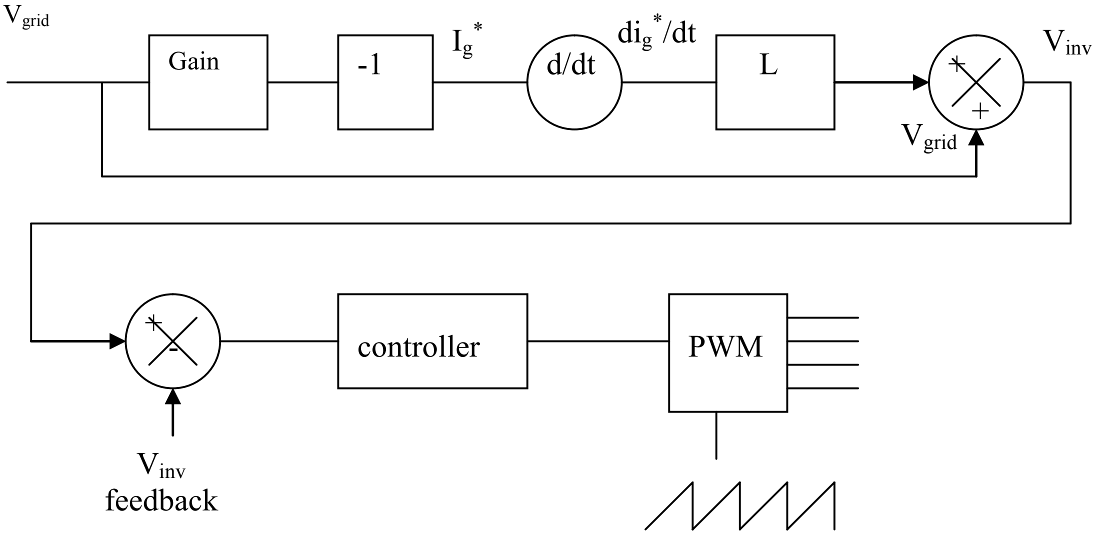
$$v_L = L \cdot \frac{di_L}{dt} \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (1)$$

$$i_L = \frac{1}{L} \cdot \int v_L \cdot dt \quad \ldots\ldots (2)$$

Also

$$\frac{di_L}{dt} = \frac{v_L}{L} = \frac{v_{inv} - v_{grid}}{L} \quad \ldots\ldots (3)$$

The above equation can be realized as follows:



The starting reference is the grid voltage V_{grid}. The current I_g^* proportional to the grid voltage is fed through a differentiator giving dI_g^*/dt. This is equivalent to a value given in equation (3). Multiplying this value by L gives ($V_{inv} - V_{grid}$). Adding this to V_{grid} taken directly from the grid gives V_{inv}. This is compared to the actual V_{inv} measured at the output of the inverter. If the error is zero, then the voltage across the grid and the voltage at the output of the inverter are same and hence can be connected to each other. If there is an error signal then the controller changes the duty cycle of PWM such that the error signal becomes zero.

Harnessing wind power by means of windmills can be traced back to about four thousand years from now when they were used for milling and grinding of grains and for pumping of water. However there has been a renewed interest in wind energy in the recent years as it is a potential source of electricity generation with minimum environmental impact [1]. According to present growth the accumulated world wide installed wind electric generation capacity will reach to 50GW at the end of year 2005[2]. India has the fifth position in the generation of wind electric generation. In India Wind power plants have been installed in Gujarat, Maharashtra, Tamilnadu and Orissa where wind blows at a speeds of 30Km/hr during summer [3] but India has lot of potential for generation of wind power at other places in Andhra Pradesh, Madhya Pradesh, Karnatka and Kerala. The total estimated wind power potential in India is about 45195MW[4].

Wind electric systems directly feeding to the local load are known as the isolated wind energy system but the wind energy system that are connected to grid are known as grid connected system. Wind is not available all the time for the generation of electric power and power output of wind turbine is proportional to the cube of the velocity of wind and the power output is optimal for a particular wind velocity. So Large wind electric generator (WEG) systems are connected to utility grid where they feed the power to grid.

The connection of cage rotor Induction Generator to grid again cause the problems in terms of drawing large magnetizing current from grid at very low power factor. Under the low wind conditions when the machine draws only reactive power from grid and stator power factor is very poor. Lagging power factor is compensated by connecting capacitor banks across the line. Depending on the active power generated these capacitors are either cut-in or cutout to regulate the power factor. The switching of capacitors may cause the over voltage in power system [1]. So various techniques for connecting the WEG to grid has been proposed [2,5,6]. The stand -alone system can be better utilized by using load-matching techniques [7].

5. Wind Energy Regions in India

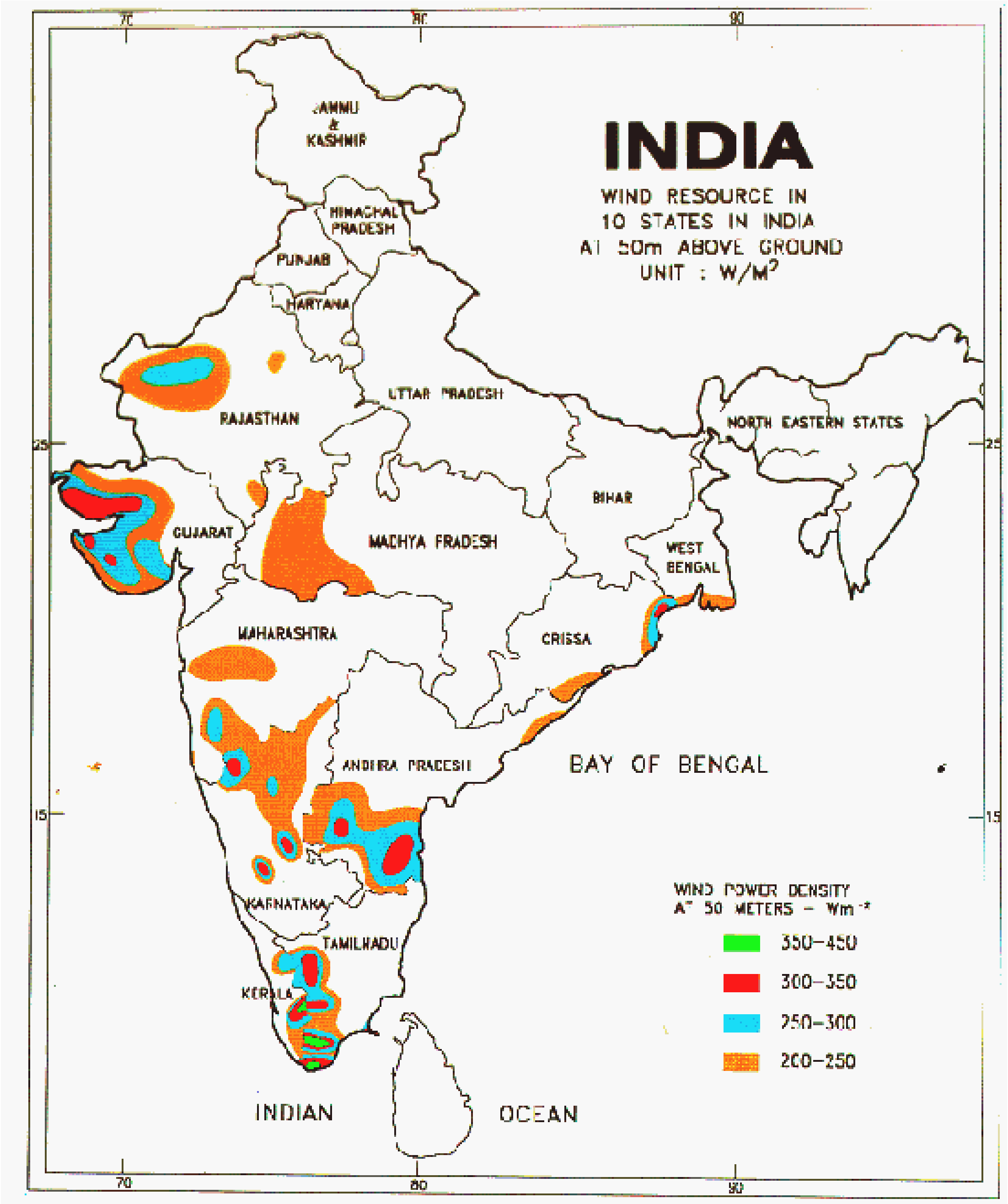
India has several on shore and off shore wind energy sites. India has a lot of scope in terms of harnessing wind power using these sites. The state wise estimated wind power potential in India is shown in table1 (Gross potential is based on assuming 1% of land availability for wind power generation in potential areas.)

Si No.	State	Gross Potential (MW)	Total Capacity (MW) (31-09-04)	Technical Potential (MW)
1	Andhra Pradesh	8275	101.3	1750
2	Gujarat	9675	218.5	1780
3	Karnataka	6620	274.2	1120
4	Kerala	875	2	605
5	Madhya pradesh	5500	26.35	825
6	Maharashtra	3650	411.15	3020
7	Rajasthan	5400	212.0	895
8	Tamilnadu	3050	1683.6	1750

9	West Bengal	450	1.1	450
10	Others	2990	3.1	-
11	Total (All India)	45195	2884.75	12875

Table: 1

WEG of 2 MW capacity is installed in suzlon (Tamilnadu) is the largest power rating in India. Maximum WEG installations are in Tamilnadu of capacity about 1639MW.Maximum gross estimated Wind potential is in Gujarat of 9675 MW. The map of India is shown below indicating the various wind energy sites in India.


INDIA
WIND RESOURCE IN
10 STATES IN INDIA
AT 50m ABOVE GROUND
UNIT : W/M²
JAMMU & KASHMIR
HIMACHAL PRADESH
PUNJAB
HARYANA
RAJASTHAN
UTTAR PRADESH
NORTH EASTERN STATES
BIHAR
GUJARAT
MADHYA PRADESH
WEST BENGAL
MAHARASHTRA
ORISSA
ANDHRA PRADESH
BAY OF BENGAL
KARNATAKA
TAMILNADU
KERALA
INDIAN
OCEAN
WIND POWER DENSITY
AT 50 METERS - Wm⁻²
350-450
300-350
250-300
200-250
70
80
90
25
15

Limitations of Present day WEG 's

Most of the present day WEG 's are the constant speed installations. These WEG'S have some limitations as given below

A- *Poor Energy Capture –*

This is due to low aerodynamic efficiency of WEG and the variation in efficiency over the entire operating range.

Power output of turbine

$$Pt = .5\ Cp\ \rho\ A\ v^3$$

ρ = Air density, A = swept area, v =wind velocity, Cp is called the power coefficient and is dependent on the linear velocity of the blade tip ($R\omega$) and the wind velocity (v). The ratio, known as the tip-speed ratio, is defined as

$\lambda = R\omega/v$ where R is the radius of the turbine

From fig 1 it is observed that the power coefficient is maximum for a particular tip ratio. So power capture is not optimum at other wind velocity.

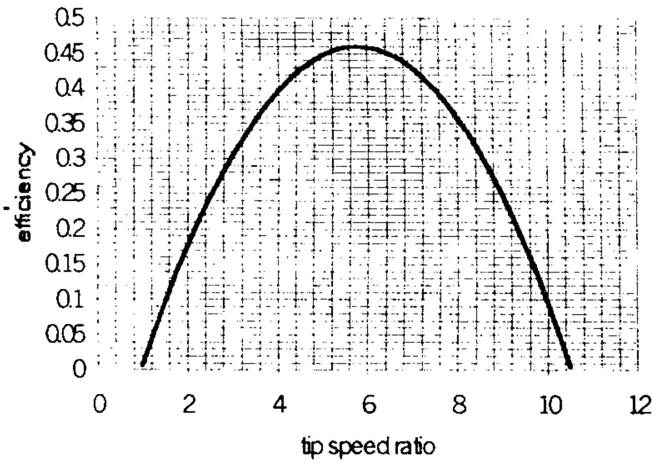


Fig: 1

B- *Reactive Power Consumption –*

Since most WEG 's employ induction generators as electromechanical energy converters these WEG 's draw reactive power from grid for excitation. This leads to additional T&D losses and changes in voltage stability margins.

C- *Unstable grid frequency -*

Most WEG 's have their blade design based on expected speed of the IG (grid frequency). The aerodynamic efficiency greatly reduces when the grid frequency is not maintained a constant at the specified level due to the changes in the tip speed ratio.

By considering above-mentioned problems it is preferable to run WEG at variable speed. A variable speed WEG enables enhanced power capture as compared to constant speed WEG. The rotor speed can be made to vary with changing wind velocity so the turbine always operates with max Cp within the power and speed limits of the system.

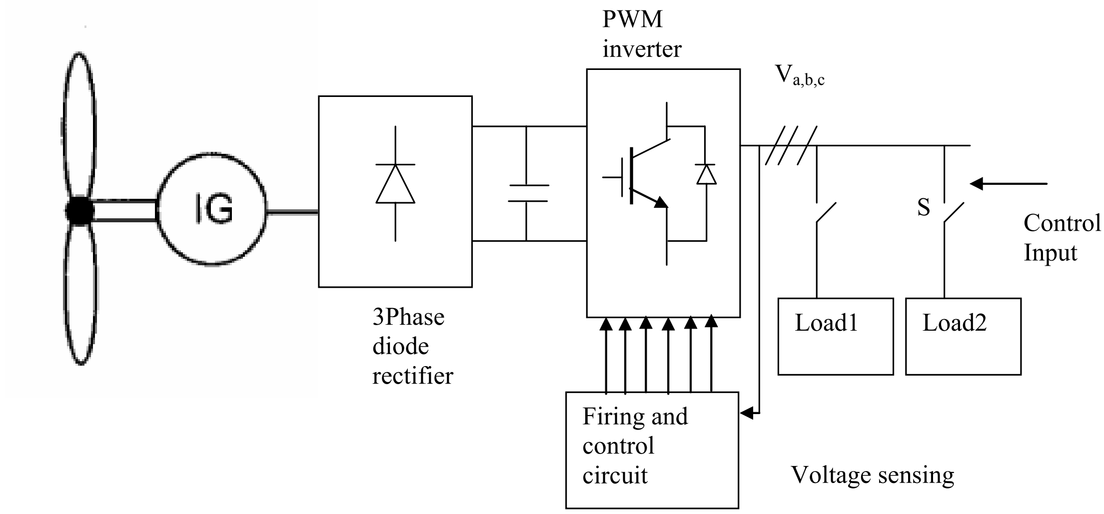
Various control schemes are used for both Isolated WEG and grid connected WEG running at variable speed.

Isolated WEG

A- *Load Matching*-

When wind driven self excited Induction generator (SEIG) running at variable

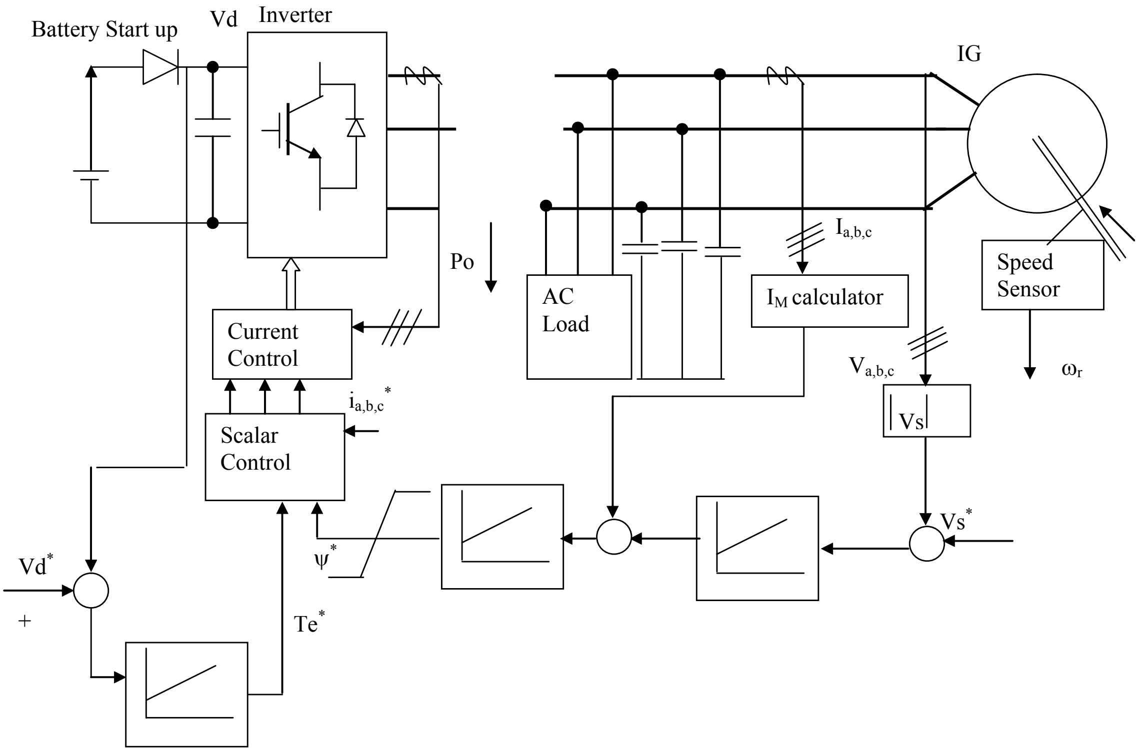
Speed, it is essential that the power output of the generator increase with increasing power input to the prime mover, which in the case of wind turbine varies approximately as the cube of the wind speed. If this load matching is not planned properly, the generator would either over speed at high wind speed or come out of excitation at low wind speeds. Further, since the output voltage and frequency of the generator varies with wind speed for many applications requiring constant voltage, some kind of power electronic controller is needed between the generator and load. Fig shows a scheme employing a PWM inverter to obtain the voltage of required magnitude and frequency at the load terminal. Loads are connected through control switch, which could appropriately be activated by monitoring the wind speed as shown in the fig2.



B- *Scalar Control of IG -*

Scalar control of IG means control of magnitude of voltage and frequency so as to achieve suitable speed with an impressed slip. Scalar control disregards the coupling effect on the generator; that is, the voltage will be set to control the flux and the frequency in order to control the torque.

If the IG is primarily in stand-alone operation, reactive power must be supplied for proper excitation. The overall scheme of control is shown below in fig3.



The capacitor bank is bulk uncontrolled source of reactive current. The static VAR compensator is an inverter providing a controlled source of reactive current. Machine torque and flux input will be used in this application to regulate both DC link voltage at the capacitance C and generator voltage supplied for the AC load. These regulators have to reject the disturbances produced by load and speed variations. A DC link voltage regulator has been implemented to achieve high enough DC link voltage for proper current controlled inverter operation. The regulator input is the difference between the DC link reference and measured value.

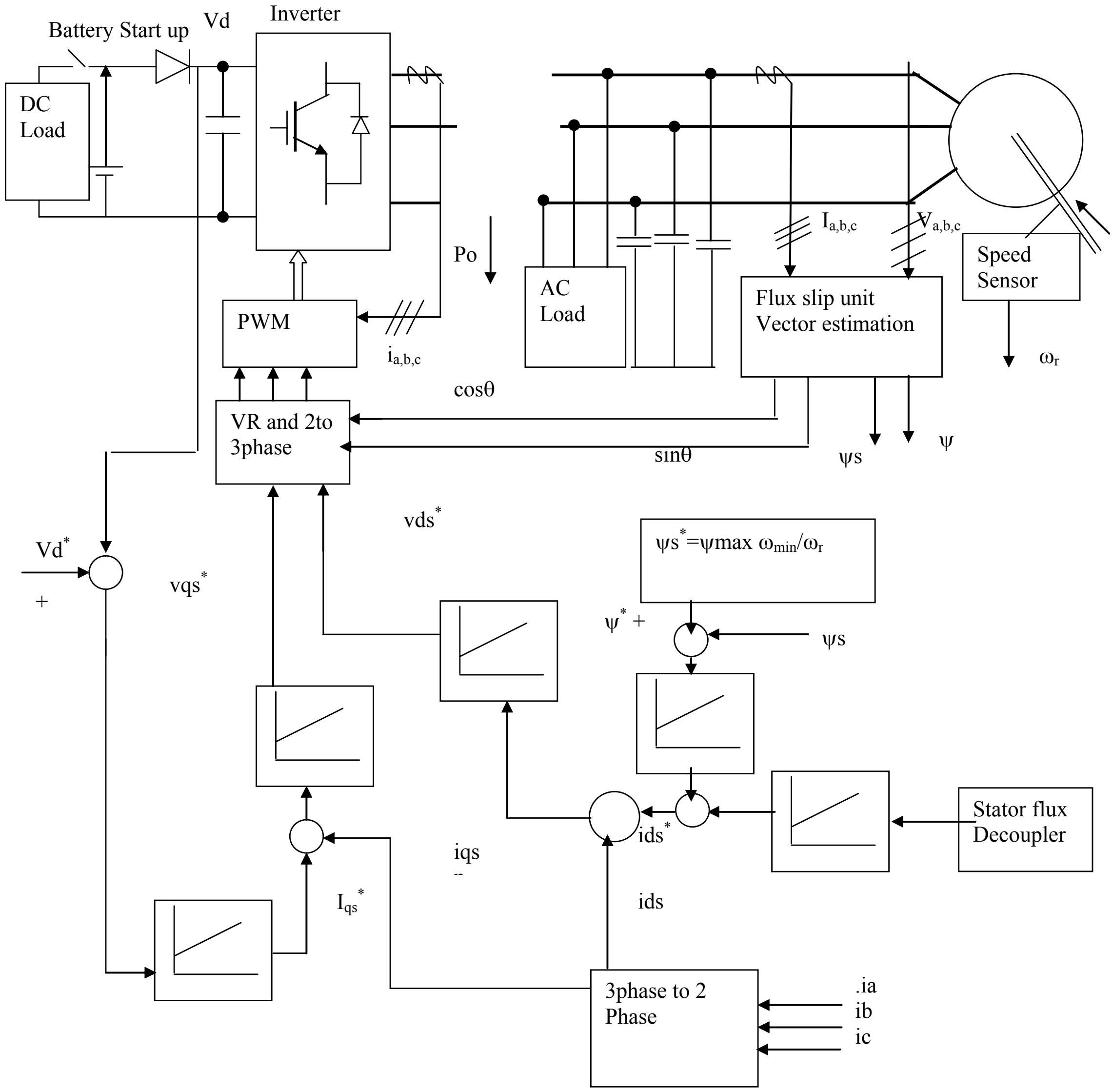
At the generator side terminal current and voltages are measured to calculate the magnetizing current needed for the generator, and the instantaneous peak voltage is compared to the stator voltage reference, which generates a set point for flux through the feedback loops on the inverter side. This system requires a charged battery startup. That can be recharged with an auxiliary circuit after the system is operational. Since stator voltage is kept constant the frequency can be stabilized at about 50Hz for the AC load, but some slight frequency variation is still persists and the range of turbine shaft variation should be within the critical slip in order to avoid instability. Therefore AC loads should not be too sensitive for frequency variation in this stand- alone application.

C- *Vector Control of IG-*

The decoupled flux and torque control of IG is known as vector control.

For an IG operating in stand- alone mode, a procedure to regulate the output voltage is required as shown in the fig4.

The DC link voltage across the capacitor is kept constant and machine impressed terminal frequency will vary with variable speed.
Since the frequency of generated voltage depends on the wind speed (rotor speed), the product of the rotor speed and the flux linkage should be remain constant so that the terminal voltage will remain constant, where the maximum rotor speed corresponding to maximum saturated flux linkage. The system starts up with a battery connected to the inverter. Then, as the system DC link voltage is regulated a higher value across the capacitor, the battery will be turned off by the diode and the DC load can be supplied across the capacitor. The machine terminals are also capable of supplying the power to an auxiliary load at variable frequency.

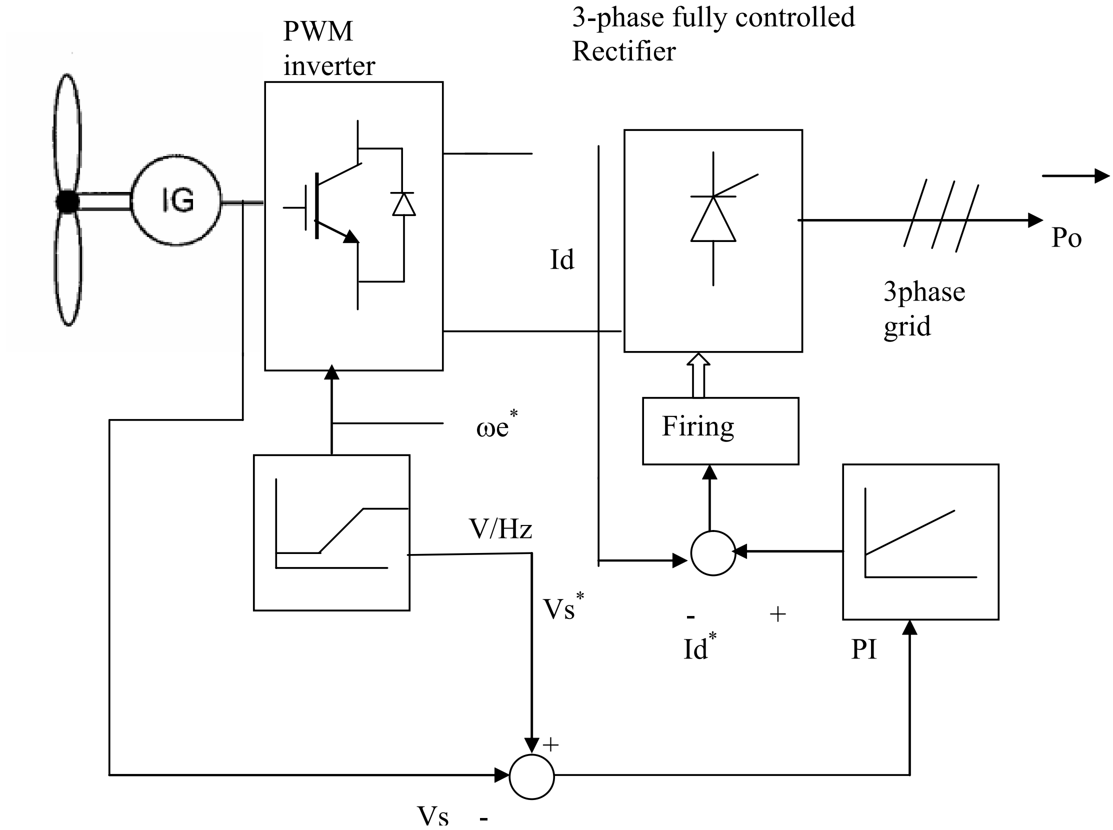


Generator Connected to Grid

A -*Scalar Control*

A current –fed link system for grid connection with constant V/Hz is depicted in fig5.

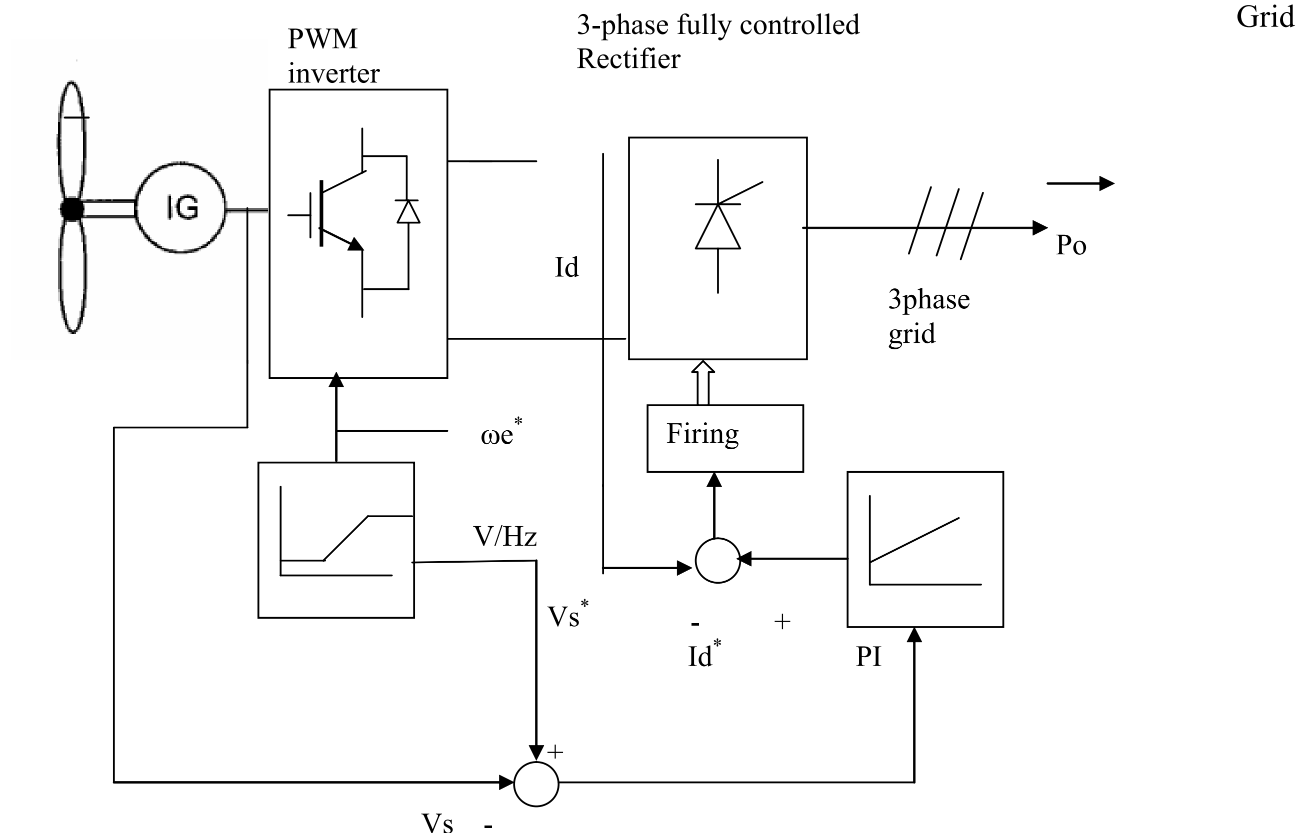
The DC link current allows easy bi-directional flow of power. Although the DC link current is unidirectional, a power reversal is achieved by a change in polarity of the mean DC link voltage and symmetrical voltage and symmetrical voltage blocking switches are required. A thyristor-based controlled rectifier manages the three phase utility side and machine side inverter can use a transistor with a series diode. The system is commanded by the machine stator frequency reference (ω^*_e). A PI control produces set point for DC link current, and firing for the thyristor bridge controls the power exchange (P_o) with the grid. The stator frequency reference ω^*_e can be varied in order to optimize the power tracking of IG.



B-*Vector Control*

Squirrel cage and Wound rotor IG are commonly used in WEG 's. These machines have different control strategies. The WRIG is more advantageous as compared to SQIG for variable speed constant frequency (VSCF) type of operation.

The variable frequency, variable voltage power generated by the machine is converted to fixed frequency, fixed voltage power by the power converter and supplied to the grid. The power converter supplies the lagging excitation current to the machine while the reactive power is supplied to the utility grid can be controlled independently as shown in fig6. The converter is a back-to-back two level converter but the converter could be theoretically any 3-phase converter allowing by bi-directional power flow.



Generator-Inverter Control

Input to the generator-inverter control scheme is the desired electromechanical torque at the generator shaft. From the torque reference, the flux reference is calculated-alternatively; the flux reference level may be set manually. Based on measurements of the generator voltages and currents, the actual flux and torque are estimated and compared with their respective reference values. The error is input to a hysteresis controller. Based on the output from these two hysteresis controllers the desired switch vector is chosen. In order to track the maximum power point, the maximum power point algorithm can be used to set the torque as described in [1].

To control the active power through the grid inverter, the dc-link voltage is measured and compared to the actual dc-link voltage. The dc-link voltage error is fed to a PI controller having a power reference as output. To provide a fast response of the grid inverter control, the measured power from the generator measured in the dc-link, is fed forward. The power error is input to another PI controller, giving the active current reference as output. The active current reference is compared to the actual active current all transformed to the synchronously rotating reference frame. The current error is then fed into a third PI controller having the q-axis voltage reference as output. Similarly, the reactive current reference is compared to the actual reactive current and the error is input to a PI controller having the d-axis voltage reference. These 2 d and q voltage references are transformed back to stationary reference frame and the gate signals are calculated

Above scheme has following advantages as compared to conventional system

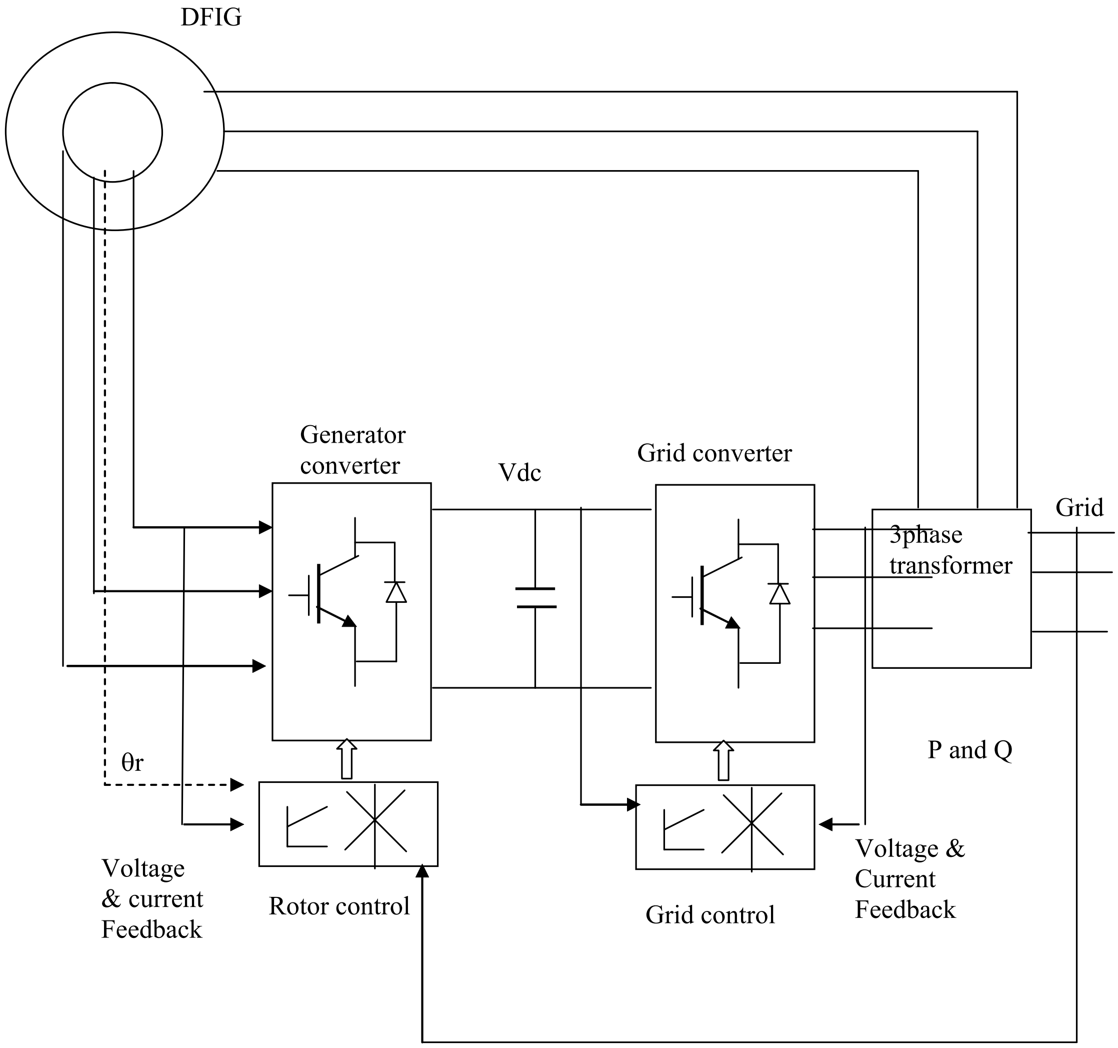
1-For same turbine it allows higher power capture, thereby increasing the annual energy output significantly.

2-This system is capable of providing the reactive power of IG from DC bus capacitance.

3-Since the torque of the machine is controlled the generator cannot be overloaded at any point of time beyond the prescribed limits.

Doubly Fed Induction Generator (DFIG)

Compared to the squirrel-cage induction generator, the main difference is that the doubly fed induction generator provides access to the rotor windings, thereby giving the possibility of impressing a rotor voltage. By this, power can be extracted or impressed to the rotor circuit and the generator can be magnetized from either the stator circuit or the rotor circuit. Speed control can be applied to the doubly fed induction generator by slip power recovery scheme. Figure7 slip-power recovery scheme.



Slip power recovery scheme-

The doubly fed induction generator is controlled by a bi-directional power converter- in the present diagram back-to-back two-level converter. By this scheme, the generator can be operated as a generator at both sub- and super synchronous speed and the speed range depends only on the converter ratings. Besides nice features such as variable-speed operation, active and reactive power control, and fractional power conversion through the converter, the system suffers from the inevitable need for slip rings, which may increase the maintenance of the system and decrease its reliability. Further, the system comprises a step-up gear. The two inverters-the grid side inverter and the rotor side inverter-in Fig. 8 can be controlled independently, and by a proper control the power factor at the grid side can be controlled to unity or any desired value. By more sophisticated control schemes the system can be used for active compensation of grid-side harmonics.

Rotor-Converter Control Scheme-

Inputs to the control structure are the desired active and reactive power along with the measured rotor currents and measured active and reactive power. The error between measured active/reactive power and reference values are fed into a PI-controller giving d and q axis rotor reference currents These current references are compared to the actual currents and the errors are inputs to a set of PI-controllers giving the d and q axis rotor voltage references *as* outputs. From these voltage references the gating signals *for* controlling the rotor inverter are calculated, the detection of the slip angle can either be done by the use of an optical encoder or by position-sensor less schemes.

The grid -inverter control scheme is similar to cage rotor grid –inverter control scheme.

Above scheme has following advantages as compared to cage rotor IG

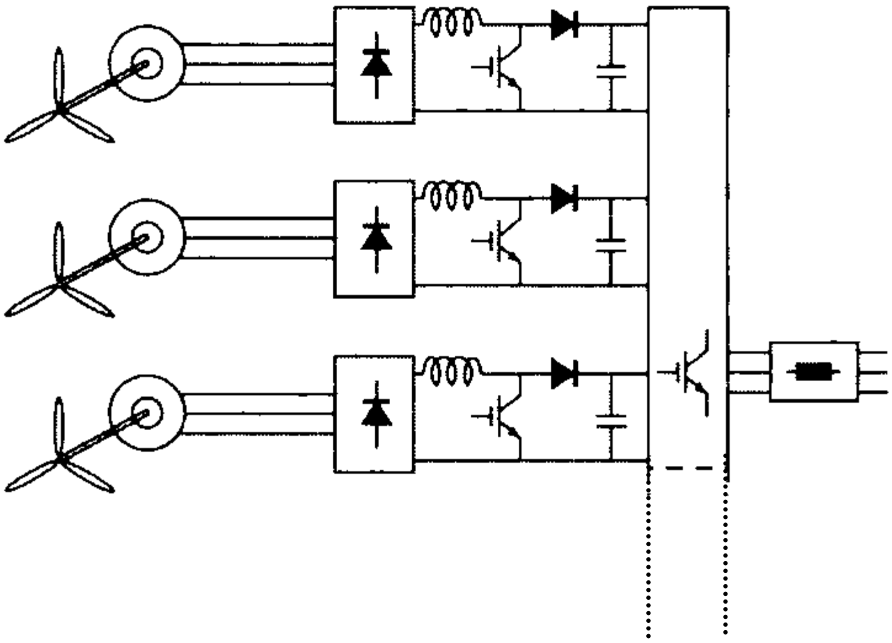
1-The ratings of the converters are significantly reduced.

2-A lower DC bus voltage is required. This reduces the voltage rating of capacitor banks.

Connection of Large Wind Farm to grid with Asynchronous Link

Previously, wind turbines were sited on an individual basis or in small concentrations making it most economical to operate each turbine as a single unit. Today and in the future, wind turbines will be sited in remote areas (including off-shore sites) and in large concentrations counting up to several hundred megawatts of installed power. For such a large system, using asynchronous link can give the best interconnection to grid especially for weak AC system. HVDC system can give such type of asynchronous link

Today most wind farms and single units are directly connected to the AC-grid. With increasing wind power coming on line, it is today, Already difficult to enter high amount of wind power in often weak Part of the AC-network. The development towards big wind farms will in most cases make it necessary to have an interface between the wind farm and the AC-grid. This is because out-put from a wind generator generates disturbances to the AC-grid, which is not acceptable. In order to maintain power quality and stability, the AC-grid must fulfill certain criteria's, if not, measures have to be taken. If the AC-grid is strong, i.e. the short circuit capacity is high in relation to the capacity of the wind farm; it may be possible to connect the farm directly to the grid. However, wind farms are often located in areas where the AC-grid is very weak, and can therefore not be directly connected. The introduction of HVDC Light now offers an alternative, superior to other techniques HVDC Light. HVDC Light is the ideal interface between any wind farm and any AC grid. Fig gives the connection of individual wind power generator to the grid through the central power converter. Each wind turbine contains a power converter connected to the common DC link bus. This HVDC park solution provides all the features of variable speed concept since all the turbines are connected independently.



The main features are

1- the distance from the farm to the connection point in the AC-grid has no technical limitations.

2- the wind farm is from a disturbance point of view isolated from the AC-grid.

3- HVDC Light generates the reactive power needed by the generators.

4- the power quality at the connection point is improved.

5- Controlled power production. During periods with reduced transmission capacity in the grid, the wind farm must be able to operate at reduced power levels with all turbines running.

6- No re-enforcement's in the AC-grid is necessary.

6. Conclusion

A comparison with existing scheme shows, that for a machine of similar rating energy capture can be enhanced by using wound rotor induction generator. In this case rated torque is maintained at super synchronous speeds whereas in a system using cage rotor IG, field weakening has to be employ beyond synchronous speed leading to the reduction in torque. Although DFIG has more advantages as compared to other methods but it has drawbacks in terms of complex control structure and maintenance problems as compared to cage rotor IG. The use of HVDC link for large wind farms is the best choice in terms of advantages of grid interaction and long distance power transmission.

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Biomass Energy

In the past few years, there have been significant improvements in renewable energy technologies along with declines in cost. The growing concern for the environment and sustainable development, have led to worldwide interest in renewable energies and bio-energy in particular. Biomass can be converted into modern energy forms such as liquid and gaseous fuels, electricity, and process heat to provide energy services needed by rural and urban populations and also by industry. This paper explains the different ways of extracting energy from biomass and a comparison is made among them. This paper also explains about the potentiality of biomass energy in India, analyses current situation compares bio-energy and other options for promoting development, brings out the advantages over the other renewables putting forth the drawbacks to be overcome to make it still more successful. This paper analyses current situation compares bio-energy and other options for promoting development, explore the potential for bio-energy.

1. Introduction

In past 10 years or so, considerable practical experience has accumulated in India as well as in other developing and industrialized countries, on biomass energy production and conversion. India is pioneer among developing countries, with significant indigenous efforts in promoting renewable energy technologies. The importance of bio-energy as a modern fuel has been recognized. India has about 70,000 villages yet to be connected to the electricity grid. The supply of grid power to rural areas is characterized by

(a) Low loads
(b) Power shortages
(c) Low reliability
(d) Low and fluctuating voltages
(e) High transmission and distribution costs and power losses

Decentralized power generation based on renewables is an attractive option to meet the energy needs. The availability of biomass such as wood, cow-dung, leaf litter in rural areas is more. Hence a choice of biomass energy especially in rural areas is more reasonable but at the same time the technology is being developed to meet the large-scale requirements using biomass.

Biomass energy has played a key role in the time of Second World War when there was a fuel deficiency. Many vehicles, tractors and trucks used wood gasifies, which generate producer’s gas, running an internal combustion Engine. One of the major advantages of biomass energy is that it can be used in different forms. For e.g., Gas generated from the biomass can be directly used for cooking or it can be used for running an internal combustion Engine for developing stationary shaft power or otherwise coupled to generator for generating electric power.

The subsequent sections explain about the different ways of extracting energy from biomass, explaining about technological and economic aspects followed by a case study. The issue of land availability for biomass (wood) production is also discussed.

2. Motivation

There are several renewable and non-renewable energy options for power generation at the decentralized level. It is necessary to understand why biomass-based energy options should receive priority over other options and to discuss the advantages to local and global communities as well as the environment.

Biomass is renewable fuel used in nearly every corner of the developing countries as a source of heat, particularly in the domestic sector. Biomass energy includes energy from all plant matter (tree, shrub, and crop) and animal dung. Biomass, unlike other renewables, is a versatile source of energy, which can be converted to modern forms such as liquid and gaseous fuels, electricity, and process heat. For example, small-scale (5-100 KW), medium-scale (1-10 MW), and large scale (about 50 MW).

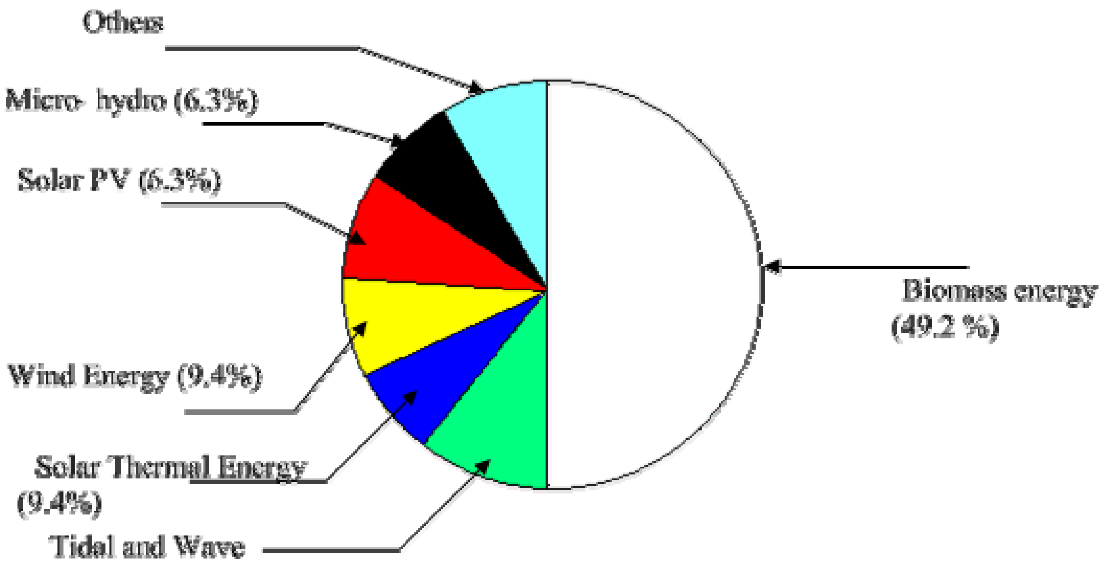

Fig 1: Expenditure on different renewable energy programmes for 1992-1997 indicating the share of bioenergy technologies for renewables in India

It can be seen from the figure the importance of biomass energy in Indian context.

Advantages of biomass gasify energy over other renewable energy options:

1. Suitable in most locations

2. Varying capacity can be installed; any capacity can be operated, even at lower loads; no seasonality.
3. Need for storage of energy is not required.

Advantages and drawbacks of biogas energy over other renewable energy options:

1. It can be used directly for cooking, or heating water from the abundantly available dung and dried plant leaves in rural areas.
2. Capacity determined by availability of dung. Not suitable for varying loads.
3. Not feasible to locate at all the locations.

3. Different Ways of extracting energy from biomass

The different methods of biomass extraction can be broadly be classified as:

1. Anaerobic Digestion
2. Gasification
3. Liquefaction

(a) Solid fuel combustion

The simplest and most common way of extracting energy from biomass is by direct combustion of solid matter. Majority of the developing countries especially in rural areas obtain the majority of their energy needs from the burning of wood, animal dung and other biomass. But burning can be inefficient. An open fireplace may let large amounts of heat escape, while a significant proportion of the fuel may not even get burnt.

(b) Gasification

Gasification is a process that exposes a solid fuel to high temperatures and limited oxygen, to produce a gaseous fuel. This is a mix of gases such as carbon monoxide, carbon dioxide, nitrogen, hydrogen and methane.

Gasification has several advantages over burning solid fuel. One is convenience – one of the resultant gases, methane, can be treated in a similar way as natural gas, and used for the same purposes.

Another advantage of gasification is that it produces a fuel that has had many impurities removed and will therefore cause fewer pollution problems when burnt. And, under suitable circumstances, it can produce synthesis gas, a mixture of carbon monoxide and hydrogen. This can be used to make almost any hydrocarbon (e.g., methane and methanol), which can then be substituted for fossil fuels. But hydrogen itself is a potential fuel of the future.

(c) Paralysis

Paralysis is an old technology with a new lease of life. In its simplest form it involves heating the biomass to drive off the volatile matter, leaving behind the black residue we know as charcoal. This has double the energy density of the original material. This means that charcoal, which is half the weight of the original biomass, contains the same amount of energy – making the fuel more transportable. The charcoal also burns at a much higher temperature than the original biomass, making it more useful for manufacturing processes. More sophisticated Paralysis techniques have been developed recently to collect the volatiles that are otherwise lost to the system. The collected volatiles produce a gas rich in hydrogen (a potential fuel) and carbon monoxide. These compounds, if desired, can be synthesized into methane, methanol and other hydrocarbons. 'Flash' Paralysis can be used to produce bio-crude – a combustible fuel.

(d) Digestion

Biomass digestion works by the action of anaerobic bacteria. These microorganisms usually live at the bottom of swamps or in other places where there is no air, consuming dead organic matter to produce, among other things, methane and hydrogen.

We can put these bacteria to work for us. By feeding organic matter such as animal dung or human sewage into tanks – called digesters - and adding bacteria, we can collect the emitted gas to use as an energy source. This can be a very efficient means of extracting usable energy from such biomass – up to two-thirds of the fuel energy of the animal dung is recovered.

Another, related, technique is to collect gas from landfill sites. A large proportion of household biomass waste, such as kitchen scraps, lawn clippings and pruning, ends up at the local tip. Over a period of several decades, anaerobic bacteria are at work at the bottom of such tips, steadily decomposing the organic matter and emitting methane. The gas can be extracted and used by 'capping' a landfill site with an impervious layer of clay and then inserting perforated pipes that collect the gas and bring it to the surface.

(e) Fermentation

Like many of the other processes described here, fermentation isn't a new idea. For centuries, people have used yeasts and other microorganisms to ferment the sugar of various plants into ethanol. Producing fuel from biomass by fermentation is just an extension of this old process, although a wider range of plant material can now be used, from sugar cane to wood fiber. For instance, the waste from a wheat mill in New South Wales has been used to produce ethanol through fermentation. This is then mixed with diesel to produce 'dishelm', a product used by some trucks and buses in Sydney and Canberra.

An elaborated discussion on Digestion and Gasification, which are the major ways employed in India, are explained in subsequent sections.

4. Anaerobic Digestion

Anaerobic Digestion is a biochemical degradation process that converts complex organic material, such as animal manure, into methane and other byproducts.

What is Anaerobic Digester?

Anaerobic digester (commonly referred to as an AD) is a device that promotes the decomposition of manure or "digestion" of the organics in manure to simple organics and gaseous biogas products. Biogas is formed by the activity of anaerobic bacteria. Microbial growth and biogas production are very slow at ambient temperatures. These bacteria occur naturally in organic environments where oxygen is limited. *Biogas is comprised of about 60% methane, 40% carbon dioxide, and 0.2 to 0.4% of hydrogen sulfide.* Manure is regularly put into the digester after which the microbes break down the manure into biogas and a digested solid. The digested manure is then deposited into a storage structure. The biogas can be used in an engine generator or burned in a hot water heater. AD systems are simple biological systems and must be kept at an operating temperature of 100 degrees F in order to function properly. The first methane digester plant was built at a leper colony in Bombay, India. Biogas is very corrosive to equipment and requires frequent oil changes in an engine generator set to prevent mechanical failure. The heating value of biogas is about 60% of natural gas and about 1/4 of propane. Because of the low energy content and its corrosive nature of biogas, storage of biogas is not practical.

There are two major types of biogas designs promoted in India

1. Floating Drum
2. Fixed Dome

The floating drum is an old design with a mild-steel, Ferro-cement or fiberglass drum, which floats along a central guide frame and acts as a storage reservoir for the biogas produced. The fixed dome design is of Chinese origin and has dome structure made of cement and bricks. It is a low-cost alternative to the floating drum, but requires high masonry skills and is prone to cracks and gas leakages. Family biogas plants come in different size depending on the availability of dung and the quantity of biogas required for cooking. *The average size of the family is 5-6 persons, and thus biogas plant of capacity 2-4 m^3 is adequate. The biomass requirement is estimated to be 1200 liters for a family.*

Comparison between two designs:

Fixed dome	**Floating Drum**
Digester and gas holder, masonry or concrete structure	Digester, masonry, Gas holder, mild steel or fiberglass
Requires high masonry skills	Low masonry or fabricating skills
Low reliability due to high construction failure	High reliability, gas holder prefabricated
Variable gas pressure	Constant gas pressure
Digester could be inside the ground	Requires space above ground for three tanks; inlet, digester, outlet
Low Cost (2 m^3 = Rs.5000)	Low Cost (2 m^3 = Rs.8000)

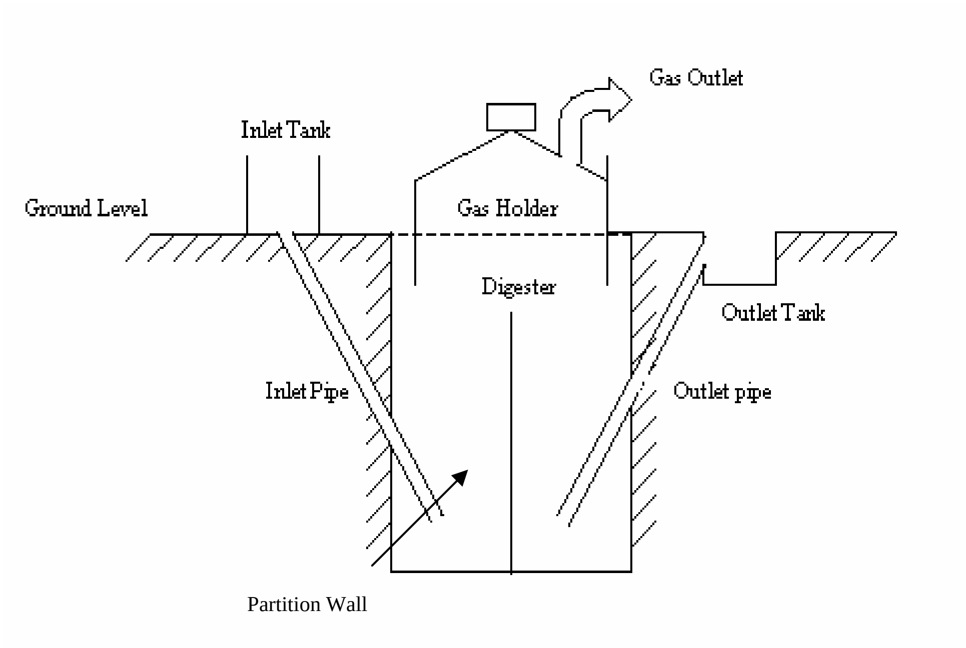

Figure 2: Floating Gasholder drum design (a conventional Indian design)

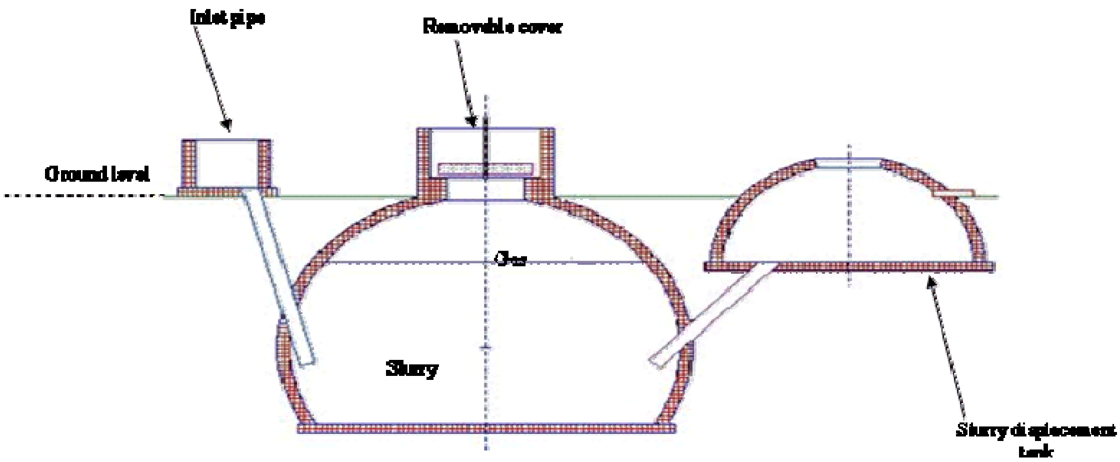

Figure 3: Spherical shaped fixed - dome plant

Uses of Biogas

Biogas can be directly used for cooking by supplying the gas though pipes to households from the plant. Biogas has been effectively used as a fuel in industrial high compression spark ignition engines. To generate electricity an induction generator can be used and is the simplest to interface to the electrical grid. Induction generators derive their voltage, phase, and frequency from the utility and cannot be used for stand-by power. If a power outage occurs generator will cease to operate. Synchronous generator can also be used to connect to the grid. However, they require expensive and sophisticated equipment to match the phase, frequency and voltage of the utility grid. Biogas can also be used as fuel in a hot water heater if hydrogen sulfide is removed from the gas supply.

5. Case Study of Community Biogas programmes in India

Biogas Electricity in Pure Village

In India, Biogas option is considered largely as a cooking fuel. The need for considering decentralized electricity options and the potential of biogas is analyzed. A field-demonstration programme was implemented in pure village in South India to use cattle dung in a community biogas plant to generated electricity for services such as pumping drinking water and home lighting.

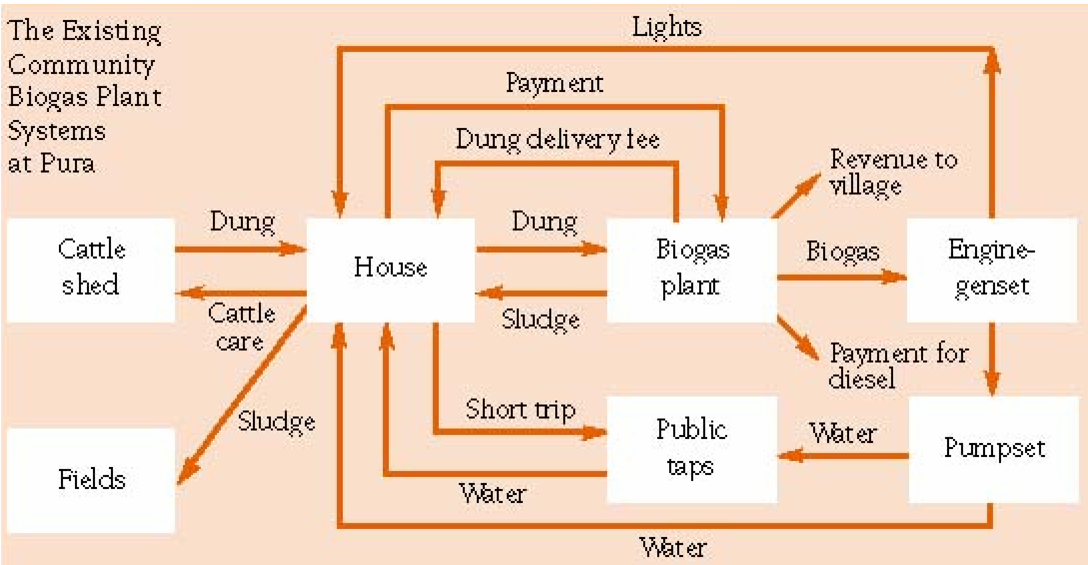

Fig 4: Community Biogas Plant in Pura Village

Technology

The Indian floating-drum design shown in fig.1 with modified dimensions for cost reductions was used. The Pure biogas plants have a capacity to digest up to 1.2 t cattle dung/day and produce 42.5-m3 biogas/day. Sand bed filters were installed to remove excess water and convert the sludge to dung-like consistency for subsequent use as a fertilizer. The filtrate, which contains the required anaerobic microorganisms, is mixed with the input dung. A 5 kW diesel engine is connected to a 5kVA, 440 V three-phase generator of electricity generation.

Lighting

Out of 87 house holds in the village 39 already had grid electricity, there are 103 fluorescent tube lights of 20 W capacity connected biogas generated electricity. Forty-seven houses opted for one tube light and 25 houses have two tube lights. Lighting is provided in the evening for 2.5 hours/day. Even homes connected to the grid had lighting connections from the biogas system.

Water supply

A submersible pump is connected to a tube well and water is pumped to storage tanks for 1 hour and 40 minutes/day. The majority of the households have opted for private taps at their doorsteps.

Basic Statistics on Pura Village

	July, 1987	1991	1994
Population	430	463	485
Cattle population	241	248	254
Human/cattle ratio	1.78	1.87	1.91
No. of Households	80	87	88
Households with grid electricity			
(number)	34	39	52
(percent)	(43%)	(45%)	(59%)
Households with grid + biogas electricity			
(number)		24	34
(percent)		(28%)	(39%)
Households with only biogas electricity			
(number)		48	36

Fig 5: Table showing the statistics on Pura village

6. Biomass Gasifies:

Biomass, or more particularly wood, can be converted to a high-energy combustible gas for use in internal combustion engines for mechanical or electrical applications. This process is known as gasification and the technology has been known for decades, but its application to power generation is of recent origin. A biomass gasified consists of a reactor where, under controlled temperature and air supply, solid biomass is combusted to obtain a combustible gas called *Producers gas* (consisting of H_2 and CH_4). This gas passes through a cooling and cleaning system before it is fed into a compression ignition engine for generation of mechanical or electricity (by coupling to a generator). An assessment of its potential concluded that India presents a unique opportunity for large-scale commercial exploitation of biomass gasification technology to meet a variety of energy needs, particularly in the agricultural and rural sectors. The large potential of biomass gasification for water pumping and power generation for rural electrification was recognized.

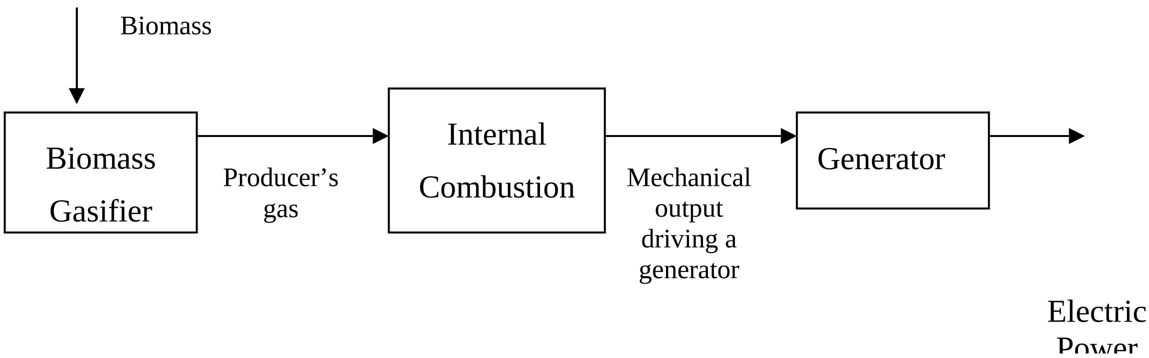

Figure 6: Block diagram of a producers gas electricity system

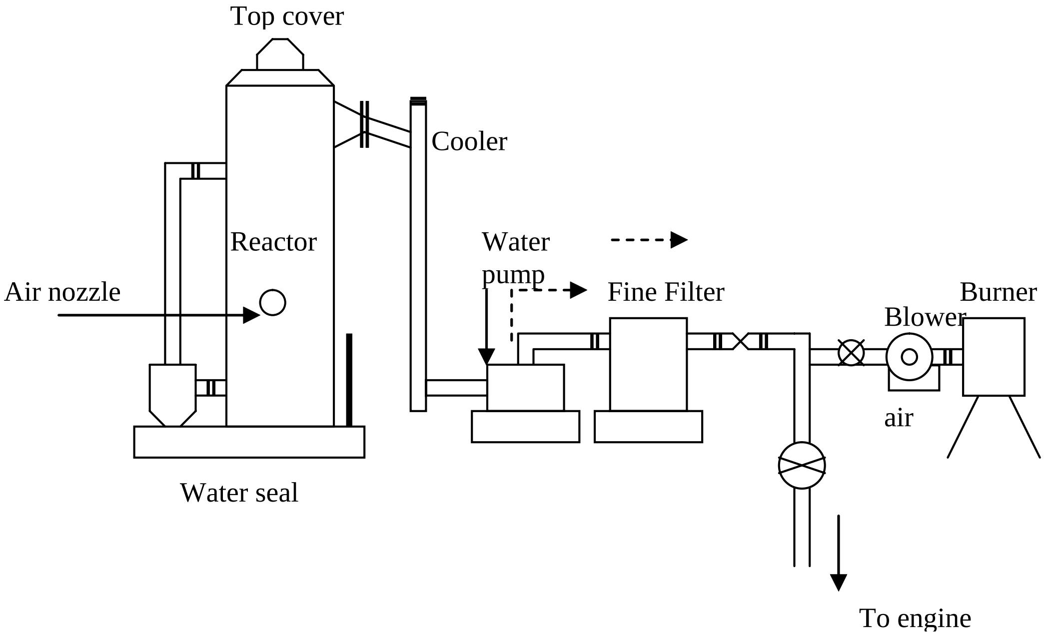

Figure 7: A 20 kW gasifier with cooling and cleaning system

Feed Stocks for producer-gas systems:

A range of crop residues and woody biomass from trees could be used as feedstocks for producer-gas systems. Currently, wood-based systems are available, and designs using other low-density biomass are under development and should soon be available in India. Crop residues with fuel potential are limited, since nearly all cereal and most pulse residues are used as fodder or manure and thus are not available as fuel. It is important to note that currently crop residues are used and have an opportunity cost. Rice husks are used in the cement industry, in rice mills and in the manufacture of bricks. Coconut leaves are used as thatch and the husk as fiber and sugarcane biogases is used in sugar mills. In Punjab, for rice-husk-based power generation systems, the price of residues such as rice husk could increase once new uses and demands are developed. Crop residues may continue to be used as fuel in domestic sector assuming that cooking-energy requirements are going to be met from bio-energy options. Constant supply of crop residues as feedstock cannot be assured over a long period on continuous basis and the transportation of low-density residues is not feasible.

Woody biomass would be the dominant source of feedstock for gasification. The availability of woody biomass and production potentials are discussed in the following section.

7. Case Studies of Producer’s gas electricity:

(a) Electrification of Hosahalli, a south Indian village

A small-capacity one-top wood gasified has been developed and implemented a field demonstration program in the non-electrified South Indian village of Hosahalli. The village has a population of 250 and was unelectrified. The farmers’ income is mainly from growing mulberry crops, as the area is silk producing. A 20 kW one-top wood gasified was setup to meet the demand for electricity. The plant is providing electricity to the people, who in turn have improved the overall economy and living conditions of the villagers. The loads being served by the power plant include domestic lights, streetlights, drinking water and irrigation tube wells, and a flourmill. The villagers themselves are managing the power plant.

<u>Services provided with Producer-gas electricity</u>

The electricity produced was used for three services: lighting, pumping domestic water, and flour milling.

Lighting

All the 42 houses were provided with a 40 W fluorescent tube and a 15 W incandescent bulb, along with eight streetlights. Connected load is 2.68 kW. Hours of operation: 6 p.m. to 10 p.m.

Water Supply

A submersible pump of 3 hp capacity was connected to a deep tube well. Water is pumped to storage tanks to provide 2-3 hours of water supply per day.

Flour milling

A 7.5 hp flourmill was connected to the producer gas diesel-engine generator. The flourmill, which operated for 2 hours/day, was operated for a few months in 1992; its operation was suspended, as the rate of milling was lower than the desired rate by the village community due to limitations of the 5-kVA system.

Installation: HOSAHALLI, Karnataka

Application: Village Electrification – Illumination, drinking water and irrigation

Rating: 20 kW

Year of Installation: Version I – 1988 (3.75 kWe)
Version II – 1999 (20 kWe)

Biomass Used: Forest wood

Hours of Operation: 7000 hours

Fig 8: Biomass Gasifier Installed in Hosahalli, Karnataka.

(b) Electrification of Chhotomollakhali, a village in West Bengal

Chhottomollakhali Island in Sunderbans situated in the district of South 24 Parganas, is about 130 km. away from Kolkata. It has a population of about 28,000. The main occupation of the people is fishing and agriculture. It is difficult to extend grid electricity to Chhottomollakhali Island due to prohibitive cost involved in crossing of various rivers and creeks. In the absence of electricity, the economic activities of the Island were suffering. The switching on of the 4x125 kW Biomass Gasifier based Power Plant on 29th June 2001 has changed the life the inhabitants of this remote Island. The plant is catering to electricity needs of domestic, commercial and industrial user's drinking water, hospital, ice factory, etc. Four villages of Chhottomollakhali Island will be benefited with electricity from the power plant.

Plant capacity: 4 x 125 kW

No. Of consumers: 800

Total Project Cost: Rs.1, 46, 70,390/-

Hours of operation:5 PM to 11 PM

Tariff Structure: 4.00 / unit Domestic

4.50 / unit Commercial

5.00 / unit Industrial

Energy Plantation Area: 40 hectares

Fuel Consumption pattern under full:

Load condition

(a) Biomass: 70%

(b) Diesel : 30%

Generation cost (per unit) under full load condition: Rs.2.75

8. Biomass availability issues:

Before assessing the country's bioenergy production potential, it is important to:

i. Estimate the land availability for biomass production,

ii. Identify and evaluate the biomass production options—yield/ha and financial viability,

iii. Estimate sustainable biomass production potential for energy,

iv. Estimate the energy potential of biomass production,

v. Assess the investment required and barriers to producing biomass sustainably for energy.

Different options for wood supply

1. Conservation potential of wood used in cooking.
2. Producing wood on community, government, or degraded forest land.
3. Producing wood on degraded private or farm land.
4. Sustainable harvest from existing forest.
5. Logging waste.

Consideration of options 2 and 3 involves a range of related issues, such as land availability, land quality, competitive uses of land, and sustainability of wood production.

Some proportion of wood currently burnt, as cooking fuel would become available for the producer-gas electricity option. Tree plantations, farm trees, homestead gardens, and degraded lands are the various sources of fuel wood used for cooking. Among these sources, only wood from tree plantations could be considered as easily available as feedstock for power generation.

Woody biomass would be the dominant source of feedstock for gasification. The availability of woody biomass and production potentials are discussed in the following section.

Estimates of degraded land availability in India (Mha):

SPWD; degraded (waste) land quoted in PC	Degraded forest, Degraded non-forest, Total degraded land	Total degraded land 130 Mha
Chambers; land available for tree planting	Cultivated lands, Strips and boundaries, Uncultivated degraded land, Degraded forest land, Land for tree planting	Total Land for tree planting 84 Mha
Kapoor; land available for tree plantation	Agricultural land, Forest land, Pasture land, Fallow, Urban	Total land for tree planting 106 Mha
Ministry of Agriculture	Forest land with < 10% tree crown cover, Grazing land, Tree groves, Culturable waste, Old fallow,	Total degraded land 66 Mha

References:

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MODULE-I

ENERGY

- The word energy‘ itself is derived from the Greek word en-ergon, which meains n-work’ or work content.
- A systemic study of various forms of energy & energy transformations is called energy science

The need for alternatives:

- The average rate of increase of oil production in the world is declining & a peak in production may be reached around 2018
- The production of natural gas is continuing to increase at a rate of about 4% every year.
- As oil & natural gas becomes scarcer, a great burden will fall on coal. It is likely that the production of coal will touch a maximum somewhere around 2050.

Classification of energy resources:

1.Based on usability of energy:

a)Primary resources:

Resources available in nature in raw form is called primary energy resources. Ex: Fossil fuels (coal, oil & gas), uranium, hydro energy. These are also known as raw energy resources.

b)Intermediate resources:

This is obtained from primary energy resources by one or more steps of transformation & is used as a vehicle of energy.

c)Secondary resources:

The form of energy, which is finally supplied to consume for utilization. Ex: electrical energy, thermal energy (in the form of steam or hot water), chemical energy (in the form of hydrogen or fossil fuels

2.Based on traditional use:

a)Conventional:

Energy resources which have been traditionally used for many decades. Ex: fossil fuels, nuclear & hydro resources

b)Non-conventional:

Energy resources which are considered for large scale & renewable. Ex : solar, wind & bio-mass

3.Based on term availability:

a)Non-renewable resources:

Resources which are finite, & do not get replenished after their consumption. Ex : fossil fuels, uranium *b)Renewable resources:*

Resources which are renewed by nature again & again & their supply are not affected by the rate of their consumption. Ex : solar, wind, bio-mass, ocean (thermal, tidal & wave), geothermal, hydro

4.Based on commercial application:

a)Commercial energy resources:

The secondary useable energy forms such as electricity, petrol, and diesel are essential for commercial activities. The economy of a country depends on its ability to convert natural raw energy into commercial energy. Ex : coal, oil, gas, uranium, & hydro

b)Non-commercial energy resources:

The energy derived from nature & used –directly without passing through commercial outlet. Ex: wood, animal dung cake, crop residue.

5.Based on origin :

Fossil fuels energy • Bio-mass energy

Nuclear energy • Geothermal energy

Hydro energy • Tidal energy

Solar energy • Ocean thermal energy

Wind energy • Ocean wave energy

Conventional and non-conventional sources energy

Conventional energy sources

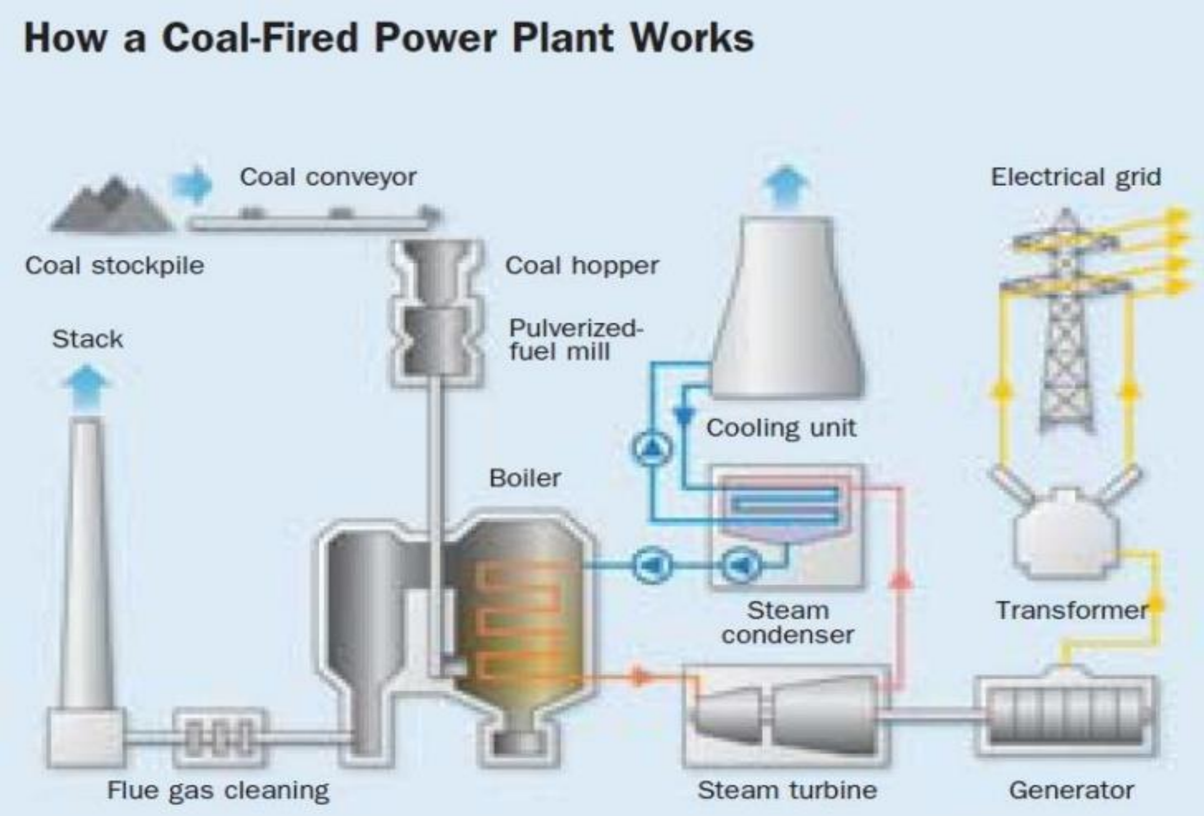
Conventional energy sources

- Fossil fuel energy
- Hydraulic energy
- Nuclear energy

Fossil fuel energy

- Coal, petroleum, and natural gas are called Fossil fuel
- as these are formed by the decomposition of the remains of dead plants and animals buried under the earth for a long time.
- These are non-renewable sources of energy, which, if exhausted, can not be replenished in a short time.
- Their reserves are limited and are considered very precious.
- These are also contributing to the global environmental pollution.

Coal



- Since the advent of industrialization coal has been most common source of energy.
- In the last three decades, the world switched over from coal to oil as a Major source of energy because it is simpler and cleaner to obtain useful energy from oil.
- Coal is a complex mixture of compounds of carbon, hydrogen and oxygen. Small amounts of nitrogen and Sulphur compounds are also present in coal.
- It is mainly available in Bihar, West Bengal, Orissa and Madhya Pradesh.
- The big coal mines in our country are at Jharia and Bokaro in Bihar and at Raniganj in West Bengal.
- It is considered as the backbone of the energy sector for its use in industry, transportation and electric power generation.

Depending upon the carbon contents of coal, it is classified as follows

Type of coal	**Carbon content (%)**
Peat	60
Lignite (soft coal)	70

Bituminous (house hold coal)	80
Anthracite (hard coal)	90

Petroleum or Oil

- It is a dark coloured, viscous and foul smelling crude oil.
- The petroleum means rock oil.
- It is normally found under the crust of earth trapped in rocks.
- The crude oil is a complex mixture of several solid liquid gaseous hydrocarbons mixed with water, salt and earth particles.
- It is a natural product obtained from oil wells.

Some of the crude oil producing locations in our country are:

- Ankleshwar and Kalol in Gujarat
- Rudrasagar and Lakwa in Assam; and
- Bombay high (off-shore area)

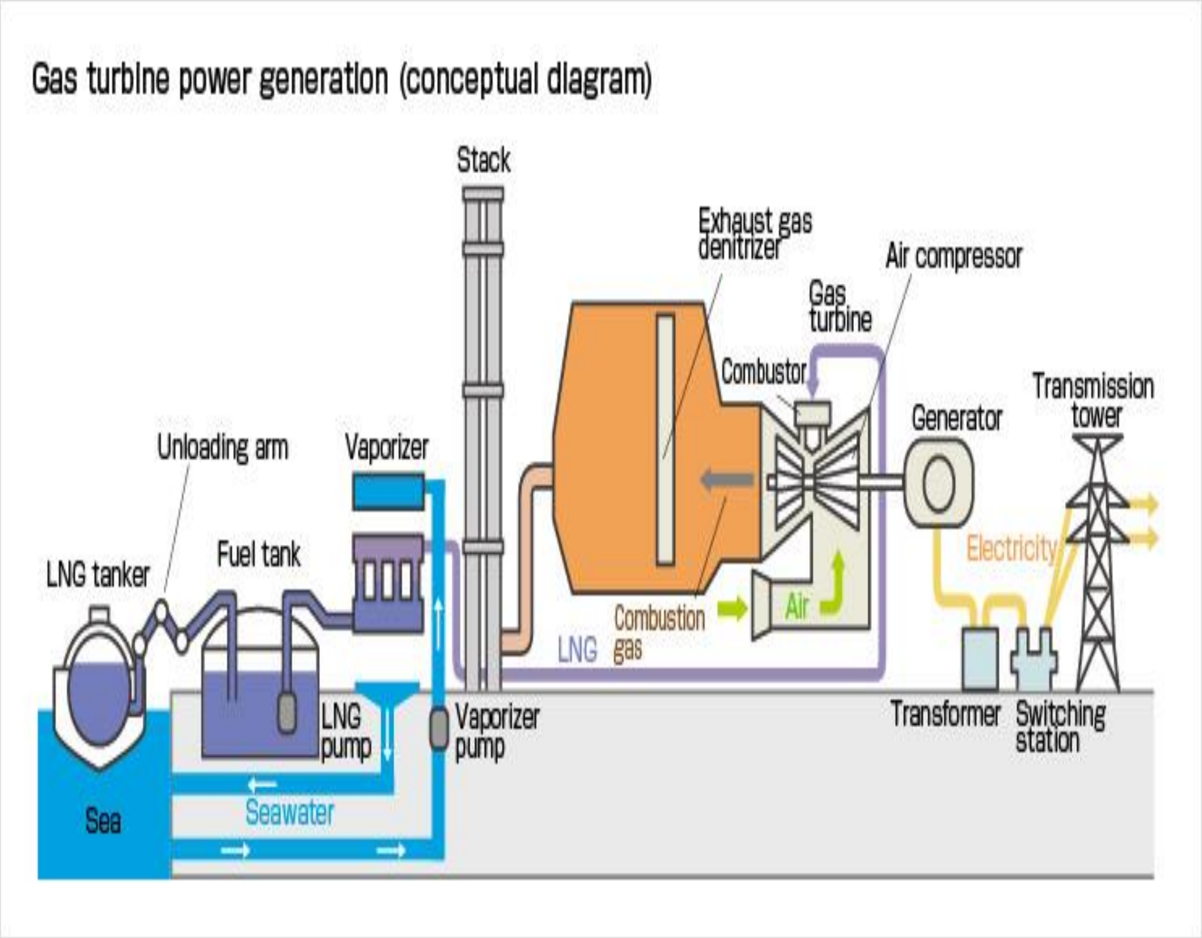
Petroleum or Oil

- The oil wells of Bombay high are producing about 22 million tons of crude petroleum oil per year,
- which is little less than half of the total requirement of the country.
- The crude petroleum is refined by the process of fractional distillation to obtain more useful petroleum products
- The crude petroleum is heated to a temperature of about 400oC in a furnace
- and vapors thus formed are passed into a tall fractioning column from near its bottom.
- As the mixture of hot vapours rises in the column, it starts getting cooled gradually.

The products obtained from crude petroleum as follows:

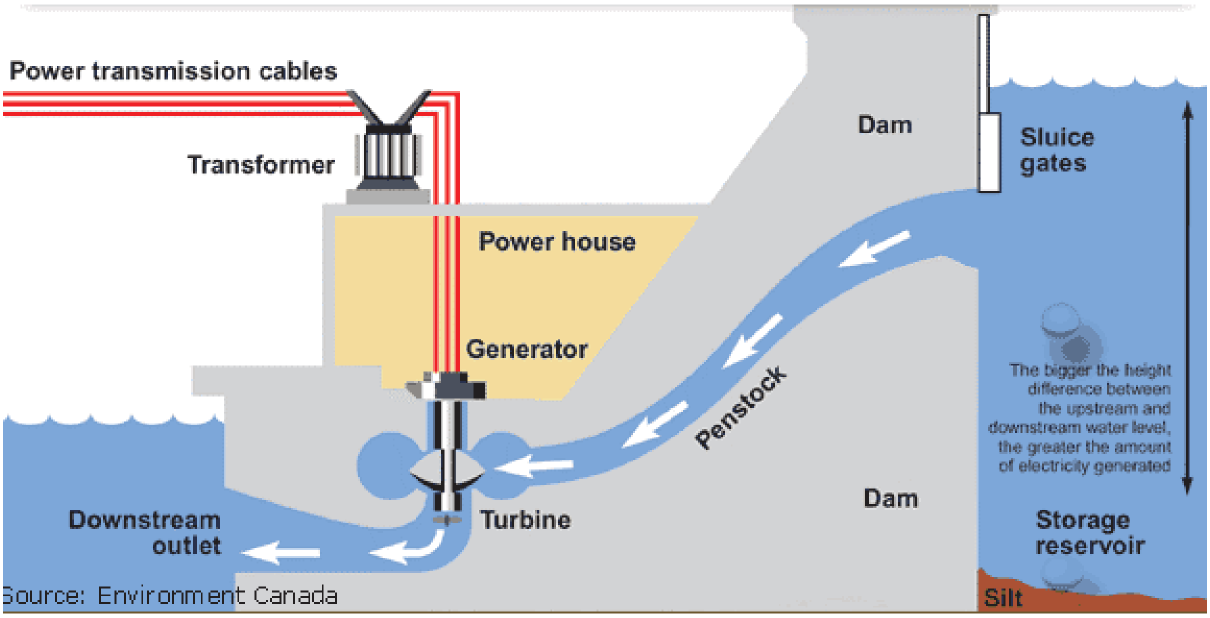
- Petroleum gas (below 40oC) used as LPG.
- Petrol (40oC to 170oC) for light vehicles.
- Kerosene (170 to 250oC) for household and industrial use.
- Diesel oil (250 to 350oC) for heavy vehicles.
- Residual oil ; (a) Lubrication oils (b) paraffin wax and (c) asphalt
- Fuel oil (350 to 400oC) for boilers and furnaces.

Natural gas



- It consists about 95% Methane and rest ethane and propane.
- It occurs deep under the crust of the earth either alone or a long with oil above the petroleum deposits.
- It is a product of petroleum mining.
- The gas is available in Tripura, Jaisalmer, off-shore areas of Bombay High and in the Krishna – Godavari delta.
- It is used as a domestic and industrial fuel.
- The natural gas is now also available as CNG (Compressed Natural Gas) a substitution of petrol in automobiles.

Hydraulic energy (or) Water power



- Water power is developed by allowing water to fall under the force of gravity.
- It is used almost exclusively for electric power generation
- Potential energy of water is converted into Mechanical energy by using prime moves known as hydraulic turbines.
- Water power is quite cheap where water is available in abundance.
- Although capital cost of hydro electric power plants is higher as compared to other types of power plants
- but their operating Costs are quite low, as no fuel is required in this case

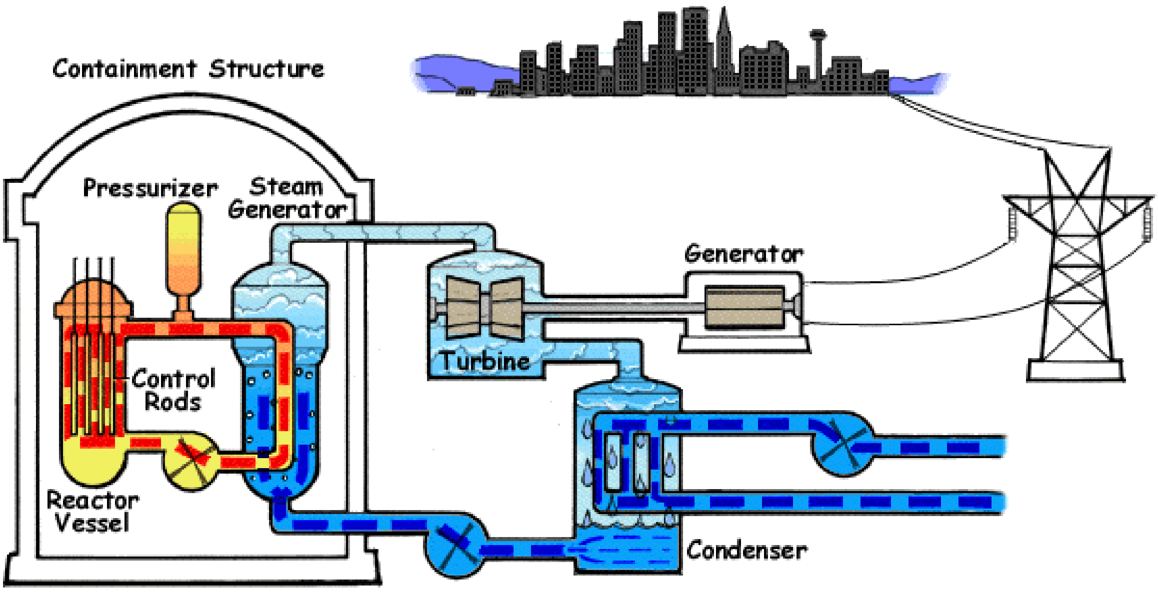
The development rate of hydropower is still low, due to the following problems:

- In developing a project, it will take about 6-10 years time for planning, investigation and construction.
- High capital investment is needed, and some parts of the investment have to be designed from foreign sources.
- There are growing problems on relocation of villages, involved, compensation for damage,
- selecting the suitable resettlement area and environmental impact.

In order to reduce the cost of development several Measures have been considered as follows:

- Development of low cost turbines and generators.
- Participation of villages in the development and operation of the project.
- Using the appropriate technology and tolerable substandard requirement and project civil work component at the beginning stage.

Nuclear energy



- According to modern theories of atomic structure, matter consists of minute particles known as atoms.
- Heavier unstable atoms such as U235, Th239, liberate large amount of heat energy.
- The energy released by the complete fission of one Kg of Uranium (U235), is equal to the heat energy obtained by burning 4500 tonnes of coal (or) 220 tons of oil.
- The heat produced by nuclear fission of the atoms of fissionable material is utilized in special heat exchangers for the production of steam which is then used to drive turbo generators as in the conventional power plants.
- However there are some limitations in the use of nuclear energy namely high capital cost of nuclear power plants, limited availability of raw materials, difficulties associated with disposal of radio active waste and shortage of well trained personnel to handle the nuclear power plants.

However there are some limitations in the use of nuclear energy namely

- high capital cost of nuclear power plants,
- limited availability of raw materials,
- difficulties associated with disposal of radio active waste
- and shortage of well trained personnel to handle the nuclear power plants.
- The Uranium reserves in the world at present are small.
- These reserves are recoverable but are expensive

The presently working power plants are:

- Tarapur atomic power station in Maharashtra
- Ranapratap sagar atomic power station near Tota, Rajasthan

- Kalpakkam atomic power station near Madras, Tamilnadu.
- Narora atomic power station in U.P.
- About 3% of the energy produced in India is obtained from nuclear power plants.

ADVANTAGES & DISADVANTAGES OF CONVENTIONAL ENERGY RESOURCES:

ADVANTAGES:

- Coal: as present is cheap.
- Security: by storing certain quantity, the energy availability can be ensured for a certain period.
- Convenience: it is very convenient to use.

DISADVANTAGES:

- Fossil fuels generate pollutants: CO, CO2, Particulate matter & heat. The pollutants degrade the environment, pose health hazards & cause various other problems.
- Coal: it is also valuable petro-chemical & used as source of raw material for chemical, pharmaceuticals & paints, industries, etc. From long term point of view, it is desirable to conserve coal for future needs.

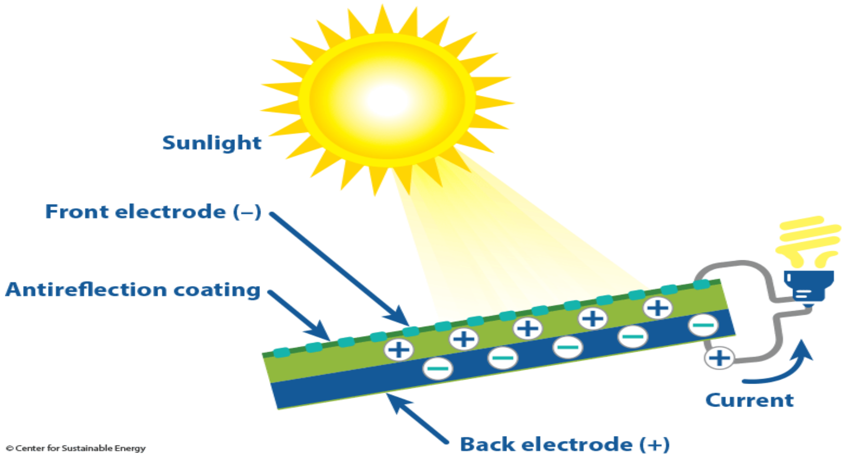
Non-Conventional Energy Sources

- The sources of energy which are being produced continuously in nature and are in exhaustible are called renewable sources of energy (or) non-conventional energy.

Some of these sources are:

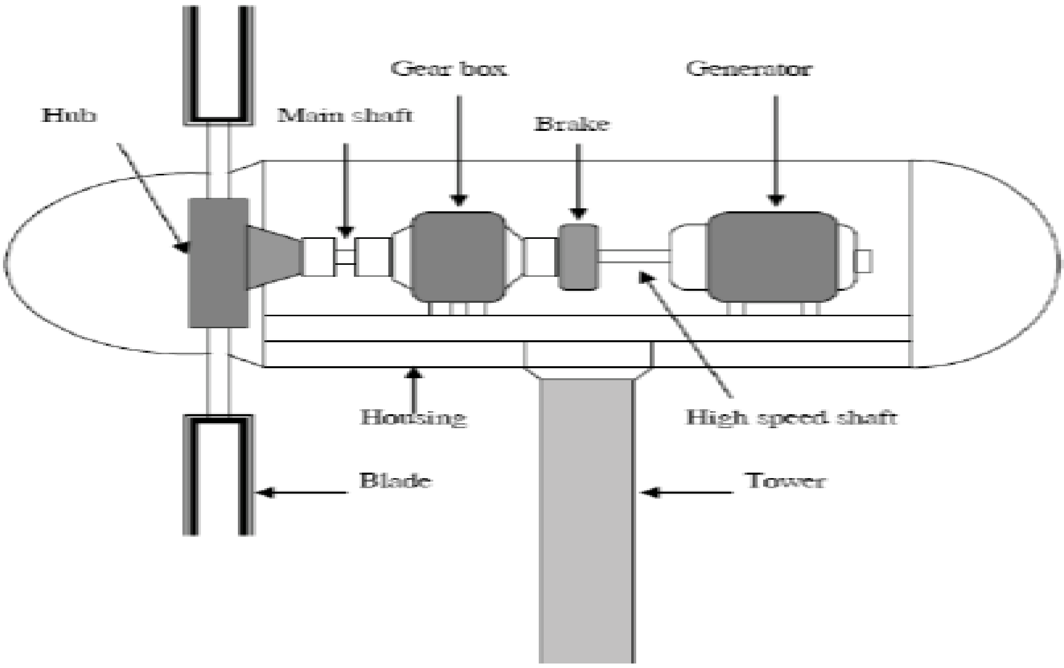
- 1. Solar enrgy
- 2. Wind energy
- 3. Bio mass
- 4. Tidal energy
- 5. Wave energy
- 6. Geo thermal

SOLAR ENERGY:



- Solar energy is a very large, inexhaustible source of energy.
- The power from the Sun intercepted by the earth is approximately 1.8×1011 MW which is many thousands of time larger than the present consumption rate on the earth of all commercial energy sources.
- Thus, in principle solar energy could supply all the present & future energy needs of the world on a continuing basis.
- Solar energy is received in the form of radiation, can be converted directly or indirectly into other forms of energy, such as heat & electricity.
- This energy is radiated by the Sun as electromagnetic waves of which 99% have wave lengths in the range of 0.2 to 4 micro meters.
- Solar energy reaching the top of the Earth's atmosphere consists about 8% U.V radiation, 46% of visible light, 46% Infrared radiation
- Safety of nuclear plants: it is a controversial subject.
- Hydro electrical plants are cleanest but large hydro reservoirs

WIND ENERGY:

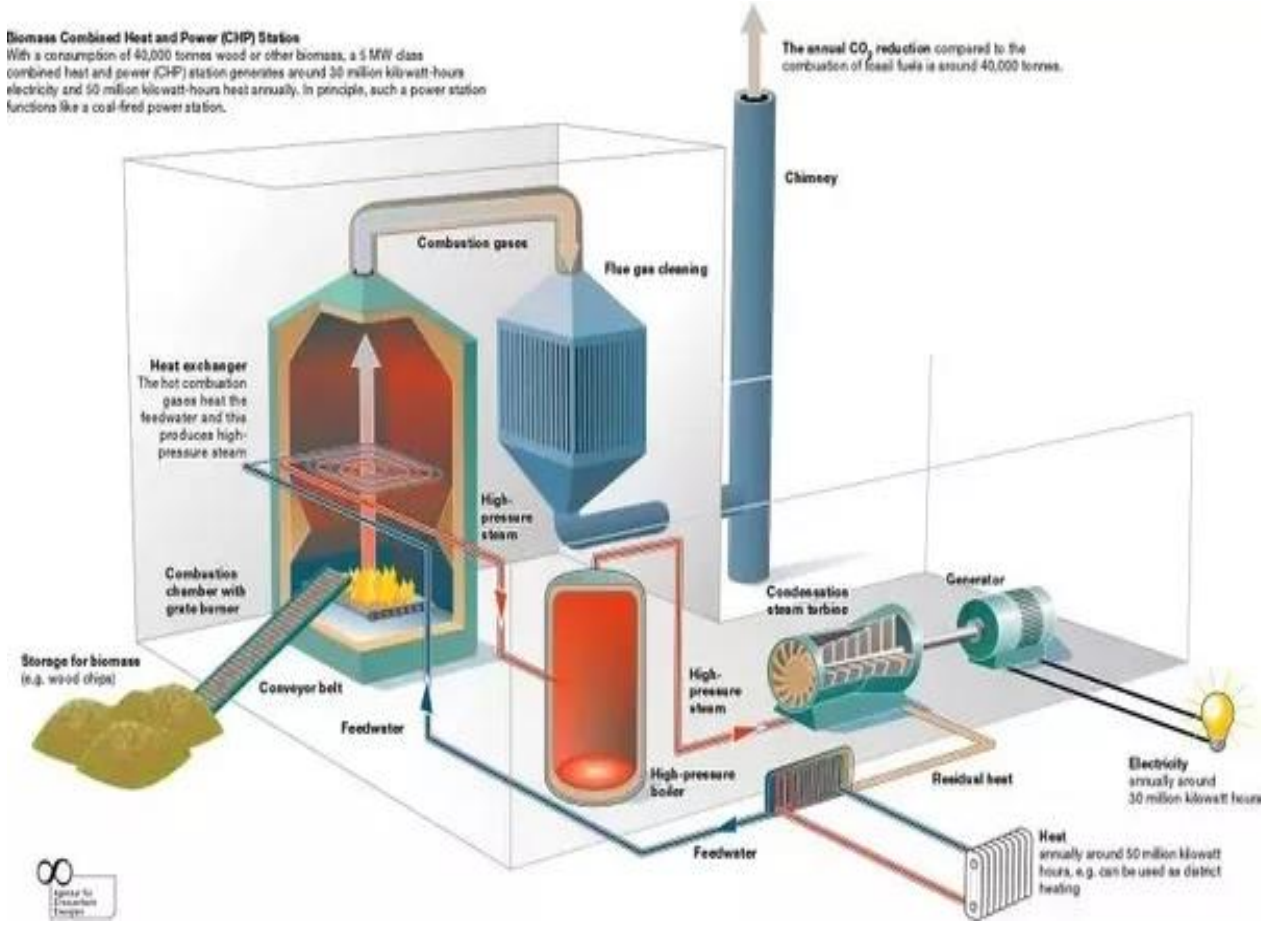


- Energy of wind can be economically used for the generation of electricity.
- Winds are caused from 2 main factors:

1. Heating & cooling of the atmosphere which generates convection currents. Heating is caused by the absorption of solar energy on the Earth's surface & in the atmosphere.
2. The rotation of the Earth with respect to atmosphere & its motion around the sun

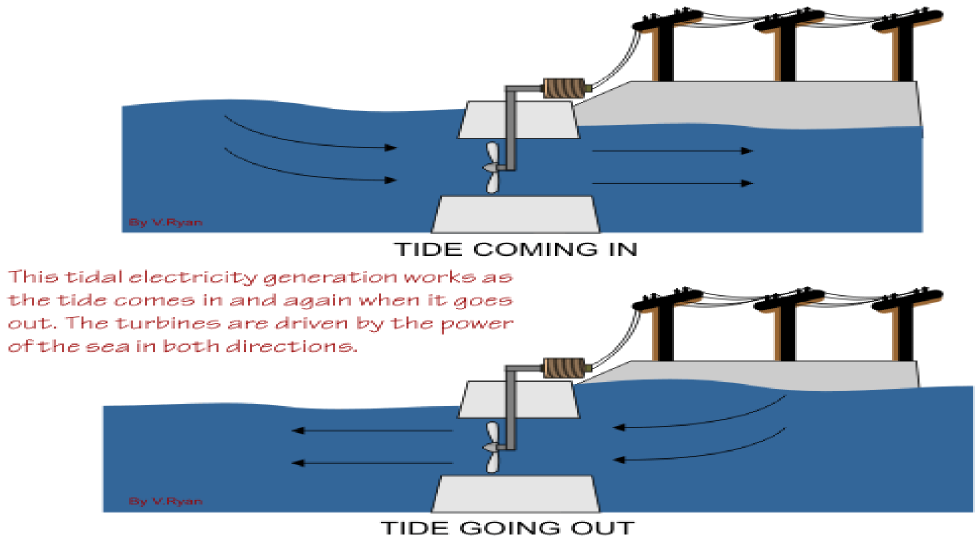
- The energy available in the wind over the Earth's surface is estimated to be 1.6×107 MW

BIO MASS:



- Bio-mass means organic matter.
- The energy obtained from organic matter, derived from biological organisms (plants & animals) is known as bio-mass energy.
- The average efficiency of photosynthesis conversion of solar energy into bio mass energy is estimated to be 0.5% - 1.0%.
- To use biomass energy, the initial biomass maybe transformed by chemical or biological processes to produce intermediate

TIDAL ENERGY:

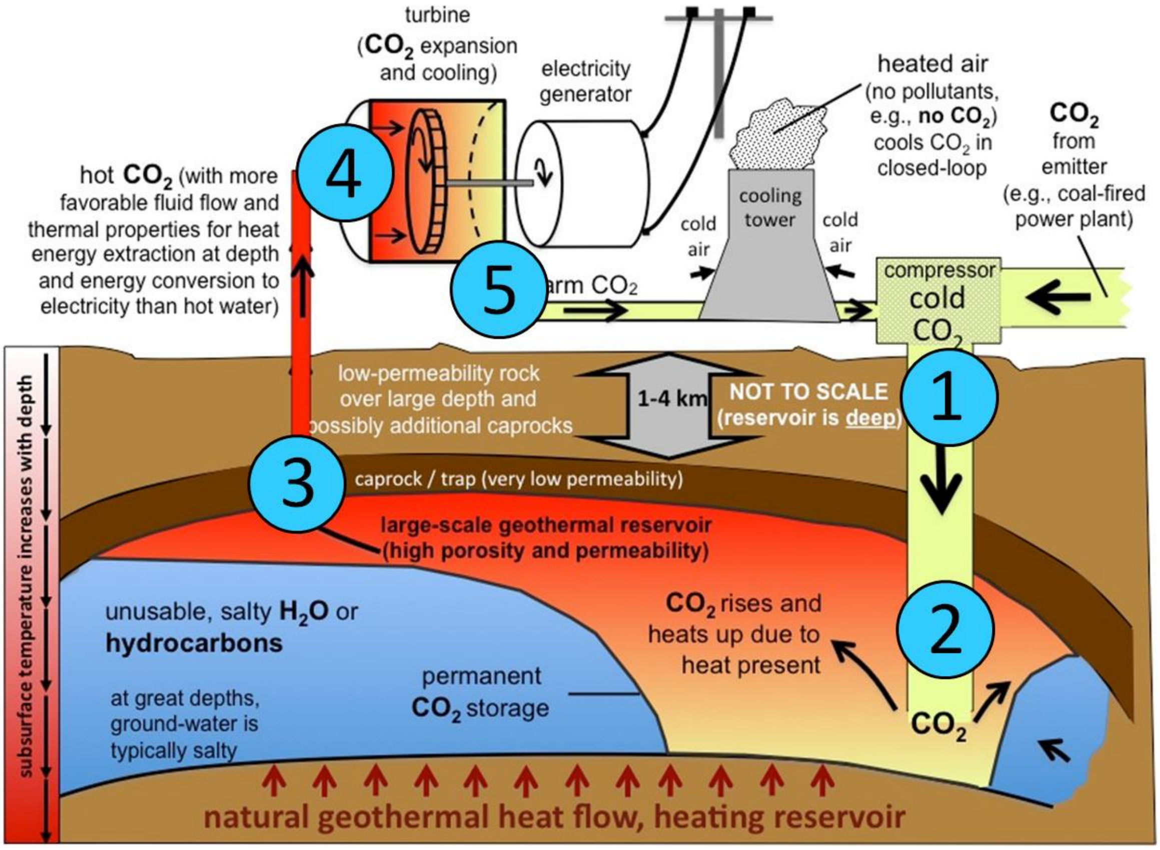


- The tides in the sea are the result of the universal gravitational effect of heavenly bodies like SUN & MOON on the Earth.
- Periodic rise & fall of the water level of sea is called TIDE.
- These tides can be used to produce electrical power which is known as tidal power.
- When the water is above the mean sea level called flood tide.
- When the water is below the mean sea level called ebb tide

WAVES ENERGY:

- Waves are caused by the transfer of energy from surface winds to sea.
- The rate of energy transfer depends upon the wind speed & the distance over which interacts with water.
- The energy flux in waves is more than that available from solar, wind & other renewable sources.
- The power in the waves is proportional to the square if its amplitude & to the period of its motion.
- The energy stored is dissipated through friction at shore & turbulence at rates depending on characteristics of wave & water depth.

GEOTHERMAL ENERGY:



- Geothermal energy is energy coming out of the molten interior (in the form of heat) of the earth towards the surface. Volcanoes, Geysers, Hot springs & boiling mud pots are visible evidence of the great reservoirs of heat that lies within the earth.
- Most Geothermal energy produces low grade heat at about 50-70˚c which can be used directly for thermal applications.
- Occasionally, geothermal heat is available at temperature about 90˚c & so electrical power production from turbines can be contemplated.

Indian Energy Scenario

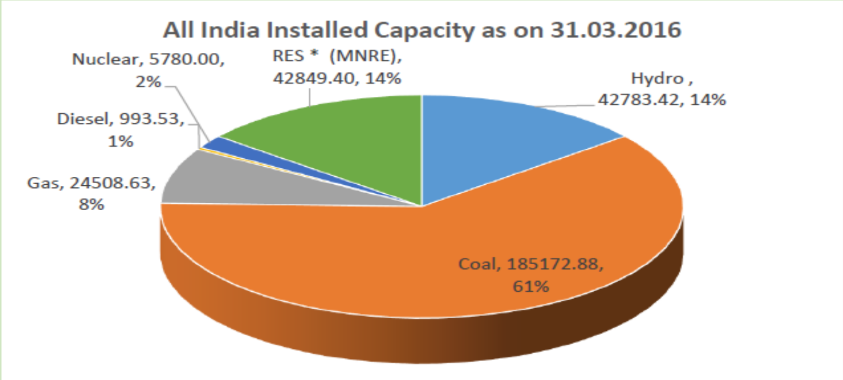
1.2 POWER SCENARIO IN THE COUNTRY

1.2.1 Installed Capacity

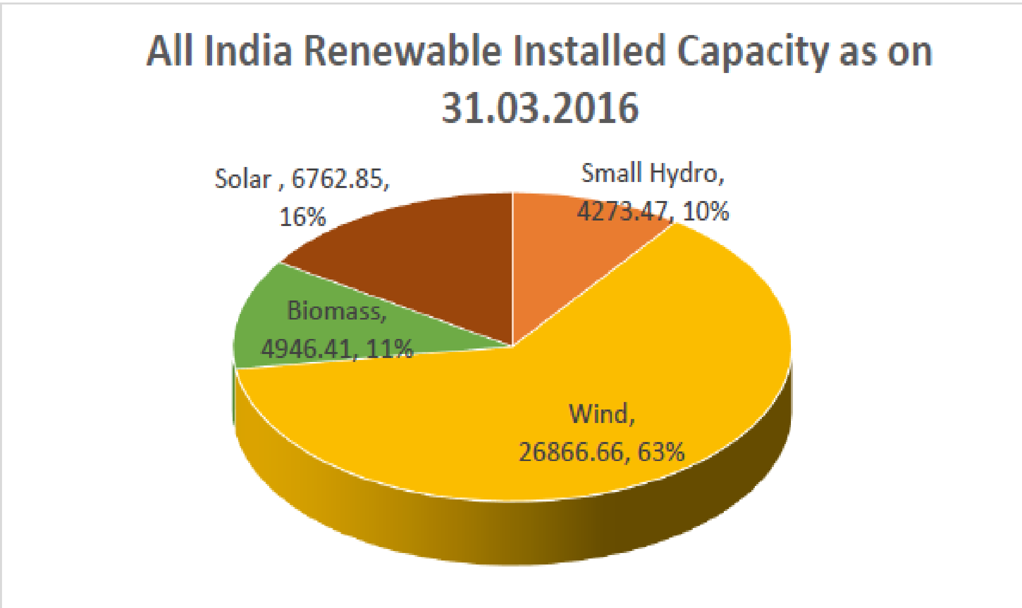
The Installed Capacity of the country as on 31.03.2016 was 3,02,088 MW comprising of 2,10,675 MW thermal, 5,780 MW Nuclear, 42,784 MW hydro and 42849 MW renewables and is depicted in the **Exhibit 1.1.**

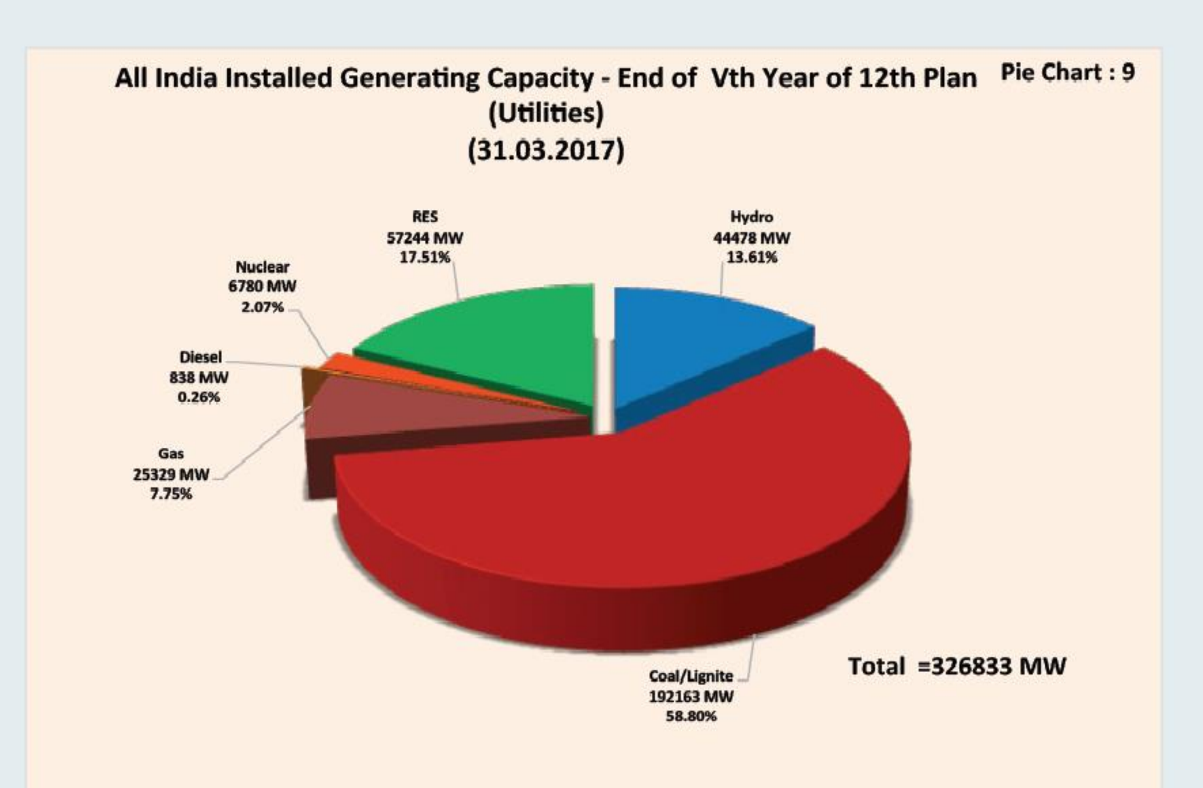
Exhibit 1.1.

(All figures in MW)



(All figures in MW)





Total Installed Capacity (As on 31.05.2018) - Source : Central Electricity Authority (CEA)

Sector	MW	% of Total
State Sector	84,627	24.6%
Central Sector	103,761	30.2%
Private Sector	155,511	45.2%
Total	**3,43,899**	

Fuel		MW	% of Total
Total Thermal		2,22,693	64.8%
	Coal	1,96,958	57.3%
	Gas	24,897	7.2%
	Oil	838	0.2%
Hydro (Renewable)		45,403	13.2%
Nuclear		6,780	2.0%
RES* (MNRE)		69,022	20.1%
	Total	**343,899**	

Growth of Installed Capacity & Electricity Generation

Plan/Year	Installed Capacity (MW)	Generation (BU)	Growth rate in (%)	Compound Growth (%)
		10th Plan		
2002-03	107877	531.61	3.2	**5.16**
2003-04	112684	558.34	5.0	
2004-05	118426	587.42	5.2	
2005-06	124287	617.51	5.1	
2006-07	132329	662.52	7.3	
		11th Plan		
2007-08	143061	704.47	6.3	**5.77**
2008-09	147965	723.79	2.7	
2009-10	159398	**771.60**	**6.6**	
2010-11	173626	**811.10**	**5.1**	
2011-12	199877	**877.00**	**8.1**	
		12th Plan		
2012-13	223344	**912.05**	**4.0**	**6.14**
2013-14	245259	**967.15**	**6.0**	
2014-15	271722	**1048.67**	**8.4**	
2015-16	302,088	**1107.38**	**5.6**	

1.2.2 Per Capita Electricity Consumption

The per capita electricity consumption was 883.64 kwh at the beginning of the 12th five-year plan i.e. 01.04.2012 and as on 31.03.2015 the per capita electricity consumption has increased to 1010 kwh. The per capita electricity consumption target for the year 2015-16 was 1101 kwh. The per capita electricity consumption during four years of 12th Plan is summarized in **Table 1.2.**

Table 1.2

Per Capita Electricity Consumption

YEAR	PER CAPITA CONSUMPTION (KWH)
2012-13	914.41
2013-14	956.64
2014-15	1010.00
2015-16	1101.00 (provisional)

1.2.4 Plant Load Factor of Coal/Lignite Based Power Plant

The national average Plant Load Factor (PLF) of Coal based power generating stations during last four years i.e. 2012-13, 2013-14,2014-15 and 2015-16 is 69.93% ,65.55%, 64.46% and 62.28% respectively. The year wise PLF is shown in **Exhibit 1.5**

Exhibit 1.5

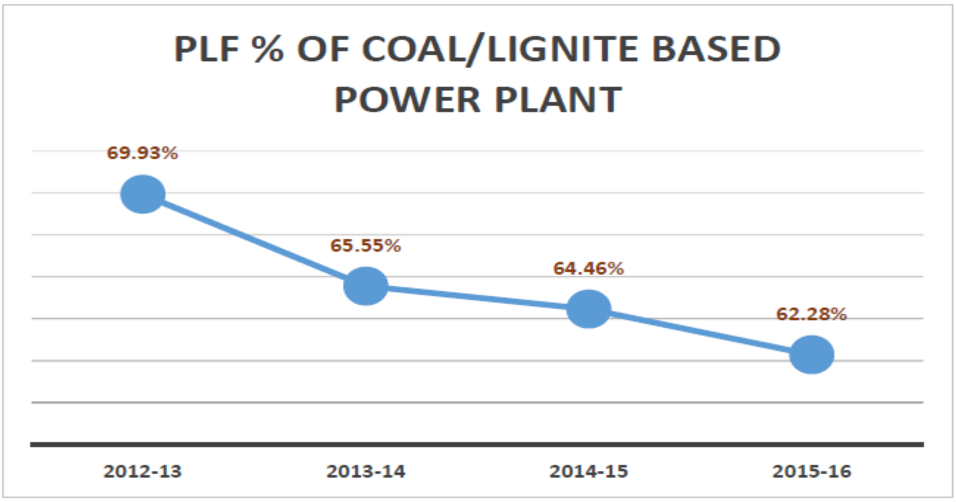
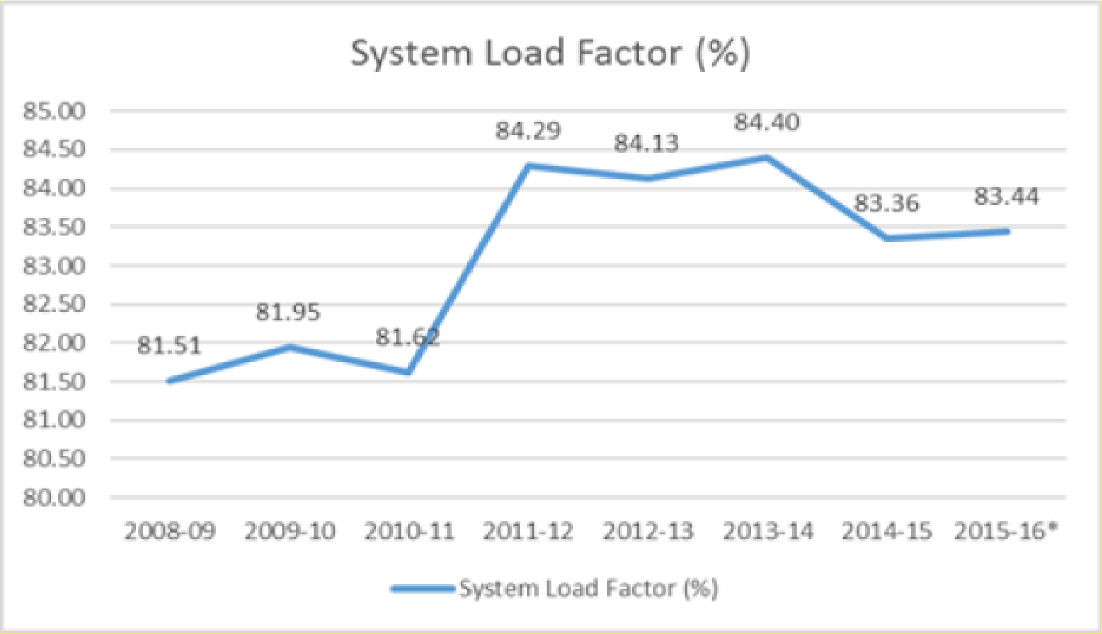
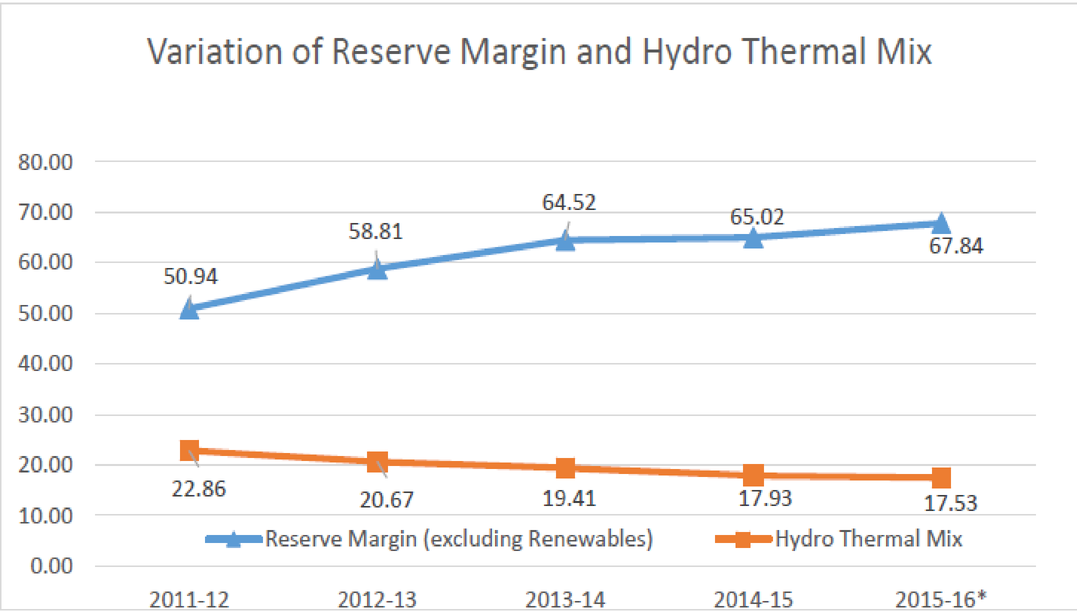


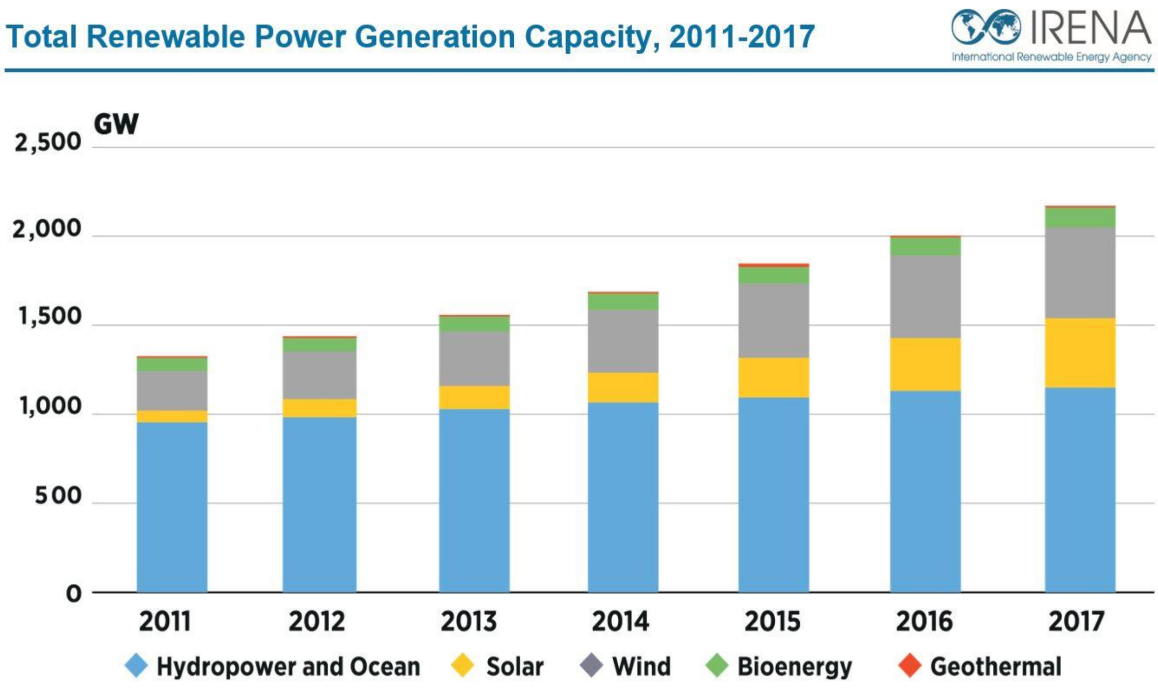
Exhibit 1.6

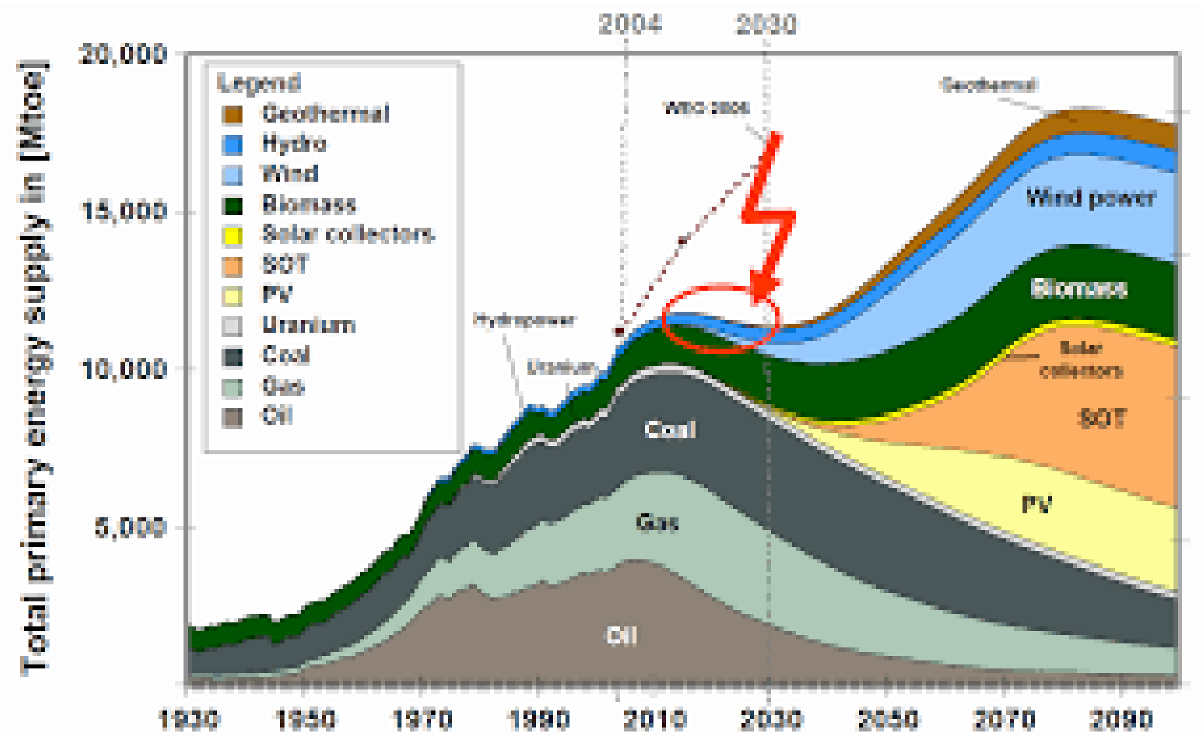


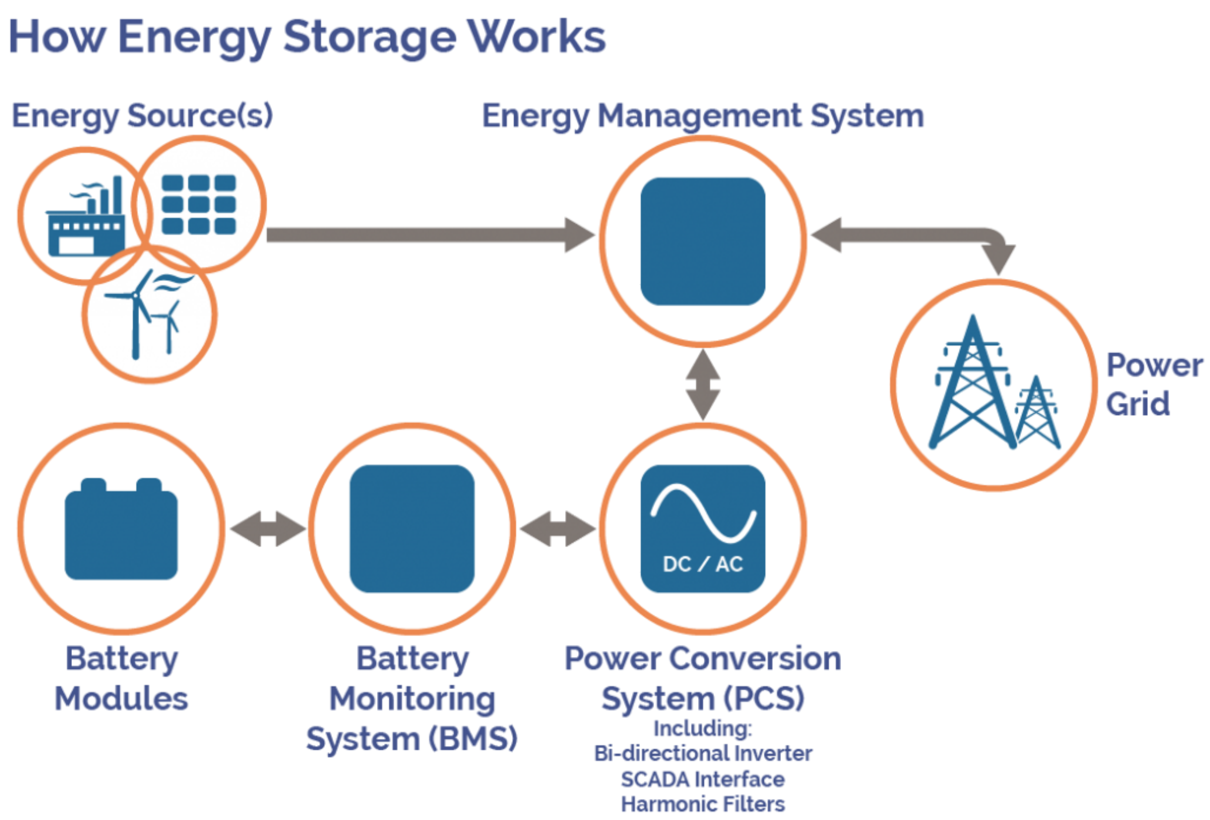


This increase in Reserve Margin is on account of decrease in thermal PLF from 73.32 % in 2011-12 to 63.20 % in 2015-16 up to January, 2016. This is illustrated in the **Exhibit 1.7**.

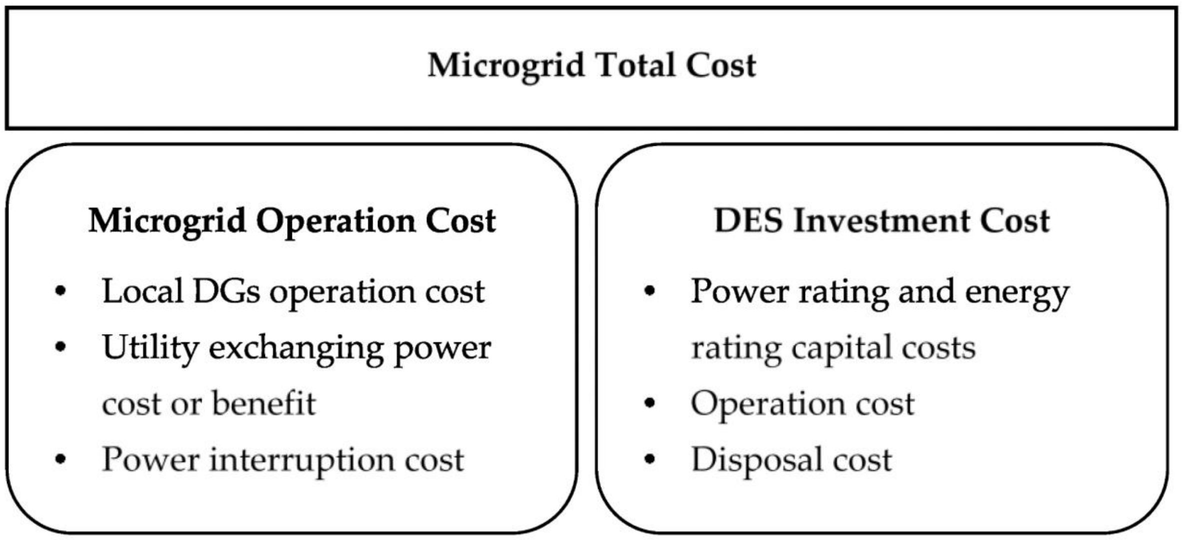
World Energy Scenario



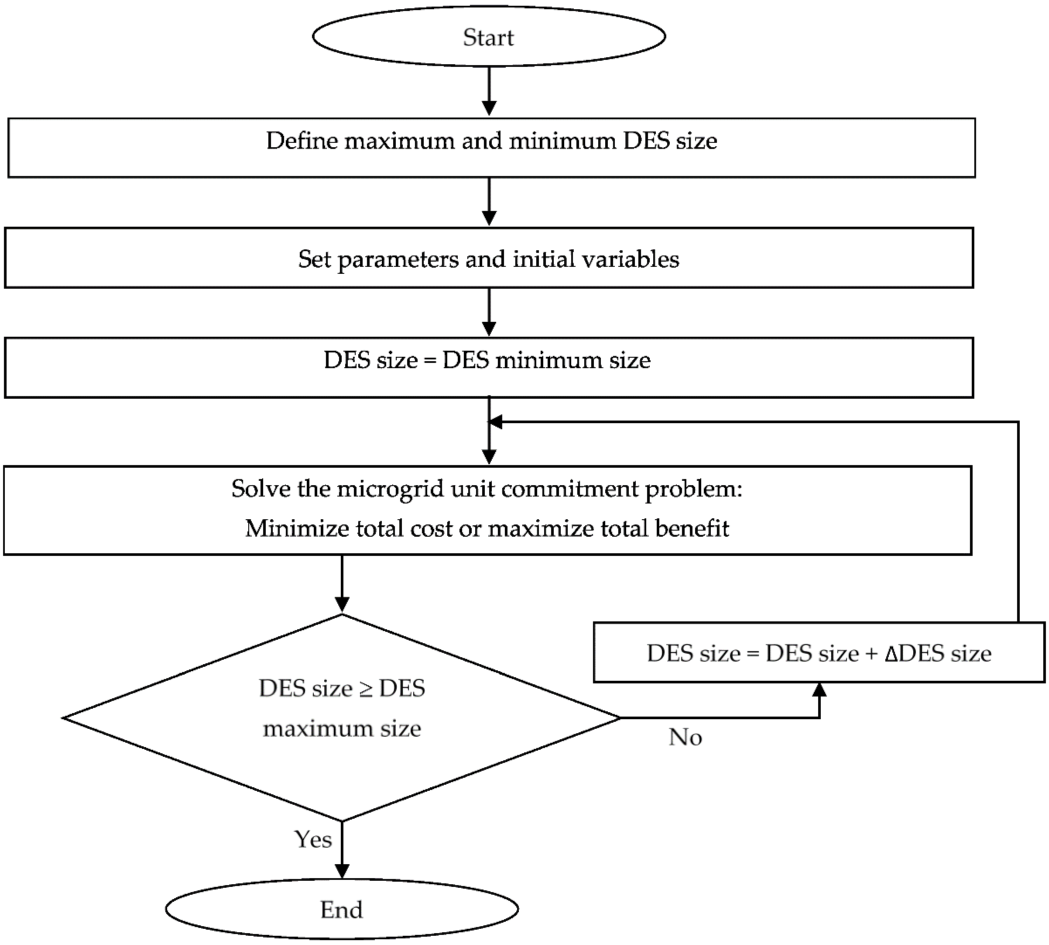


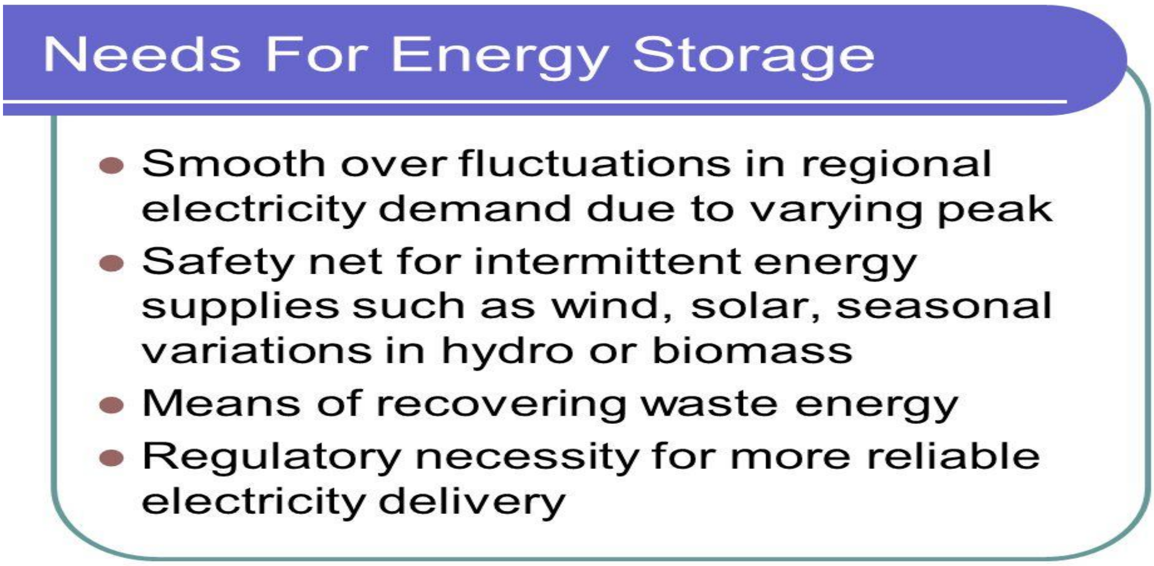


Sizing of Energy Storage

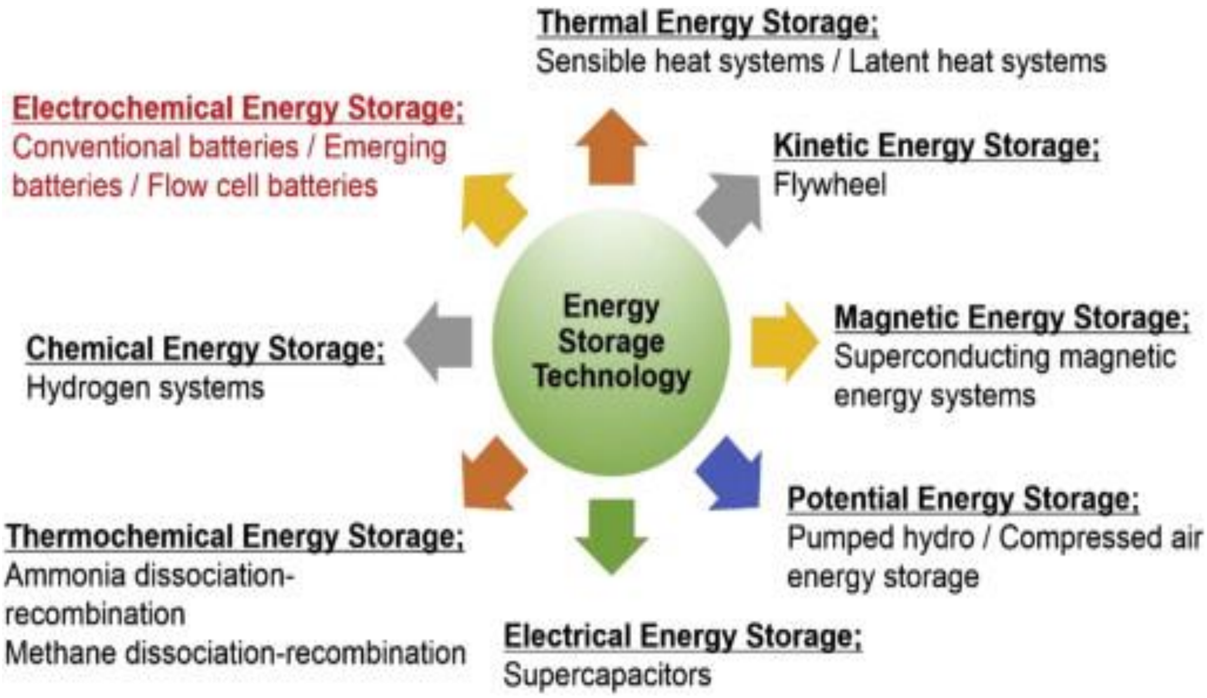


Storage Size optimization



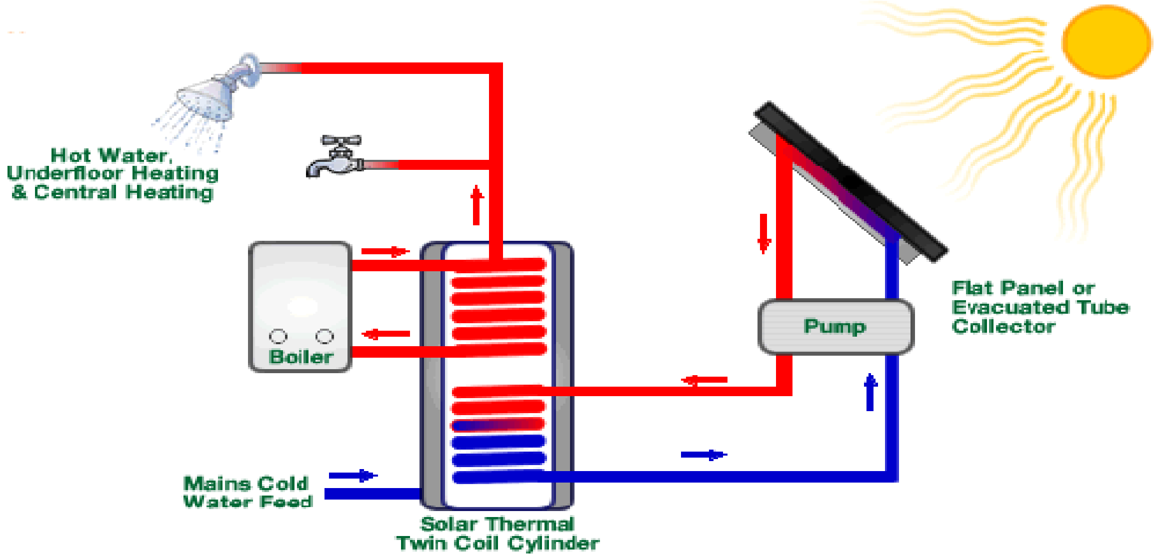


Types of storage



MODULE II

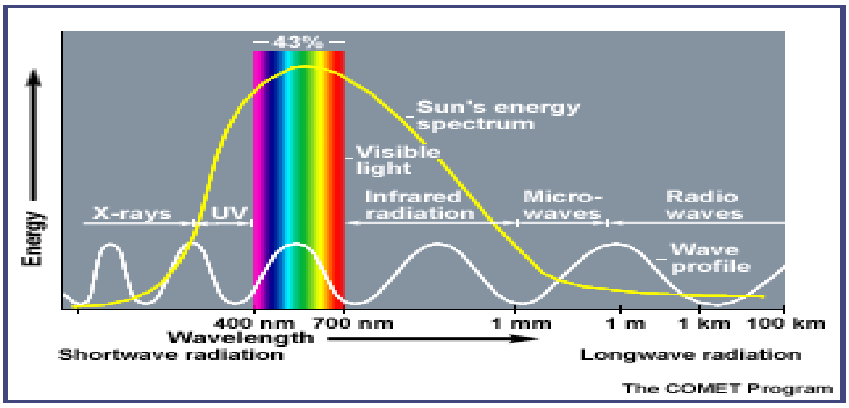
SOLAR THERMAL SYSTEMS: Introduction, Solar Constant, Basic Sun-Earth Angles, Measurement of Solar Radiation Data- Pyranometer and Pyrheliometer, Principle of Conversion of Solar Radiation into Heat- Solar Thermal collectors- General description and characteristics- Flat plate collectors- Heat transfer Processes- Solar Concentrators(parabolic trough, parabolic dish, central tower collectors)- performance evaluation.



WHY SOLAR ENERGY

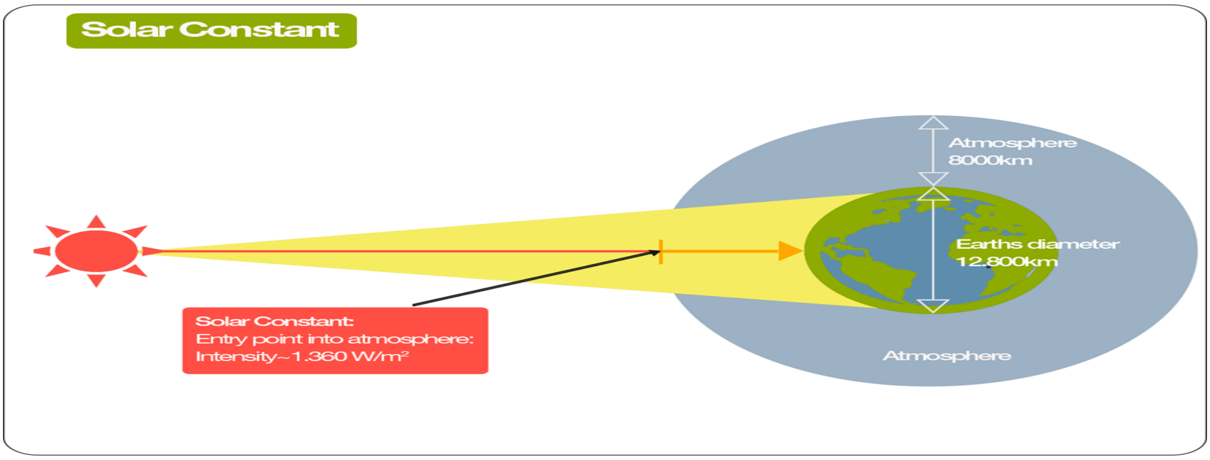
- Non-conventional source of energy
- Readily available
- Free
- Non-polluting
- Solar energy received in the form of radiation, can be converted directly or indirectly into other forms of energy, such as heat and electricity.
- Energy supplied by the sun in one hour is almost equal to the amount energy required by the human population in one year.

WHAT IS SOLAR ENERGY



- Originates with the thermonuclear reactions occurring in the sun.
- Represents the entire electromagnetic radiation (visible light, infrared, ultraviolet, x-rays, and radio waves).
- Energy is radiated by the sun as the electromagnetic waves of which 99 percent have wavelengths in the range of 0.2 to 4.0 micrometers.

SOLAR CONSTANT



- The rate at which Solar energy arrives at the top of the atmosphere is called the Solar Constant (Isc).
- It is defined as the energy received from the sun per unit time on a unit surface area perpendicular to the direction of propagation of solar radiation at the top of earth's atmosphere when the earth is at its mean distance(1.50 x 10^8 km) from the sun.
- The standard value (NASA)-1353 watts/sq.metre.
- The extra-terrestrial radiation can be determined by using solar constant as follows:

Iext =Isc*(Rav/R) W/m

where

Iext is the extra-terrestrial radiation

Isc is the solar constant

Rav is the mean distance between the sun and the earth

R is the actual sun-earth distance

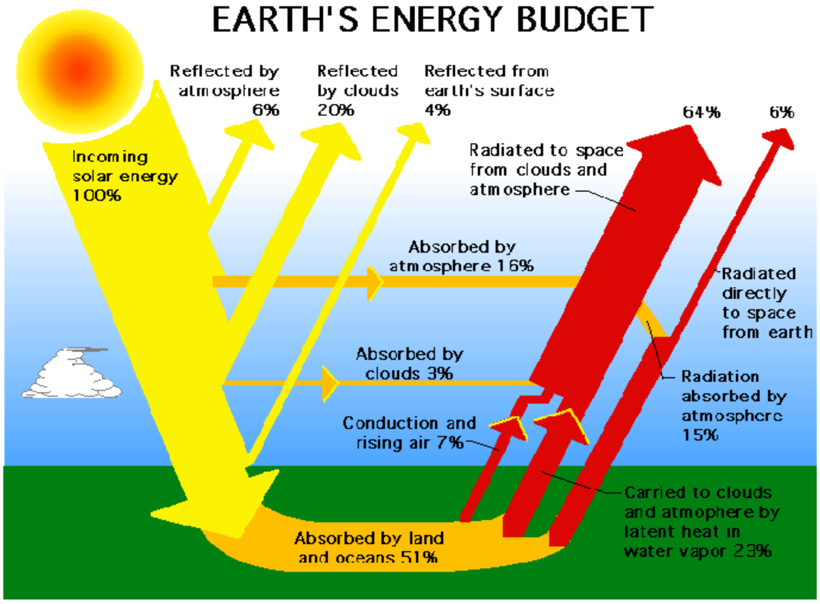
SOLAR RADIATION

- Solar Radiation = Beam Radiation + Diffuse Radiation
- **Beam Radiation (Direct radiation)** – Reaches directly to the earth surfaces, which produces the shadow effect.
- **Diffused Radiation** – Solar radiation from the sun after its direction has been changed.
- Variation in Solar Radiation due to REFLECTION, ABSORPTION AND SCATTERING

- **<u>Also called Insolation</u>**: Total solar radiation received on a horizontal surface of unit area on the ground in unit time (1 day).
- Insolation varies with date, time, altitude of sun and with weather conditions (clouds, humidity).

ABSORPTION AND SCATTERING

- *Reflection*: by surface and clouds
- *Absorption* : Short wave Ultra-violet rays by ozone and long wave infra red by CO2 and moisture in the atmosphere.
- *Scattering* : As Solar radiation passes through the earth's atmosphere the components of the atmosphere, such as water vapour, dust in the atmosphere causes scattering.



BASIC SUN EARTH ANGLES

<u>Latitude or angle of latitude(λ)</u>

- The latitude of a location on earth's surface is the angle made by the radial line joining the specified location to the centre of earth with the projection of this line on the equatorial plane.
- The latitude at equator is zero and it is 90^0 at poles.

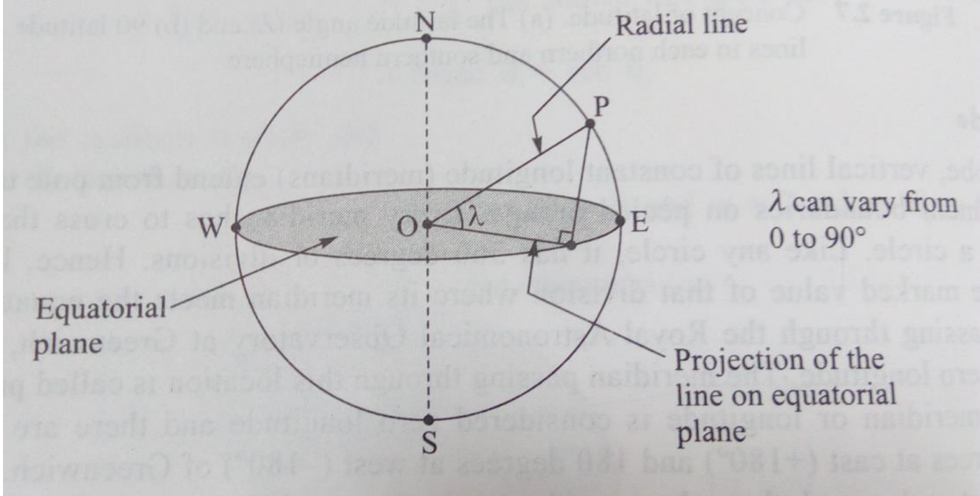


Figure 2.9 The angle of latitude.

<u>Declination angle(δ)</u>

- It is the angle made by the line joining the centres of sun and earth with the equatorial plane.
- The angle of declination varies when the earth revolves around the sun.

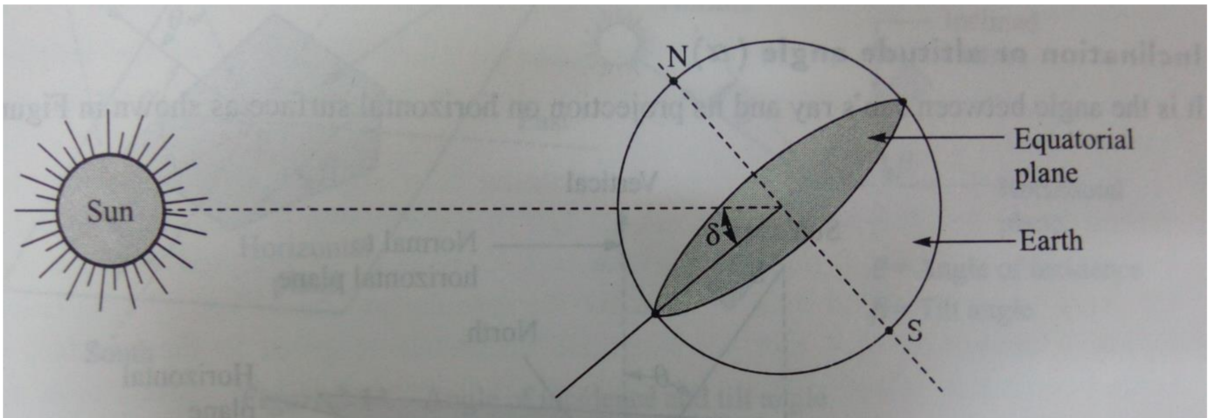


Figure 2.10 Angle of declination.

- It has maximum value of 23.45^0 when earth achieves a position in its orbit corresponding to 21 June and it has minimum value of -23.45^0 when earth is in orbital position corresponding to 22 December.
- The angle of declination is taken positive when it is measured above the equatorial plane in the northern hemisphere.
- The angle of declination can be given by
- $$\delta = 23.45 \times \sin\left[\frac{360}{365}(284 + n)\right]$$

  where *n* is the number of days counted from 1 January

Hour angle(ω)

- It is an angular measure of time.
- The hour angle at any instant is the angle through which the earth has to turn to bring the meridian of the observer directly in line with sun's rays.

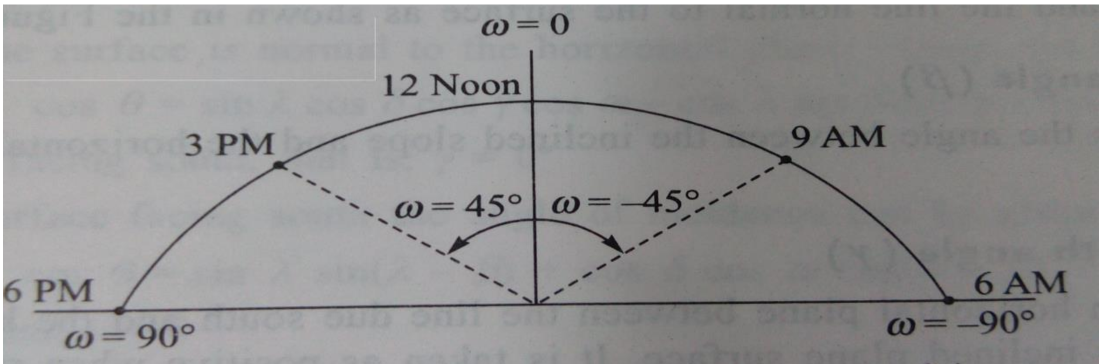
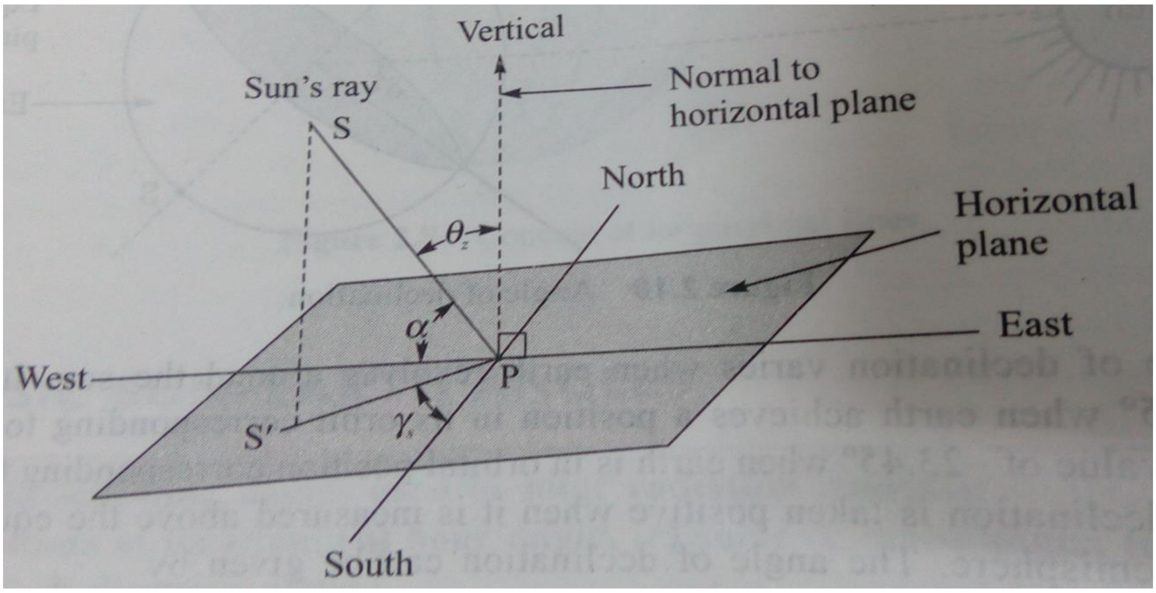


Figure 2.11 Hour angle is an angular measure of time.

- It is the angle in degree traced by the sun in 1 hour with reference to 12 noon of the location.
- The convention of measuring it is that the noon based calculated local apparent time(LAT) is positive in afternoon and negative in forenoon.
- I hour corresponds to 15^0 of earth's rotation.(360^0 in 24 hour).
- As at solar noon the sun rays is in line with local meridian or longitude, the hour angle at that instant is zero.
- The hour angle can be given as:

$$\omega = [\text{solar time} - 12] \times 15^0$$



<u>Inclination or altitude angle(α)</u>

- It is the angle between sun's ray and its projection on horizontal surface.

<u>Zenith angle(θz)</u>

- It is the angle between sun's ray and normal to the horizontal plane.

<u>Solar azimuth angle(γs)</u>

- It is the angle between the projection of sun's ray to the point on the horizontal plane and line due south passing through that point. The value of the azimuth angle is taken positive when it is measured from south towards west.

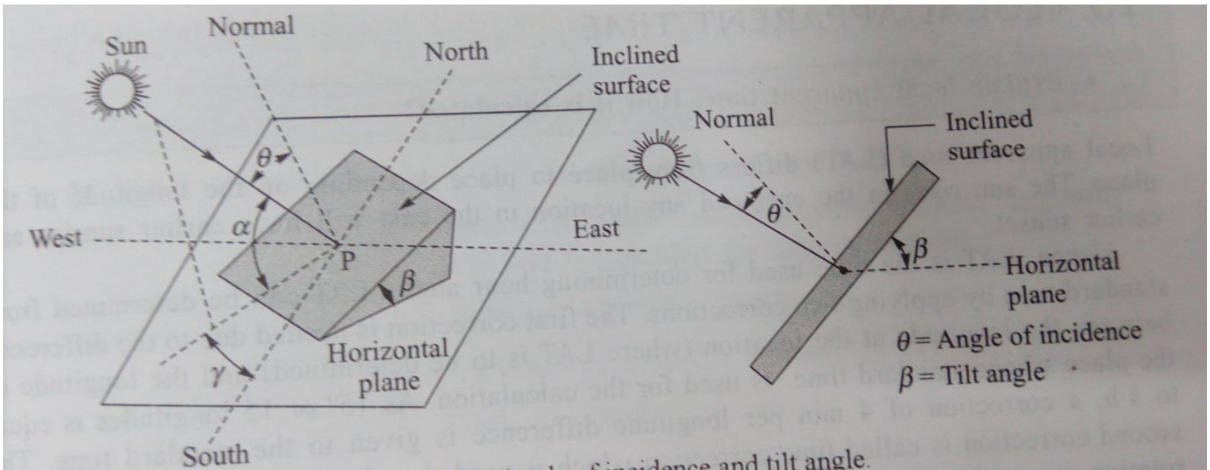


Figure 2.13 Angle of incidence and tilt angle.

<u>Angle of incidence(θ)</u>

- The angle of incidence for any surface is defined as the angle formed between the direction of the sun ray and the line normal to the surface.

<u>Tilt or slope angle(β)</u>

- The tilt angle is the angle between the inclined slope and the horizontal plane.

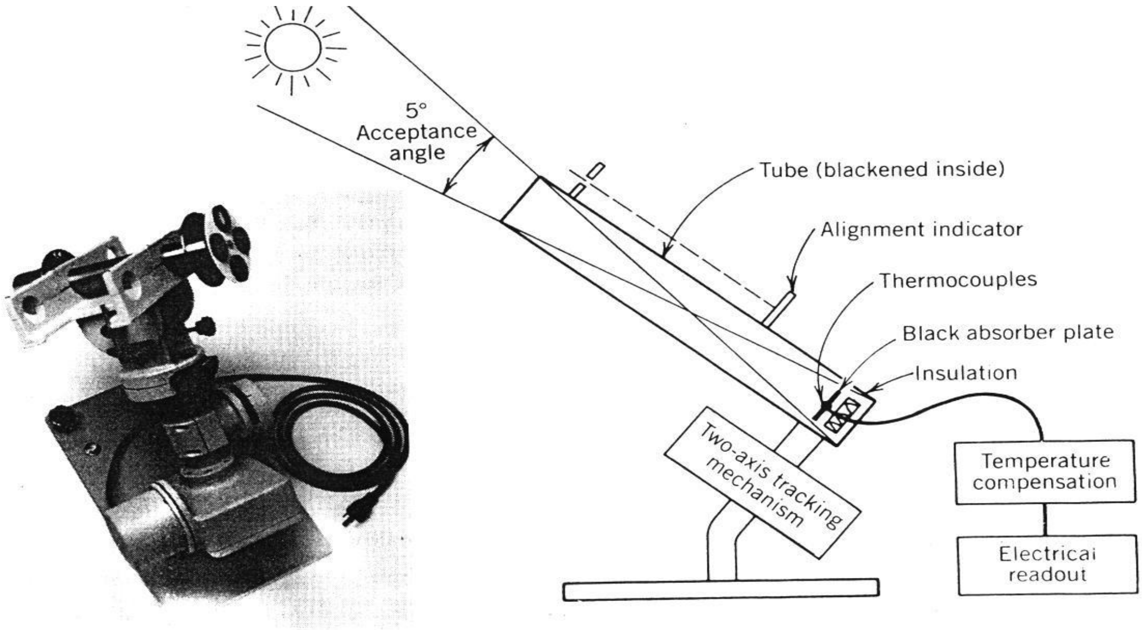
<u>Surface azimuth angle(γ)</u>

- It is the angle in horizontal plane between the line due south and the horizontal projection normal to the inclined plane surface. It is taken as positive when measured from south towards west.

MEASUREMENT OF SOLAR RADIATION DATA

- Must measure both direct and diffuse radiation.
- Solar Radiation measured by two basic type of instruments
  - Pyrheliometer-Collimates the radiation to determine the <u>beam intensity</u> as a function of incident angle
  - Pyranometer-It measures the <u>total hemispherical solar radiation.</u>

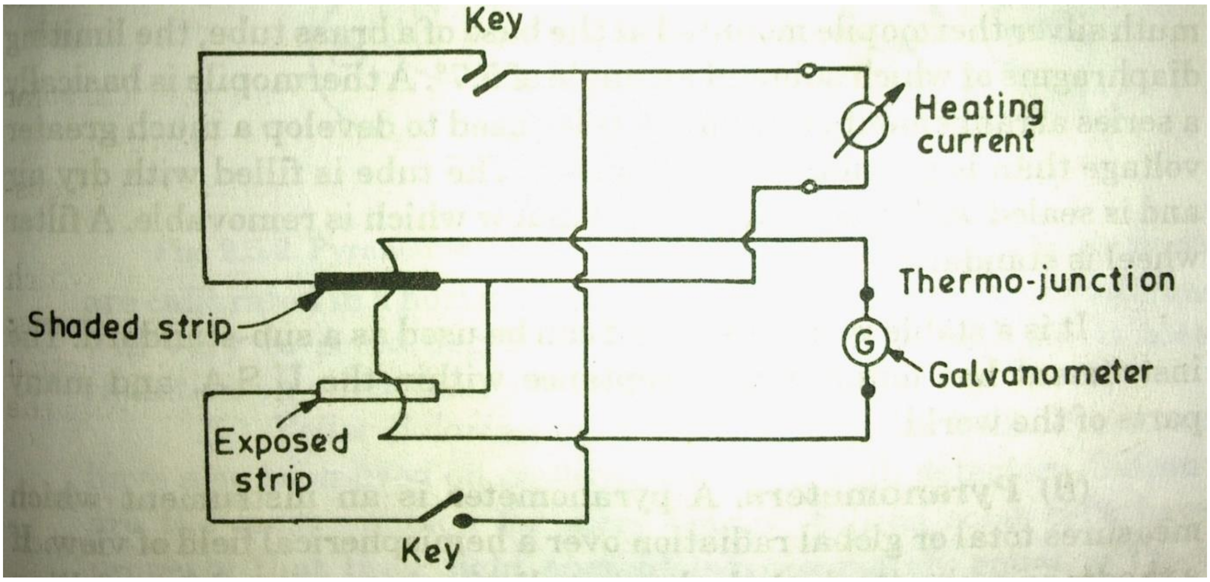
TYPES OF PYRHELIOMETERS



- Pyrheliometers – measures beam radiation, blocks diffuse radiation.
- Used for routine measurements.
- Types :
  - Angstrom pyrheliometer
  - The Abbot Silver disc pyrheliometer
  - Eppley pyrheliometer

<u>Angstrom Compensation Pyrheliometer</u>

- A thin blackened shaded manganin strip is heated electrically up to the same strip exposed to solar radiation.
- The thermocouples on the back of each strip connected in opposition through a galvanometer to check the equality of temperature.



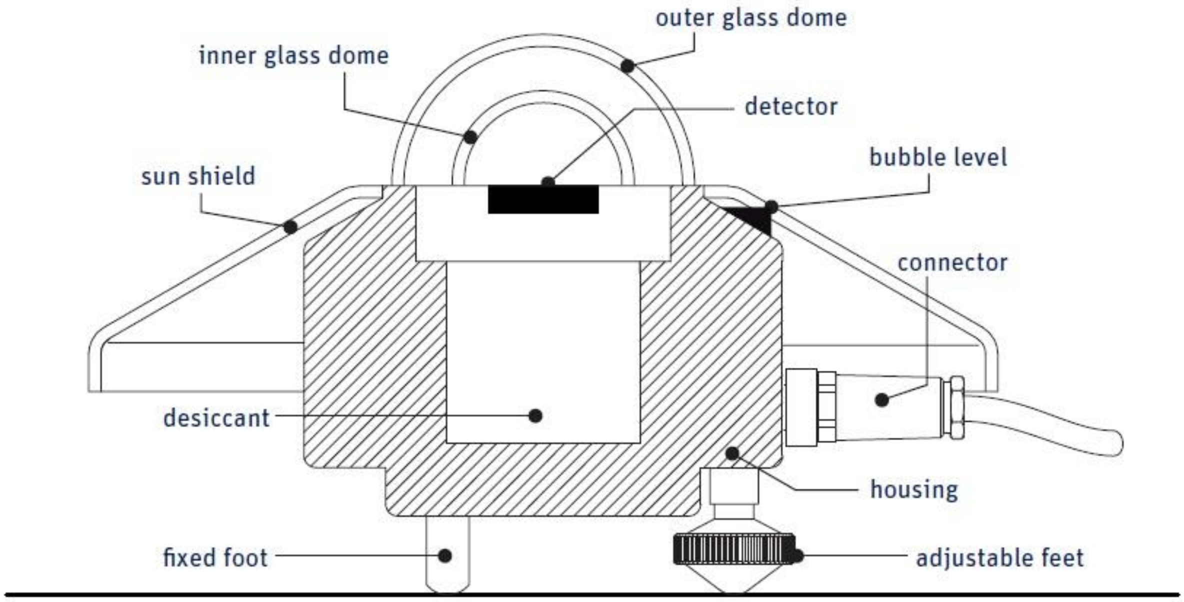
Abbot Silver Disk Pyrheliometer

- It consist of blackened silver disk positioned at the lower end of tube with diaphragms to limit to the aperture to 5.7deg .
- A Mercury in glass thermometer is used to measure the temperature of the disk and shutter made of 3 polished metal leaves is provided at the upper end of tube to allow solar radiation to fall on the disk at regular intervals.
- The thermometer steam is bend through 90 deg so that it lies along the tube to minimize its exposure to the sun.
- Used as calibrating instruments.

Eppley Pyrheliometer

- Bismuth-silver thermopile with 15 junctions mounted at the base of a brass tube, the limiting diaphragms subtend an angle of 15 degrees
- A thermopile is basically a series arrangement of thermocouples used to develop a much greater voltage than its possible using only one.
- The tube is filled with dry air and sealed with crystal quartz window which is removable.
- The instrument has found wide acceptance within the U.S.A and many parts of the world.

TYPES OF PYRANOMETERS



- Measures total or hemispherical or global radiation over a hemispherical point of view.
- Hot and cold junctions of a thermopile.
- Emf proportional to solar radiation is received.- range of 0 to 10mV
- Types: Eppley pyranometer

  Yellot solarimeter(photovoltaic solar cell)

  Thermoelectric pyranometer

  Moll-Gorczyheski solarimeter

Eppley Pyranometers

- The temperature is sensed on the concentric silver ring (0.25 mm thick) consist of black (absorb radiation) and white surface (reflect radiation) with a thermopile
- 10 or 50 thermocouple junctions to detect the temperature difference between the coated rings and it is enclosed in hemispherical glass cover.

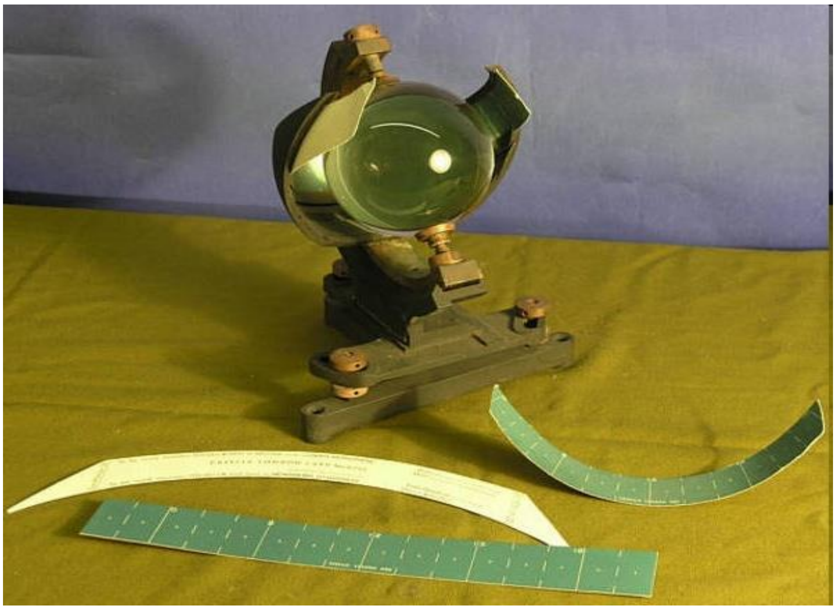
Yellot Solarimeter

- Used on photovoltaic detectors.
- Silicon cells are used to measure solar radiations.
- The incident radiations are converted to the equivalent electrical energy.

Sunshine Recorder

Measures duration of bright sunshine in a day

- The duration of sun shine is measured by means of sun's rays are focused by a glass sphere to point on a card strip held in a groove in a spherical bowl concentrically with the sphere.
- Burnt space with length equal to duration of sunshine is obtained on the strip.



PRINCIPLE OF CONVERSION OF SOLAR RADIATION INTO HEAT

- Heat conversion by green house effect.
- Energy from the sun comes in the form of light, a shortwave radiation. When this radiation strikes a solid or liquid, it is absorbed and transformed into heat energy, the material become warm and stores the heat, conducts it to surrounding materials(water, air, other solids or liquids) or reradiates into other materials of lower temperature. This radiation is a long wave radiation.

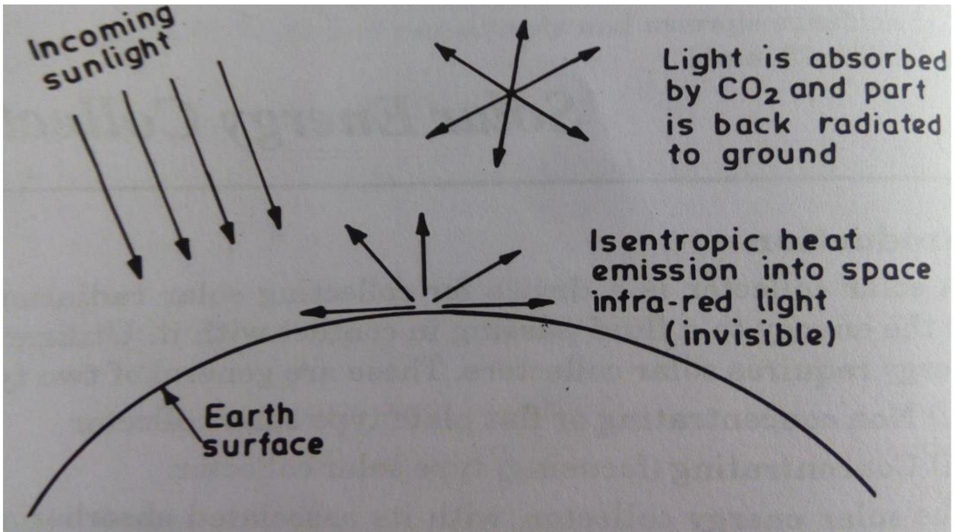


Fig. 3.2.1. The green house effect radiated to the CO_2 content of the atmosphere.

- Glass easily transmits short wave radiation, which means that it poses little interference to incoming solar energy, but it is a very poor transmitter of long wave radiation.
- Once the sun's energy has passed through the glass windows and has been absorbed by some material inside, the heat will not be reradiated back outside.
- Glass act as heat trap.

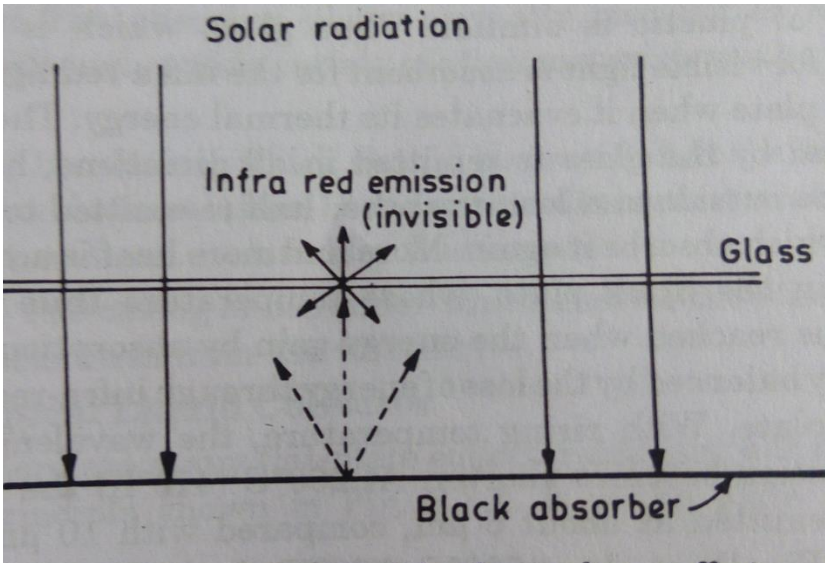


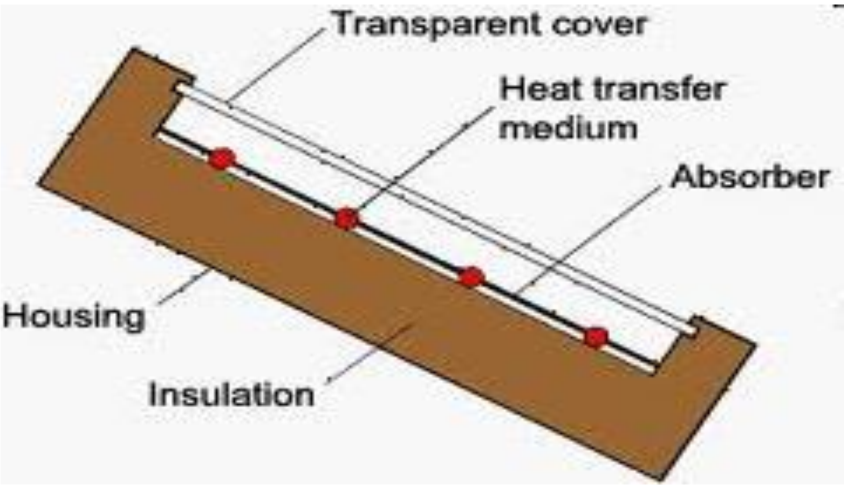
Fig. 3.2.2. Principle of green house effect.

- A black painted plate absorbs the incoming sunlight. About it, is fixed a plate of ordinary window glass. When the temperature of the black plate increases, it emits an increment of thermal heat in the form of infrared light.
- Emission increases with temperature(T).
- Earth surface= black plate
- CO_2= glass
- Wein,s law:
  - λmax. T= constant=2989 µm Kelvin

SOLAR THERMAL COLLECTORS

- Solar collector is a device for collecting solar radiation and transfer the energy to a fluid passing in contact with it.
- Two types of solar collectors
  - Non-concentrating (or) Flat plate type
  - Concentrating (focusing type) type

FLAT PLATE COLLECTORS



Main Components

1. **Transparent cover** which maybe one or more sheets of glass or radiation transmitting plastic film or sheet
2. **Tubes, fins, passages or channels** to carry water, air or other fluid.
3. **The absorber plate**, normally metallic or black surface
4. **Insulation** at the back and sides to minimize heat losses. Standard insulating materials like fiber glass can also be used.
5. **Casing** for protection.

Flat-plate solar collectors may be divided into two main classifications based on the type of heat transfer fluid used.

- Liquid heating collectors are used for heating water and non-freezing aqueous solution and occasionally for non-aqueous heat transfer fluids.
- Air or gas heating collectors are employed as solar air heaters.

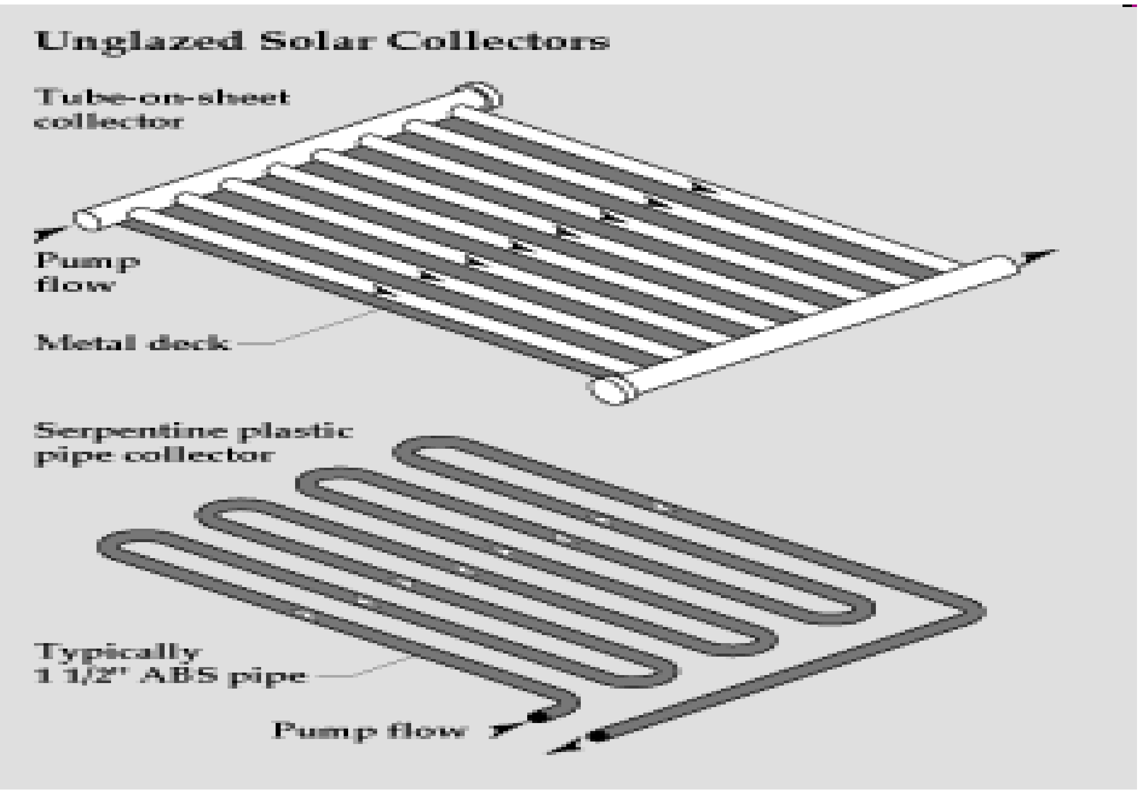
Advantages of Flat plate collectors

- They have the advantages of using both beam and diffuse solar radiation.
- They do not require orientation towards the sun.
- They require little maintenance.
- They are mechanically simpler than the concentrating collectors, absorbing surfaces and orientation devices of focusing collectors.

Applications of Solar Air Heaters

- Residential buildings.
- Drying agricultural produce and lumber.

- Heating green houses.
- Air conditioning buildings
- Using air heaters as the heat sources for a heat engine such as a Brayton or Stirling cycle.



Concentrating Collectors

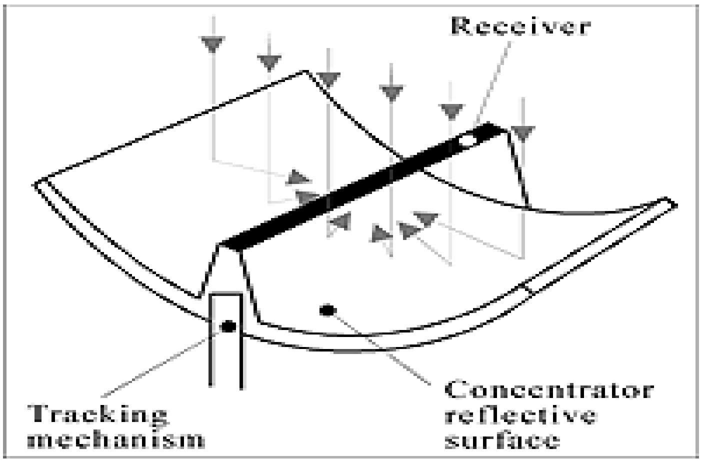
- Concentrating collectors use mirrored surfaces to concentrate the sun's energy on an absorber called a receiver.
- Concentrating collectors also achieve high temperatures, when direct sunlight is available.
- Some designs concentrate solar energy onto a focal point, while others concentrate the sun's rays along a thin line called the focal line. The receiver is located at the focal point or along the focal line.
- A heat-transfer fluid flows through the receiver and absorbs heat.
- However, concentrators can only focus direct solar radiation, with the result being that their performance is poor on hazy or cloudy days.
- Concentrators perform best when pointed directly at the sun. To do this, these systems use tracking mechanisms to move the collectors during the day to keep them focused on the sun.
- trackers need frequent maintenance.
- commercial applications

Types of Concentrating Collectors

- Parabolic trough collector
- Mirror strip reflector
- Fresnel Lens collector
- Flat plate collector with adjustable mirrors
- Compound parabolic concentrator

Parabolic trough system

Parabolic troughs are devices that are shaped like the letter "u". The troughs concentrate sunlight onto a receiver tube that is positioned along the focal line of the trough. Sometimes a transparent glass tube envelops the receiver tube to reduce heat loss .



Parabolic Trough Reflector

- Parabolic trough reflectors have been made of highly polished aluminium,or silvered glass or of a thin film of aluminized plastic on a firm base.
- For the solar radiation to be brought to a focus by parabolic trough reflector, the sun must be in such a direction that it lies on the plane passing through the focal line and the vertex.
- Trough type of collectors are generally oriented in the east-west or north-south directions.

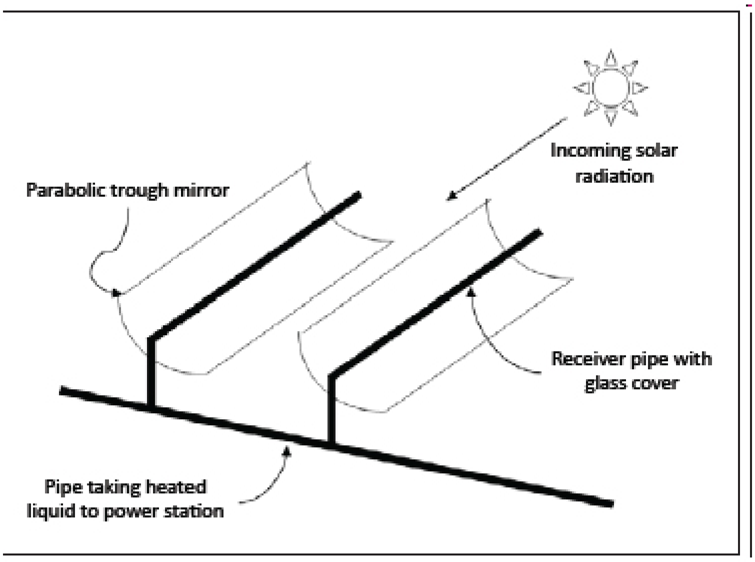


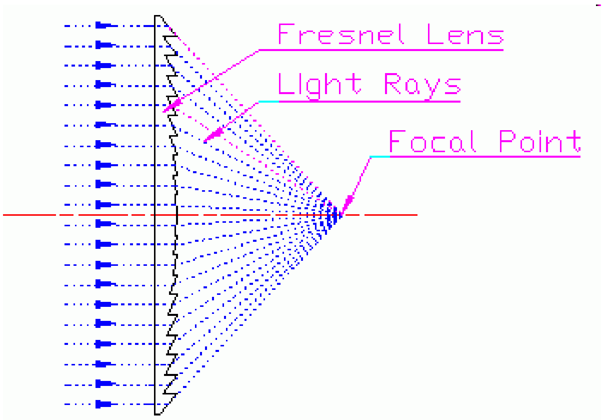
FIGURE 1: The layout of a solar trough.

Mirror Strip Reflector

- In another kind of focusing collector, a number of plane or slightly curved mirror strips are mounted on a flat base.
- The angles of the individual mirrors are such that they reflect solar radiation from a specific direction on to the same focal line.
- The angles of the mirrors must be adjusted to allow for changes in the sun's elevation, while the focal line remains in a fixed position.

Fresnel Lens Collector

- Made of acrylic plastic sheets, flat on one side, with fine grooves on other side.
- The angles of grooves are designed to bring the radiation to a line focus.

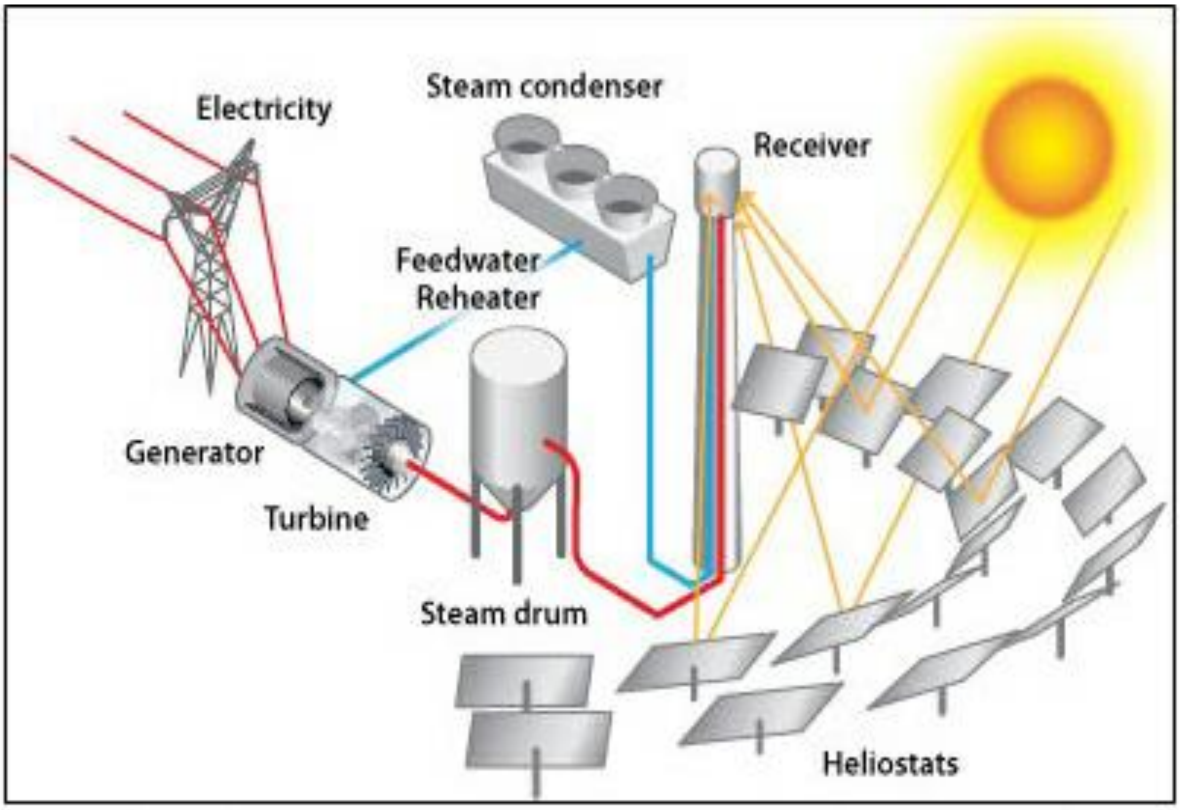


Central Receiver Collector

- Solar radiation is reflected from field of heliostats to a centrally located reciever on a tower.

Principle and working

- A large field of mirrors, called heliostats, track the sun.
- A tower collects light concentrated by the heliostats onto a central receiver on top of a tower. Tower heights range from approximately 300 to 650 feet.
- HTF, composed of either water or molten nitrate salt, moves through the receiver and is heated to temperatures over 500 °C.
- The heated HTF is then sent to a heat exchanger where water is turned into steam, which then drives a turbine generator.

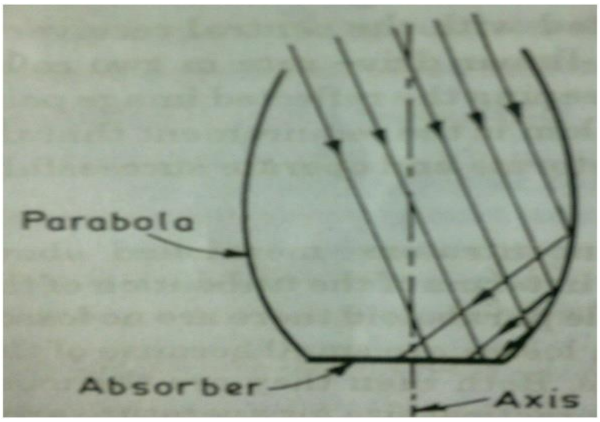


Description

- Tower with the central receiver on top
- Heat conversion subsystem
- Heat storage device
- Field of oriented mirrors

COMPOUND PARABOLIC CONCENTRATOR

- CPC is non-focusing-but solar radiation from many directions is reflected toward the bottom of the trough.
- CPC provides moderately good concentration, although less than a focusing collector in an east-west direction without adjustment for sun tracking..



Advantages of Compound Parabolic Concentrator

- There is no need of tracking ,as it has high acceptance angle, only essential adjustments are required.
- The Efficiency for accepting diffuse solar radiation is much larger than conventional concentrators.
- Its Concentration ratio is equal to the maximum value possible for given acceptance angle.
- The Maximum concentration ratios are available with parabolic system, is of the order of 10,000.

Advantages and Disadvantages of Concentrating collectors over Flat-plate Type Collectors

Advantages

- Reflecting surfaces required less material and are structurally simpler than flat-plate collectors.
- For a concentrator system the cost per unit area of solar collecting surface is therefore potentially less than that for flat-plate collectors.
- The absorber area of a concentrator system is smaller than that of a flat-plate system for same solar energy collection and therefore the isolation intensity is greater.
- Concentrating systems can be used for electric power generation when not used for heating or cooling. The total useful operating time per year can therefore be large for a concentrator system than for a flat-plate collector and the initial installation cost of the system can be regained by saving in energy in a shorter period of time.
- Little or no anti-freeze is required to protect the absorber in a concentrator system whereas the entire solar energy collection surface requires anti-freeze protection in a flat-plate collector.

Disadvantages

- Out of the beam and diffuse solar radiation components, only beam component is collected in case of focusing collectors because diffuse component cannot be reflected.
- Additional requirements of maintenance particular to retain the quality of reflecting surface against dirt, weather, oxidation etc.
- Non- uniform flux on the absorber whereas flux in flat-plate collectors is uniform.
- Additional optical losses such as reflectance loss and the intercept loss

- High initial cost.

Need for Energy Storage

- The electricity grid is a complex system in which power supply and demand must be equal at any given moment.
- Constant adjustments to the supply are needed for predictable changes in demand, such as the daily patterns of human activity, as well as unexpected changes from equipment overloads and storms.
- Energy storage plays an important role in this balancing act and helps to create a more flexible and reliable grid system.

Need for Energy Storage

- For example, when there is more supply than demand, such as during the night when low-cost power plants continue to operate, the excess electricity generation can be used to power storage devices.

- When demand is greater than supply, storage facilities can discharge their stored energy to the grid.

- Pumping water back behind hydroelectric dams has been used for decades as a form of storage that absorbs excess capacity from the grid and returns capacity to the grid later when it is needed.

- In the future, as more storage technology options emerge and the United States transitions to a cleaner energy economy, energy storage is poised to play an even greater role.

Benefits of Energy Storage

Renewable energy technologies – such as wind and solar – have variable outputs, storage technologies have great potential for smoothing out the electricity supply from these sources and ensuring that the supply of generation matches the demand.

Energy storage is also valued for its rapid response – most storage technologies can begin discharging power to the grid very quickly, while fossil fuel sources tend to take longer to ramp up.

This rapid response is important for ensuring stability of the grid when unexpected increases in demand occur.

Benefits of Energy Storage

- Energy storage also becomes more important the farther you are from the electrical grid.
- For example, when you turn on the lights in your home, the power comes from the grid; but when you turn on a flashlight while camping, you must rely on the stored energy in the batteries.
- Similarly, homes that are farther away from the transmission grid are more vulnerable to disruption than homes in large metropolitan areas.
- Islands and microgrids that are disconnected from the larger electrical grid system depend on energy storage to ensure power stability, just like you depend on the batteries in your flashlight while camping.

Sizing of Energy Storage Systems

- Sizing based on Load
- Sizing based on Solar Array
- Power Requirements

Sizing based on Load

- Based on desired or required amount of energy storage
- For a battery – measure the kWh-per day
- The minimum kWh-per-day value can be calculated based on the wattage and runtime of all potential loads to be supported by the system.
- From there, the system size may be adjusted depending on whether the system is intended for daily cycling or backup power.
- The load profile and desired duration of backup power should also be considered.

Battery Parameters

- **State of charge** (**SoC**) is the level of charge of an electric battery relative to its capacity.
- **Depth of Discharge (DoD)** is the fraction or percentage of the capacity which has been removed from the fully charged battery.
- It is an alternative method to indicate a battery's State of Charge (SoC).
- The Depth of Discharge is the complement of State of Charge: as one increases, the other decreases.
- The units of SoC are percentage points (0% = empty; 100% = full). An alternative form of the same measure is the **depth of discharge** (**DoD**), the inverse of SoC (100% = empty; 0% = full).
- SoC – indicates current state of the battery
- DoD – indicates lifetime of a battery

Example:

- Load calculations: 10 kWh per day
- Customer requests: 1.5 days of backup power
- Available Battery Size - 2.8 kWh at 80% DoD
- 10 kWh x 1.5 days = 15 kWh of desired storage
- 15 kWh/2.8 kWh (battery size) = 5.3 batteries
- So 5 or 6 storage elements can be used. If 6 – Cushion for other loads, 5 – cost cutting

Sizing based on Size of Solar Array

When retrofitting an existing PV installation to add storage, battery bank size is most often computed based on the size of the solar array.

It is important to consider peak sun hours, PV Watts data (realistic energy production based on location), and PV size (kW) as part of the calculation.

In addition, it's critical that the system cannot exceed the maximum continuous charge rate of the battery bank to prevent damage and ensure a long life.

Example

- Battery for system: 3.5 kWh battery with maximum charge of 1.7 kW continuous
  PV array size: 4 kW
  Average PV daily production: 20 kWh per day
  4 kW (PV) / 1.7 kW (Max. battery charge) = 2.3 batteries
- Round up the 2.3 battery units to determine that the minimum number of batteries would be three of the 3.5 kWh batteries.
- Based on daily PV production: 20 kWh (PV per day) / 3.1 kWh (battery at 90% DoD) = 6.4 (3.5 kWh batteries)
- From this calculation, you can round up to 7 or round down to 6 batteries based on customer preference (such as mode of operation).

Power Requirements

- Every battery has a maximum charge and discharge capacity.
- Those rates must be adhered to for adequately charging the battery, like PV system size (charge rate) and the continuous load value to be supported by the battery (discharge rate).
- Example:
- Battery for system:
  - 3.5 kWh with a maximum continuous discharge of 1.7 kW
    Home maximum continuous discharge: 6 kW
    6 kW (continuous load) / 1.7 kW (battery maximum discharge) = 3.5 batteries
- When it comes to power requirements, you always round up to determine the minimum battery bank size. In this example, the system requires 4 of the 3.5 batteries.

Battery Size Calculations

Parameters Required:

- **Load type (ampere or watt):** Mention the unit in which the load will be specified, ampere or watt.
- **Load (watt)**: If the load type is watt, mention the load in watt, for example 100 W.
- **Load (ampere):** If the load type is ampere, mention the current in ampere, for example 10 A.
- **Voltage (V)**: Specify the battery voltage, if the load type is watt.
- **Required duration (hours):** Specify the duration that the load must be supplied for.
- **Battery type:** Select the battery type, lead-acid or lithium-ion.
- **Remaining charge (%):** Specify the required remaining charge.
  - To prolong the life of a battery, a lead-acid battery should not frequently be discharged below 50 %, and Lithium-ion battery below 20%.
  - Note that 0% is a flat battery and 100% if a full battery.

From these parameters we calculate the Required battery size (Ah). The recommend battery size in Ah.

Current Calculation

- If the load is specified in watt, the current **I** is calculated as:
- $I = P/V$ A
- where, **P** is the power in watts, and **V** is the voltage in volts.

Lithium-ion batteries:

The required battery size B_{li-ion} for lithium-ion batteries is calculated by the battery size calculator as:

B_{li-ion} = (100 * I * t) /(100-Q)

Where,
I = Current in A
t = Time duration in Hours
Q = required remaining charge in %

Lead-acid batteries

- The battery rating of a lead-acid batteries is proportional to the discharge rate.
- They are typically rated for a discharge rate over 20 hours.
- For example, a 20 Ah battery can deliver 1 A for 20 hours, which amounts to 20 Ah.
- The rating of the battery reduces by approximately 62% if it is discharged in 1 hour.
- For example, if the same 20 Ah battery is discharged in one hour, it can only deliver 12.4 A for one hour, which amounts to 12.4 Ah.
- The battery size calculator derates the battery linearly based in this characteristic.

Lead Acid Batteries

- The required battery size $B_{lead-acid}$ for lead-acid batteries is calculated by the battery size calculator as:

- $B_{lead-acid} = (100*I*t)/[(100-Q)*(0.02*t+0.6)]$

Where,

- I = Current in A
- t = Time duration in Hours
- Q = required remaining charge in %

SOLAR PV SYSTEM

SOLAR PV SYSTEMS

- this involves the generation of electricity from solar energy.
- The major advantage of PV system are
  - Sustainable nature of solar energy as fuel.
  - Minimum environmental impact.
  - Reduction in customer's electricity bill due to free availability of sunlight.
  - Long functional life time over 30 years with minimum maintenance.
  - Silent operation.

Disadvantages are :

- Installation cost is high.
- Efficiency is poor.

Small PV installations are more cost effective.

Generated power is Dc hence suitable Peis are required for AC to DC conversion

Solar Pv systems are potential contributors to micro grid

Solar PV……

- Solar energy reaching PV cell has two components :
  - A) direct (85%)
  - B) diffuse(15%)- comes through scattered diffusion in the atmosphere
- Solar cell behaves as a photo diode.
- Photo current is produced as light energy incident on the cell.
- Photo current produced by the cell depends on:
  - A) surface area
  - B) incident irradiance and
  - C) ambient temperature.

Solar PV …….

- A large no. of solar cells are connected in series parallel to obtain higher voltage and power.
- Most PV modules are equipped with MPPT system to maximise the power output from modules by shifting the operating point with solar irradiance .
- PV modules are classified as:
  - A) mono crystalline silicon
  - B) multy crystalline silicon
  - c)thin film silicon and
  - D) hybrid

Solar PV .....

MONO CRYSTALLINE SILICON

- Cells saw-cut from a single cylindrical crystal of silicon.
- Efficiency 15%
- Manufacturing process is expensive and complicated

Solar PV ....

Multi crystalline silicon.

- Cells are cut from ingot of melted and recrystallized silicon

- Cheaper than monocrystalline silicon.
- Efficiency is 12%.

Solar PV ……………….

Thin film silicon

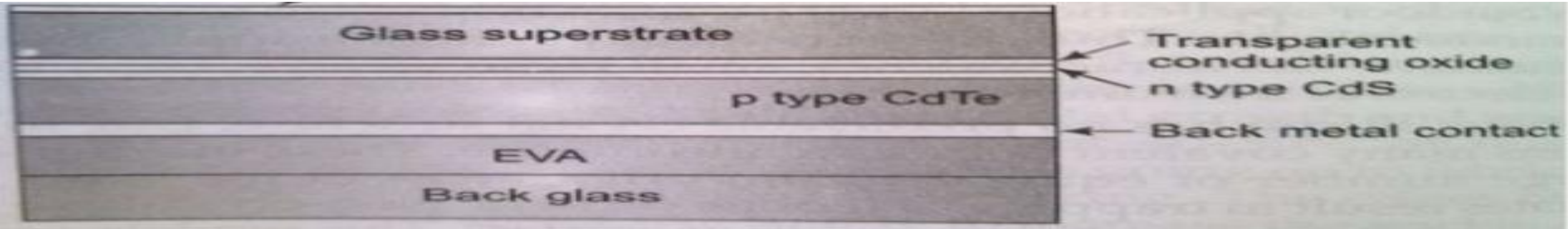
- Amorphous silicon –not crystalline.
- Made from silicon atoms in a thin homogenous layer.
- Absorbs light more effectively than crystalline silicon.
- Easy to manufacture
- Can be deposited on any surface –curved or block
- Efficiency 6%.
- Apart from Silicon Cadmium Telluride(C_dT_e)and copper indium deselinide (CIS) are also used for thin film PV cells .they are easier for manufacturing and more efficient than silicon thin film PV cells.

SolarPV …………

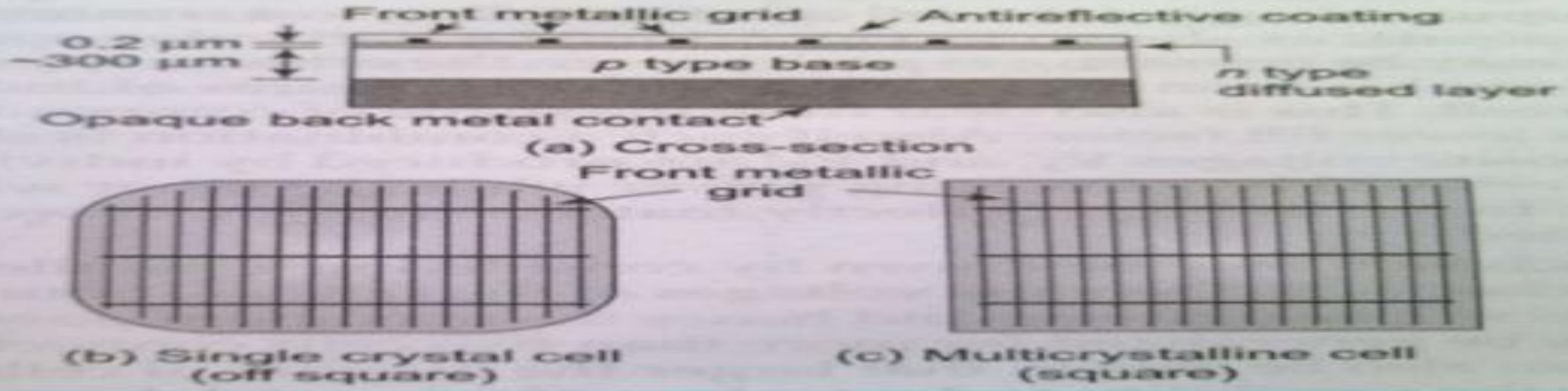
Amorphous

- Amorphous silicon/silicon crystalline heterojunction solar cells
- Simple production process.
- Produced as a combination of thin filmand crystalline by interleaving thin layer in between crystal wafers of multy crystalline PV cells.
- Excellent performance
- Efficiency 17%.

Solar PV cells



Basic structure of CdTe cell

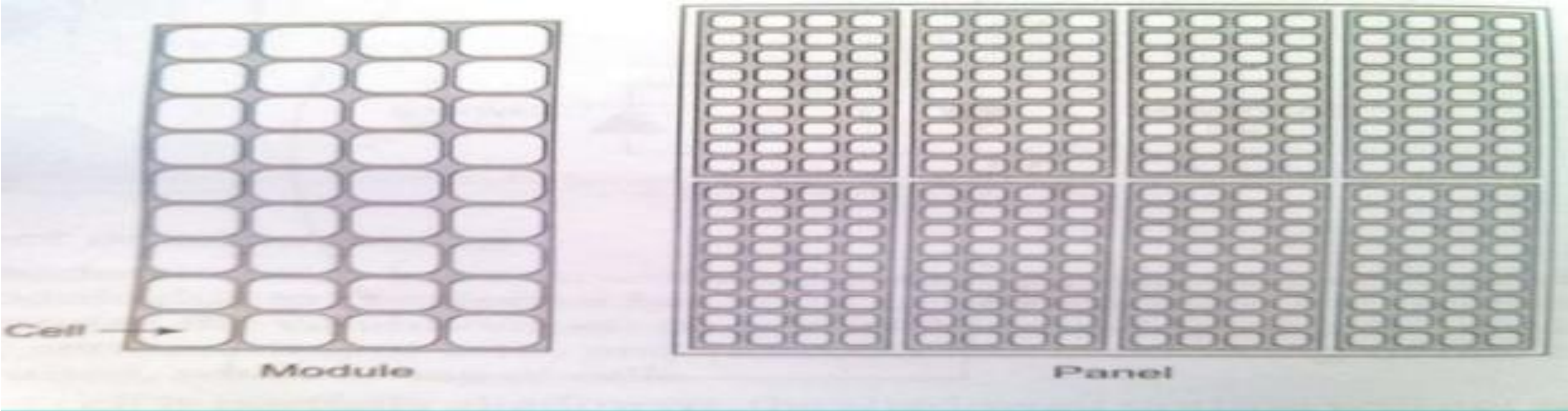


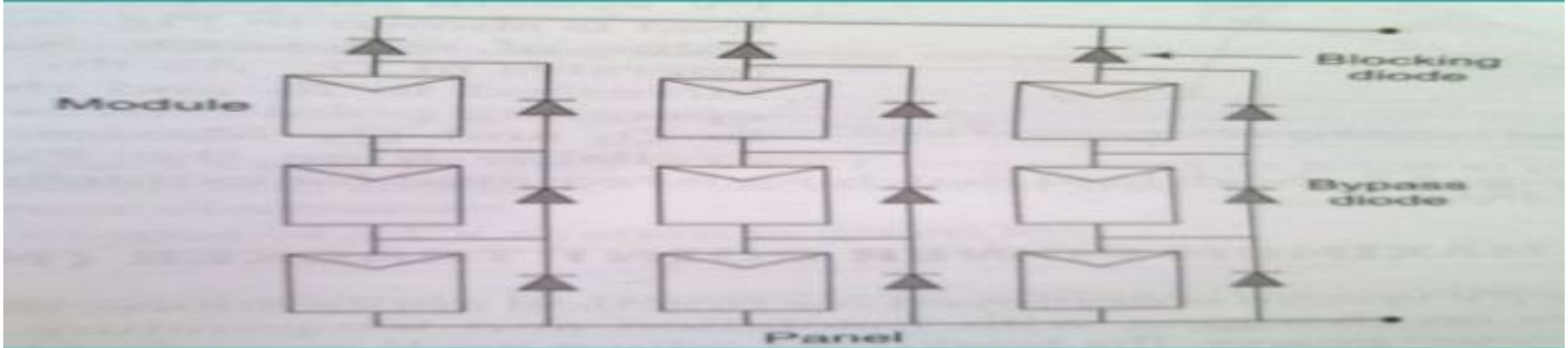
Comparison of PV Cells

PV technology	Monocrystalline	Multicrystalline	Thin film	Hybrid
Cell efficiency at Standard Test Conditions (STC) (%)	16–17	14–15	8–12	18–19
Module efficiency (%)	13–15	12–14	5–7	16–17
Area needed per kW_p (for modules) (m^2)	7 (Sharp)	8 (Sharp)	15.5 (Kaneka) 16 (Unisolar)	6–6.5 (Sanyo)
Annual energy generated per kW_p in the UK (south facing, 30° tilt) (kWh/kW_p)	830	810	800	865
Annual energy generated per m^2 (south facing, 30° tilt) (kWh/m^2)	107	100	50–52	139–150
Annual CO_2 savings per kW_p (kg/kW_p)	471	460	454	491
Annual CO_2 savings per m^2 (kg/m^2)	61	57	28	79–85

- **SOLAR CELL**:- It is basically a bulk silicon cell where the bulk material is the p-type silicon. A thin layer of n-type silicon is formed at the top surface. There is anti-reflective coating, textured rear surface.
- **SOLAR PV MODULE**:-It is the basic building block of a PV system. It is the interconnection of a number of cells and all these cells should have the same characteristics. Partial shadowing may damage the module.
- **SOLAR PV PANEL**:-Several solar modules are connected in series/parallel to increase the voltage/current ratings. Solar panel is a group of several modules connected in series parallel combination in a frame that can be mounted on a structure. The combination of such panels are called as an **SOLAR ARRAY**.

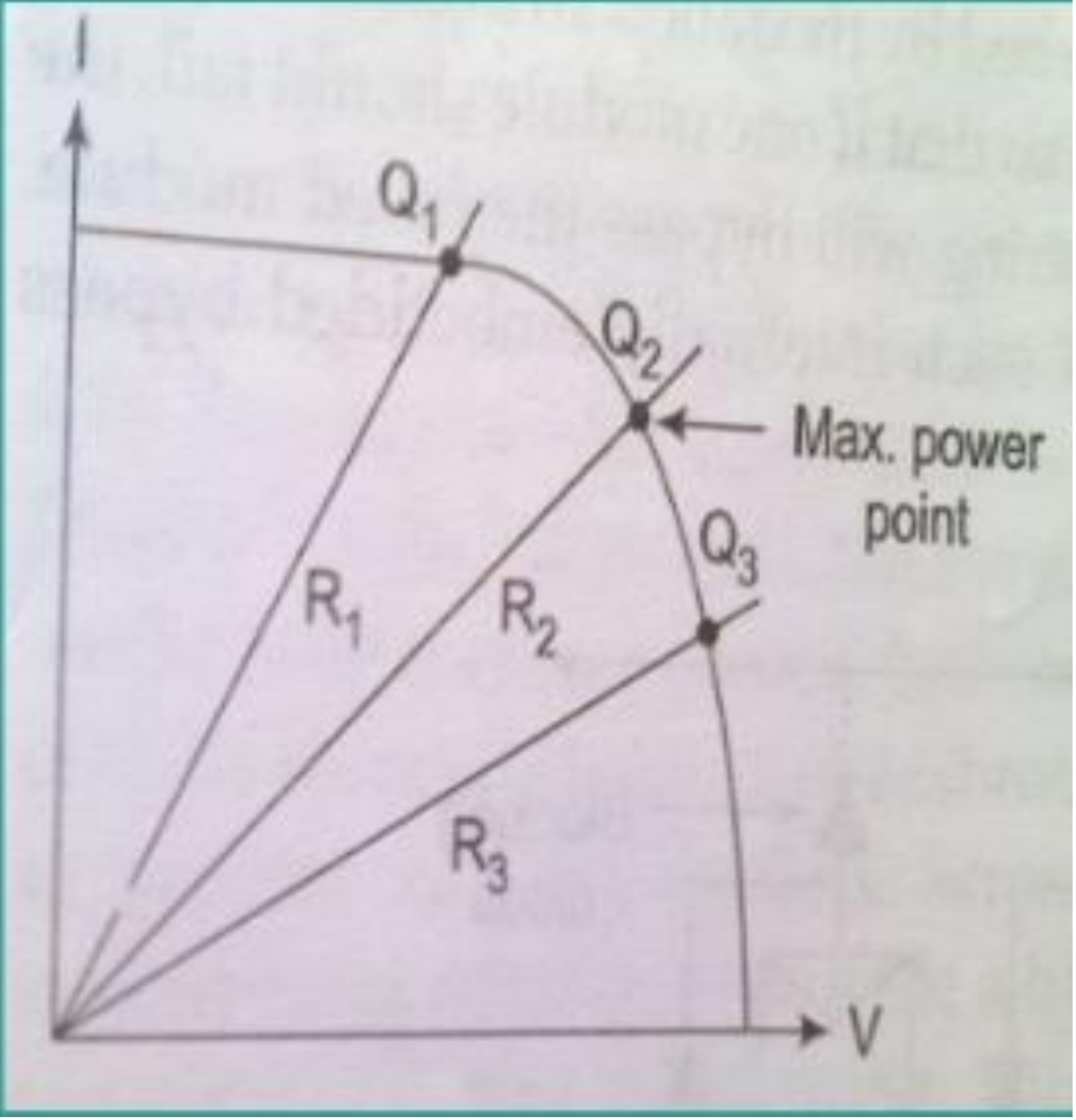
PV Panels


Cell
Module
Panel


Blocking diode
Module
Bypass diode
Panel

MAXIMIZING THE SOLAR PV OUTPUT AND LOAD MATCHING

- The best use of Solar PV system is made by maximizing the output.
- First by mechanically orienting the Panel for sun tracking to receive maximum solar radiation.
- Secondly by electrically tracking the operating point by manipulating the load.



MAXIMUM POWER POINT TRACKER(MPPT)

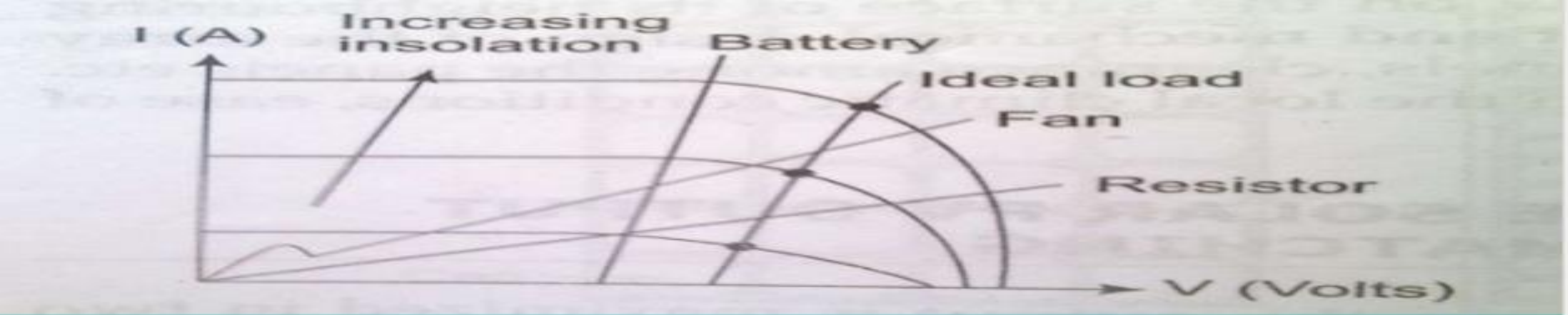
- To receive the maximum power, the load must adjust itself accordingly to track the maximum power point.
- Generally **MPPT** is an adaptation of dc-dc switching voltage regulator.
- A **buck-boost Converter** is normally used.
- Three possible strategies for operation of **MPPT** are:-

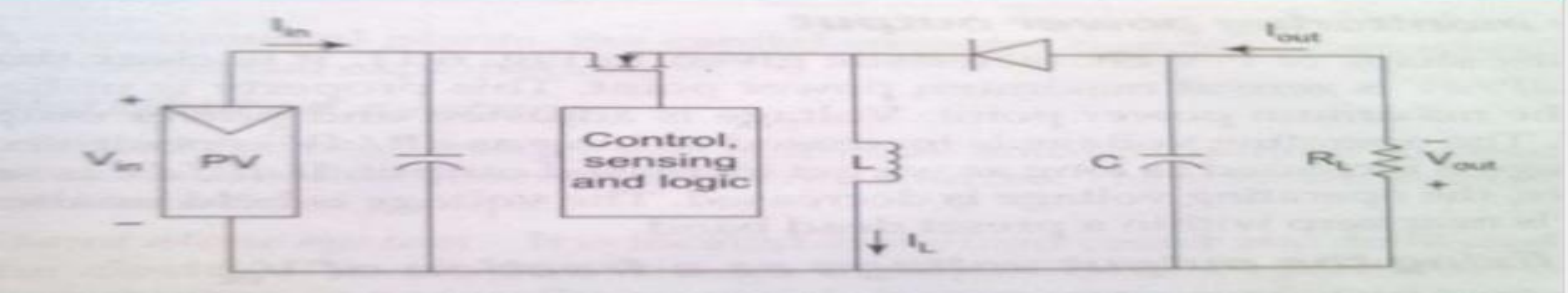
  1)By monitoring dynamic and static impedances.

  2)By monitoring the power Output.

  3)By fixing the output voltage.

MPPT using Buck Converter





SOLAR PV SYSTEM CLASSIFICATION

- **Central Power Station System**:- These are conceptually similar to any other conventional power station. They feed power to the grid to meet day time peak loads. The capital costs are high.
- **Distributed System**:- This system is much more successful and unique. It can be further classified into 3 types:

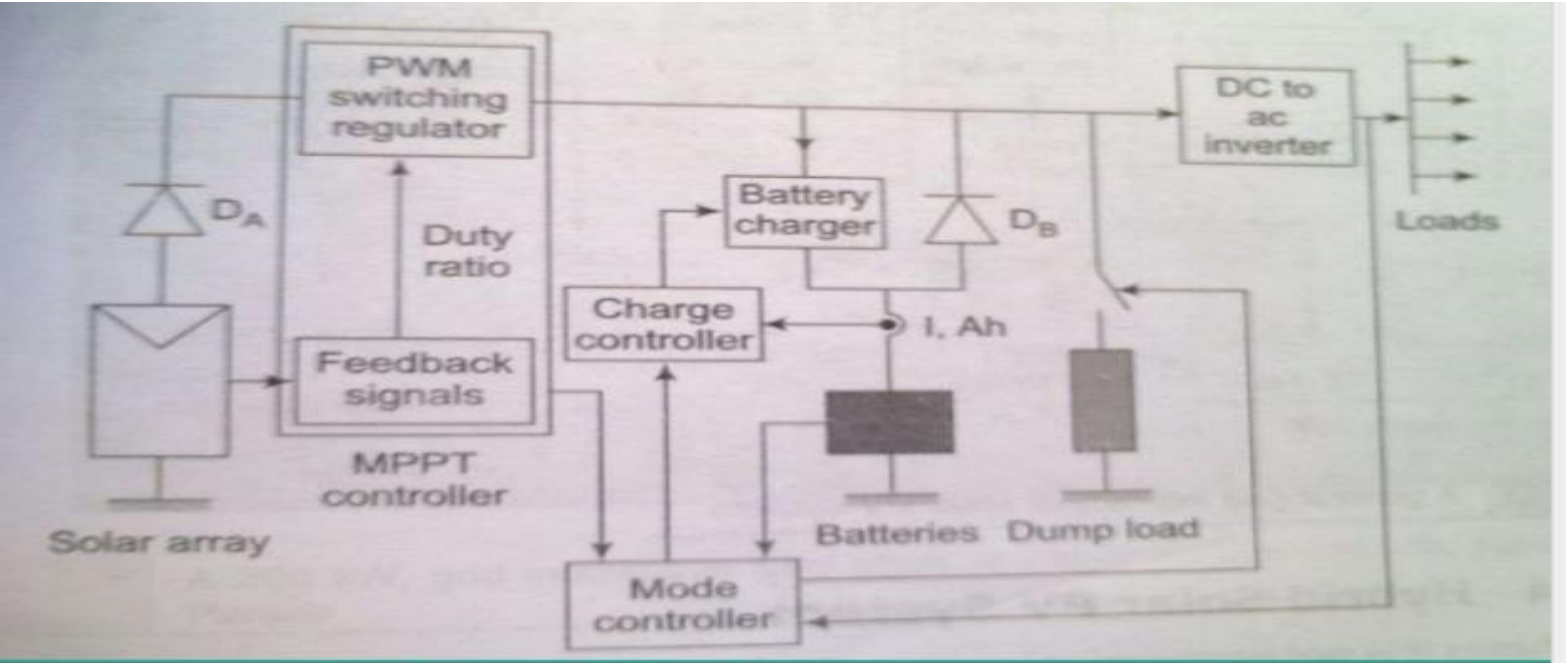
  1)Stand-alone System

  2)Grid-Interactive System

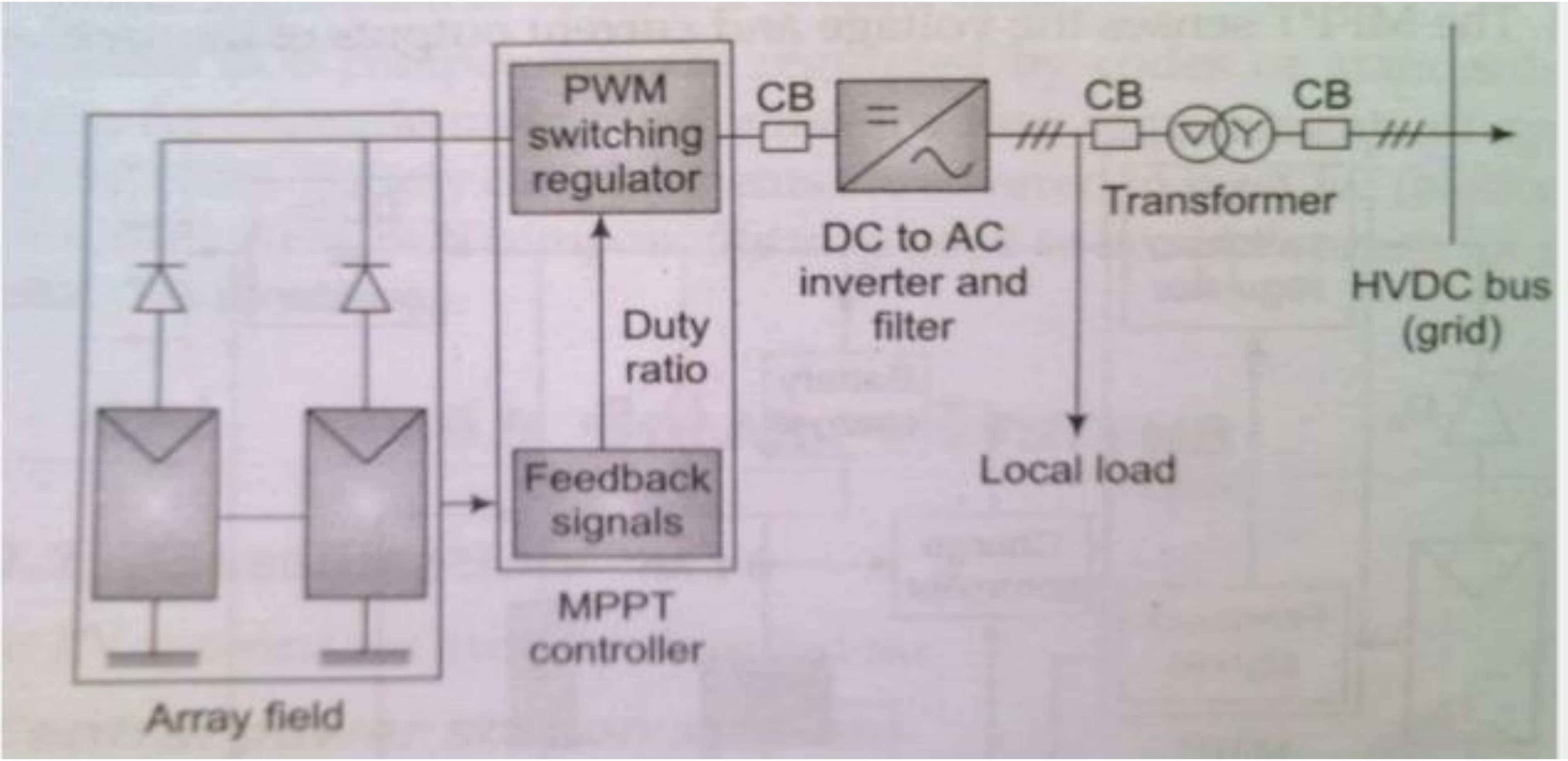
  3)Hybrid Solar PV System (Consumer applications)

- **Stand-alone Solar PV system**:-Located at the load center and dedicated to meet all the electrical loads of a village/community or a specific set of loads basically in remote or rural areas which have no access to grid supply.
- **Grid-Interactive System**:- It is connected to utility grid with two-way metering system. It is meant for the whole village of community. It is relatively a bigger system.
- **Hybrid Solar PV system**:- These systems are meant for low energy consumer devices. Basically designed for indoor applications.

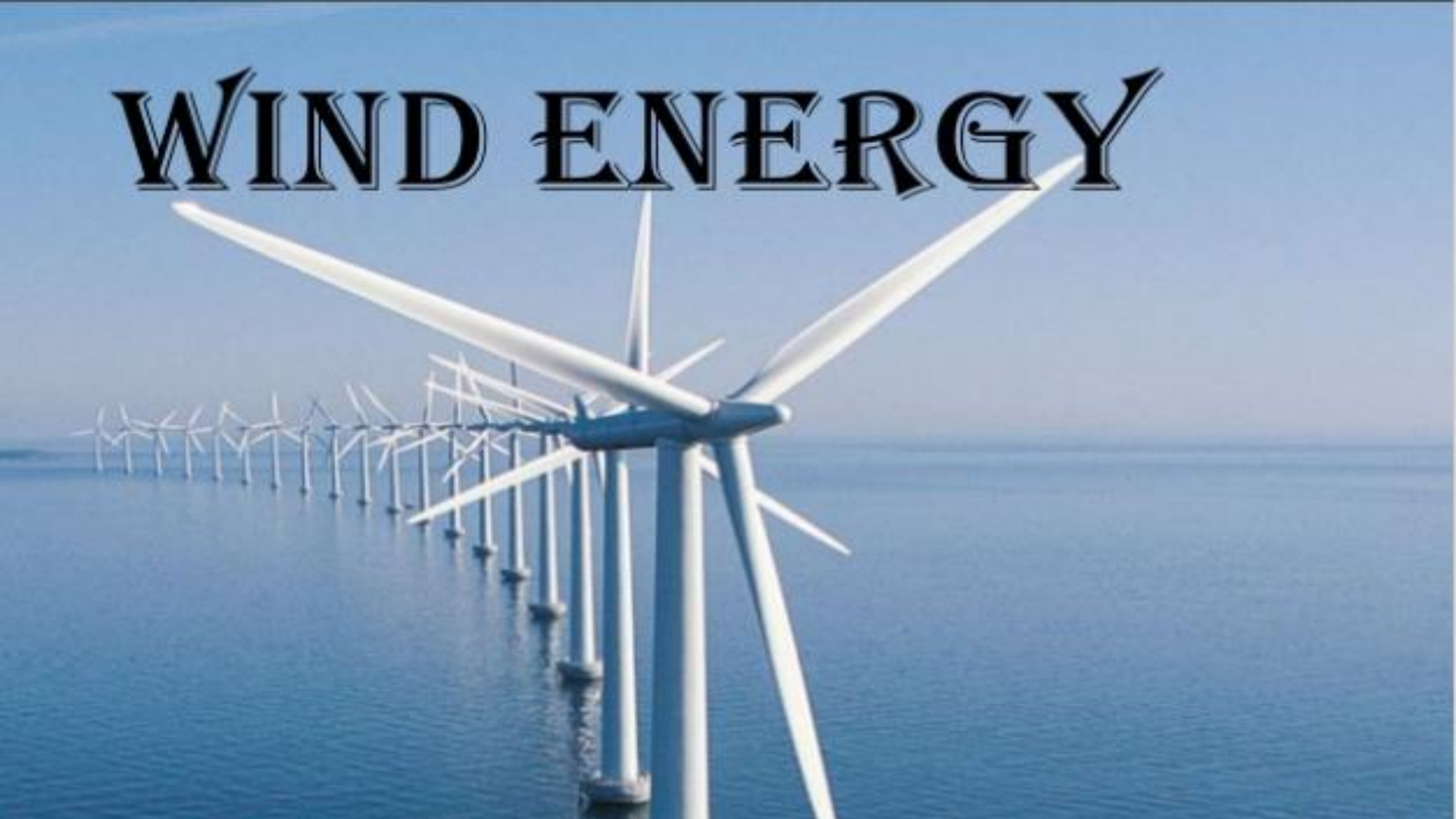
General Stand Alone Solar PV System



A grid Interactive PV System



WIND ENERGY CONVERSION SYSTEMS IN MICROGRID


WIND ENERGY

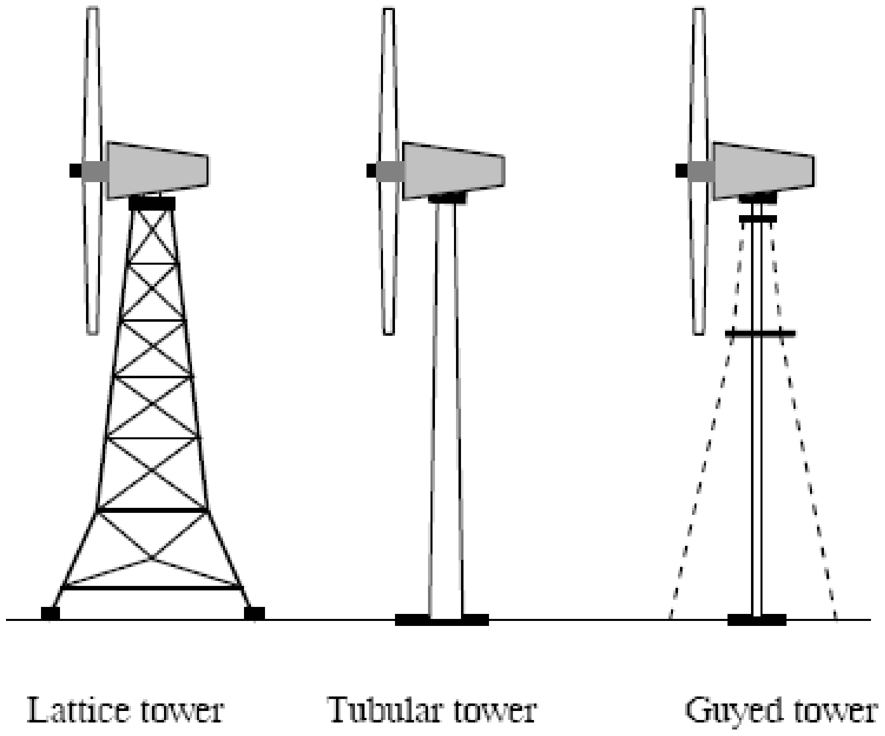
Wind Energy Conversion systems

- Converts wind energy directly into electricity.
- Principal component is wind turbine which is combined to agenerator through a multiple –ratio gear box.
- Induction generators are used normally.
- Wind turbine consists of tower ,rotor and nacelle.
- Nacelle accommodates transmission mechanism and generator .
- It consists of two or more blades.
- Turbine captures kinetic energy of wind and transfers the energy to induction generator through gear box. Function of gear box is to transfer the slower rotational speed of the turbine to higher rotational speed to generator side.
- Turbine may have horizontal or vertical axis configuration.
- Output voltage and frequency are kept within specified range by supervisory meters ,control and protection techniques

Components of wind turbine

- Electricity generation is the most important application of wind energy today.
- The major components of a commercial wind turbine are:
- 1. Tower
- 2. Rotor
- 3. High speed and low speed shafts
- 4. Gear box
- 5. Generator
- 6. Sensors and yaw drive
- 7. Power regulation and controlling units
- 8. Safety systems

Tower



WCS Tower…..

- Tower supports the rotor and nacelle of a wind turbine at the desired height. The major types of towers used in modern turbines are lattice tower, tubular steel tower and guyed tower.

Tower………..

- The lattice towers are fabricated with steel bars joined together to form the structure as shown in the figure. They are similar to the transmission towers of electric utilities. Lattice towers consume only half of the material that is required for a similar tubular tower. This makes them light and thus cheaper. For example, lattice tower for a typical turbine may cost $ 25,000 less than the tubular option of similar size.
- Legs of these towers are spread widely as shown in the figure.
- As the load is distributed over a wider area, these towers require comparatively lighter foundation, which will again contribute to the cost reduction.

Tower……………

- Tubular towers are fabricated by joining tubular sections of 10 to 20 m length. The complete tower can be assembled at the site within 2 or 3 days. The tubular tower, with its circular cross-section, can offer optimum bending resistance in all directions. These towers are aesthetically acceptable and pose less danger to the avian population.

Tower…………

- For small systems, towers with guyed steel poles are being used. By partially supporting the turbine on guy wires, weight and thus the cost of the tower can be considerably reduced. Usually, four cables equally spaced and inclined at 45^{o},support the tower. As accesses to these towers are difficult, they are not popular with large scale installations.

Components of WCS

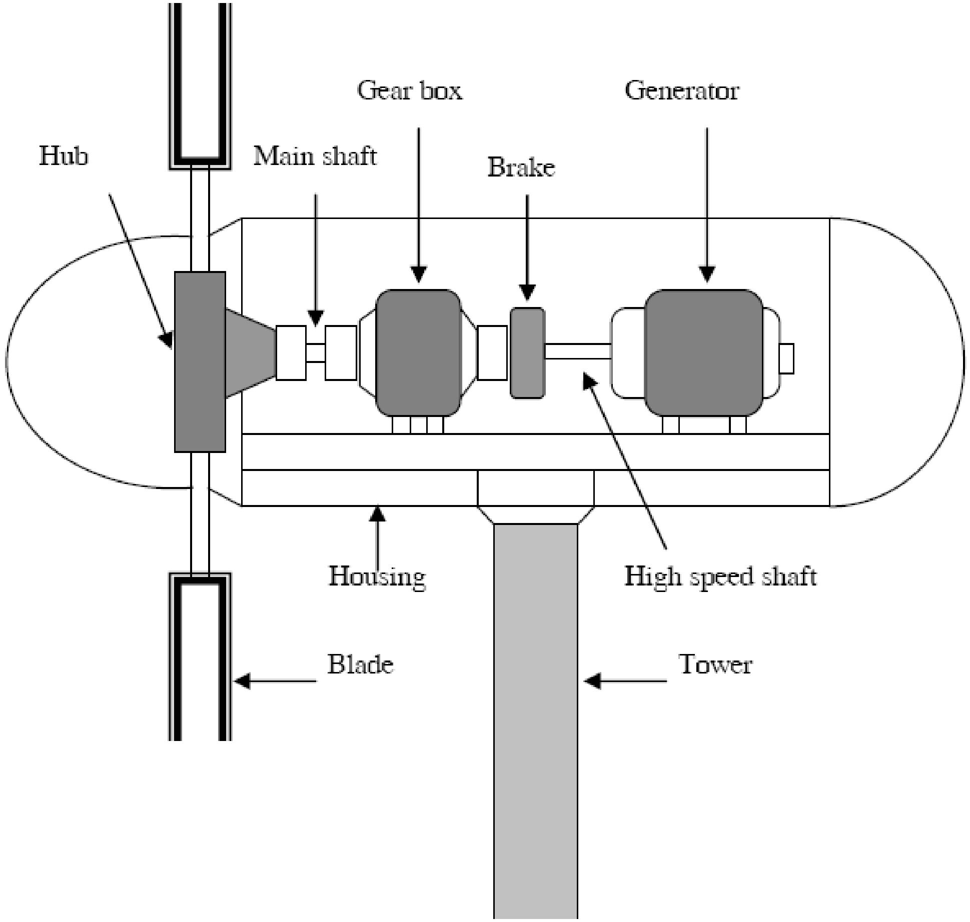


Fig. 4.1. Components of a wind electric generator

Gear box

- Gear box is an important component in the power trains of a wind turbine. Speed of a typical wind turbine rotor may be 30 to 50 r/min whereas, the optimum speed of generator may be around 1000 to1500 r/min. Hence, gear trains are to be introduced in the transmission line to manipulate the speed according to the requirement of the generator.

Gear ……

- An ideal gear system should be designed to work smoothly and quietly-even under adverse climatic and loading conditions-throughout the life span of the turbine. Due to special constraints in the nacelle, the size is also a critical factor.

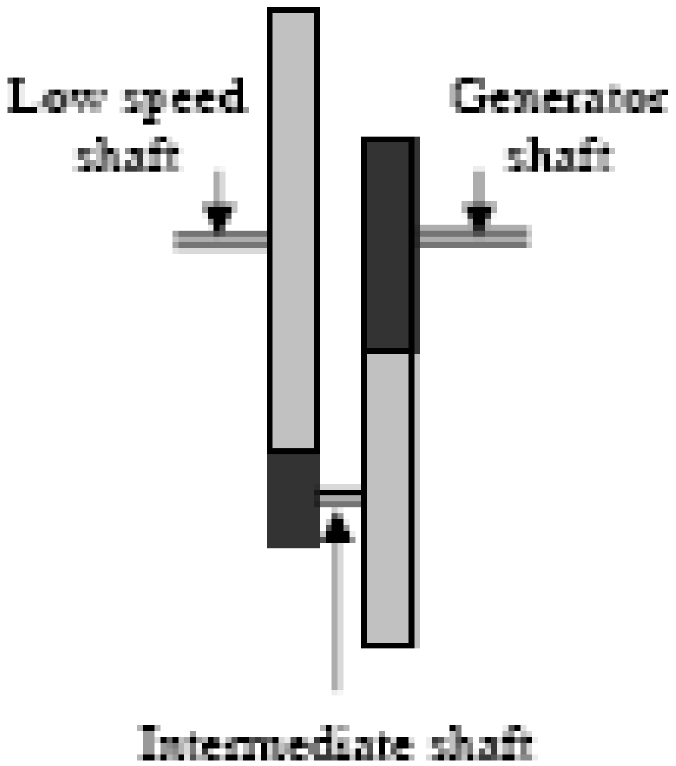


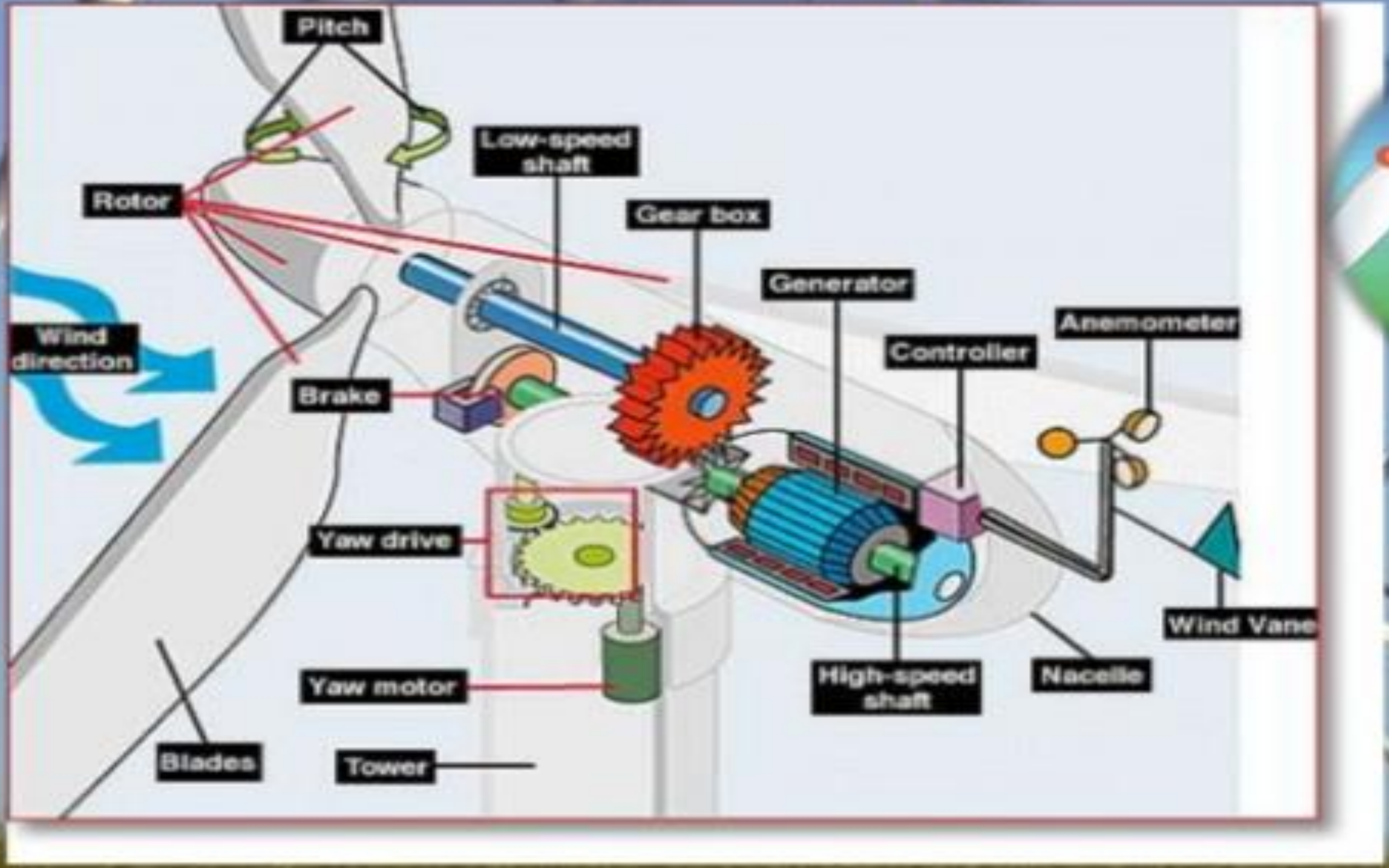
Fig. 4.8. Gear arrangements of a small wind turbine

Rotor

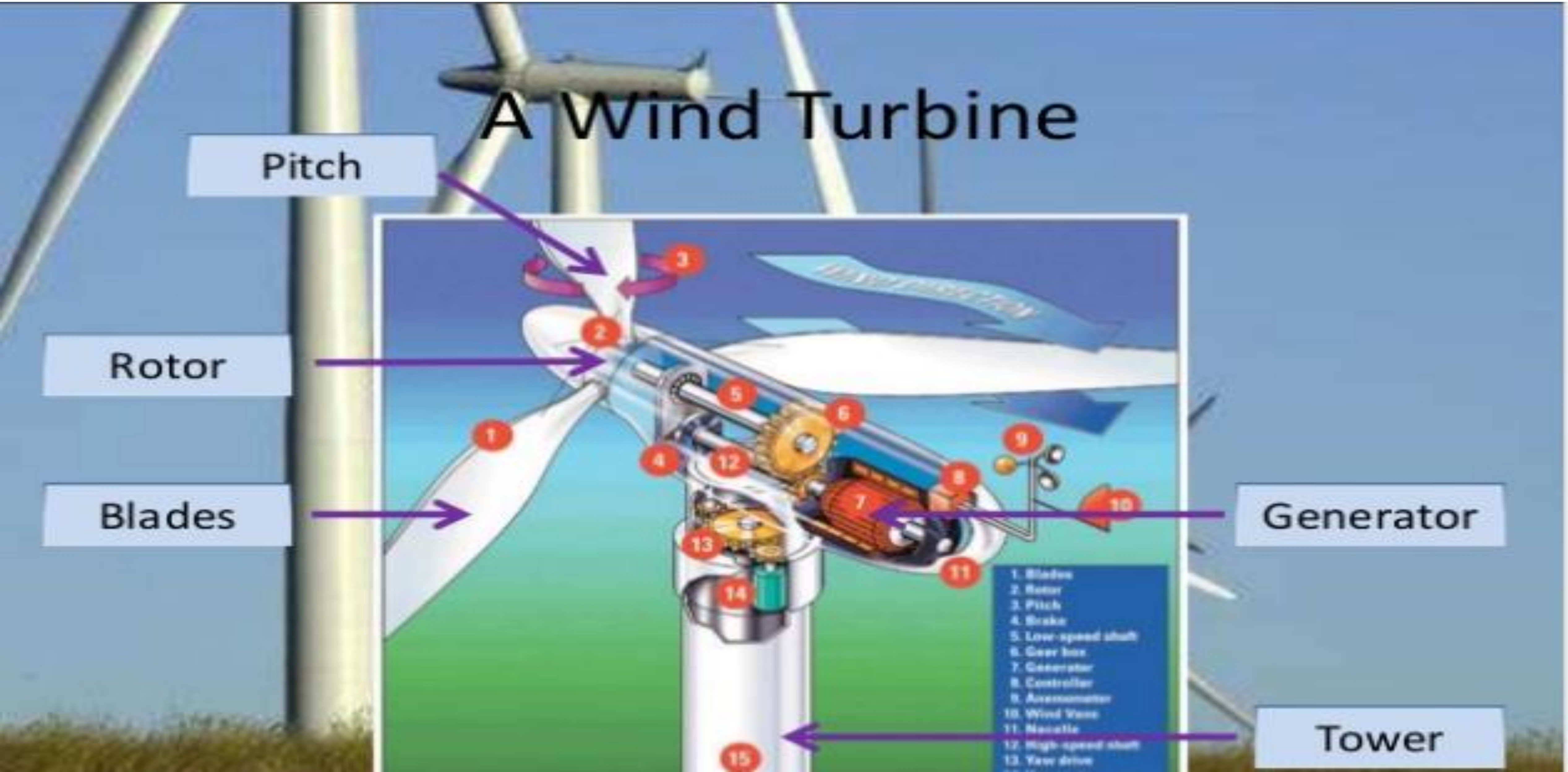
- Rotor is the most important and prominent part of a wind turbine. The rotor receives the kinetic energy from the wind stream and transforms it into mechanical shaft power. Components of a wind turbine rotor are blades, hub, shaft, bearings and other internals.
- Though it is possible to design the rotor with a single blade, balancing of such rotors would be a real engineering challenge. Rotors with single blade run faster and thus create undue vibration and noise. Further, such rotors are not visually acceptable.

- Two bladed rotors also suffer from these problems of balancing and visual acceptability. Hence, almost all commercial designs have three bladed rotors.
- Some of the small wind turbines, used for battery charging, have more number of blades- four, five or even six-as they are designed to be self starting even at low wind speeds.
- Size of the rotor depends on the power rating of the turbine. The turbine cost, in terms of $ per rated kW, decreases with the increase in turbine size. Hence, MW sized designs are getting popular in the industry.

Components of WCS



Parts of wind turbine



Components of Wind Tower

How the does a wind turbine works?

Wind turbines operate on a simple principle:

The energy in the wind turns the propeller-like blades around a rotor. The pitch of the blades makes optimum use of the wind direction.

The rotor is connected to the main drive shaft, which spins a generator to create electricity.

Wind turbines are mounted on a tower to capture the most energy. At 30 metres or more above ground, they can take advantage of faster and less turbulent wind.

Wind turbines can be used to produce electricity for a single home or building, or they can be connected to an electricity grid for more widespread electricity

WCS………..

- Output power depends on several factors like
  - Wind velocity
  - Size and shape of the turbine etc.

- Power out put $P = \frac{1}{2} C_p \rho V^3 \mathrm{A}$

Where P –Power, C_p-power coefficient, V-velocity of wind and A

swept area of rotor blades.C_p gives the amount of energy extracted by the turbine. Its value varies with rotor design and Tip Speed Ratio (TSR).

TSR - Ratio of relative speed of rotor and wind.practicalmax value is 0.4

WCS…………..

- Torque output often suffers from dynamic variations due to fluctuation in wind speed caused by tower shadow , wind shear and turbulence .This leads to dynamic perturbations in the output power resulting flicker in output power.
- Due to intermittent nature of generation net capacity will be less than the nameplate capacity.
- Wind turbines are classified as
  - 1) constant speed wind turbines and
  - 2) variable speed wind turbines.

WCS…………….

Constant speed wind turbine operating systems have the following advantages:

(1) They have a simple, robust construction and are electrically efficient.
(2) They are highly reliable due to fewer parts.
(3) No current harmonics are generated as there is no frequency conversion.
(4) They have a lower capital cost as compared to variable speed wind turbines.

However, they have the following disadvantages as compared to variable speed turbines:

(1) They are aerodynamically less efficient.
(2) They are prone to mechanical stress and are more noisy.

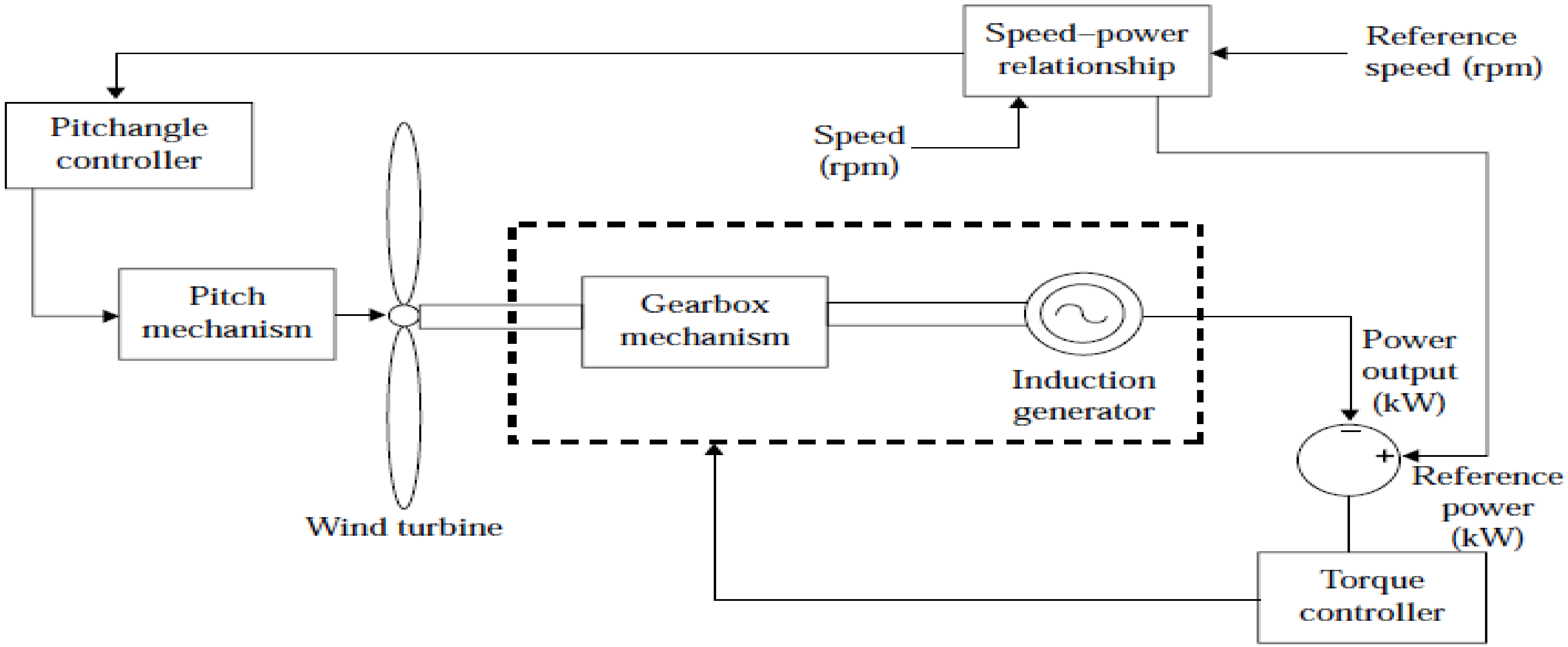
Variable Speed Wind Turbine Advantages

- They have high energy capture capacity and are subjected to less mechanical strength
- They are aerodynamically designed and have low transient loss
- No mechanical damping system are required as electrical system provide damping.
- Do not suffer from synchronization problems or voltage sag due to stiff electrical control

Disadvantages

- Efficiency is low
- More expensive and sometimes requires complex control strategies

Variable speed Wind Turbine



Advantages and Disadvantages???

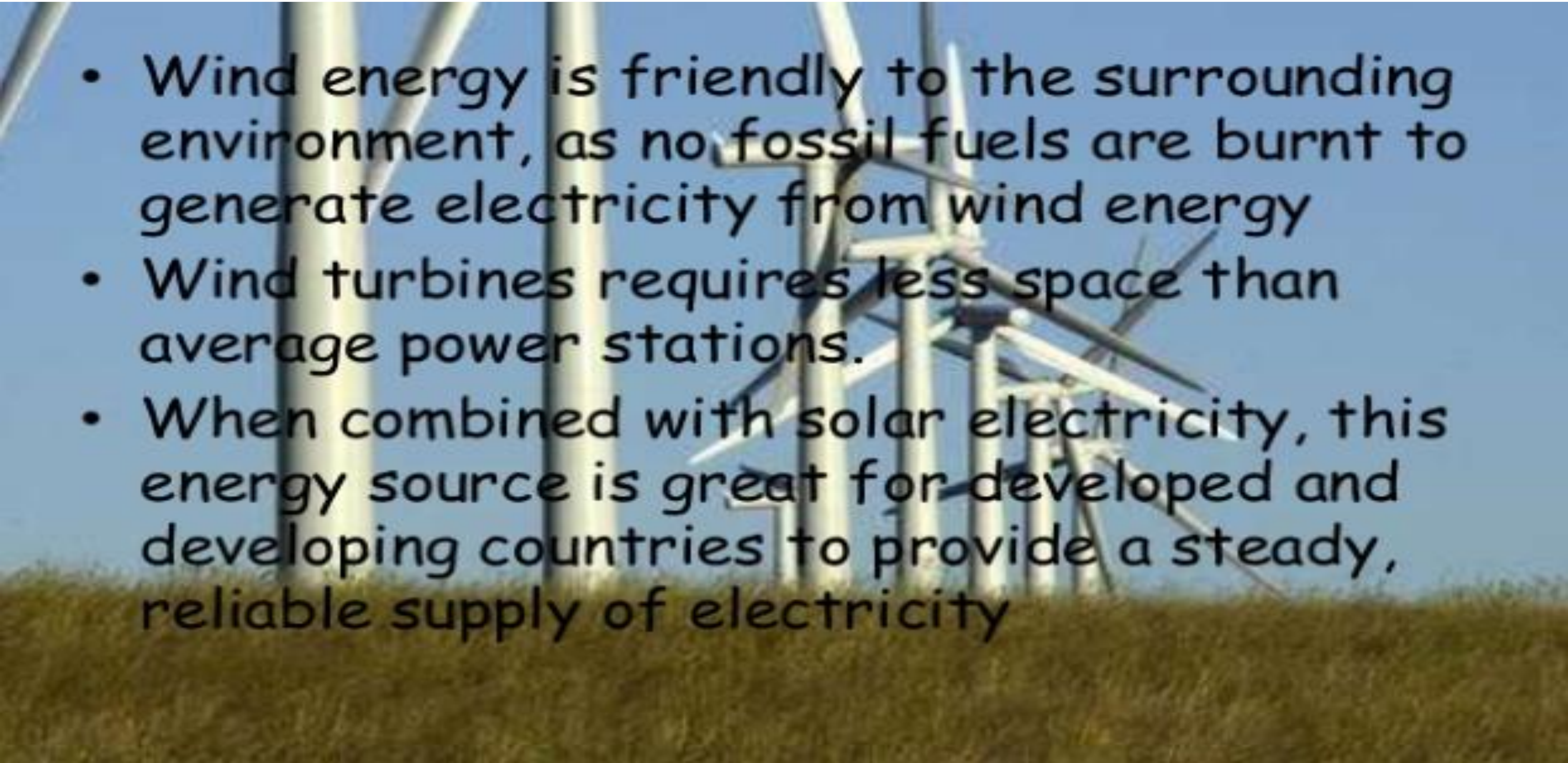
Advantages:

- No pollution.
- Lowest prices renewable resources
- Don’t produce atmospheric emissions that cause acid rains and green house effects.

Disadvantages:

- Depending on how energetic a wind site is, the wind farm may or may not be cost competitive.
- Wind energy cannot be stored (unless batteries are used)
- Good wind sites are often located in remote locations
- Wind resource development may compete with other uses for the land and those alternative uses may be more highly valued than electricity generation.
- sometimes birds have been killed by flying into the rotors

Advantages of WCS



General disadvantages

- The main disadvantage regarding wind power is down to the winds unreliability factor. In many areas, the winds strength is not enough to support a wind turbine
- Wind turbines generally produce allot less electricity than the average fossil fuelled power station, which means that multiple wind turbines are needed to make an impact.

STORAGE DEVICES

Sorage Devices used in microgrid

- For ensuring uninterupted power supply storage devices are used.
- Storage devices are cnnected to the grid and provided with ride-through capabilities
- Commonly used storage devices are
  - Storage Batteries
  - Fly wheels
  - Ultra capacitors

FLY WHEEL

- Basically Fly Wheels a disk with a certain amount of mass that spins ,holding kinetic energy
- Modern Fly Wheels are built with disk attached to a rotor
- They are charged with an electric motor which acts as a agenerator when discharging

FlyWheel

- Efficiency is limited due to friction
- In order to increase efficiency friction has to be reduced.
- Measures are :
  - Let the disk spin in vacuum
  - Bear the spinning rotor on permanent and electromagnetic bearings
- Modern Fly Wheels are possible with 16000rpm and 25kW capacity

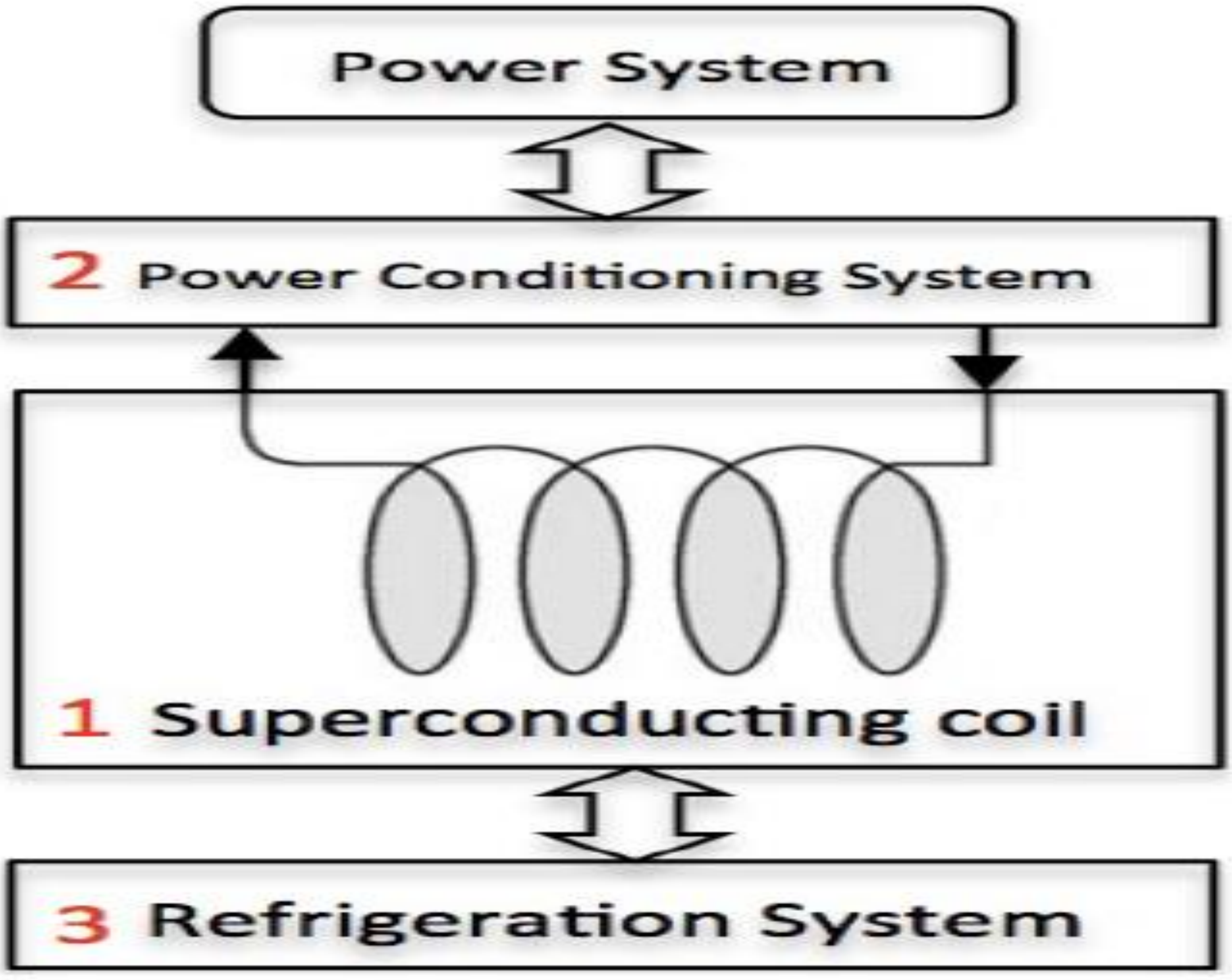
Parts of Fly Wheel

Fly Wheel

Pros and Cons

- + Low maintenance and long lifespan: up to 20 years
- + Almost no carbon emissions
- + Fast response times
- + No toxic components
- − High acquisition costs
- − Low storage capacity
- − High self-discharge (3 –20 percent per hour)

Super Conducting Magnetic Enery Storage



SMES

- Main parts are :
  - Coil
  - Power conditioning system\
  - Cooling system
- Stores energy in the form of electromagnetic field surrounding the coil
- Coil is superconducting
- 90-96% energy can be stored in SMES without loss

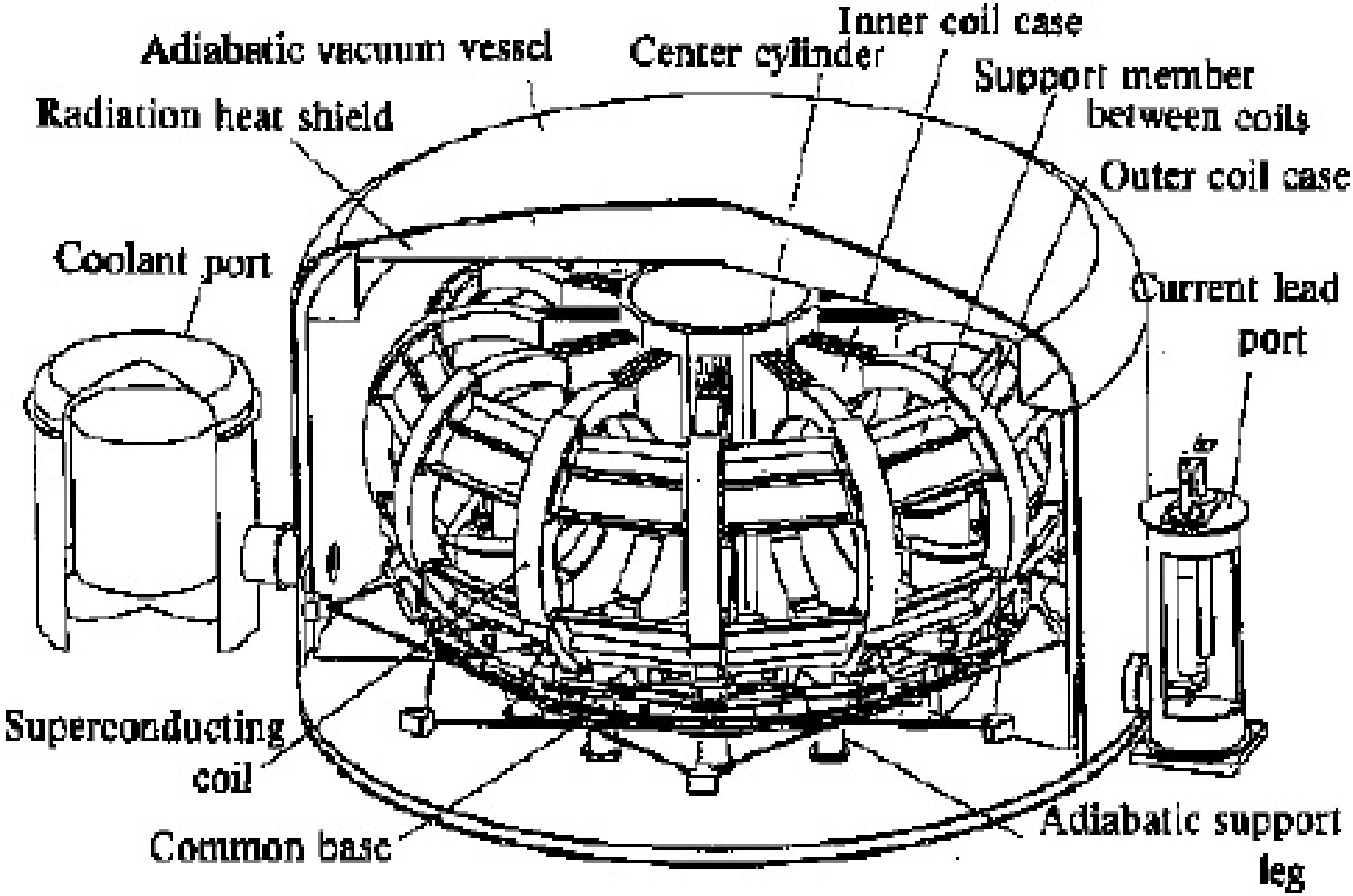
SMES

- Superconducting materials are working at temp. below -253^0 centigrade (20^0 Kelvin)
- Niobium Titanium 9^0 Kelvin
- Niobium Tin 18^0 Kelvin
- Refrigeration system with liquefied Helium is used. But the efficiency reduces and cost is high.
- High temp. Superconductors are developed recently with Nitrogen cooling .But materials are brittle and production process is costlier

SMES-PCS

- Power Conditioning System (PCS) is the interface between Power System and coil.
- It is a AC-DC converter and vice versa as only ac can be stored in coil.

SMES



Adiabatic vacuum vessel
Center cylinder
Inner coil case
Support member
between coils
Radiation heat shield
Outer coil case
Coolant port
Current lead
port
Superconducting
coil
Common base
Adiabatic support
leg

SMES

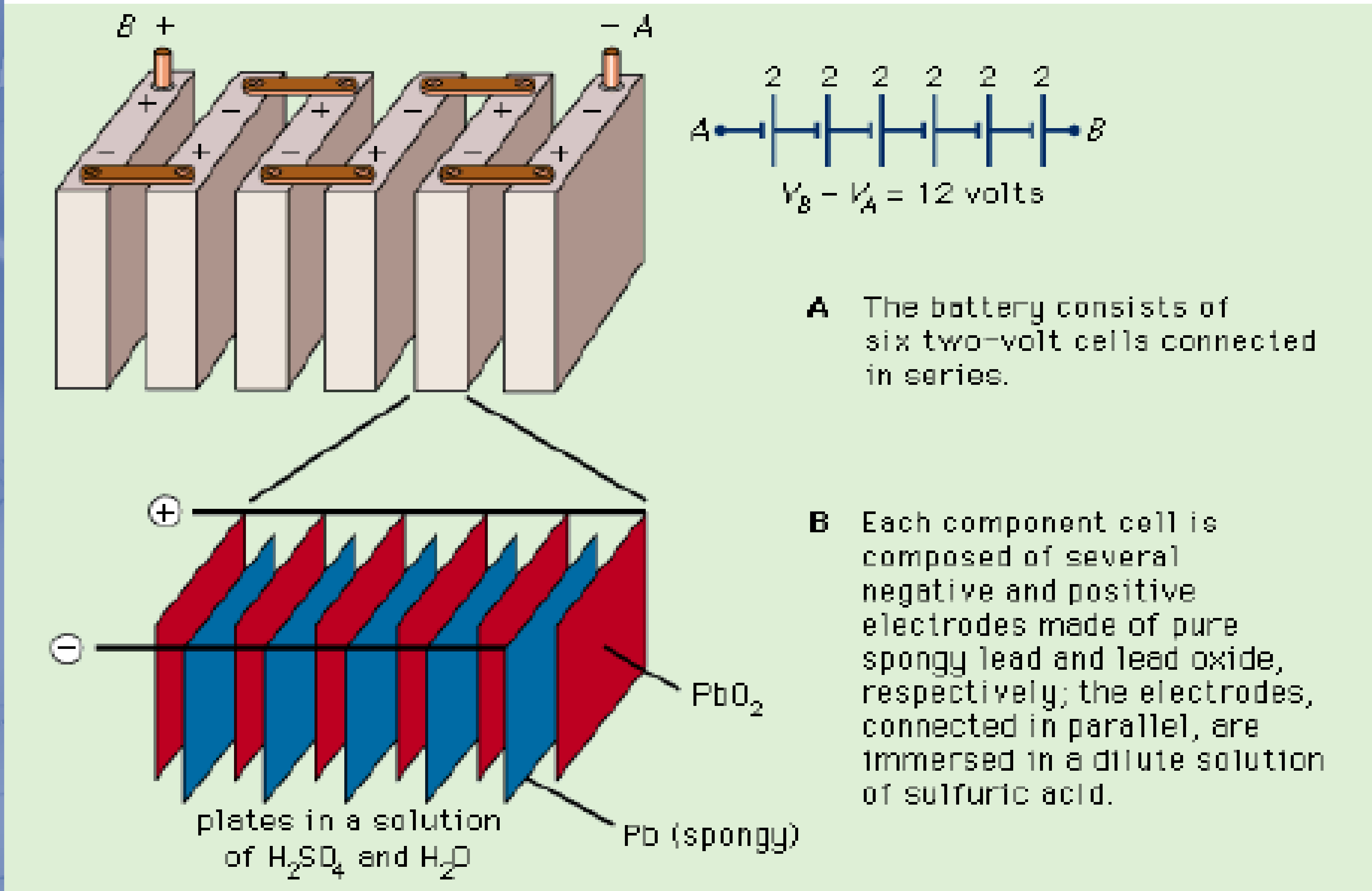
Pros and Cons

- \+ Fast respond times
- \+ Capable of partial and deep discharges
- \+ No environmental hazard
- − High energy losses (~12 percent per day)
- − Very expensive in production and maintenance
- − Reduced efficiency due to the required cooling process

BATTERIES

- Device which produce electrical enegy from chemical reaction.
- Consists of positive and negative electrodes connected through load (electrical appliance)
- Negative electrode supplies supplies current of electrons and is flow through the load and is accepted by positive electrode.

Lead Acid Batteries



Lead Acid Battery

- Oldest type rechargeable battery
- Invented in 1859 by French Physisist Gaston Plante
- Known for cost effective still today.
- Used in car (as SLI), golf car ,wheel chairs etc.
- They will remain first choice until new battery technology emerges

Lead Acid Battery

Concept

A lead-acid battery usually has several in-series connected cells, each delivering 2 volts (V) and each consisting several spongy pure lead cathodes, positive loaded lead oxide anodes and a 20 –40 percent solution of sulfuric acid that acts as an electrolyte. When discharged, both the anode and the cathode undergo a chemical reaction with the electrolyte that progressively changes them into lead sulfate that releases electrical energy in the process. This reaction can be almost completely reversed by supplying the electrodes with electricity, which is the reason a lead-acid battery can be recharged.

Lead Acid Batteries

The cycle life and the ability to tolerate deep discharges depend on the type. Starting-lighting-ignition (SLI) batteries used in cars are not designed to be discharged to more than 50 percent as they have thinner lead plates. Doing so on a regular base will damage them and shorten their cycle life dramatically, whereas deep cycle batteries with thicker plates can handle this much better but are as a result heavier and bulkier.

Leac Acid Battery

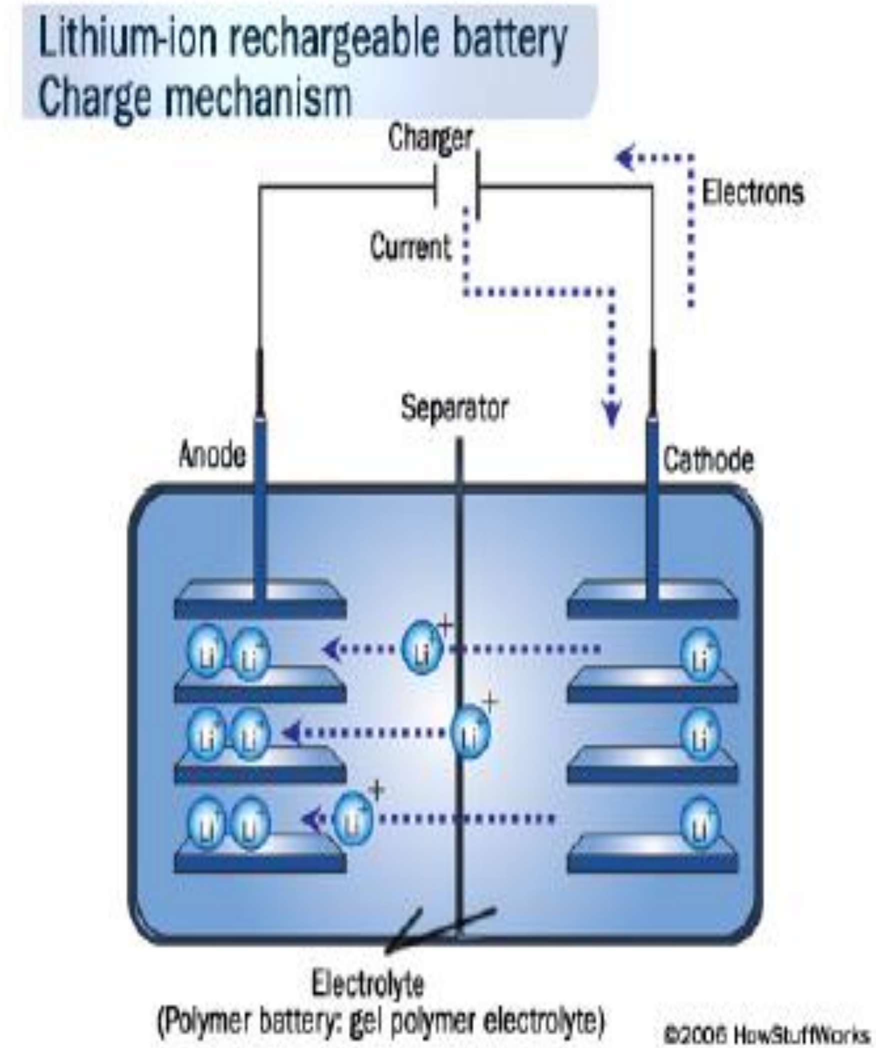
Pros and Cons

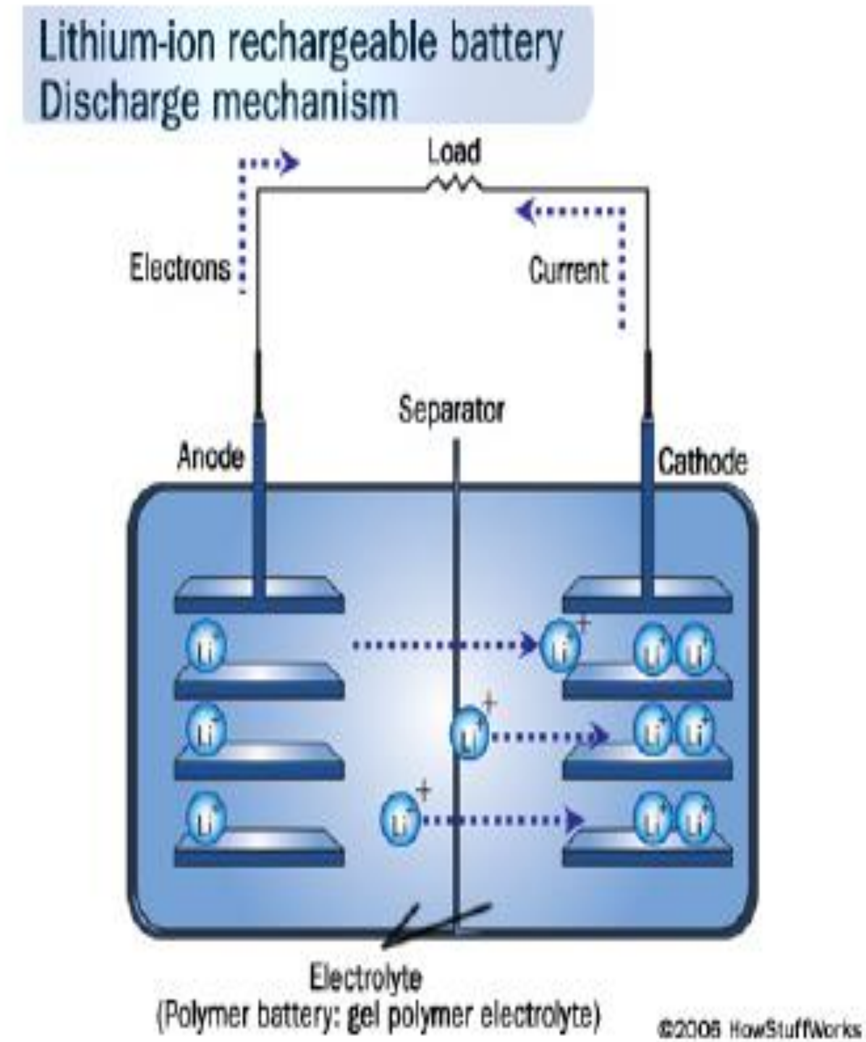
- + Easy and therefore cheap to produce
- + Mature technology, more than 150 years of experience and development
- + Very high surge-to-weight-ratio; capable of delivering a high jolt of electricity at once, which is why they are so suitable as car starters
- + Easily recyclable
- − Very heavy and bulky
- − Rather short lived
- − Environmental concerns: although pretty safe, lead is very toxic and exposure can cause severe damage to people and animals
- − Corrosion caused by the chemical reactions

Lead Acid Battery

- Existing batteries are not suitable for storing huge amount of energy.
- Life cycle is only a few years
- Heavy

Lithium Iron Batteries –charging and Discharging





Li-Acid Battery

Concept

Lithium is the lightest metal with the highest potential due to its very reactive behavior, which, in theory, makes it very fitting as a compound for batteries. Just as the lead-acid and most other batteries the Lithium-Ion battery by definition uses chemical reactions to release electricity. Although all are called lithium-ion batteries, there's a variety of types with slightly different chemical compounds. The construction looks somehow similar to a capacitor, using three different layers curled up in order to minimize space. The first layer acts as the anode and is made of a lithium compound; the second one is the cathode and is usually made of graphite. Between anode and cathode is the third layer – the separator that, as suggested by the name, separates them while allowing lithium-ions to pass through. The separator can be made of various compounds allowing different characteristics and with that, different benefits and flaws. In addition, the three layers are submerged in an organic solvent – the electrolyte, allowing the ions to move between the anode and the cathode.

In the charging process, the lithium ions pass through the microporous separator into spaces between the graphite (though not compounded), receiving an electron from the external power source.

Concept ……

During the discharge process the lithium atoms located between the graphite release its electrons again that migrates over the external circuit to the anode providing a current. The lithium ions move back to the anode as well, parallel to their released electrons.

Because lithium is a very reactive compound and can burst into flames, safety measures have to be included, such as onboard control chips to manage the temperature and prevent a complete discharge.

Li Acid Battery

Pros and Cons

- + Highest energy density in commercial available batteries with huge potential
- + Provides higher voltages per cell (3.7V compared to 2.0V for lead-acid)
- + Low energy loss: only about 5 percent per month
- + Lithium and graphite as resources are available in large amounts
- − Very expensive
- − Complete discharge destroys the cells
- − Deteriorates even if unused (Lifecycle of about 5 years)
- − Lithium is flammable in contact with atmospheric moisture

Li Acid Batteries

Future Prospects

Lithium-ion batteries would be suitable for storing large amounts of energy if it weren't for the costs. The rather expensive processing and the safety measures make them too expensive for commercial use besides small electronic devices like smartphones and laptops. Even for small decentralized systems, competitors like lead-acid batteries are more cost-effective right now, although that will change as they become cheaper.

However, lithium-based batteries have an incredibly huge potential. IBM is currently working on a project called *Battery 500*. This project's goal is to develop a battery using lithium and the air of the atmosphere as components (both the two lightest elements suitable for this purpose), capable of storing enough energy to power an electric car for 500 miles (~804 kilometers).[3] Commercial use is targeted somewhere between 2020 and 2030 as there are still a lot of obstacles to overcome.

Other Batteries in DEVELOPMENT

REDOX FLOW Battery

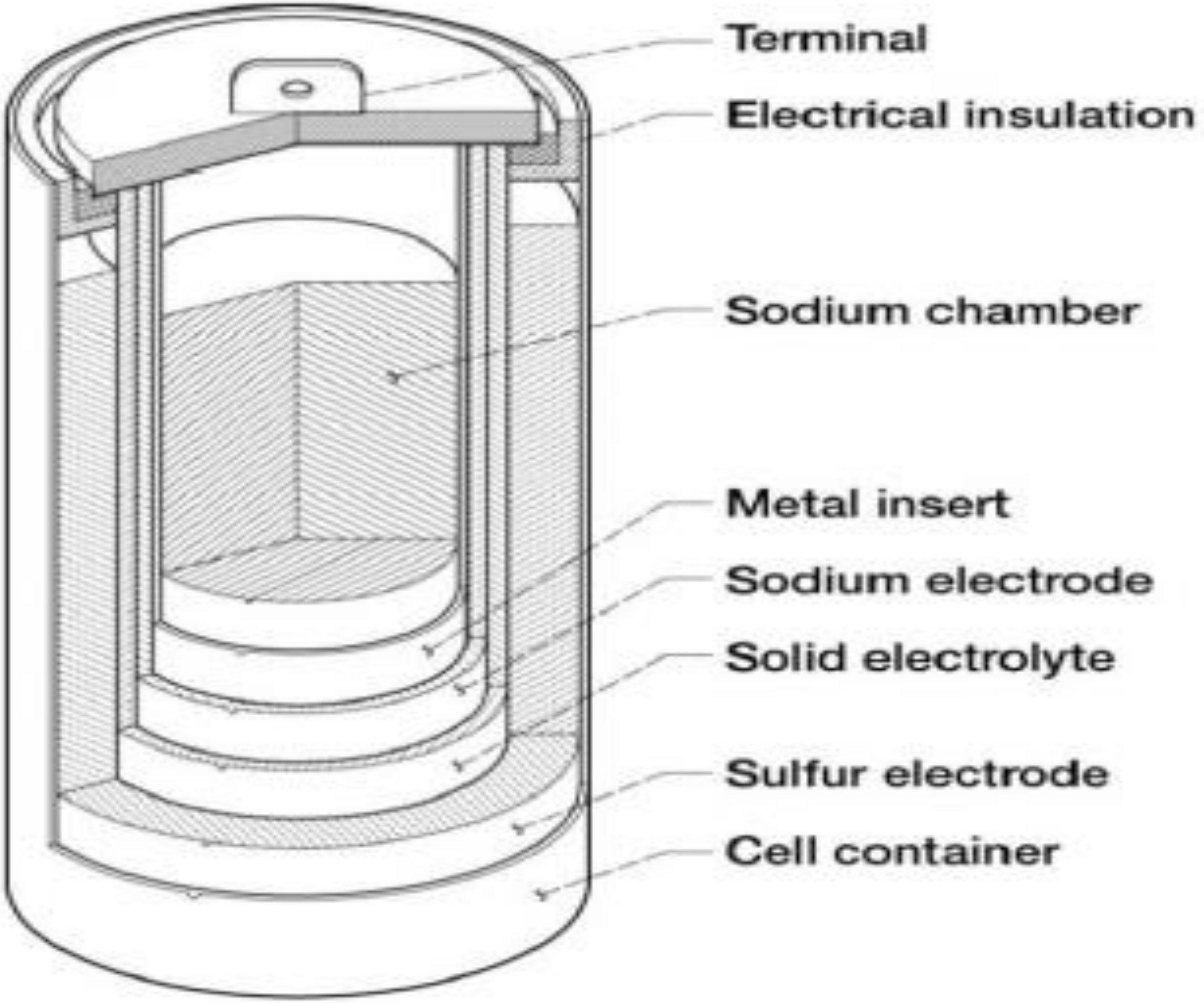
- Similar to conventional Batteries except that electrolyte can be exchanged.
- Power density is only 35 Wh/kg while that of lead acid battery is 200Wh/kg
- Life is up to 40 years
- Capacity can easily be increased by increasing the tanks and adding more electrolyte

Other Batteries

SODIUM BATTERY

- Used in Japan –250MW of power is installed
- Density 240Wh/kg
- 10-15 years life span
- 75-90 efficiency
- But to liquefy Sodium high temp.(623degree kelvin) is required-costlier and dangerous

Sodium Battery



Other Batteries

ZINC AIR BATTERY

- Uses air as a second component.
- More density
- Zinc is commonly available material
- Research is going on to improve efficiency and life