Unit-I

Classification of Energy Resources

Energy resources can be classified in the following ways:

1. Based on Usability of Energy

(a) ***Primary Resources***: These include resources embodied in nature prior to undergoing any human-made conversions or transformations. This only involves extraction or capture. *Examples of primary energy resources* the primary energy resources are coal, crude oil, sunlight, wind, running rivers, vegetation, uranium, etc. These resources are generally known as raw energy resources.

Generally this form of energy cannot be used as such.
These are located, explored extracted, processed, and are converted to a form as required by the consumer.

Thus, some energy is spent in making the resource available to a user in a usable form.

The energy yield ratio of an energy extraction process is,

$$Energy\ yield\ ratio = \frac{Energy\ received\ from\ raw\ energy\ source}{energy\ spent\ to\ obtain\ raw\ energy\ source}$$

Only resource for which the energy yield ratio is fairly high, are considered worth exploration.

(c) ***Secondary Resources***: The energy resources supplied directly to consumer for utilization after one or more steps of transformation are known as secondary are useable energy.
e.g., electrical energy, thermal energy (in the form of steam or hot water)
e.g., refined fuels or synthetic fuels such as hydrogen fuels, etc.

2. Based on Traditional Use

(a) *Conventional Energy* resources which are being traditionally used for many decades and were in common use around the oil crisis of 1976, are called conventional energy resources, e.g., fossil fuels, nuclear and hydro resources.

(b) *Non-Conventional* Energy resources which are consider for large-scale use after the oil crisis of 1973, are called non-conventional energy sources, e.g., solar, wind, biomass, etc.

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3. Based on Long-term Availability

(a) *Non-renewable* Resources which are finite and do not get replenished after their consumption are called non-renewable, e.g., fossil fuels, uranium, etc.

(b) *Renewable* Renewable energy is energy obtained from sources that are essentially inexhaustible. Examples of renewable resources include wind power, solar power, geothermal energy, tidal power hydroelectric power.

4. Based on commercial Application

(a) *Commercial Energy resources* The energy sources that are available in the market for a definite price are known as commercial energy. By far the most important forms of commercial energy are electricity, coal and refined petroleum products. Commercial energy forms the basis of industrial, agricultural, transport and commercial development in the modern world.

(b) Non-commercial Energy The energy sources that are not available in the commercial market for a price are classified as non-commercial energy. Non-commercial energy sources include fuels such as firewood, cattle dung and agricultural wastes, which are traditionally gathered, and not bought at a price, used especially in rural households.

Examples of non-commercial energy are: firewood, agro waste in rural areas, solar energy for water heating, animal power for transport, irrigation and crushing of sugarcane, etc.

5. Based on Origin

(a) Fossil fuels energy
(b) Nuclear energy
(c) Hydro energy
(d) Solar energy
(e) Wind energy
(f) Biomass energy
(g) Geothermal energy
(h) Tidal energy
(i) Ocean thermal energy
(J) Ocean Wave energy

Importance of Non-conventional energy sources

The concern for environment due to ever-increasing use of fossil fuels and rapid depletion of these resources has led to development of alternative sources of energy, which are renewable and environment friendly.

The following points may be considered for the importance of non-conventional energy sources:

1. Conventional sources (except hydro) are non-renewable and finite assets. With present rate of consumption their availability is rapidly decreasing.

2. The demand of energy is increasing exponentially due to rapid industrialization and population growth, the conventional sources of energy alone will not be sufficient in the long run, to meet the growing demand.

3. conventional sources (fossil fuels, nuclear) also cause pollution leading to degradation of the environment. ultimately, there use has to be restricted within acceptable limits.

4. large hydro resources affect wild life, cause deforestation and pose various social problems.
5. In addition to supplying energy, fossil fuels are also used extensively as feedstock for the manufacture of organic chemicals. As reserves deplete, the need for using fossil fuels exclusively for such purposes may become greater.

Due to these reasons, it has become important to explore and develop non-conventional energy resources to reduce too much dependence on conventional resources.

However, the present trend of developments of non-conventional sources indicate that these will serve as supplement rather than substitute for conventional sources for some more time to come.

Realising the importance of non-conventional energy sources, in march 1981 the government of India established a commission for additional sources of energy (case) in the department of science and technology on the lines of the space and atomic energy commissions.

In 1982, CASE was incorporated in the newly created department of Non-Conventional Energy Sources (DNES) under Minister of energy.

India was the first country in the world to set up a full-fledged ministry of non-conventional energy resources.

Advantages and Disadvantages of Conventional Energy Sources

Fossil fuels, nuclear and hydro resources are considered as conventional sources. Their use has following advantages and disadvantages.

Advantages

1. *Cost*: At present, these are cheaper than non-conventional sources. The approximate cost of electrical energy derived from different sources at present is given as:

   Rs 1.90 per kWh from gas, Rs 1.65 per kWh from coal, Rs 3.0 per kWh from diesel, Rs 1.0 per kWh from hydro resource, Rs 1.20 per kWh from nuclear resource.

2. *Security*: As strong is easy and convenient, by storing a certain quantity, the energy availability can be ensured for certain period.

3. *Convenience*: these sources are very convenient to use as technology for their conversion and their use is universally available.

Disadvantages

1. Fossil fuels generate pollutants. Main pollutants generated in the use of these sources are CO, CO_2, $NO_{X,}$ $SO_{X,}$ particulate matter and heat. These pollutants degrade the environment, pose health hazards and cause various other problems. CO_2 is mainly responsible for global warming.

2. Coal is also a valuable petrochemical and is used as raw material for chemical, pharmaceutical and paint industries. From the long-term point of view, it is desirable to conserve coal for future needs.

3. Safety of nuclear plants is a conventional subject. The major problems with nuclear energy are the following:

   (a) The waste material generated in nuclear plants has radioactive quotients of dangerous levels; it remains above the safe limit for long period of time, and thus is a health hazard. Its safe disposal, which is essential to prevent radioactive pollution, is a challenging task. Also, the disposed radioactive waste is required to be guarded for a long period (till its radioactive level comes down to a safe limit) lets it goes in wrong hands.

   (b) There is possibility of accidental leakage of radioactive material from reactor (as happened in Chernobyl, former USSR, in April 1986).

   (c) Uranium resource, for which the technology presently exists, has a limited availability.

   (d) Sophisticated technology is required for using nuclear resources. Only few countries posses the technology required to use nuclear energy.

4. Hydroelectric plants are cleanest but large hydro reservoirs cause the following problems:

   (a) A large land area submerges into water leading to deforestation
   (b) Causes ecological disturbance such as earthquakes
   (c) Affects wildlife
   (d) Causes dislocation of a large population and their rehabilitation.

ENVIRONMENTAL ASPACT OF ELECTRIC ENERGY CONVERSION

Coal as thermal fuel

Coal is the raw fuel that provides 42% of the world‘s electricity. This distinguishes coal as the world‘s primary energy source for electricity generation. The name coal refers to a family of solid, organic fuels with different properties. Coal is mainly composed of elemental carbon and is formed by the conversion of deposited organic material. The lowest grade of coal formed is peat. Under the influence of high pressures and temperatures, the peat is transform into the coal. Using coal to generate power or heat is an old technique. The heat energy of these fuels is converted into mechanical energy by suitable prime movers such as steam engines, steam turbines, internal combustion engines etc.

Coal mining

There are two types of coal mining, strip mining and underground long wall mining. The environmental impacts from surface versus underground mining are not significantly different. The main difference between these two mining techniques is that the surface mining subsystem results in a higher amount of airborne ammonia emissions due to the production of ammonium nitrate explosives which are used at the mine. Another important difference is that underground mining requires limestone which emits a large amount of particulates during its production. The problematic pollutants in emission of coal based generating plants are Sulfur dioxide (SO_2), Nitrogen oxides (NO_x), carbon monoxide (CO) and carbon dioxide (CO_2) and certain hydrocarbons.

Oxides of sulphur (SO_2)

Most of the sulphur present in the fossil is oxidized to SO_2 in the combustion chamber before being emitted by the chimney. In atmosphere it gets further oxidized to H_2SO_4 and metallic sulphates which are the major source of concern as these can cause acid rain, impaired visibility, damage to buildings and vegetation. Sulphate concentrations of 9-20 $\mu g/m^3$ of air aggravate asthma, lung and heart disease.

Acidification

Acidification is one of the main problems arising from existing coal power. It takes place during many steps in the life cycle of electricity produced by coal combustion. Pumped mine water contains mud, dissolved sulphate and metal ions. It is also acidic and, therefore, needs to be neutralizing before being discharged. Drainage water from refuse piles with excavated and residual minerals can be very acidic, particularly if the rocks contain pyrite (ferric sulphide) that undergoes oxidation processes when exposed to the atmosphere. These oxidation processes take place in natural environments, but are greatly accelerated by mining activities, especially when no alkaline rocks are present to neutralize the acid formed.

Impact on biodiversity

The main environmental effect of electricity produced by coal combustion is probably related to the ubiquitous emission of greenhouse gases. The release to the atmosphere of such gases is larger from coal use than for any other fuel used for generating electricity. It is a general contention that any additional increase of greenhouse gases in the atmosphere will exacerbate global warming. This can lead to rapid changes in local weather conditions and can thus have many and profound influences on biodiversity. Organisms that cannot adapt or migrate successfully under changing climate conditions will be adversely affected.

ENVIRONMENT IMPACTS OF RENEWABLE ENERGY TECHNOLOGIES

Developing renewable energy technologies that exploit the sun, the wind, and geothermal energy is critical to addressing concerns about climate change and some environmental issues. However, using renewable energy sources will not eliminate all environmental concerns. Although renewable energy sources produce relatively low levels of Green House Gas emissions and conventional air pollution, manufacturing and transporting them will produce some emissions and pollutants. The production of some photovoltaic (PV) cells, for instance, generates toxic substances that may contaminate water resources. Renewable energy installations can also disrupt land use and wildlife habitat, and some technologies consume significant quantities of water.

To develop sound policies, policy makers must understand the relative environmental impacts of alternative energy sources, including how the impacts of renewable energy technologies compare to those of fossil-fuel technologies and to opportunities for improvements in energy efficiency. Understanding the potential environmental impacts of renewable energy technologies is also essential for identifying and pursuing designs, manufacturing methods, project siting, utility operations, and so on to mitigate or offset these effects.

Life cycle uses of energy

For renewable energy sources, net energy ratio (NER) is expected to be greater than one, indicating a positive return over the fossil-fuel energy investment. For fossil-fuel and nuclear technologies, NERs are smaller than one and essentially represent the overall life cycle efficiency of the project. NERs are strongly influenced by a number of underlying assumptions, such as plant capacity and life expectancy. For electricity generation from wind and solar energy, the strength of the resource (which will affect the capacity factor of the installed technology) is also a critical assumption. For silicon PV specifically, the NER is highly dependent upon the thickness of the wafer and the efficiency of the cell/module produced. NERs would be significantly higher for waste biomass.

Local and regional air pollution

Most renewable energy technologies have much lower life cycle emissions of conventional air pollutants than conventional coal and natural gas plants. One exception is electricity generation from biomass, which can produce significant NOx, particulate matter, and hazardous air pollutants, such as polycyclic aromatic hydrocarbons (PAHs). Although biomass has lower nitrogen content than fossil fuels, a substantial quantity of NOx is formed whenever high-temperature combustion occurs in air, through oxidation of atmospheric nitrogen (N2) at high temperatures. Although direct emissions of NOx and SOx are expected to be low for geothermal power plants, flash and dry-steam geothermal facilities can produce significant quantities of hydrogen sulfide (H2S) from geothermal reservoirs, unless steps are taken to decrease it.

Land and water use

The amount of land used is a rough substitute for other impacts of new development, including impacts on ecosystems, cultural and historical resources, scenery, and agricultural land. When the impacts on land use are measured simply by the surface area they occupy during their life cycle, some renewable energy technologies appear to have heavy land-use requirements.

However, this approach does not take into account the intensity of land use or whether the technology allows for simultaneous use of land for other purposes. Whereas coal- fired power plants fully occupy the sites where they are constructed, small-scale PV installations may be placed on rooftops where they cause little or no interference with the primary use of the land for commercial or residential buildings. Thus, smaller scale or distributed solar technologies may have less of an impact on land use and habitat loss than large-scale, central station plants. Land-use concerns may also be addressed by deploying renewable energy systems on previously developed sites, rather than in undeveloped areas.

Water is a scarce resource in large portions. Recent global circulation model projections suggest that, if climate change proceeds as expected, under current business-as-usual scenarios, freshwater supplies will become even scarcer in some parts of the world. Electricity production using thermoelectric technologies requires vast amounts of water, primarily for cooling. In is about 43 percent of existing thermoelectric generating capacity uses once-through cooling, 42 percent uses re-circulating wet towers, 14 percent uses re-circulating cooling ponds, and 1 percent uses dry cooling. Water use by power plants is characterized by withdrawals and consumption. Although consumption is sometimes emphasized over withdrawals, the latter is important, because power plant operation may be constrained by the amount of water available for withdrawal and power plant uses may compete with other demands for water. Furthermore, water returns can be significant sources of thermal pollution and may include discharges of chemical pollutants, such as chlorine or other biocides used in cooling towers.

ENVIRONMENT IMPACTS OF DIFFERENT RENEWABLE ENERGY SOURCES

All energy sources have some impact on our environment. Fossil fuels—coal, oil, and natural gas—do substantially more harm than renewable energy sources by most measures, including air and water pollution, damage to public health, wildlife and habitat loss, water use, land use, and global warming emissions. However, renewable sources such as wind, solar, geothermal, biomass, and hydropower *also* have environmental impacts, some of which are significant. The exact type and intensity of environmental impacts varies depending on the specific technology used, the geographic location, and a number of other factors. By understanding the current and potential environmental issues associated with each renewable energy source, we can takes steps to effectively avoid or minimize these impacts as they become a larger portion of our electric supply.

Environmental impacts of wind energy

Land use

The land use impact of wind power facilities varies substantially depending on the site: wind turbines placed in flat areas typically use more land than those located in hilly areas. However, wind turbines do not occupy all of this land; they must be spaced approximately 5 to 10 rotor diameters apart (a rotor diameter is the diameter of the wind turbine blades). Thus, the turbines themselves and the surrounding infrastructure (including roads and transmission lines) occupy a small portion of the total area of a wind facility. Offshore wind facilities, require larger amounts of space because the turbines and blades are bigger than their land-based counterparts.

Wildlife and habitat

The impact of wind turbines on wildlife, most notably on birds and bats, has been widely document and studied. A recent survey founded evidence of bird and bat deaths from collisions with wind turbines and due to changes in air pressure caused by the spinning turbines, as well as from habitat disruption. Offshore wind turbines can have similar impacts on marine birds, but as with onshore wind turbines, the bird deaths associated with offshore wind are minimal. Wind farms located offshore will also impact fish and other marine wildlife.

Public health and community

Sound and visual impact are the two main public health and community concerns associated with operating wind turbines. Most of the sound generated by wind turbines is aerodynamic, caused by the movement of turbine blades through the air. There is also mechanical sound generated by the turbine itself. Overall sound levels depend on turbine design and wind speed. Some people living close to wind facilities have complained about sound and vibration issues. Under certain lighting conditions, wind turbines can create an effect known as shadow flicker. This annoyance can be minimized with careful siting, planting trees or installing window sunshades, or curtailing wind turbine operations when certain lighting conditions exist.

Water use

There is no water impact associated with the operation of wind turbines. As in all manufacturing processes, some water is used to manufacture steel and cement for wind turbines.

Life-cycle global warming emissions

While there are no global warming emissions associated with operating wind turbines, there are emissions associated with other stages of a wind turbine‘s life-cycle, including materials production, materials transportation, on-site construction and assembly, operation and maintenance, and decommissioning and dismantlement. Estimates of total global warming emissions depend on a number of factors, including wind speed, percent of time the wind is blowing, and the material composition of the wind turbine.

Environmental impacts of solar energy systems

Land use

Depending on their location, larger utility-scale solar facilities can raise concerns about land degradation and habitat loss. Total land area requirements vary depending on the technology, the topography of the site, and the intensity of the solar resource. Estimates for utility-scale PV systems range from 3.5 to 10 acres per megawatt, while estimates for concentrated solar power (CSP) facilities are between 4 and 16.5 acres per megawatt. Smaller scale solar PV arrays, which can be built on homes or commercial buildings, also have minimal land use impact.

Water use

Solar PV cells do not use water for generating electricity. However, as in all manufacturing processes, some water is used to manufacture solar PV components. Concentrating solar thermal plants (CSP), like all thermal electric plants, require water for cooling. Water use depends on the plant design, plant location, and the type of cooling system. CSP plants that use wet-recirculation technology with cooling towers withdraw between 600 and 650 gallons of water per megawatt-hour of electricity produced. CSP plants with once-through cooling technology have higher levels of water withdrawal, but lower total water consumption (because water is not lost as steam). Dry-cooling technology can reduce water use at CSP plants by approximately 90 percent. However, the exchanges to these water savings are higher costs and lower efficiencies.

Hazardous materials

The PV cell manufacturing process includes a number of hazardous materials, most of which are used to clean and purify the semiconductor surface. These chemicals, similar to those used in the general semiconductor industry, include hydrochloric acid, sulfuric acid, nitric acid, hydrogen fluoride, tri-chloroethane and acetone. The amount and type of chemicals used depends on the type of cell, the amount of cleaning that is needed, and the size of silicon wafer. Workers also face risks associated with inhaling silicon dust. Thus, PV manufactures must follow the rules to ensure that workers are not harmed by exposure to these chemicals and that manufacturing waste products are disposed of properly.

Life-cycle global warming emissions

While there are no global warming emissions associated with generating electricity from solar energy, there are emissions associated with other stages of the solar life-cycle, including manufacturing, materials transportation, installation, maintenance, and decommissioning and dismantlement. Most estimates of life-cycle emissions for photovoltaic systems are between 0.07 and 0.18 pounds of carbon dioxide equivalent per kilowatt-hour.

Environmental impacts of geothermal energy systems

Water quality and use

Geothermal power plants can have impacts on both water quality and consumption. Hot water pumped from underground reservoirs often contains high levels of sulfur, salt, and other minerals. Most geothermal facilities have closed-loop water systems, in which extracted water is pumped directly, back into the geothermal reservoir after it has been used for heat or electricity production. In such systems, the water is contained within steel well casings cemented to the surrounding rock. Water is also used by geothermal plants for cooling and re-injection. Depending on the cooling technology used, geothermal plants can require between 1,700 and 4,000 gallons of water per megawatt-hour. However, most geothermal plants can use either geothermal fluid or freshwater for cooling; the use of geothermal fluids rather than freshwater clearly reduces the plants overall water impact.

Air emissions

The distinction between open- and closed-loop systems is important with respect to air emissions. In closed-loop systems, gases removed from the well are not exposed to the atmosphere and are injected back into the ground after giving up their heat, so air emissions are minimal. In contrast, open-loop systems emit hydrogen sulfide, carbon dioxide, ammonia, methane, and boron. Hydrogen sulfide, which has a distinctive ―rotten egg‖ smell, is the most common emission. Once in the atmosphere, hydrogen sulfide changes into sulfur dioxide (SO2). This contributes to the formation of small acidic particulates that can be absorbed by the bloodstream and cause heart and lung disease. Sulfur dioxide also causes acid rain, which damages crops, forests, and soils, and acidifies lakes and streams. However, SO2 emissions from geothermal plants are approximately 30 times lower per megawatt-hour than from coal plants.

Some geothermal plants also produce small amounts of mercury emissions, which must be mitigated using mercury filter technology. Scrubbers can reduce air emissions, but they produce a watery sludge composed of the captured materials, including sulfur, vanadium, silica compounds, chlorides, arsenic, mercury, nickel, and other heavy metals. This toxic sludge often must be disposed of at hazardous waste sites.

Land use

The amount of land required by a geothermal plant varies depending on the properties of the resource reservoir, the amount of power capacity, the type of energy conversion system, the type of cooling system, the arrangement of wells and piping systems, and the substation and auxiliary building needs. The Geysers, the largest geothermal plant in the world, has a capacity of approximately 1,517 megawatts and the area of the plant is approximately 78 square kilometers, which translates to approximately 13 acres per megawatt. Like the Geysers, many geothermal sites are located in remote and sensitive ecological areas, so project developers must take this into account in their planning processes.

Life-cycle global warming emissions

In open-loop geothermal systems, approximately 10 percent of the air emissions are carbon dioxide and a smaller amount of emissions are methane, a more potent global warming gas. Estimates of global warming emissions for open-loop systems are approximately 0.1 pounds of carbon dioxide equivalent per kilowatt-hour. In closed-loop systems, these gases are not released into the atmosphere, but there are a still some emissions associated with plant construction and surrounding infrastructure. Enhanced geothermal systems, which require energy to drill and pump water into hot rock reservoirs, have life-cycle global warming emission of approximately 0.2 pounds of carbon dioxide equivalent per kilowatt-hour. To put this into context, estimates of life-cycle global warming emissions for natural gas generated electricity are between 0.6 and 2 pounds of carbon dioxide equivalent per kilowatt-hour and estimates for coal-generated electricity are 1.4 and 3.6 pounds of carbon dioxide equivalent per kilowatt- hour.

Environmental impacts of hydroelectric energy systems

Land use

The size of the reservoir created by a hydroelectric project can vary widely, depending largely on the size of the hydroelectric generators and the topography of the land. Hydroelectric plants in flat areas tend to require much more land than those in hilly areas or canyons where deeper reservoirs can hold more volume of water in a smaller space. Flooding land for a hydroelectric reservoir has an extreme environmental impact: it destroys forest, wildlife habitat, agricultural land, and scenic lands.

Wildlife impacts

Dammed reservoirs are used for multiple purposes, such as agricultural irrigation, flood control, and recreation, so not all wildlife impacts associated with dams can be directly attributed to hydroelectric power. However, hydroelectric facilities can still have a major impact on aquatic ecosystems. For example, though there are a variety of methods to minimize the impact including fish ladders and in-take screens), fish and other organisms can be injured and killed by turbine blades. Apart from direct contact, there can also be wildlife impacts both within the dammed reservoirs and downstream from the facility. Reservoir water is usually more stagnant than normal river water. As a result, the reservoir will have higher than normal amounts of sediments and nutrients, which can cultivate an excess of algae and other aquatic weeds. These weeds can crowd out other river animal and plant-life, and they must be controlled through manual harvesting or by introducing fish that eat these plants. In addition, water is lost through evaporation in dammed reservoirs at a much higher rate than in flowing rivers.

Life-cycle global warming emissions

Global warming emissions are produced during the installation and dismantling of hydroelectric power plants, but recent research suggests that emissions during a facility‘s operation can also be significant. Such emissions vary greatly depending on the size of the reservoir and the nature of the land that was flooded by the reservoir. Small run-of-the-river plants emit between 0.01 and 0.03 pounds of carbon dioxide equivalent per kilowatt-hour. Life- cycle emissions from large-scale hydroelectric plants built in semi-arid regions are also modest: approximately 0.06 pounds of carbon dioxide equivalent per kilowatt-hour. However, estimates for life-cycle global warming emissions from hydroelectric plants built in tropical areas are much higher. After the area is flooded, the vegetation and soil in these areas decomposes and releases both carbon dioxide and methane. The exact amount of emissions depends greatly on site-specific characteristics. However, current estimates suggest that life-cycle emissions can be over 0.5 pounds of carbon dioxide equivalent per kilowatt-hour.

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Environmental IMPACTS of Biomass energy systems

Deforestation and land degradation

Biomass comprising traditional fuels constitutes about 50% of energy consumption in developing countries. Deforestation leading to soil erosion, risks of floods, desertification on account of clearing of forests and woodlands for agriculture and livestock, and so on, are the common concerns of environmentalists at macro levels. At a micro level, the concerns range from non-suitability of forest soils for agricultural purposes, health problems due to smoke caused by burning of fuel-wood, loss in soil fertility due to use of agricultural residues and so on. Even a shift towards non-wood biomass fuels creates direct competition with animals that rely upon crop remains and the plants for food. Imbalance between the demand and production of fuel-wood is reported to be one of the primary factors responsible for forest depletion. The increasing use of fuel-wood for meeting the domestic and industrial needs of both rural and urban areas has contributed to forest decline. The environmental impacts of urban fuel-wood consumption have been severe due to commercial exploitation of fuel-wood for charcoal production. The demand for charcoal in urban areas has spread deforestation, which begins at the surrounding areas of urban centres and moving outwards.

Loss of soil nutrients

Agricultural residues constitute an important source of energy in rural areas of developing countries when left on fields improves the fertility of the soil. The use of agricultural residues for energy would thus be an issue if it reduces the fertility of the soil. It is important to note that all residues do not have the same effect on the soil. Some residues such as corncobs, rice husk, jute sticks, cotton stock, coffee pruning, and coconut shells do not decompose easily and have potential as energy sources. The choice of agricultural residues thus has an impact on the environment. Cattle dung, similarly, though it is a fertilizer, loses its value as fertilizer if burnt or left under the sun for a few days. The two categories of residues from agriculture sector are crop residue and cattle dung. Currently crop residue of cereals is largely used as food and woody residues are used as fuel. Burning of woody crop residue may not lead to any significant loss of nutrients to soil. Burning of cattle dung as fuel leads to loss of organic matter and other nutrients affecting crop production.

Environmental impacts of tidal energy systems

Understanding environmental impacts

In spite of the many benefits of exploiting tidal power, there are negative impacts, as well. For example, the risk to the marine environment and marine mammals is largely unknown. In order to operate tidal power stations appropriately and analyze the potential contribution tidal power can make in terms of renewable energy, we must better understand the environmental impacts of this technology. One important mention is the difference between environmental effects and environmental impacts. On one hand, environmental effects refer to the wide range of potential interactions between tidal energy equipment and the marine ecosystems. On the other hand, environmental impacts are those particular effects that we know for sure will cause deleterious ecological alterations.

Environmental impacts of Tidal energy

In many ways, the environmental impacts of harnessing tidal power are similar to those of offshore wind power generation. Several assessments over the past few years have identified the following potential environmental impacts. These indirect ecological impacts would result from lengthy installation of offshore renewable energy projects.

- Changing of substrates, sediment transit and deposition;
- Alteration of waves and sea currents;
- Noise pollution during installation and operation;
- Alteration of ecosystems for regional organisms;
- Emission of harmful electromagnetic fields;
- Intrusion upon animal migrations; and
- Potential strikes by any moving parts of the tidal system.

Environmental impacts of Hydrogen-based energy systems

There is increasing interest in the role that hydrogen-based energy systems may play in the future, especially in the transport sector. They appear to be an attractive alternative to current fossil fuel-based energy systems in the future, since these have been proven to affect climate due to greenhouse gasses emissions. However, any future hydrogen-based economy would need to assess the possible global environmental impacts of such alternative energy production. Emissions of hydrogen lead to increased burdens of methane and ozone and hence to an increase in global warming. Therefore, hydrogen can be considered as an indirect greenhouse gas with the potential to increase global warming. The scientists have estimated that the potential effects on climate from hydrogen-based energy systems would be much lower than those from fossil fuel-based energy systems. However, such impacts will depend on the rate of hydrogen leakage during its synthesis, storage and use. The researchers have calculated that a global hydrogen economy with a leakage rate of 1% of the produced hydrogen would produce a climate impact of 0.6% of the fossil fuel system it replaces. If the leakage rate was 10%, then the climate impact would be 6% of that of the fossil fuel system.

Environmental Impacts of Hydrokinetic Energy systems

Hydrokinetic energy, which includes wave and tidal power, encompasses an array of energy technologies, many of which are still in the experimental stages or in the early stages of deployment. While actual impacts of large-scale operations have not been observed, a range of potential impacts can be projected. For example, wave energy installations can require large expanses of ocean space, which could compete with other uses—such as fishing and shipping—and cause damage to marine life and habitats. Some tidal energy technologies are located at the mouths of ecologically-sensitive estuary systems, which could cause changes in hydrology and salinity that negatively impact animal and plant life.

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Greenhouse gas emissions (GHG)

Compared to fossil-fuel-based electricity generation, renewable energy technologies offer a major advantage in lower emissions of CO2 and other GHGs. In addition, all forms of renewable electricity production are expected to have significantly lower life cycle GHG emissions than electricity production from conventional coal and natural gas plants. Renewable energy would have less of an advantage if carbon capture and sequestration were included with fossil-fuel power plants, or if energy storage systems, such as battery energy storage, compressed air energy storage, or pumped hydro storage, were included as part of renewable energy systems. GHG emissions for some renewable technologies are difficult to estimate. For example, emissions from bio-power vary, depending on which feedstock is used and the assumptions about their production. Most CO2 emission (CO2e) values for bio-power range from 15 to 52 g CO2e/kWh for biomass derived from cultivated feed-stocks, excluding emissions associated with initial land conversion. If carbon capture and storage were added to bio-power systems, there would also be large reductions in CO2e values.

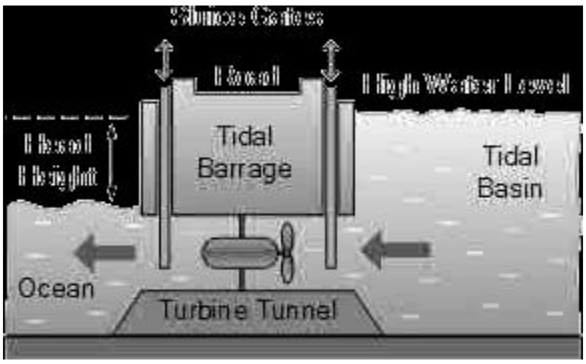
QUALITATIVE STUDY OF DIFFERENT RENEWABLE ENERGY RESOURCES

Ocean Power

Tidal Energy Generation

Tidal energy, just like hydro energy transforms water in motion into a clean energy. The motion of the tidal water, driven by the pull of gravity, contains large amounts of kinetic energy in the form of strong tidal currents called tidal streams. The daily ebbing and flowing, back and forth of the oceans tides along a coastline and into and out of small inlets, bays or coastal basins, is little different to the water flowing down a river or stream. The movement of the sea water is harnessed in a similar way using waterwheels and turbines to that used to generate hydroelectricity. But because the sea water can flow in both directions in a tidal energy system, it can generate power when the water is flowing in and also when it is ebbing out. Therefore, tidal generators are designed to produce power when the rotor blades are turning in either direction. However, the costs of reversible electrical generators are more expensive than single direction generators.

Different Types of Tidal Energy Systems



Tidal Barrage

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Tidal Barrage:

A Tidal Barrage is a type of tidal power generation that involves the construction of a fairly low dam wall, known as a ―barrage‖ and hence its name, across the entrance of a tidal inlet or basin creating a tidal reservoir. This dam has a number of underwater tunnels cut into its width allowing sea water to flow through them in a controllable way using ―sluice gates‖. Fixed within the tunnels are huge water turbine generators that spin as the water rushes past them generating tidal electricity. Tidal barrages generate electricity using the difference in the vertical height between the incoming high tides and the outgoing low tides. As the tide ebbs and flows, sea water is allowed to flow in or out of the reservoir through a one way underwater tunnel system. This flow of tidal water back and forth causes the water turbine generators located within the tunnels to rotate producing tidal energy with special generators used to produce electricity on both the incoming and the outgoing tides.

Tidal Stream

TIDAL STREAM

A Tidal Stream Generation system reduces some of the environmental effects of tidal barrages by using turbine generators under the surface of the water. Major tidal flows and ocean currents, like the Gulf Stream, can be exploited to extract its tidal energy using underwater rotors and turbines. Tidal stream generation is very similar in principal to wind power generation, except this time water currents flow across turbines rotor blades which rotates the turbine, much like how wind currents turn the blades for wind power turbines. In fact, tidal stream generation areas on the sea bed can look just like underwater wind farms. Tidal streams are formed by the horizontal fast flowing volumes of water caused by the ebb and flow of the tide as the profile of the sea bed causes the water to speed up as it approaches the shoreline.

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Advantages and disadvantages of Tidal Energy

Advantages

- Tidal energy is a renewable energy resource because the energy it produces is free and clean as no fuel is needed and no waste bi-products are produced.
- Tidal energy has the potential to produce a great deal of free and green energy.
- Tidal energy is not expensive to operate and maintain compared to other forms of renewable energies.
- Low visual impact as the tidal turbines are mainly if not totally submerged beneath the water.
- Low noise pollution as any sound generated is transmitted through the water.
- Tidal barrages provide protection against flooding and land damage.
- Large tidal reservoirs have multiple uses and can create recreational lakes and areas where before there were none.

Disadvantages of Tidal Energy

- Tidal energy is not always a constant energy source as it depends on the strength and flow of the tides which themselves are affected by the gravitational effects of the moon and the sun.
- Tidal Energy requires a suitable site, where the tides and tidal streams are consistently strong.
- Must be able to withstand forces of nature resulting in high capital, construction and maintenance costs.

- High power distribution costs to send the generated power from the submerged devices to the land using long underwater cables.
- Danger to fish and other sea-life as they get stuck in the barrage or sucked through the tidal turbine blades.

Wave energy

Waves are caused by the wind blowing over the surface of the ocean. In many areas of the world, the wind blows with enough consistency and force to provide continuous waves along the shoreline. Ocean waves contain tremendous energy potential. Wave power devices extract energy from the surface motion of ocean waves or from pressure fluctuations below the surface. Wave power varies considerably in different parts of the world. While an abundance of wave energy is available, it cannot be fully harnessed everywhere for a variety of reasons, such as other competing uses of the ocean (i.e. shipping, commercial fishing, naval operations) or environmental concerns in sensitive areas. Therefore, it is important to consider how much resource is recoverable in a given region.

Ocean thermal energy conversion (OTLC)
Closed-Cycle of OTLC

Closed-cycle systems use fluids with a low boiling point, such as ammonia, to rotate a turbine to generate electricity. Warm surface seawater is pumped through a heat exchanger, where the low-boiling-point fluid is vaporized. The expanding vapor turns the turbo-generator. Cold deep seawater—which is pumped through a second heat exchanger—then condenses the vapor back into a liquid that is then recycled through the system.

Open-Cycle of OTLC

Open-cycle systems use the tropical oceans' warm surface water to make electricity. When warm seawater is placed in a low-pressure container, it boils. The expanding steam drives a low-pressure turbine attached to an electrical generator. The steam, which has left its salt behind in the low-pressure container, is almost pure, fresh water. It is condensed back into a liquid by exposure to cold temperatures from deep-ocean water.

Hybrid OTLC

Hybrid systems combine the features of closed- and open-cycle systems. In a hybrid system, warm seawater enters a vacuum chamber, where it is flash-evaporated into steam, similar to the open-cycle evaporation process. The steam vaporizes a low-boiling-point fluid (in a closed-cycle loop) that drives a turbine to produce electricity.

Complementary Technologies

OTEC has potential benefits beyond power production. For example, spent cold seawater from an OTEC plant can chill fresh water in a heat exchanger or flow directly into a cooling system. OTEC technology also supports chilled-soil agriculture. When cold seawater flows through underground pipes, it chills the surrounding soil. The temperature difference between plant roots in the cool soil and plant leaves in the warm air allows many plants that evolved in temperate climates to be grown in the subtropics.

Biomass power plants

The most common types of boilers are hot water boilers and steam boilers. Wood chips, residues and other types of biomass are used in the boilers, in the same way as coal, natural gas and oil. Fuel is stored in a bunker for further transport to the boiler. In the boiler, water is heated to high temperature under pressure. Steam from the boiler powers the turbine, which is connected to the generator. Steam has passed through the turbine, heats area heat ing water, which is distributed through the area heating network's piping. Co-firing biomass with coal (replacing a portion of coal with biomass) is an effective method of using biomass for energy purposes and to reduce CO2 emissions. Coal plants can be made suitable to replace part of the coal by biomass or even to convert fully to biomass – turning a coal plant into a 100% renewable energy plant.

Biomass used for electricity generation

Forest products: Woody biomass from multi-functional forests constitutes the majority of today's biomass. Pellets and briquettes are manufactured by compressing by-products from the forestry industry, such as sawdust, bark or small diameter wood. They are easy to transport and therefore suitable for export.

Waste, by-products and residues: Residues include manure, sewage, sludge and other degradable waste. Liquid biomass waste, such as manure, household waste and sewage plant residues, can be digested to biogas.

Energy crops: Energy crops are not used on a large scale for electricity or heat production today. As demand for sustainable biomass increases over time, such energy crops may play a more important role in the future. Examples include woody short rotation forestry/crops such as eucalyptus, poplar and willow. But also herbaceous (grassy) energy crops such as miscanthus can be used. Especially with the use of energy crops, it is important to ensure these plantations are established and managed in a sustainable manner.

Solar energy

Concentrating solar power (CSP) technologies

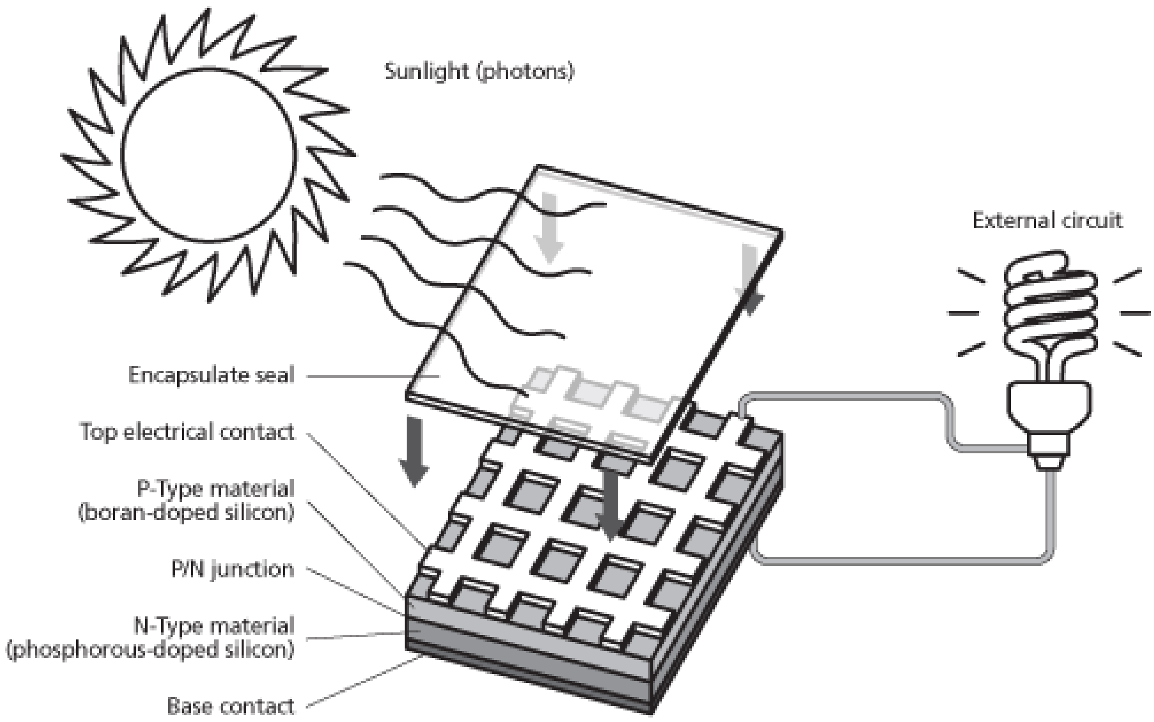
Concentrating Solar Power (CSP) technologies use mirrors to concentrate (focus) the sun's light energy and convert it into heat to create steam to drive a turbine that generates electrical power. CSP technology utilizes focused sunlight. CSP plants generate electric power by using mirrors to concentrate (focus) the sun's energy and convert it into high-temperature heat. That heat is then channeled through a conventional generator. The plants consist of two parts: one that collects solar energy and converts it to heat, and another that converts the heat energy to electricity.

Solar photovoltaic technology basics

Solar cells, also called photovoltaic (PV) cells by scientists, convert sunlight directly into electricity. PV gets its name from the process of converting light (photons) to electricity (voltage), which is called the PV effect. Traditional solar cells are made from silicon, are usually flat-plate, and generally are the most efficient. Second-generation solar cells are called thin-film solar cells because they are made from amorphous silicon or non-silicon materials such as cadmium telluride. Thin film solar cells use layers of semiconductor materials only a few micrometers thick. Because of their flexibility, thin film solar cells can double as rooftop shingles and tiles, building facades, or the glazing for skylights. Third-generation solar cells are being made from a variety of new materials besides silicon, including solar inks using conventional printing press technologies, solar dyes, and conductive plastics. Some new solar cells use plastic lenses or mirrors to concentrate sunlight onto a very small piece of high efficiency PV material. The PV material is more expensive, but because so little is needed, these systems are becoming cost effective for use by utilities and industry.

Solar PV array module

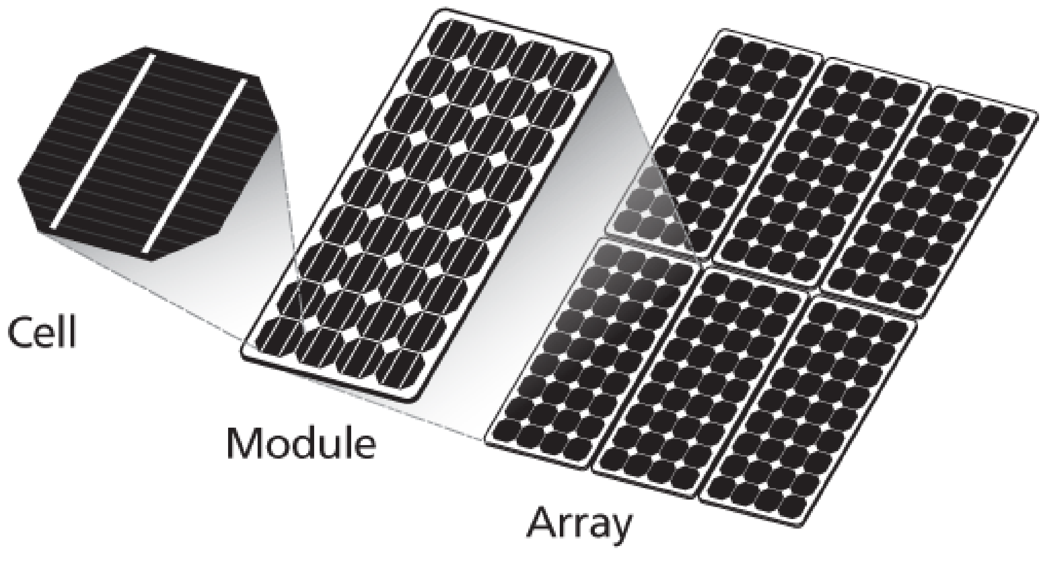
The basic element of a PV System is the photovoltaic (PV) cell, also called a Solar Cell. An example of a PV / Solar Cell made of Mono-crystalline Silicon. This single PV / Solar Cell are like a square but with its four corners missing (it is made this way). A PV / Solar Cell is a semiconductor device that can convert solar energy into DC electricity through the Photovoltaic effect (Conversion of solar light energy into electrical energy). When light shines on a PV / Solar Cell, it may be reflected, absorbed, or passes right through. But only the absorbed light generates electricity.



Construction and Working of PV / Solar Cell

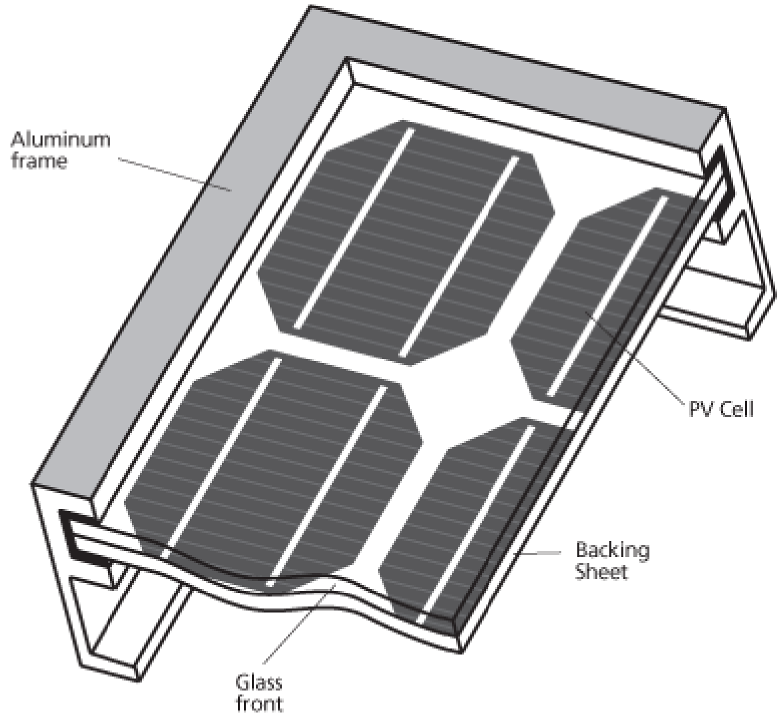
PV module / panel and PV array

To increase their utility, a number of individual PV cells are interconnected together in a sealed, weather-proof package called a Panel (Module). For example, a 12 V Panel (Module) will have 36 cells connected in series and a 24 V Panel (Module) will have 72 PV Cells connected in series To achieve the desired voltage and current, Modules are wired in series and parallel into what is called a PV Array. The flexibility of the modular PV system allows designers to create solar power systems that can meet a wide variety of electrical needs.



PV Cell, Module and Array

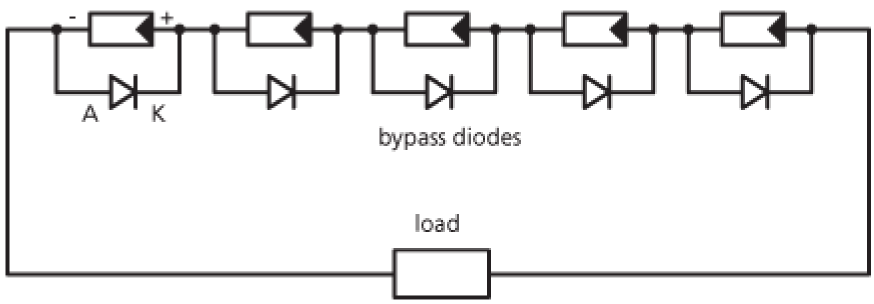
The cells are very thin and fragile so they are sandwiched between a transparent front sheet, usually glass, and a baking sheet, usually glass or a type of tough plastic. This protects them from breakage and from the weather. An aluminum frame is fitted around the module to enable easy fixing to a support structure.



Construction of a typical Mono-crystalline PV / Solar Panel

Bypass diodes

As mentioned, PV / Solar cells are wired in series and in parallel to form a PV / Solar Panel (Module). The number of series cells indicates the voltage of the Panel (Module), whereas the number of parallel cells indicates the current. If many cells are connected in series, shading of individual cells can lead to the destruction of the shaded cell or of the lamination material, so the Panel (Module) may blister and burst. To avoid such an operational condition, Bypass Diodes are connected anti-parallel to the solar cells as in Figure. As a result, larger voltage differences cannot arise in the reverse-current direction of the solar cells. In practice, it is sufficient to connect one bypass diode for every 15-20 cells. Bypass diodes also allow current to flow through the PV module when it is partially shaded, even if at a reduced voltage and power. Bypass diodes do not cause any losses, because under normal operation, current does not flow through them.



Parallel PV cell with bypass diodes

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Photovoltaic Power Systems

Photovoltaic (PV) technology converts one form of energy (sunlight) into another form of energy (electricity) using no moving parts, consuming no conventional fossil fuels, creating no pollution, and lasting for decades with very little maintenance. The use of a widely available and reasonably reliable fuel source—the sun—with no associated storage or transportation difficulties and no emissions makes this technology eminently practicable for powering remote scientific research platforms. The completely profitable nature of the technology also lends itself well to varying power requirements–from the smallest autonomous research platforms to infrastructure-based systems. Based on semiconductor technology, solar cells operate on the principle that electricity will flow between two semiconductors when they are put into contact with each other and exposed to light (photons). This phenomenon is known as the photovoltaic effect.

FUEL CELL

A fuel cell is an electrochemical energy conversion device that continuously converts chemical energy of a fuel directly into electrical energy. Continuous operation requires supply of fuel and oxidant and removal of water vapor, spent fuel, spent oxidant, inert residue and heat. It is known as a cell because of some similarities with a primary cell. Like a conventional primary cell it also has two electrodes and an electrolyte between them and produces dc power. It is also a static power-conversion device. However, active materials are generally supplied from outside unlike a conventional cell where it is contained inside the cell. Fuel is supplied at the negative electrode, also known as fuel electrode or anode and the oxidant is supplied at positive electrode, also known as oxidant electrode or *cathode*.

The only exhaust of a fuel cell, if pure hydrogen is used as fuel (and pure oxygen as oxidant), is water vapour, which is not a pollutant. In case of a hydrocarbon fuel, carbon dioxide is also produced. If air is used as oxidant, nitrogen (spent air) is also produced in the exhaust. No other pollutant such as particulate matter, NO_x and SO_x are produced. Some amount of heat is also produced, which can be easily dissipated to the atmosphere or used locally for heating purposes. No cooling water is required unlike conventional thermal power-conversion devices where a substantial quantity of cooling water is required. As the conversion of chemical energy of fuel to electrical energy occurs directly without intermediate thermal stage, the efficiency of conversion is better and not limited by Carnot efficiency of thermal stage. The efficiency of a practical fuel cell may be around 50%. The average cell voltage is typically about 0.7 V (on rated load) and several cells may be connected in series to increase the voltage. The current depends on the electrode area and can be increased by connecting several cells in parallel. Thus modules of different sizes can be constructed by series-parallel connection of the required number of cells. A general large-scale use will require the development of a low-cost fuel cell with a reasonably long life.

The main advantages of a fuel cell are: (i) it is quiet in operation as it is a static device, (ii) it is less pollutant, (iii) its conversion efficiency is more due to direct single-stage energy conversion, (iv) fuel cell plant can be installed near the point of use, thus transmission and distribution losses are avoided, (v) no cooling water is needed as required in the condenser of a conventional steam plant. The heat generated can be easily removed and discharged to the atmosphere or used locally, (vi) because of modular nature, any voltage/current level can be realized and the capacity can be added later on as the demand grows, (vii) fuel-cell plants are compact and require less space, (viii) availability of choice from large number of possible fuels, (ix) can be used efficiently at part load from 50% to 100%, and (x) no charging is required.

Potential Applications

Once fuel cells of reasonably low cost and long life become available, they will be preferred in a large number of applications. Some of their potential applications are listed below:

1. Fuel cells can be effectively used for load leveling. When the generation exceeds the demand, excess generated energy can be converted and stored as hydrogen by electrolysis of water. During peak load time, when the demand exceeds the generation, the stored hydrogen would be used in fuel cells to meet additional demand.
2. A central station power plant using fuel cell is also possible using gasified coal as fuel. The efficiency of such a plant would be higher due to direct energy conversion as compared to conventional thermal plants. Thus coal will be used more efficiently with reduced emissions.
3. Fuel cells are also suited for dispersed generation. By locating the fuel cells near the load centre, transmission and distribution cost would be avoided/reduced, although there would be some cost for transporting the hydrogen.
4. To meet the demand of isolated sites such as construction sites, military camps and small village communities or hamlets, fuel cells are more suited than diesel generator sets.
5. For remote and inaccessible locations, fuel cell can be used unattended for a long period.
6. Emergency/auxiliary supply to critical loads such as hospitals, etc., can be better met using fuel cells as compared to diesel generator sets.
7. Fuel cells can also be used as a mobile power source in vehicles, submarines and spacecrafts. A hydrogen—oxygen alkali fuel cell has been used successfully in USA to provide electric power in shuttle spacecrafts such as Apollo.
8. Fuel cells are also proposed as a power source for propulsion of electric vehicles.
9. Fuel cells can be used to power portable electronic devices (e.g., mobile phones and other low-power appliances, especially those used in military) as substitute for primary or rechargeable batteries. Instead of waiting for several hours for recharging, a small cartridge of methanol can be replaced in the same way as an ink cartridge in a computer printer.

Classification of Fuel Cells

Fuel cells can be classified in several ways.

(1) Based on the Type of Electrolyte

a) Phosphoric Acid Fuel Cell (PAFC)
b) Alkaline Fuel Cell (AFC)
c) Polymer Electrolytic Membrane Fuel Cell (PEMFC) or Solid Polymer Fuel Cell (SPFC) or Proton Exchange Membrane Fuel Cell (PEMFC)
d) Molten Carbonate Fuel Cell (MCFC)
e) Solid Oxide Fuel Cell (SOFC)

(2) Based on the Types of the Fuel and Oxidant

a) Hydrogen (pure) - Oxygen (pure) fuel cell
b) Hydrogen rich gas - air fuel cell
c) Hydrazine - Oxygen/hydrogen peroxide fuel cell

d) Ammonia-air fuel cell
e) Synthesis gas-air fuel cell
f) Hydrocarbon (gas) - air fuel cell
g) Hydrocarbon (liquid)-air fuel cell

(3) Based on Operating Temperature

a) Low temperature fuel cell (below 150PC)
b) Medium temperature fuel cell (150°G-250°C)
c) High temperature fuel cell (250°C-800°C)
d) Very high temperature fuel cell (800°G-1100°C)

(5) Based on Application

a) Fuel cell for space applications
b) Fuel cell for vehicle propulsion
c) Fuel cell for submarines
d) Fuel cell for defense applications
e) Fuel cell for commercial applications

(6) Based on the Chemical Nature of Electrolyte

a) Acidic electrolyte type
b) Alkaline electrolyte type
c) Neutral electrolyte type

Phosphoric Acid Fuel Cell (PAFC)

PAFC was developed in the 1980s. The basic phosphoric acid fuel cell is shown in Fig. 1. It consists of two electrodes of porous conducting material (commonly nickel) to collect charge, with concentrated phosphoric acid filled between them, to work as an electrolyte. Pure hydrogen or a hydrogen-rich gas is supplied at the negative electrode and oxygen or air is supplied at the positive electrode. The pores provide an opportunity for the gas, electrolyte and electrode to come into contact for electrochemical reaction. The reaction is normally very slow and a catalyst is required in the electrode to accelerate the reaction.

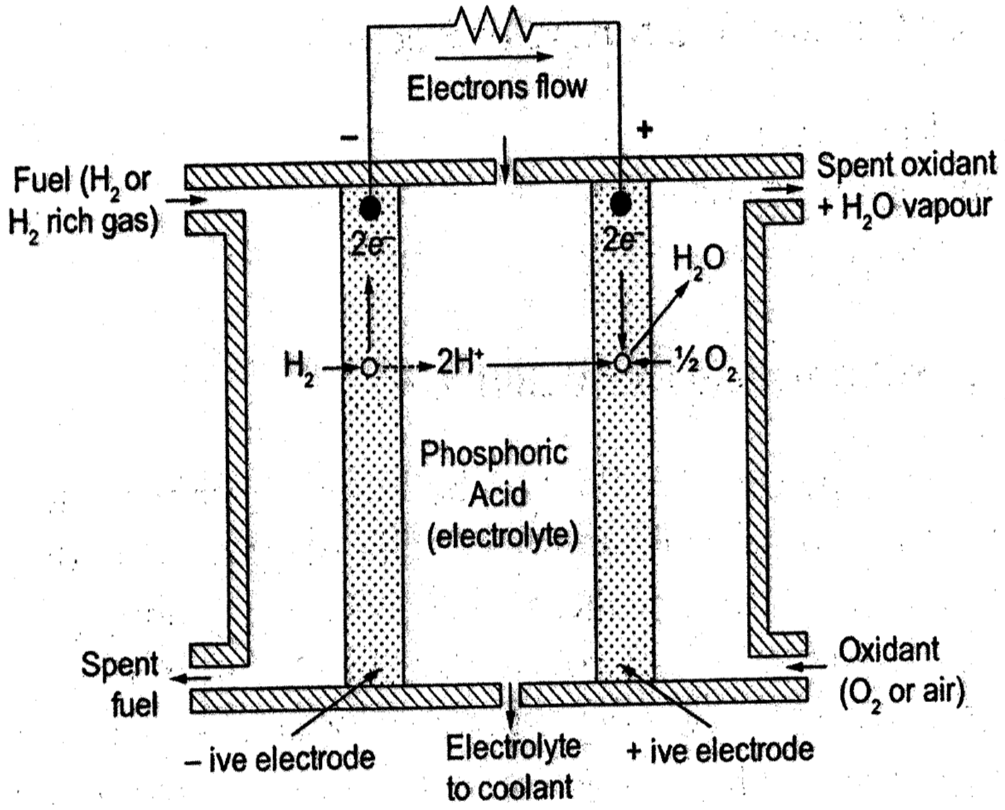

Fig. 1 Phosphoric Acid Fuel Cell

Platinum serves as the best catalyst for both electrodes and used for premium fuel cells. In general, a less expensive material such as nickel (for negative electrode) and silver (for positive electrode) is used wherever possible. Thus, finely divided platinum or nickel/silver deposited on the outer surface of electrodes are used as catalyst. During the usage of the cell, the catalyst gradually loses its activity. This loss of activity is often attributed to 'poisoning' (inactivation) of the catalyst by the impurities (mostly sulphur compounds) in the fuel.

At the negative electrode, hydrogen gas is converted to hydrogen ions (H+) and an equal number of electrons (e~). Thus,

$$H_2 \rightarrow 2H^+ + 2e^-$$

The electrons originating at the negative electrode flow through the external load to the positive electrode. Also, the H+ ions migrate from the negative electrode towards the positive electrode through the electrolyte. On reaching the positive electrode, they interact with 02 to produce water. Thus, (e^-)

$\frac{1}{2}O_2 + 2H^+ 2e^- \rightarrow H_2O$

Combining the above equations indicates that a fuel cell combines H_2 and O_2 to produce water (plus electrical energy). The overall reaction is therefore,

$\frac{1}{2}O_2 + 2H^+ 2e^- \rightarrow H_2O$

The above reaction is true for any type of hydrogen-oxygen cell. The operating temperature of PAFC is 150°C-200°C. At atmospheric pressure it produces an ideal emf of 1.23 V at 25°C, which reduces to 1.15 V at 200°C. The actual value is always less than this and decreases with current. Normally, at rated values of current the voltage lies between 0.7 V to 0.8 V.

Alkaline Fuel Cell (AFC)

An alkaline fuel cell, the oldest of all fuel cells, uses 40% aqueous KOH as electrolyte. The operating temperature is about 90°C. The electrodes and other details are same as explained for PAFC. Like PAFC it also works with H_2 and O_2 active materials and the same level of emf is produced. The operation and movements of charge carriers is shown in Fig. 2. At the positive electrode, oxygen, water (from electrolyte) and returning electrons from the external load combine to produce OH^- ions:

$$\frac{1}{2}O_2 + H_2O + 2e^- \rightarrow 2OH^-$$

These OH^- ions migrate from the positive to the negative electrode through the electrolyte. On reaching the positive electrode, these OH^- ions combine with H_2 to produce water. An equivalent number of electrons are liberated that flow through external load towards positive electrode. Thus:

$$H_2 + 2OH \rightarrow 2\ H_2O + 2e^-$$

The overall reaction is same as that with PAFC. That is:

$$H2 + \frac{1}{2}\ O_2 \rightarrow H_2O$$

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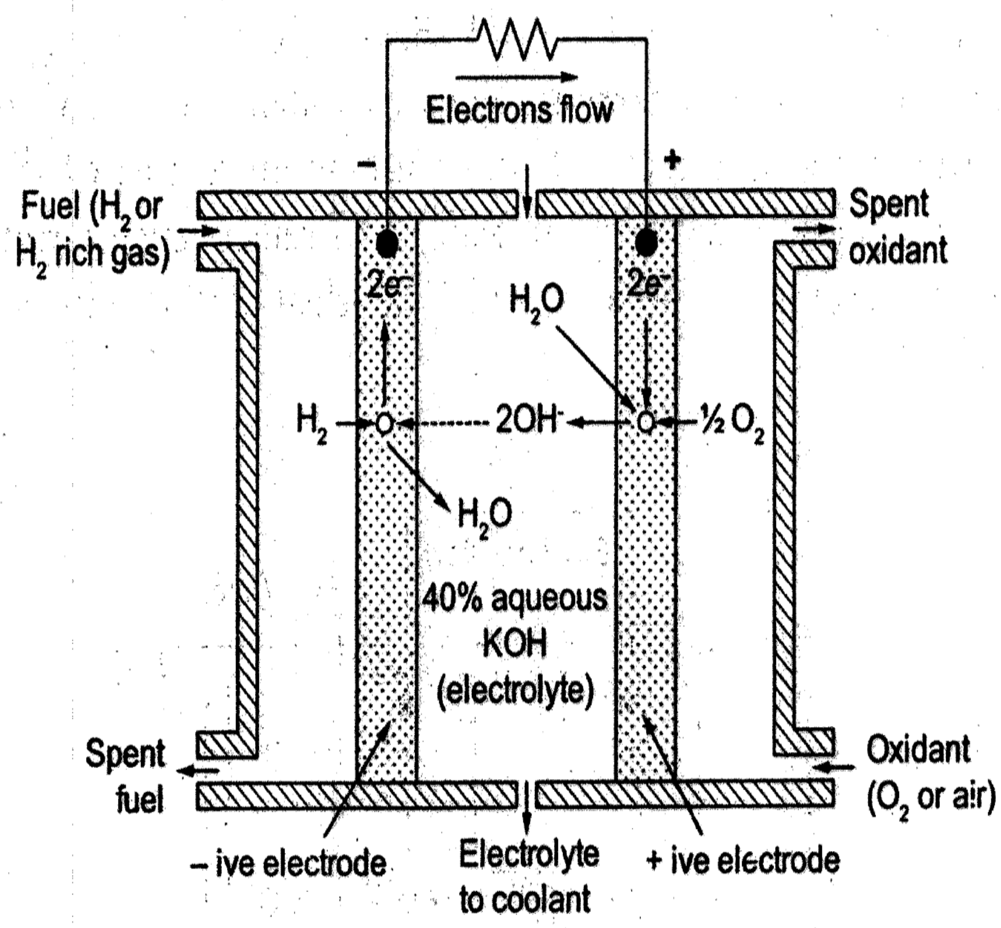

Fig. 2 Alkaline Fuel Cell

Polymer Electrolyte Membrane Fuel Cell (PEMFC) or Solid Polymer Fuel Cell (SPFC) or Proton-Exchange Membrane Fuel Cells (PEMFC)

A solid membrane of organic material (such as polystyrene sulphonic acid) that allows H^+ ions to pass through it, is used as an electrolyte. The desired properties of the membrane are (i) high ionic conductivity, (ii) non-permeable (ideally) to reactant gases, i.e., hydrogen and oxygen, (Hi) low degree of electro-osmosis, (iv) high resistance to dehydration, (v) high resistance to its oxidation or hydrolysis, and (vi) high mechanical stability.

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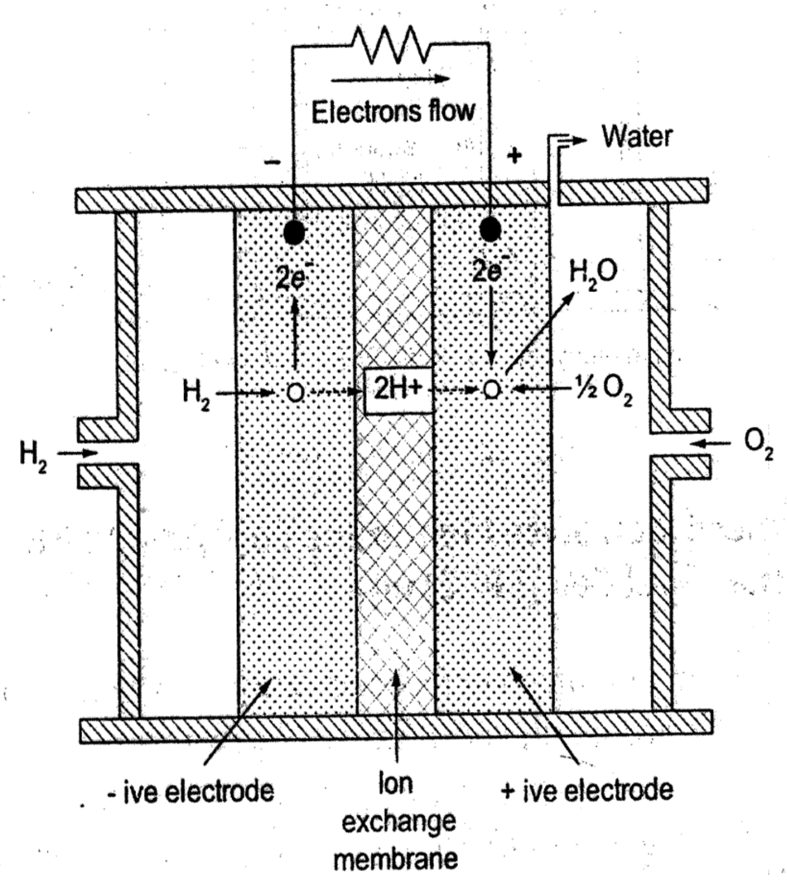

Fig. 3 Polymer Electrolyte Membrane Fuel Cell

The basic components of the cell are shown in Fig. 3. A thin layer (about 0.076 cm thickness) of the membrane is used to keep the internal resistance of the cell as low as possible. Finely divided platinum deposited on each surface of the membrane serves as the electrochemical catalyst and current collector. Hydrogen enters a closed compartment, interacts with negative electrode and converted into H^+ ions and equal number of electrons ($2e^-$):

$$H_2 \rightarrow 2H^+ + 2e^-$$

The H^+ ions are transported to a positive electrode through the membrane and electrons return to a positive electrode through external resistance. At positive electrode, the ions, electrons and oxygen (02) interact to produce water.

$$\tfrac{1}{2}O_2 + 2H^+ + 2e^- \rightarrow H_2O$$

Thus the overall reaction is

$$H_2 + \tfrac{1}{2} O_2 \rightarrow H_2O$$

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On the positive electrode, the coolant tubes run through the ribs of current collectors. The current collectors also hold wicks, which absorb water, produced in electrochemical reaction and carry it over by capillary action. Water leaves the oxygen compartment through an exit. The advantageous feature of this membrane is that it retains only limited quantity of water and rejects excess water produced in the cell. The cell operates at 40°C-60°C. The ideal emf produced is 1.23 V at 25°C.

Direct Methanol Fuel Cell (DMFC)

In a modified version of this fuel cell, methanol is used directly without reforming, instead of pure hydrogen. This is known as Direct Methanol Fuel Cell (DMFC). The complicated catalytic reforming process is not required. Storage of methanol is much easier than that of hydrogen because it does not need to be done at high pressures or low temperatures.

The liquid methanol (CH_3OH) is oxidized in the presence of water at the anode, generating CO_2, hydrogen ions and the electrons. The hydrogen ions travel through the electrolyte and react with oxygen from the air and the electrons from the external circuit to form water at the anode completing the circuit. The excess water and CO_2 are discharged as1 exhaust.

Anode Reaction $CH_3OH + H_2O \rightarrow CO_2 + 6H^+ + 6e^-$

Cathode Reaction $3/2\ O_2 + 6H^+ + 6e^- \rightarrow 3H_2O$

Overall Cell Reaction $CH_3OH + 3/2\ O_2 \rightarrow CO_2 + 2HR_2O$

These, cells have been tested in a temperature range from about 50°C -120°C. They can produce a small amount of power over a long period of time. Thus low-operating temperature, long life and no requirement for a fuel reformer make the DMFC an excellent candidate for very small to mid-sized applications, such as cellular phones, digital cameras, laptop computers and other consumer products. These micro-fuel cells offer longer life compared to lithium-ion batteries and may be instantly recharged by replacing the disposable fuel cartridge.

One of the drawbacks of the DMFC is that the low-temperature oxidation of methanol to hydrogen ions and carbon dioxide requires a more active catalyst, which typically means that a larger quantity of expensive platinum catalyst is required than in conventional PFMFCs.

One other concern driving the development of an alcohol-(ethanol) based hp fuel cell is the fact that methanol is toxic and flammable. Therefore, some companies have embarked on developing a Direct Ethanol Fuel Cell (DEFC).

Molten Carbonate Fuel Cell (MCFC)

In MCFC, carbonate of alkali metals (Na, K or li) in molten (liquid) phase is used as electrolyte. This requires the cell operation at a temperature above melting points (i.e., about 600°C - 700°C) of the respective carbonates. Because of high temperature of operation, a catalyst is not necessary. Porous nickel is used for electrodes and the electrolyte is held in sponge-like ceramic matrix.

A special feature of these cells is that during operation they oxidize hydrogen to water and carbon monoxide (present in fuel) to carbon dioxide. Hence gaseous mixtures of hydrogen and carbon monoxide (synthesis gas), which are relatively inexpensive to manufacture can also be used. This feature offers the prospects for use of a variety of fossil fuels including coal (gasified). These fuels are first converted (reformed) to get H2 and CO and desulphurized to prevent poisoning of electrodes. The theoretical value of emf at no load is approximately 1 V at 700°C. However, actual voltage at load is somewhat lower (about 0.8 V).

The discharges mainly consisting of steam, carbon dioxide and nitrogen from spent oxidant (air) are at a temperature exceeding 540°C. These hot gases could be used to provide industrial process heat or to generate additional power employing waste heat boilers (heat exchanger) and steam turbines. The overall efficiency of fuel would thus be increased substantially.

The operation of MCFC is explained with the help of a diagram shown in Fig. 4. At the fuel electrode H_2, and CO react with CO_3 ions present in the electrolyte and release two electrons each to the electrode as given below:

$$H_2 + CO_3^{--} \rightarrow H_2O + CO_2 + 2e^-$$

$$CO + CO_3^{--} \rightarrow 2CO_2 + 2e^-$$

These electrons circulate through external resistance, forming load current, and reach the oxidant electrode. The CO_2 produced at the fuel electrode is circulated through an external path to the oxidant electrode, where it combines with O_2 and the returning electron through the external path to produce CO_3^{--}

$O_2 + 2CO_2 + 4e^- \rightarrow 2CO_3$

The CO_3^{--} ions thus produced are responsible for transportation of charge from positive to negative electrode within the electrolyte. The overall reaction may be written as:

$H_2 + CO + O_2 \rightarrow H_2O + CO_2$

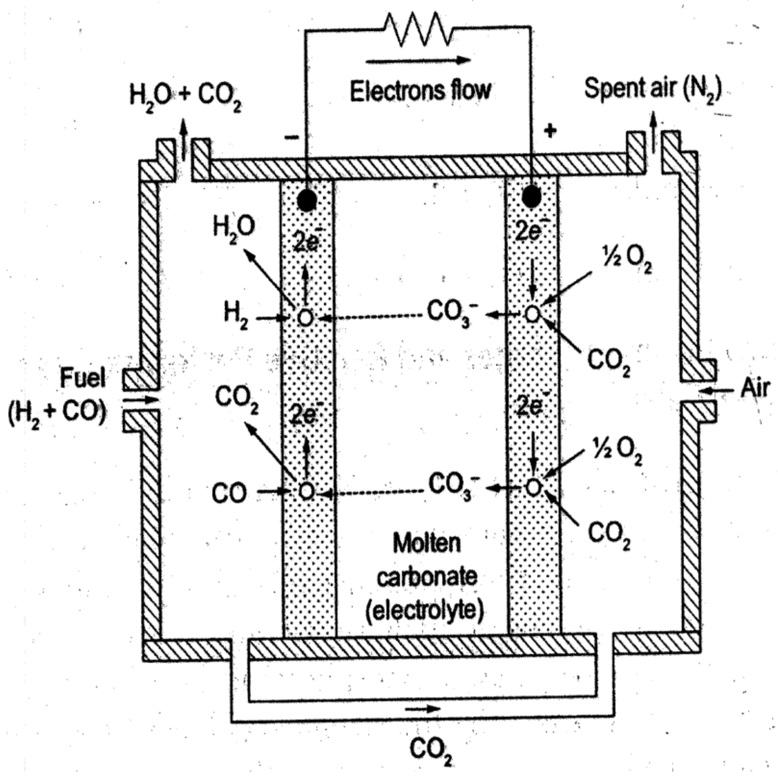

Fig. 4 Molten Oxide Acid Fuel Cell

Solid Oxide Fuel Cell (SOFC)

Certain solid oxides (ceramics) at high temperature can be used as electrolyte. For example, zirconium oxide containing a small amount of other oxide to stabilize the crystal structure has been used as an electrolyte. The material is able to conduct O^{--} ions at high temperature. The negative electrode is made' of porous nickel and the positive electrode employs a metal oxide, e.g., indium oxide. The operating temperature is in the range of 600°C- 1000°C. Due to high temperature operation, a catalyst is not required. These cells could utilize the same fuels as used in MCFC. At the fuel electrode H_2 and CO react with O^{--} ions present in the electrolyte to produce H_2O and CO_2. The two electrons leased (per ion) flow through external path to constitute load current. Like MCFC, the heat of discharge can be utilized as process heat or for additional power generation using a steam plant. The output voltage at full load is about 0.63 V. A tubular construction of SOFC is shown in Fig.5. The reactions at the electrodes are:

At positive electrode $H_2 + O^{--} \rightarrow H_2O + 2e^-$

And $CO + O^{--} \rightarrow CO_2 + 2e^-$

At negative electrode $O2 + 4e^- \rightarrow 2O$

The overall reaction is $H_2 + CO + O_2 \rightarrow H_2O + CO_2$

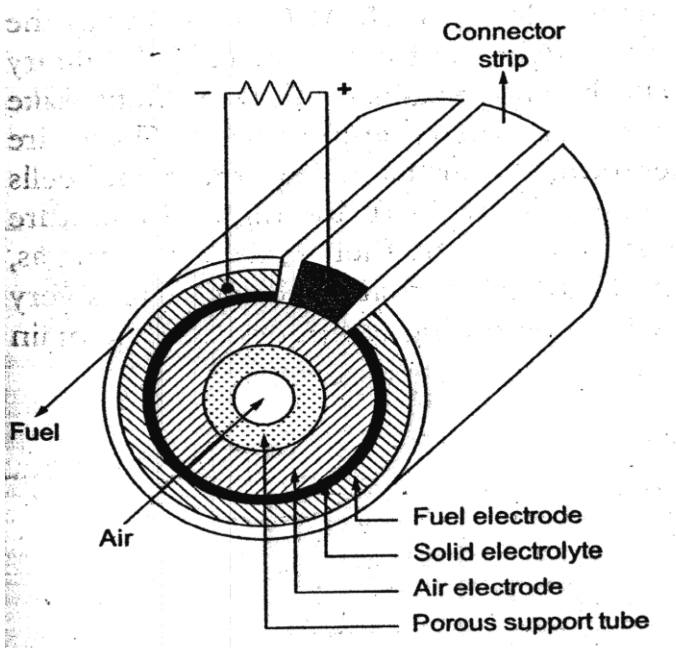

Fig. 5 Solid Oxide Fuel Cell

Development Stages and Relative Performances of Various Fuel Cells

Various characteristics of fuel cells are summarized in Table 1. PAFC has reached commercial or pre-commercial stage. It can tolerate the presence of CO_2 in the fuel.

To poisoning of catalysts and cause corrosion of internal parts (coolant circuit).

High temperature operation is limited by the stability problem of electrode material. Thus a moderate operating temperature of 150-200°C is maintained. Efforts are on to increase the life of a cell to at least 5 years. PAFC is suitable for stationary applications. PEMFC is being developed as a portable power source for mobile electronic devices, transportation and domestic applications.

AFC is already in the market. Requirement of pure H2 and 02 has restricted its use to space and military applications only. MCFC and SOFC are in the early stages of development. Like PAFCs these are also being developed for stationary applications. These are more efficient than PAFC.

The main problem in MCFC is that the electrolyte is very corrosive and current density is low. Very high operating temperature is the main concern in SOFC.

Table 1 Characteristics of various fuel cells

Sl. No.	Fuel Cell	Op. Temp.	Fuel	Efficiency
1.	PEMFC	40 – 60°C	H_2	48 – 58%
2.	AFC	90°C	H_2	64%
3.	PAFC	150 - 200°C	H_2	42%
4.	MCFC	600 - 700°C	H_2 and CO	50%
5.	SOFC	600 - 1000°C	H_2 and CO	60 – 65%

Fuels for Fuel Cells

Hydrogen is a primary fuel and the main source of energy for all fuel cells. Thus pure hydrogen or hydrogen-rich gases are generally used in fuel cells. Some fuel cells (MCFC and SOFC) can also use CO along with H_2. All types of fuels can be classified into two categories: (i) direct type, and (ii) indirect type.

1. ***Direct type fuels*** are directly introduced in the cell as such, without any transformation or reforming, to serve as active material. Examples are pure hydrogen, mixture of hydrogen with other gases, hydrazine (N^H^ and methanol.
2. ***Indirect type fuels*** are hydrogen-rich fuels, which are first converted (reformed) to a mixture of H_2 and some other products, e.g., CO, C02 and N2. Hydrocarbon fuels are decomposed by reaction with steam at high temperature in the presence of a catalyst. The process is known as steam reforming of fuels. The products containing mainly H2, CO and C02 are then supplied to the fuel cell.

Common fuels used in fuel cells are listed below:

(1) Hydrogen Pure hydrogen gas is a premium fuel for all fuel cells. Pure hydrogen with pure oxygen is used in space and military applications. However, production and storage of pure hydrogen is expensive. Hydrogen-rich gases obtained from reforming of other fuels is more economical alternative.

(2) Hydrazine (N_2H_2) Hydrazine, a liquid fuel, has high energy density and is convenient to store. However, it is toxic, costly and highly reactive. It is introduced directly to a cell without any transformation.

(3) Ammonia (NH_3) Ammonia is an indirect type of fuel. It can be stored in liquid form and can be easily decomposed catalytically at high temperature. Part of the hydrogen produced is burnt in air to provide the required heat for decomposition. The product, i.e., mixture of H_2 and N_2 is introduced in a fuel cell (e.g., AFC). Nitrogen present in the mixture is discharged with exhaust.

(4) Hydrocarbons (Cases) Hydrocarbons such as methane, propane, etc., are first converted to a mixture of H_2 and CO by steam reforming.

$$\text{Hydrocarbons } (CH_4, C_3H_8 \text{ etc.}) \xrightarrow{\text{steam refofmin8 at 900°C, N1 catalyst}} H_2 + CO$$

The mixture is then used as such or after removal of CO by water-gas shift reaction, as required. Commercial fuels such as natural gas, LPG, biogas, coal gas, landfill gas and gasified coal can be used in this way for large-scale generation of power.

(5) Hydrocarbons (Liquid) Light hydrocarbons (naphtha) are first steam reformed to get H_2 and CO. The product gas mixture is then used as fuel as explained above.

(6) Synthesis Gas Mixture of H_2 and CO in various proportions, along with other impurities (known as synthesis gas) can be produced economically from conventional or non-conventional sources. The (H_2 + CO) mixture can be used as fuel in MCFC and SOFC. For use in hydrogen fuel cells, CO is to be removed and hydrogen content is increased by a process known as water gas shift reaction, as given below:

$$CO + H_2O \text{ (steam)} \xrightarrow{\text{400°C steam cobalt molybudate catalyst}} CO_2 + H_2 + 1440 \text{ kj/kg}$$

CO_2 present in the products is also removed if the mixture is to be used in AFC.

(7) Methanol: Methanol is used both as direct as well as indirect type fuel. It can be catalytically reformed with steam at about 200°C to yield a mixture of H_2 and CO.

Methanol can also be used directly without reforming in direct methanol fuel cell, a modified version of proton membrane exchange fuel cell.

Efficiency of a Fuel Cell:

In a fuel cell, electrochemical reactions take place whereby reactants are converted to products in a steady flow process.

Where

AW = work done by the flow stream on the surrounding

AH = change in enthalpy of the flow stream from entrance to exit (of the cell)

The efficiency of energy conversion of a fuel cell: $\eta = \frac{\Delta W}{-\Delta H}$

Maximum efficiency $\eta_{\max} = \frac{\Delta W_{\max}}{-\Delta H} = \frac{\Delta G}{\Delta H}$

VI Characteristics of Fuel Cell

The theoretical emf of a fuel cell can be calculated from the change in Gibbs free energy, AG during the reaction,

$$E = \frac{-\Delta G}{nF}$$

Where

n = number of electrons transferred per molecule of the reactant

F = Faraday's constant (96500 coulombs per gram mole)

The VI characteristic of a fuel cell is shown in Fig. 6. Voltage regulation is poor for small and large values of output current. Therefore, in practice the operating point is fixed in the range BC of the characteristics where voltage regulation is best and the output voltage is roughly around 0.6 – 0.8 V.

(1) Activation Polarization (Chemical Polarization)

This is related to activation energy barrier for the electron transfer process at the electrode.

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(2) Resistance Polarizations

At larger current, there is additional contribution from internal electrical resistance of the cell.

(3) Concentration Polarizations

This type of polarization tends to limit the current drawn from the cell.

(a) Electrolyte Polarization

It is due to slow diffusion in the electrolyte causing change in concentration at the electrode. This effect can be reduced by increasing the electrolyte concentration or by stirring/circulating the electrolyte.

(b) Gas-side Polarizations

It is caused due to slow diffusion of reactants through porous electrode to the site of reaction or slow diffusion of product away from the reaction site. Increasing the operating temperature also reduces this effect. '

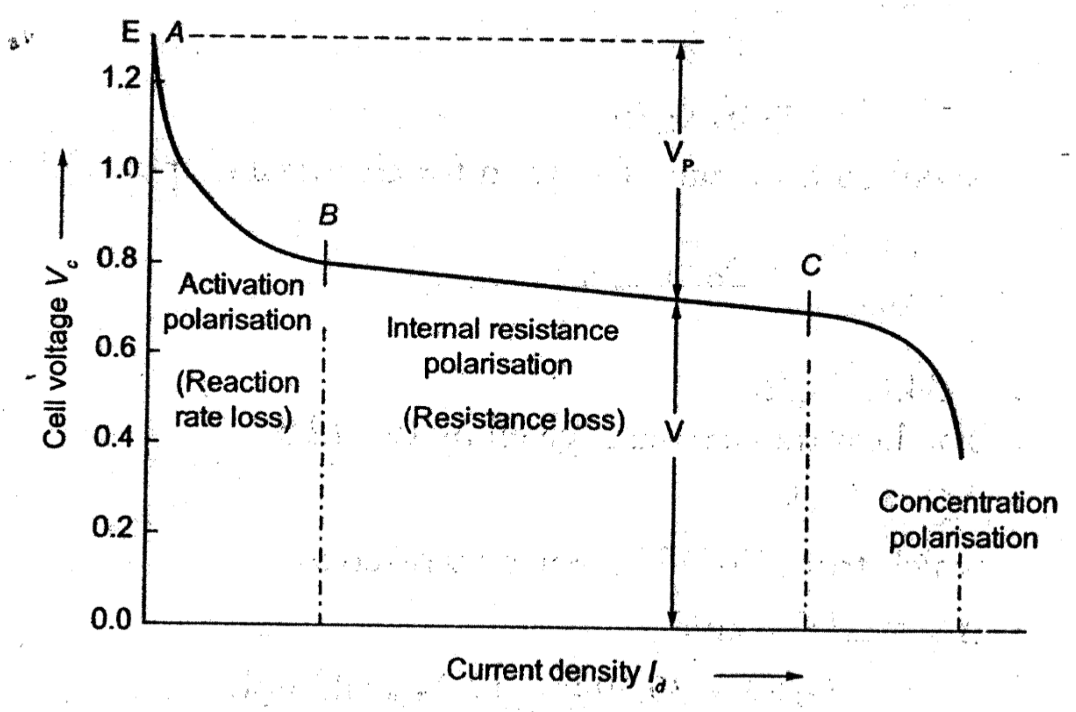

Fig. 6 VI characteristic of fuel cell

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Environmental Effects

With hydrogen as fuel, the exhaust of a fuel cell contains only water vapor, which is not a pollutant, apart from some amount of heat. If air is used as oxidant, spent air, which is mostly nitrogen, is also present in the exhaust. This is again not a pollutant. No cooling water is required as the generated heat can be easily utilized in a cogeneration unit or discharged easily to the atmosphere. The heat can also be utilized for fuel-reforming process. In case of hydrocarbon fuels, CO_2 is also produced. However, as the fuel is used more efficiently, the amount of CO_2 emission is less, compared to that when the same fuel is used in conventional thermal plants with the same output. Other pollutants are negligible compared to conventional thermal plants, as shown in Table 2.

Table 2. Emissions from various plants in kg/GJ of output

Sl. No.	Pollutant	Quantity in various type of plants			
		Fuel Cell Plant	**Coal Fired Plant**	**Oil Fired Plant**	**Natural Gas Fired Plant (Comb. Cycle)**
1.	NOx	0.0000429-0.001718	0.2607	0.15337	0.18044
2.	Particulate	0.0-0.000733	0.0644	0.02362	0.00128
3.	SO_x	0.0	0.7733	0.23199	0.0
4.	*VOCs	0.0-0.00386	--	--	--
5.	CO_2	47.258	89.79	72.6	47.258

*VOC = volatile organic compounds

HYDROGEN AS ENERGY CARRIER

Hydrogen is the simplest element. An atom of hydrogen consists of only one proton and one electron. Hydrogen doesn't occur naturally as a gas on the Earth-it is always combined with other elements. Water, for example, is a combination of hydrogen and oxygen (H_2O).

Properties of Hydrogen

Hydrogen is an odorless and colorless gas. It has the simplest and lightest atom with one proton and one electron and a molecular weight of 2.016. Important properties are listed and compared with natural gas and gasoline in Table 3.

Table 3 Comparison of various properties of hydrogen with other fuels

S. No.	Properties	Gasoline	Natural Gas	Hydrogen
1.	Density (kg/m^3)	730	0.78	0.0837
2.	Boiling point, (°C)	38 to 204	-156	-253(20.3K)
3.	Lower heating value, (MJ/kg) (MJ/m^3)	44.5 32	48 37.3	125 10.4(gas), 8520(liquid)
4.	Higher heating value, (MJ/kg) (MJ/m^3)	50.8 36.6	55 42.6	141.90 11.89(gas), 10046(liquid)
5.	Flammable limit, % in air	1.4-7.6	5-16	4-75
6.	Flame speed, (m/s)	0.4	0.41	3.45
7.	Flame temperature, (°C)	2197	1875	2045
8.	Flame luminosity	High	Medium	Low

APPLICATIONS

Hydrogen can be used in combustion-based power generation, such as gas turbine using hydrogen alone or mixed with natural gas. Such applications are proposed for stationary power generation including backup power units, standalone power plants, distributed generation for buildings and cogeneration. Alternatively, hydrogen may be obtained from steam reforming of natural gas and then used in fuel cell to generate electricity.

Portable applications for fuel-cell based generation include consumer electronics, business machinery and recreational devices. These portable power applications range from 25 W for portable electronics to 10 kW system for critical commercial and medical functions and on-site power generation for individual homes and office buildings.

Safety Issues

Like any other fuel or energy carrier, hydrogen poses risks if not properly handled or controlled. Some properties of hydrogen make it potentially less hazardous while other characteristics could make it more dangerous in certain situations.

In case of a leak, hydrogen will disperse much faster than any other fuel, thus reducing the hazard level.

Hydrogen flame is nearly invisible, which may be dangerous, because people in the vicinity of the flame may not even know there is fire.

Present Status

The United States currently produces about nine million tones of hydrogen per year. This hydrogen is used primarily in industrial processes including petroleum refining, petrochemical manufacturing, glass purification, and in fertilizers. It is also used in the semiconductor industry and for the hydrogenation of unsaturated fats in vegetable oil.

Hydrogen is the optimum choice for fuel cells, which are extremely efficient energy-conversion devices that can be used for transportation and electricity generation.

Expanding the use of hydrogen as an energy carrier requires a fundamental change in the way we produce, deliver, store, and use energy. Putting it all together is the ultimate challenge. To achieve the goal of commercially-viable hydrogen and fuel-cell systems, research and development efforts are focused on the most promising technologies, and demonstrations are validating fully integrated systems operating in real-world conditions.

REVIEW QUESTIONS

1. What is a fuel cell and what are its main advantages?
2. What are potential applications of a fuel cell?
3. Describe the classification of fuel cells.
4. Comment on relative performances of various types of fuel cells.
5. Explain the principle of operation of an alkaline fuel cell.
6. Discuss VI characteristics of a fuel cell and define various types of polarizations.
7. What is the present state of development in fuel-cell technology?
8. Comment on environmental effects of fuel cell.
9. Comment on the safety issues related to the use of hydrogen.

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Unit-II

WIND ENERGY

INTRODUCTION

Wind energy is the kinetic energy associated with movement of large masses of air.

Wind energy can be available continuously throughout a 24-hour day for much longer periods, though it can vary a great extent including no wind periods. It is a clean, cheap, and eco-friendly renewable source. The main disadvantages are that it is a dispersed, erratic and location-specific source. Wind energy is harnessed as mechanical energy with the help of a wind turbine. The mechanical energy thus obtained can either be used as such to operate farm appliances, and water pumping or converted to electric power and used locally or fed to a grid. A generator coupled to a wind turbine is known as *aero-generator*. Very slow winds are useless, having no possibility of power generation. On the other hand, very strong stormy winds cannot be utilized due to safety of turbine. Moderate to high-speed winds, typically from 5 m/s to about 25 m/s are considered favorable for most wind turbines. The global potential in winds for large-scale grid-connected power generation has been estimated as 9,000 TWh/year or 1 TWe (1T = 1012). it is also estimated that favorable winds for small-scale applications such as wind pumps, battery chargers, heaters, etc., are available on about 50% of the earth's surface which means that small-scale wind turbines can be practical in many parts of the world.

The electric power generation through wind was first proposed in Denmark in 1890 and many aero-generators were built in Europe and elsewhere.

The interest in wind energy has renewed after the oil crisis of 1973. Most modern, large-scale wind-energy systems have been built after 1980 using modern engineering designs, materials and incorporating microelectronics monitoring and control.

With modern blade materials, the expected life of a wind turbine has exceeded 20 years. In year 2014, wind energy installation has crossed 50 GW mark for the first time.

Globally, wind energy has become a mainstream energy source and an important player in the world's energy markets, and it now contributes to the energy mix in more than 70 countries across the globe.

NATURE OF WINDS

To be able to understand and predict the performance of wind turbines it is essential to have some knowledge of the behavior and structure of wind. This is also required for proper design of a supporting structure to carry the imposed load safely and at an economically viable cost. The behavior and structure of the wind varies from site to site depending on the general climate of the region, the physical geometry of the locality, the surface condition of the terrain around the site and various other factors.

Rapid fluctuations in the wind velocity over a wide range of frequencies and amplitudes, due to turbulence caused by mechanical mixing of lower layers of atmosphere by surface roughness, are commonly known as gusts.

The Beaufort scale, a wind-speed classification, gives a description of the effect of the wind. It was initially designed for sailors and described the sea state, but has been modified to include wind effects on land. It is a useful guide to wind speed. The description of wind based on Beaufort numbers is given in Table 1.

Table 1 Description of wind based on the Beaufort scale

Beaufort number	Wind speed		Observable effects	Wind Description
		km/h		
0	0.0-0.4	0.0-1.6.	Smoke rises vertically	Calm
1	0.4-1.8	1.6-6	Smoke drifts but vanes unaffected	light
2	1.8-3.6	6-13	Leaves move slightly but vanes unaffected	Light
3	3.6-5.8	13-21	Leaves in motion, flags begin to extend	Light
4	5.8-8.5	21-31	Small branches move, dust raised, pages of	Moderate
5	8.5-11	31-40	Small trees sway, wind noticeable	Fresh
6	11-14	40-51	Large branches sway, telephone lines	Strong
7	14-17	51-63	Whole tree in motion	Strong
8	17-21	63-76	Twigs break off, walking difficult	Gale
9	21-25	76-88	Slight structural (e.g., chimneys) damage	Gale
10	25-29	88-103	Trees uprooted, much structural damage	Strong gate
11	29-34	103-121	Widespread damage	Strong gate
12	>34	>121	Disastrous conditions, countryside	Hurricane

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Wind Data

All countries have national meteorological services that record and public weather-related data including wind speed and direction. Wind speed is measured by an anemometer and wind direction is measured by a wind vane attached to a direction indicator. Anemometers work on one of the following principles.

(i) The oldest and simplest anemometer is a swinging plate hung vertically and hinged along its top edge. Wind speed is indicated by the angle of deflection of the plate with respect to the vertical.

(ii) Cup anemometer consists of three or four cups mounted symmetrically about a vertical axis. The speed of rotation indicates wind speed.

(iii) Wind speed can also be recorded by measuring the wind pressure on a flat plate.

(iv) A hot-wire anemometer measures the wind speed by recording cooling effect of the wind on a hot wire. The heat is produced by passing an electric current through the wire.

According to World Meteorological Organization (WMO) recommendation, wind speed measurement should be made at an effective height of 10 m above the ground.

ESTIMATION OF WIND ENERGY AT A SITE

Power in Wind

If u_o is the speed of free wind in unperturbed state, the volume of air column passing through an area A per unit time is given by A_{uq}. If p is the density of air, the air-mass flow rate, through area A, is given as, $_\rho AU_o$. Power (P_o) available in wind, is equal to kinetic energy associated with the mass of moving air, i.e.

$$P_o = \frac{1}{2}(\rho A u_o) u_0^2$$

or

$$P_o = \frac{1}{2}(\rho A) u_0^3$$

Power available in wind per unit area is

$$\frac{P_o}{A} = \frac{1}{2}\rho u_0^3$$

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This indicates that power available in wind is proportional to the cube of wind speed. The air density ρ varies in direct proportion with air pressure and inverse proportion with temperature as:

$$\rho = \frac{P}{RT}$$

Where P is air pressure in Pa, T is air temperature in Kelvin and R is the gas constant, (= 287 J/kg K). At the standard value of air pressure, 1.0132×10^5 pa (i.e, 1 atmosphere), and at 15°C, the value of air density.

$$\rho = \frac{1.0132 \times 10^5}{287 \times 288} = 1.226 J/kg - K/m^3$$

Assuming the above value of wind density, ρ at 15°C and at sea level, the power available in moderate wind of 10 m/s is 613 W/m^2.

WIND TURBINE SITTING

The power available in wind increases rapidly with wind speed. Therefore, the main consideration for locating a wind-power generation plant is the availability of strong and persistent wind. A suitable site should preferably

1. No tail obstructions for some distance (about 3 km) in the upwind direction (i.e., the direction of incoming wind) and also as low a roughness as possible in the same direction
2. A wide and open view i.e., open plain, open shoreline or offshore locations
3. Top of smooth well-rounded hill with gentle slopes (about 1:3 or less) on a flat plain
4. An island in a lake or the sea
5. A narrow mountain gap through which wind is channeled
6. Site reasonably close to power grid
7. Soil conditions must be such that building: of foundations df the turbines and transport of road-construction materials loaded in heavy trucks is feasible.
8. Production results of existing wind turbines in the area to act as a guide to local wind conditions.

MAJOR APPLICATIONS OF WIND POWER

Wind turbines have been built-in power output range from a kilowatt to few MW to suit a wide range of applications. Major applications may be grouped in three categories..

Applications Requiring Mechanical Power

(i) Wind Pumps

Low-power turbines are used for producing mechanical power for pumping water m remote areas. These are also known as wind pumps. Simple and reliable traditional reciprocating pumps of centrifugal pumps are used. These wind pumps are used to supply water for livestock, small-scale irrigation, low head pumping for aquatic breeding and domestic water supply. Mechanical power is also used to operate farm appliances.

(ii) Heating The direct dissipation of mechanical power produces heat with 100% efficiency using a paddle wheel and other turbulent fluid ^sterns. The available hot water is used as such or employed for space heating.

2. As off Grid Electrical Power Source

i. Machines of low power with a rotor diameter of about 3 to and 40-1000) rating can generate sufficient electrical energy for space heating and pooling of homes, water heating, battery charging and lor operating domestic appliances such as fen, lights, and small tools.
ii. Applications for, somewhat more powerful turbines of about 50 kW are producing electrical power for navigation signal (e.g, lighthouse), remote
iii. Intermediate power range, roughly 100 to 250 kW aero-generators can supply power to isolated populations, farm cooperatives, commercial refrigeration, desalination and to other small industries. The generator may operate in stand-alone mode or may be connected to a mini-grid system.

Large aero-generators in the range of a few hundred kW to a few MW are planned for suiting power to a utility grid. Large arrays of aero-generators, known as *wind farms* are being deployed in open plains or offshore in shallow water for this purpose.

WIND TURBINE TYPES AND THEIR CONSTRUCTION

Wind turbines are broadly classified into two categories. When the axis of rotation is parallel to the air stream (i.e., horizontal), the turbine is said to be a Horizontal Axis Wind Turbine (HAWT), and when it is perpendicular to the air stream (i.e., vertical), it is said to be a Vertical Axis Wind Turbine (VAWT). The size of the rotor and its speed depends on rating of the turbine. Some of the features of HAWT estimated at wind speed of 12 m/s and Cp = 30% are given in Table 2.

Table 2 Typical wind turbine characteristics

Sl. No.	Features	Class										
		Small		Medium			Large			Very Large		
1.	Rated Power, kW	10	25	50	100	150	250	500	1000	2000	3000	4000
2.	Rotor diameter,m	6.4	10	14	20	25	32	49	64	90	110	130
3.	Rotor RPM	200	150	100	67	55	43	29	19	15	13	11

Horizontal Axis Wind Turbine (HAWT)

HAWTs have emerged as the most successful type of turbines. These are being used for commercial energy generation in many parts of the world. Their theoretical basis is well researched and sufficient field experience is available with them.

A. Main Components

The constructional details of the most common, three-blade rotor, horizontal axis wind turbine is shown in Fig.1. The main parts are as follows:

Turbine Blades Turbine blades are made of high-density wood or glass fibre and epoxy composites. They have an airfoil type of cross section. The blades are slightly twisted from the outer tip to the root to reduce the tendency to stall. In addition to centrifugal force and fatigue due to continuous vibrations, there are many extraneous forces arising from wind turbulence, gust, gravitational forces and directional changes in the wind. All these factors are to be taken care off at the designing stage. The diameter of a typical, MW range, modern rotor may be of the order of 100 m.

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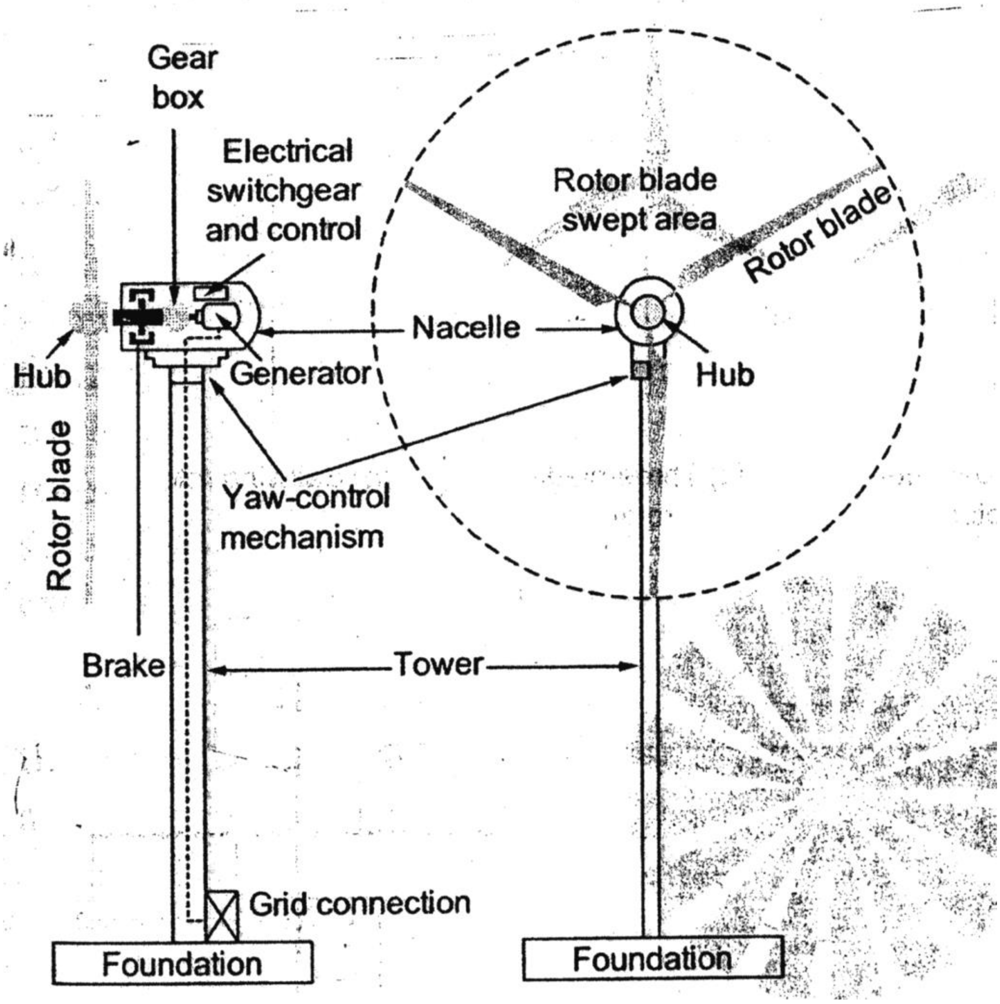


Fig. 1 Horizontal axis wind turbine

Modern wind turbines have two or three blades. Two/three blade rotor HAWT are also known as propeller-type wind turbines owing to their similarity with propellers of old aeroplanes. However, the rotor rpm in case of a wind turbine is very low as compared to that for propellers. The relative merits and demerits of two and three blade rotors are as follows:

(i) Compared to the two-blade design, the three-blade machine has smoother power output and balanced gyroscopic force.

(ii) There is no need to teeter (to be discussed later in this section) the rotor, allowing the use of simple rigid hub. The blades may be cross-linked for greater rigidity.

(iii) Adding third blade increases/the power output by about 5 per cent only, while the weight and cost of a rotor increases % 50%, thus giving a diminished rate of return for additional 50% weight arid cost.

(iv) The two-blade rotor is also simpler to erect, since it can be assembled on ground and lifted to the shaft without complicated maneuvers during the lift.

Three blades are more common in Europe and other developing countries including India. The American practice, however, is in favour of two blades.

(b) Hub

The central; sold portion of the rotor wheel is known as hub. All blades ate attached to the hub. Mechanism for pitch angle control is also provided inside the hub.

Nacelle

The term nacelle is derived from the name for housing containing the engines of an aircraft. The rotor is attached to the nacelle, and mounted at the top of a tower. It contains rotor brakes, gearbox, generator and electrical switchgear and control. Brakes are used to stop the rotor when power generation is not desired. The gearbox steps up the shaft -rpm to suit the generator. Protection and control functions are provided by switchgear and control block. The generated electrical power is conducted to ground terminals through a cable.

(d) Yaw Control Mechanism:

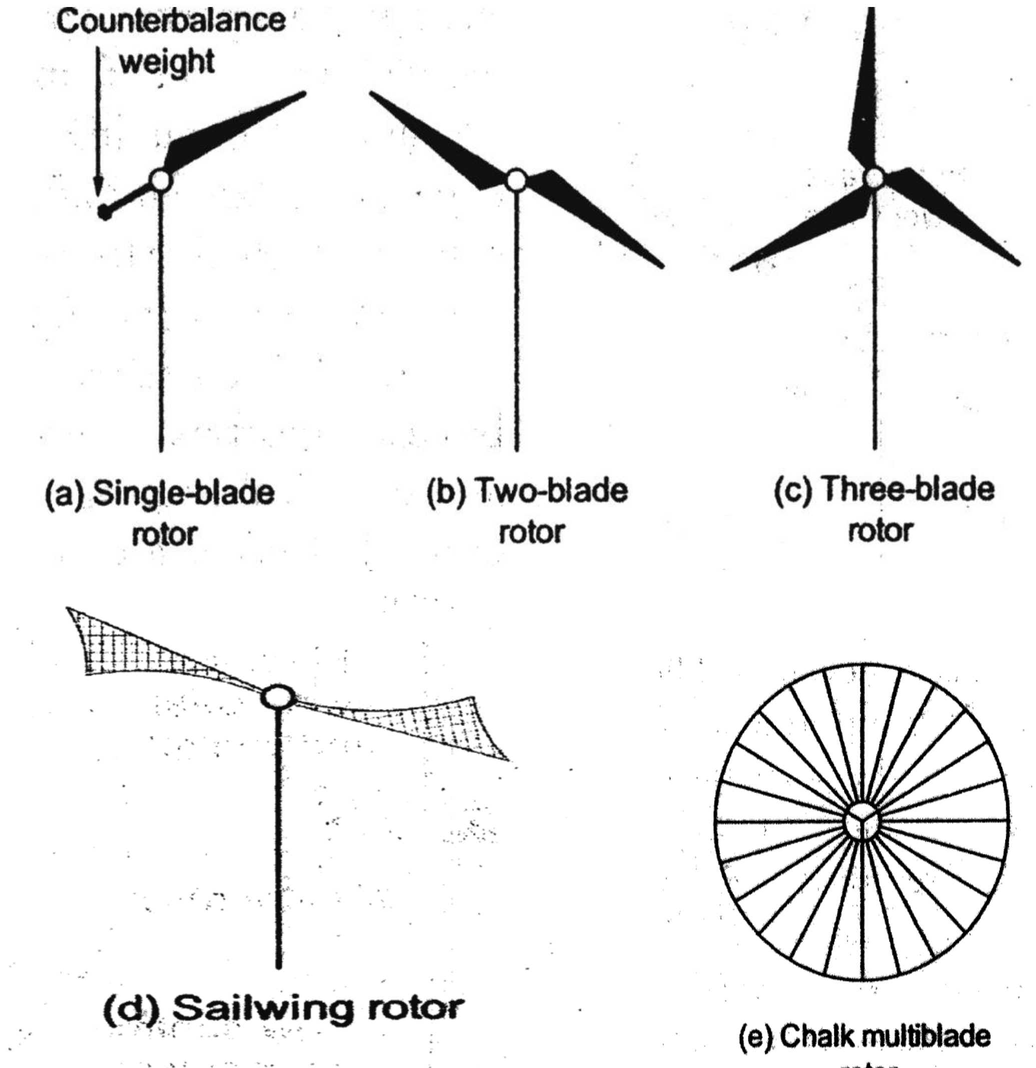
The mechanism to adjust the nacelle around vertical axis to keep it facing the wind is provided at the base of nacelle.

(e) Tower:

Tower supports nacelle and rotor. For medium and large sized turbines, the tower is slightly taller than the rotor diameter. In case of a small-sized turbine, the tower is much larger than the rotor diameter as the air is erratic at lower heights. Both steel and concrete towers are being used. The construction can be either tubular or lattice type.

2. Types of Rotors

Depending on the number of blades, wind speed and nature of application, rotors have been developed in various types of shapes and sizes. These are shown in Fig. 2. The types of rotors shown in (a) to (e) are relatively high-speed ones, suitable for applications such as electrical power generation. Large HAWTs have been manufactured with two and three blades. A single blade rotor, with a balancing counterweight is economical, has simple controls but it is noisier and produces unbalanced forces. It is used for low-power applications.



Vertical Axis Wind Turbine (VAWT)

VAWTs are in the development stage and many models are undergoing field trial. The main attractions of a VAWT are

(i) It can accept wind from any direction, eliminating the need of yaw control,

(ii) The gearbox, generator, etc., are located at the ground, thus eliminating the heavy nacelle at the top of the tower, thus simplifying the design and installation of the whole structure, including the tower,

(iii) The inspection and maintenance also gets easier, and

(iv) It also reduces the overall cost.

1. Main Components

The constructional details of a vertical axis wind turbine (Darrieus-type rotor). are shown in Fig. 3. The details of the main components are as follows:

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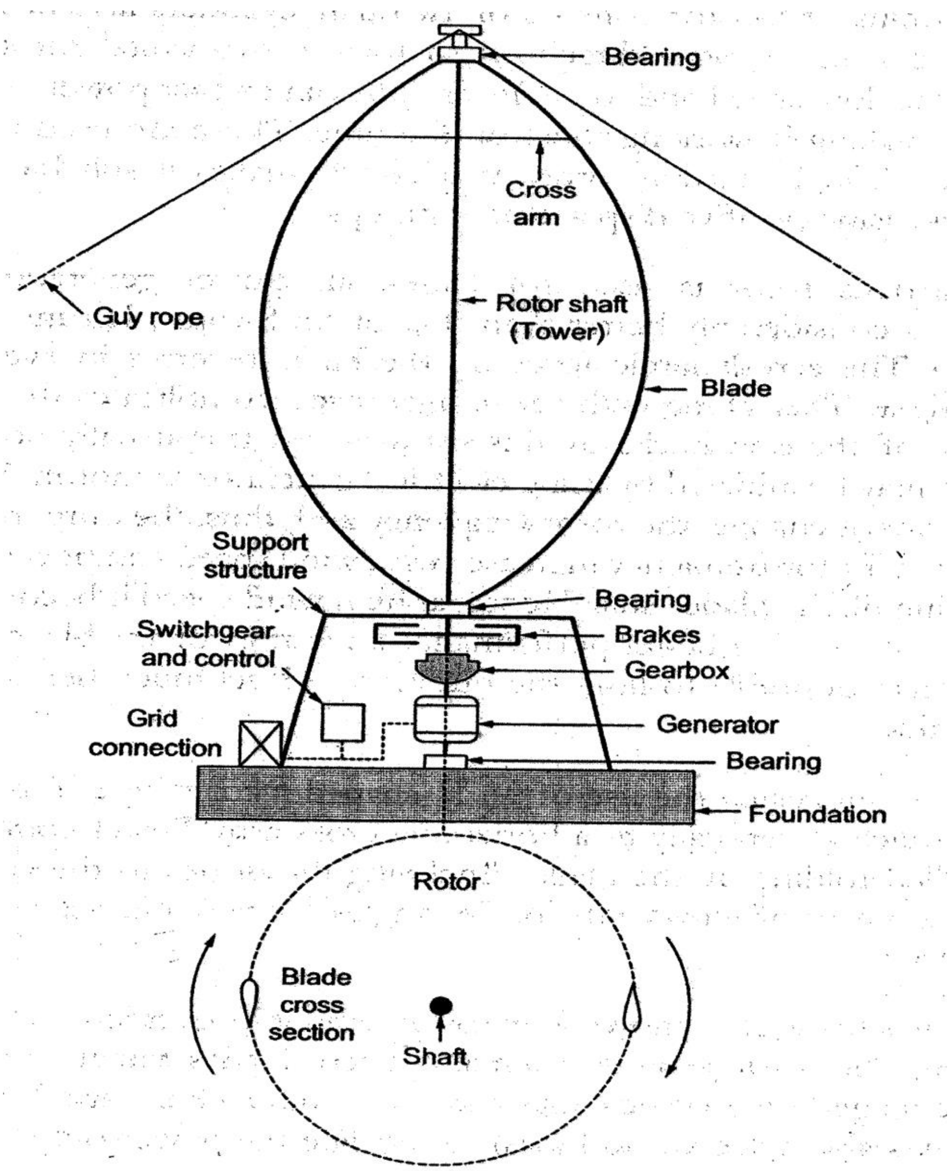

Fig. 3 Vertical axis wind (Darrieus) turbine

a) Tower (or Rotor Shaft)

The tower is a hollow vertical rotor shaft, which rotates freely about the vertical axis between the top and bottom bearings. It is installed above a support structure. In the absence of any load at the top, a very strong tower is not required, which gready simplifies its design. The upper part of the tower is supported by guy ropes. The height of the tower of a large turbine is around 100m.

(b) Blades

It has two or three thin, curved blades shaped like an eggbeater in a profile, with blades curved in a form that minimizes the bending stress caused by centrifugal forces the so called

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"Troposkien" profile. The blades have an airfoil cross section with constant chord length. The pitch of the blades cannot be changed. The diameter of the rotor is slightly less than the tower height. The first large (33 MW), Darrieus type, Canadian machine has a rotor height as 94m and the diameter as 65 m with chord of 2.4 m.

(c) Support Structure

The support structure is provided at the ground to support the weight of the rotor. Gearbox, generator, brakes, electrical switchgear and controls are housed within this structure.

2. Types of Rotors

Various types or rotors for VAWTs are shown in Fig. 7.20, the simplest being a three-or four-cup structure attached symmetrically to a vertical shaft. The drag force on the concave surface of the cup facing the wind is more than that on the convex surface. As a result, the structure starts rotating. Some lift force also helps rotation. However, it cannot carry a load and therefore cannot used as power source. The main characteristic of this rotor is that its rotational frequency is linearly related to wind speed. Therefore, it is used as a transducer for measuring the wind speed and the apparatus is known as cup anemometer.

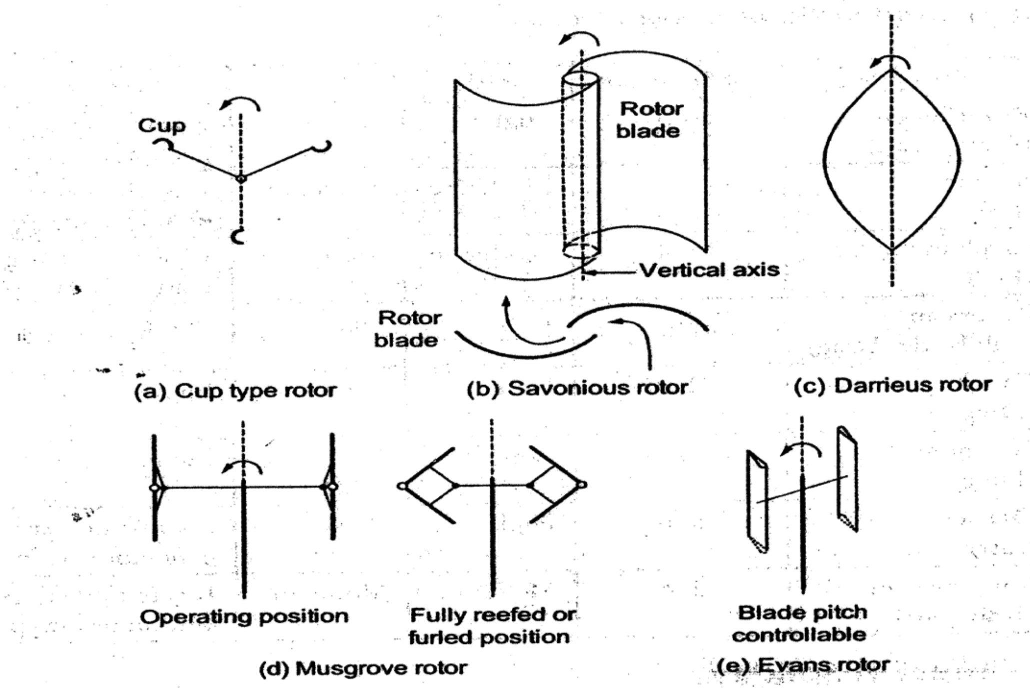

Fig. 4 Various types of rotors for VAWT

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The Savonius or S-rotor consists of two half cylinders attached to a vertical axis and facing in opposite directions to form a two-vaned rotor. It has high staring torque, low speed and low efficiency. It can extract power even from very slow wind, making it working most of the time. These are used for low-power applications. A high starting torque particularly makes it suitable for pumping applications, using positive displacement pumps.

The Darrieus rotor is used for large-scale power generation. Its power coefficient is considerably better than that of an S-rotor. It runs at a large tip-speed ratio. The aerodynamic force on the blade reverses in every revolution, causing fatigue.

Musgrove suggested the use of an H-shaped rotor where blades with a fixed pitch are attached vertically to a horizontal cross arm. Power control is achieved by controlled folding of the blades. Inclining the blades to the vertical provides an effective means of altering the blades angle of attack and hence controlling the power output.

The Evans rotor, also known as Gyromill, is an improvement over the H-shaped rotor.

Sl. No.	Rotor Type	Tip speed ratio	RPM	Torque	Typical load
1.	Propeller (1-3 blade)	6-20	High	Low	Electric power
2.	Sailwing (Lift)	4	Moderate	Moderate	Electric power gen-
3.	Chalk multi-blade	3-4	Moderate	Moderate	Electric power
4,	American multi-blade (Drag)	1	Low	High	Pump
5.	Dutch type (Drag)	2-3	Low	High	Pump
6.	Savonious (Drag)	1	Low	High	Pump
7.	Darrieus (Lift)	5-6	High	Low	Electric power
8.	Musgrove and Evan (lift)	3-4	Moderate	Moderate	Electric power

Most wind turbines used at present are of horizontal axis type. They have been well researched and have gone through extensive field trial. As a result, well-established technology is available for HAWTs. Some advantages of VAWT have recently generated considerable interest in this type of turbine. These are (i) it can accept wind from any direction without adjustment which avoids the cost and complexity of a yaw-orientation system, (ii) gearing and generators, etc., are located at ground level, which simplifies the design of tower, the installation and subsequent inspection and maintenance, and (iii) also they are less costly as compared to HAWTs,

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The principal disadvantages of VAWTs are (i) many vertical-axis machines have suffered from fatigue arising from numerous natural resonances in the structure, (ii) rotational torque from the wind varies periodically within each cycle, and thus unwanted power periodicities appear at the output.

Speed Control Strategies for Wind Turbine

Various options are available for speed control of turbine. The particular control strategy depends on the size of the turbine. Small machines use simple, low-cost methods while large machines use more sophisticated methods incorporating pitch control along with power electronic, circuit. These methods may be grouped In the following categories:

(i) No speed control at all. Various components of the entire system are designed to withstand extreme speed under gusty wind.
(ii) Yaw arid tilt control, in which the rotor axis is shifted out of wind direction, either by yaw control or by tilting the rotor plane With respect to normal vertical plane when the wind exceeds the design limit.
(iii) Pitch control which the pitch of the rotor Hades is controlled to jf regulate the speed.
(iv) Stall control, in which the blades are shifted to a position such that stall when wind speed exceeds the safe limit.

WIND ENERGY CONVERSION SYSTEMS (WECS)

A wind-energy conversion system converts wind energy into some form of electrical energy. In particular, medium and large scale WECS are designed to operate in parallel with a public or local ac grid. This is known as a grid-connected system, A small system, isolated from the grid, feeding only to a local load is known as autonomous, remote, decentralized, stand-alone or isolated, power system. A general block diagram of a grid-connected WECS is shown in Fig. 5.

The turbine shaft speed is stepped up with the help of gears, with a fixed gear ratio, to suit the electrical generator and fine-tuning of speed is incorporated by pitch control. This block acts as a drive for the generator. Use of variable gear ratio has been considered in the past and was found to add more problems than benefits. Hence dc, synchronous or induction generators are used for mechanical to electrical power conversion depending on the design of the system. The interface conditions the generated power to grid-quality power. It may consist of a power electronic converter, transformer and filter, etc.

The control unit monitors and controls the interaction among various blocks. It derives the reference voltage and frequency signals from the grid and receives wind speed, wind direction, wind turbine speed signals, etc., processes them and accordingly controls various blocks for optimal energy balance.

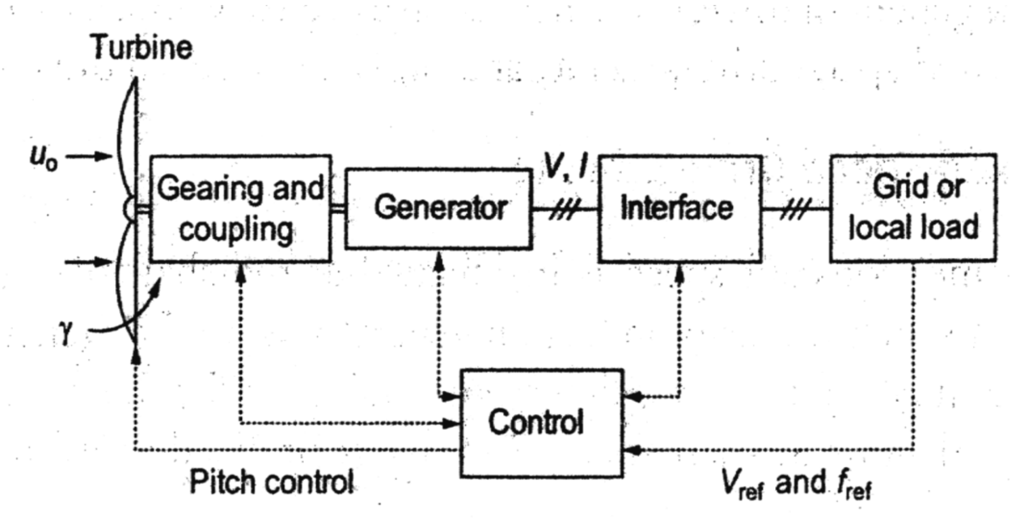

Fig. 5 General Block diagram of a WECS

Main features of various types of generators and their suitability in wind S£ power generations are discussed below:

(a) DC Generator

Conventional dc generators are not favored due to their high cost, weight and maintenance problems of the commutator. However, r^ permanent-magnet (brushless and commutator-less) dc machines are considered in small-rating (below hundred kW) isolated systems.

(b) Synchronous Generator

Synchronous generators produce high-quality output and are universally used for power generation in conventional plants. However, they have very rigid requirement of maintaining constant shaft speed and any deviation from synchronous value immediately reflects in the generated frequency. Also, precise rotor speed control is required for synchronization. Due to this reason, a synchronous machine is not well suited to wind power generation.

(iii) Induction Generator

The primary advantages of an induction machine are the rugged, brushless construction, no need of separate dc field power and tolerance of slight variation of shaft speed (±10%) as these variations are absorbed in the slip. Compared to dc and synchronous machines, they have low capital cost, low maintenance and better transient performance. For these reasons, induction generators are extensively used in wind and micro-hydroelectric plants. The machine is available from very low to several megawatt ratings.

(a) Variable Speed-drive Using Power Electronics

Modern variable speed-schemes make use of power electronic converters for power conditioning. The variable voltage and variable frequency output available from a generator (synchronous or self-excited induction generator) is first rectified to dc and then converted to fixed frequency and fixed voltage ac using an inverter. The Harmonics are filtered out to get grid quality output before connecting to the grid. The rectifier, inverter, filter and transformer constitute the main parts of interface.

ENVIRONMENTAL ASPECTS

In general, the use of energy in any form affects the environment in one way or the other at different levels. Wind energy is no exception. Although, these effects are of far less consequence as compared to that related to other sources of energy.

In terms of causing stress on water resources, wind energy is one of the most benign sources of energy. A major advantage of wind generation relative to any thermal based generation (nuclear, geothermal, fossil fuel and solar thermal) is that it does not need cooling water.

The main environmental concerns are discussed below:

1. Indirect Energy Use and Emissions

Energy is required to produce material used to construct the wind turbine and its installation. Some pollution (emission of CO_2, etc.) is caused due to use of energy during construction. But in total, the so-called indirect CO_2 emission over the total operating life of the wind generator is very low (about 1% of the system using coal).

2. Bird Life

Large wind turbines pose a threat to bird life as a result of collision with tower or blades. Their resting and breeding patterns are also affected.

3. Noise

The disturbance caused by the noise produced by a wind turbine is one of the important factors that prevent its sitting close to inhabited areas.

Some of this noise is of infra sound, at frequencies below the audible range. This infrasound may cause houses and other structures to vibrate.

4. Visual Impact

Wind turbines are massive structures quite visible over a wide area in most locations. The visual impact of wind turbines is qualitative in nature. In a study, it was found that public appreciation of a landscape decreases as more and more wind turbines are installed.

5. Telecommunication Interference

Wind turbines present an obstacle for incident electromagnetic waves (i.e., TV or microwave signals). These waves can be reflected, scattered and dithered. Thus, they interfere with telecommunication links and badly affect the quality of radio and TV reception. The effect can be mitigated by the use of cable system or by installing powerful antennas.

6. Safety

Accidents with wind turbines are rare but they do happen, as in other industrial activities. For example, a detached blade or its fragment may be thrown a considerable distance and can harm people and property. However, most wind turbines are located in isolated areas, which make it less likely to cause any damage.

Review Questions

1. What range of wind speed is considered favorable for wind power generation?
2. What do you understand by gust?
3. What principles may be used for measurement of wind speed? What is the standard height for measurement of wind speed?
4. What are the most favorable sites for installing of wind turbines?
5. Explain the major applications of wind power.
6. Derive an expression of energy available in the wind.
7. Sketch the diagram of a HAWT and explain the functions of its main components.
8. Explain various designs of blades of HAWTs and their relative features.
9. What do you understand by teetering of rotor? In what cases it is required?
10. Sketch the diagram of a VAWT and explain the functions of its main components.

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UNIT-III

POWER CONVERTERS AND ANALYSIS OF SOLAR PV SYSTEMS

INTRODUCTION: (Power Converters)

- ✓ Power converters have played an important role in renewable energy systems, particularly solar energy and wind energy.
- ✓ Power converters in power electronics are becoming essential for generating electrical power in various ways.
- ✓ The task of a power converter is to process and control the flow of electrical energy by supplying voltages and currents in a form that is optimally suited for user loads.
- ✓ State-space averaging and linearization provide an elegant solution for the application of widely known linear control techniques to most switching power converters.
- ✓ Generally, in order to provide good performance of the system, the control laws need to be designed, then the discontinuous system needs to be converted to a continuous system.
- ✓ Power converters are essential devices for integrating renewable energy sources into the grid or into standalone systems. They can perform various functions, such as converting the variable voltage and frequency of the renewable generation into a stable and compatible (well matched) output, controlling the power flow and quality, and providing protection and isolation.
- ✓ The main types of power converters used in renewable energy systems:
  Power conversions from ac-dc, dc-dc, dc-ac, and ac-ac

DC-DC converters:

- ✓ DC-DC converters are used to change the voltage level of a direct current (DC) source or load, such as a battery, a solar panel, or a fuel cell.

DC-AC converters:

- ✓ DC-AC converters, also known as inverters, are used to convert a DC source into an alternating current (AC) output, such as a grid or a local load. They can also control the frequency, phase, and amplitude of the output voltage and current.

- ✓ DC-AC converters can be classified into two categories: voltage source inverters (VSI) and current source inverters (CSI). VSI use a DC voltage source and a capacitor to generate an AC output, while CSI use a DC current source and an inductor to do the same. VSI are more widely used in renewable energy systems, as they can provide a better output quality, a wider voltage range, and a simpler control.

AC-DC converters:

- ✓ AC-DC converters, also known as rectifiers, are used to convert an AC source into a DC output, such as a battery charger or a DC bus.
- ✓ They can also control the power factor, the harmonic distortion, and the input current of the AC source.
- ✓ AC-DC converters can be classified into two categories: Uncontrolled and controlled.
- ✓ Uncontrolled converters use diodes to rectify the AC input, while controlled converters use switches, such as thyristors or transistors, to modulate the input voltage and current.

AC-AC converters:

- ✓ AC-AC converters are used to change the voltage, frequency, or phase of an AC source or load, such as a variable speed drive or a frequency converter.
- ✓ They can also control the power flow and quality between two AC systems.
- ✓ **AC-AC converters** can be **classified** into two categories: **direct and indirect.**
- ✓ **Direct converters** use switches to modify the input waveform directly, while indirect converters use a DC link and two stages of conversion (AC-DC and DC-AC) to achieve the same. Direct converters are simpler and faster, but they can cause more harmonic distortion and lower output quality.
- ✓ **Indirect converters** can offer a smoother and more flexible output, but they are more complex and less efficient.

Examples of applications:

- ✓ Power converters can be used in various renewable energy systems, such as solar photovoltaic (PV) systems, wind turbine systems, and hybrid systems.

- ✓ **DC-DC converters** can boost or buck the output voltage of PV modules, track the maximum power point, and connect them in series or parallel.

- ✓ **DC-AC converters** can invert the DC output of the PV array into an AC output that can be fed into the grid or a local load.

- ✓ For wind turbine systems, DC-AC converters can convert the DC output of the wind generator into an AC output that can be synchronized with the grid or a local load.

- ✓ **AC-DC converters** can charge a battery or a super capacitor to store excess or intermittent power from the wind generator.

- ✓ **AC-AC converters** can control the speed and torque of the wind generator to optimize power extraction and reduce mechanical stress.

- ✓ Power converters can also be used to combine different renewable energy sources into a single system that can supply reliable and stable power to the grid or a standalone load.

- ✓ Additionally, power converters can integrate energy storage devices such as batteries, flywheels, or fuel cells to improve power quality, reliability, and efficiency.

Line commutated converters (inversion-mode):

- ✓ The line commutated converter (LCC) is matured (developed) technology which is used for power conversion.

- ✓ The LCC is tied to a grid in which commutation of power devices (SCR) is achieved by grid voltage.

- ✓ Line commutated converter (LCC) still widely used for high power conversion. Conventional HVDC system has two converters operate one in rectification and another in an inversion mode.

- ✓ **Line Commutated Inverter** is an inverter that is tied to a power grid or line. The commutation of power (conversion from direct current to alternating current) is controlled by the power line

- ✓ The line commutated converter (LCC) in an inverter mode is proposed for interfacing of solar photovoltaic (PV) array and ac grid.

- ✓ LCC operates in an inversion mode named as line commutated inverter (LCI) at a firing angle greater than 90° i.e. line commutated inverter (LCI) and is used for interfacing dc voltage of PV to ac grid like a receiving end of HVDC links an ac source voltage.

- ✓ Commutation of thyristors (Thyristor also called SCR stands for Silicon Controlled Rectifier. It is a semiconductor switching device, with two power terminals, called the anode (A) and cathode (K) and one control terminal called the gate (G)) takes place due to ac source voltage. The firing angle and PV voltage decides amount of power injected in ac grid.

Configuration of the proposed grid-connected photovoltaic array using LCI.

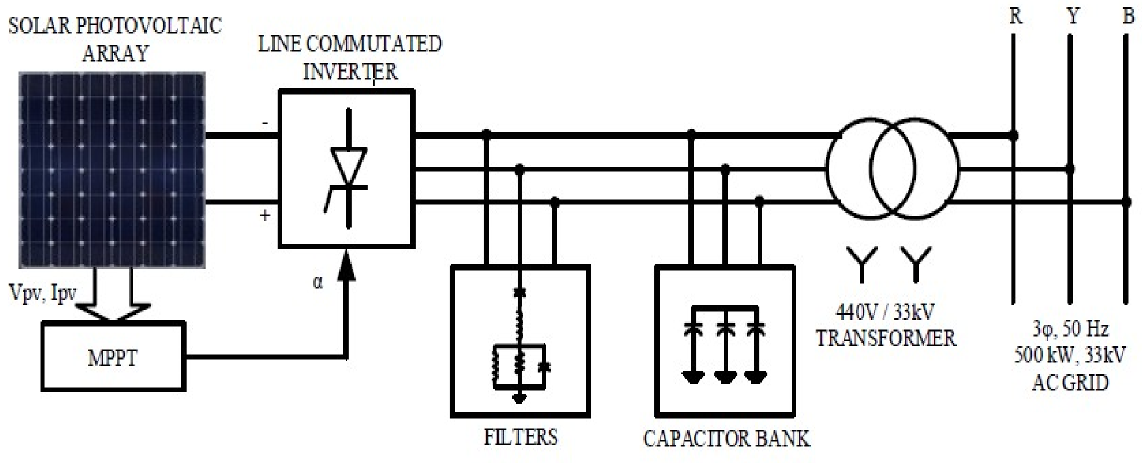


Fig: Grid-connected photovoltaic array using LCI.

Configuration of the proposed grid-connected photovoltaic (PV) array using LCI is shown in Fig.
Simple scheme employing a three phase LCI has been planned for interfacing solar PV array with the three phase utility grid.
This topology does not require to make and maintain the synchronism between converter and ac grid. In addition, it follows maximum power point tracking (MPPT) of solar PV array by changing the firing angle.
The LCC is operated in an inversion mode named as line commutated inverter (LCI) at a firing angle of 156º.

The PV array is designed to supply 500 kW power to ac grid, on the basis of that number of PV panels connected in series as well as in parallel are calculated to achieve the desired power rating.

Ac line current is highly reach with odd harmonics. However, triplen harmonics are absent in three phase system, double tuned filters are used to eliminate harmonics of the order of 5th, 7th, 11th, 13th, 17th, and 19th from the ac source current.

These filters also provide reactive power up to certain extent. Additional shunt capacitor bank is connected to satisfy requirement for reactive power compensation. Three phase 440 V/33 kV star-star transformer is used to step up voltage level at grid.

Boost and buck-boost converters:

- ✓ There are three basic types of dc-dc converter circuits, termed as buck, boost and buck-boost.

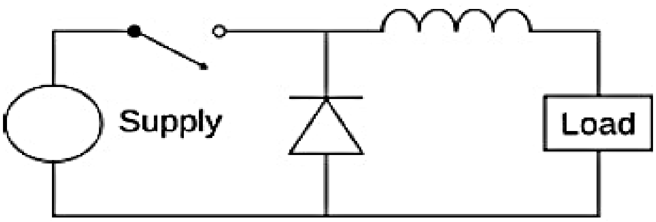
- ✓ In all of these circuits, a power device is used as a switch.

- ✓ Various DC-DC converters which can be utilized for solar photovoltaic systems are:

- **Buck converter** which decreases the input voltage without change in power.
- **Boost converter** which increases the input voltage without change in power.
- **Buck-boost converter**, which can either increase or decrease the input voltage without change in power.

DC-DC Buck Converter

A buck converter (step-down converter) is a DC-to-DC power converter which steps down voltage (while stepping up current) from its input (supply) to its output (load). It is a class of switched-mode power supply (SMPS) typically containing at least two semi-conductors and at least one energy storage element, a capacitor, inductor, or the two in combination. To reduce voltage ripple, filters made of capacitors (sometimes in combination with inductors) are normally added to such a converter's output (load-side filter) and input (supply-side filter).

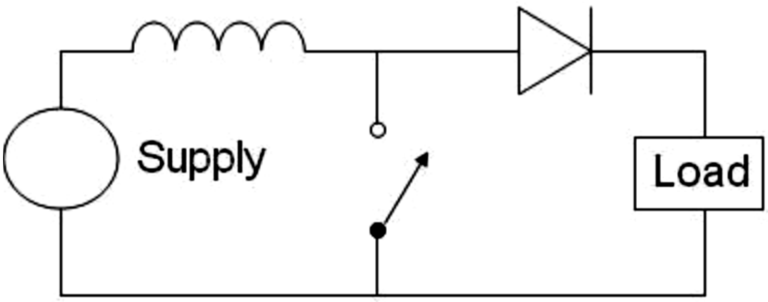


Buck converter circuit diagram.

The basic operation of the buck converter has the current in an inductor controlled by two switches. In the idealized converter, all the components are considered to be perfect. Specifically, the switch and the diode have zero voltage drop when on and zero current flow when off, and the inductor has zero series resistance.

DC-DC Boost Converters

A boost converter (step-up converter) is a DC-to-DC power converter that steps up voltage (while stepping down current) from its input (supply) to its output (load). It is a class of switched-mode power supply (SMPS) containing at least two semiconductors (a diode and a transistor) and at least one energy storage element: a capacitor, inductor, or the two in combination. To reduce voltage ripple, filters made of capacitors (sometimes in combination with inductors) are normally added to such a converter's output (load-side filter) and input (supply-side filter).

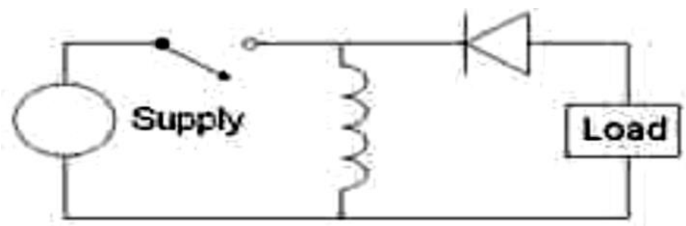


Basic schematic of a boost converter

The key principle that drives the boost converter is the tendency of an inductor to resist changes in current by creating and destroying a magnetic field. In a boost converter, the output voltage is always higher than the input voltage. When the switch is closed, current flows through the inductor in clockwise direction and the inductor stores some energy by generating a magnetic field. Polarity of the left side of the inductor is positive. When the switch is opened, current will be reduced as the impedance is higher. The magnetic field previously created will be destroyed to maintain the current towards the load. Thus the polarity will be reversed (means left side of inductor will be negative now). As a result, two sources will be in series causing a higher voltage to charge the capacitor through the diode D.

DC-DC Buck-Boost Converters

A Buck-Boost converter is a type of switched mode power supply that combines the principles of the Buck Converter and the Boost converter in a single circuit. Like other SMPS designs, it provides a regulated DC output voltage from either an AC or a DC input.



Buck-Boost Converters

It is equivalent to a fly-back using a single inductor instead of a transformer. Two different topologies are called buck–boost converter. Both of them can produce a range of output voltages, ranging from much larger (in absolute magnitude) than the input voltage, do wn to almost zero.

Modes of Buck Boost Converters

There are two different types of modes in the buck boost converter. The following are the two different types of buck boost converters.

- Continuous conduction mode.
- Discontinuous conduction mode.

Continuous Conduction Mode

In the continuous conduction mode the current from end to end of inductor never goes to zero. Hence the inductor partially discharges earlier than the switching cycle.

Discontinuous Conduction Mode

In this mode the current through the inductor goes to zero. Hence the inductor will totally discharge at the end of switching cycles.

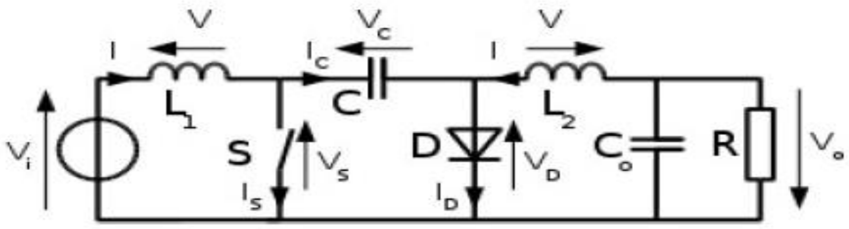
Applications of Buck boost converter

- It is used in the self regulating power supplies.
- It has consumer electronics.
- It is used in the Battery power systems.
- Power amplifier applications.

Advantages of Buck Boost Converter

- It gives higher output voltage.
- Low operating duct cycle.

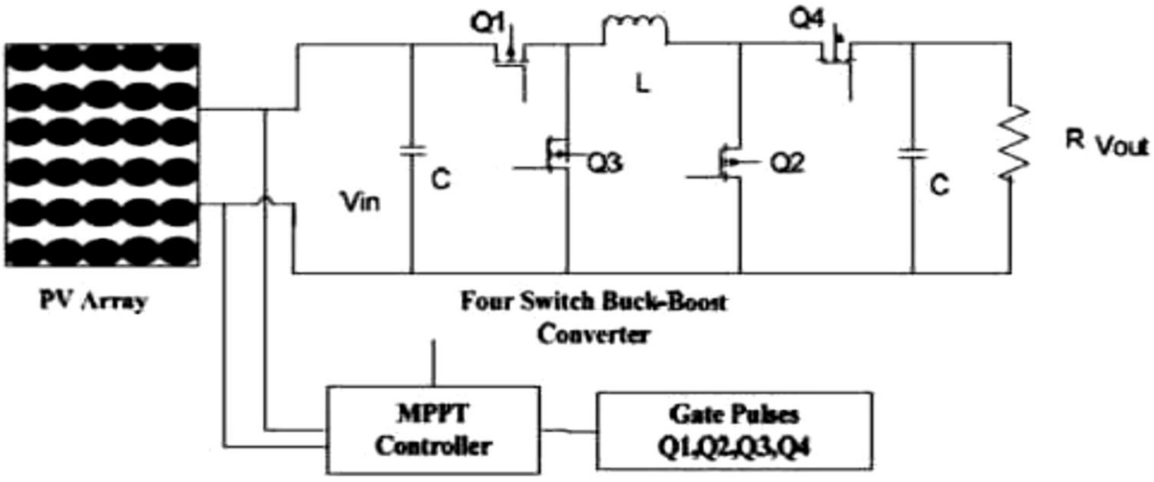
Cuk converter



Schematic of a non-isolated Cuk converter

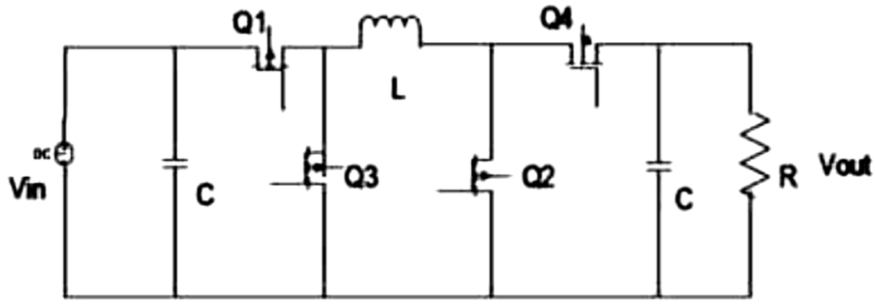
The Cuk converter is a type of DC/DC converter that has an output voltage magnitude that is either greater than or less than the input voltage magnitude. It is essentially a boost converter followed by a buck converter with a capacitor to couple the energy. Similar to the buck–boost converter with inverting topology, the output voltage of non-isolated Cuk is typically also inverting, and can be lower or higher than the input. It uses a capacitor as its main energy-storage component, unlike most other types of converters which use an inductor. There are variations on the basic Cuk converter. For example, the coils may share single magnetic core, which drops the output ripple, and adds efficiency. Because the power transfer flows continuously via the capacitor, this type of switcher has minimized EMI radiation. The Cuk converter allows energy to flow bi-directionally by using a diode and a switch.

PV fed Buck Boost Converter (Four switched topology)

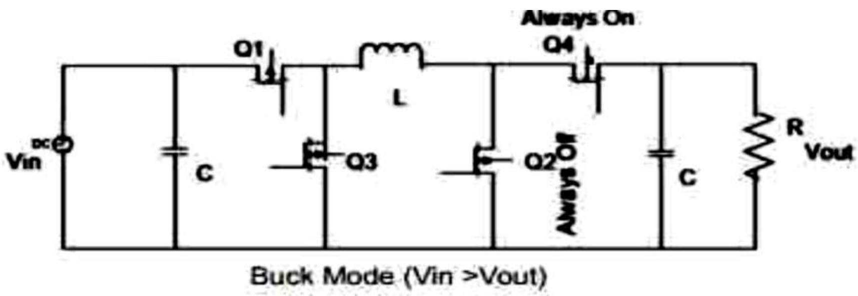


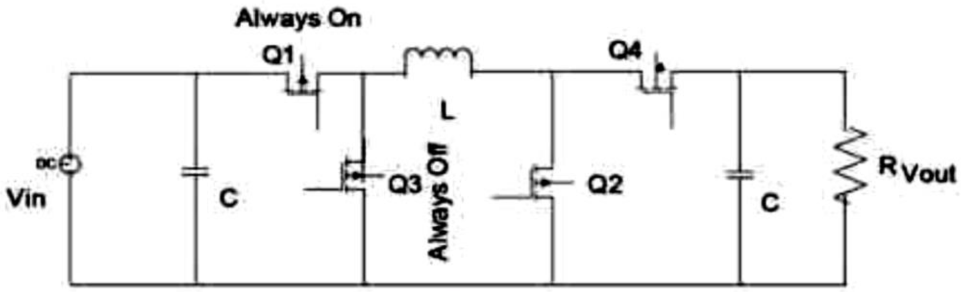
Four-switch power converter is cascaded combination of Buck converter followed by a Boost converter the converter is different from the other DC-DC converters why, because it has four switches to be controlled, that is, two gate pulses we need. This means for the same working point with different values both gate pulses can be used. Furthermore, due to its simple and cascaded combination of Buck-Boost structure, it presents high adaptability and high performance to system voltage changes.

The configuration of the system consists of the Solar PV array fed to FSBB Converter which feeds the Load. It is a combination of Buck converter followed by Boost converter; a four switch buck-boost converter can operate in buck mode or boost mode rather than conventional buck-boost converter. As such, its efficiency can be improved by synchronous rectification the power stage consist of four switches (Q1, Q2, Q3, and Q4), single inductor (L), and input and output Capacitors.



Four-switch buck-boost converter.





Boost Mode (Vin < Vout)

Equivalent circuit in Buck/Boost mode

Here the MOSFETs Q3,Q4 share the gate control signal, which is complementary to the gate control signal of MOSFETs Q1 and Q2, In the buck-boost mode the MOSFETs Q1 and Q2 share gate control signals and turn on and off simultaneously. When the MOSFETs Q1 and Q2 are turned on, the input voltage Vin is applied, the inductor L stores the energy, output capacitor supplies the load current entirely.

When Q1 and Q2 are turned off, MOSFETs Q3, Q4 are turned on in this stage the energy is transferred from the inductor to output load and capacitor. Here we are using a synchronous rectification scheme these means we are using MOSFETs instead of diodes to reduce the switching and power losses and to improve efficiency. The Figure shows the equivalent circuit of the converter in buck and boost mode. When Vin is higher than Vout, The MOSFET Q2 is always OFF, Q4 is always ON, Q1 and Q3 ON and OFF simultaneously thus it works like a buck converter (Vin > Vout) as shown in below figure. When Vin is lower than Vout, Q1 is always ON and Q3 is always OFF, Q2 and Q4 ON and OFF simultaneously it works as a boost converter (Vin
< Vout) as shown in below figure.

Current regulated PWM inverters

Current regulation technique plays the most important role in Current Regulated PWM (CR-PWM) inverters which are widely applied in ac motor drives, ac power supply and active filters. The CR-PWM inverters, also known as current mode PWM inverters, implement an on line current feedback (closed loop) type of PWM. In comparison to a conventional feed forward (open loop) voltage controlled PWM inverters they show following advantages: - control of instantaneous peak current, - overload problem is avoided, - pulse drop problem does not occur,
- extremely good dynamics, - nearly sinusoidal current waveforms, expect for the harmonics - compensation of the effect of load parameter changes (resistance and reactance). The basic problem involved in the implementation of CR-PWM inverters is the choice of suitable current regulation strategy, which affects both the parameters obtained. The main task of the control system in CR-PWM inverter is to force the current vector in the three phase load according to the reference trajectory.

Analysis: Block diagram of the solar PV systems

Once the PV array is controlled to perform efficiently, a number of other components are required to control, convert, distribute, and store the energy produced by the array.
Such components may vary depending on the functional and operational requirements of the system. They may require battery banks and controller, dc–ac inverters, in addition to other components such as overcurrent, surge protection and, other processing equipment.

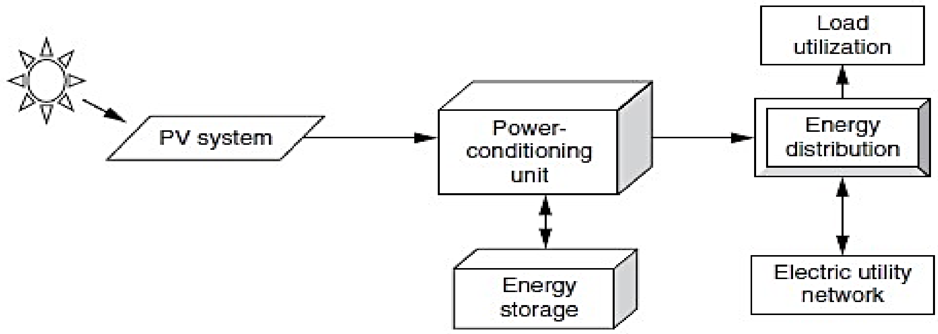


Figure (a) Major photovoltaic system components

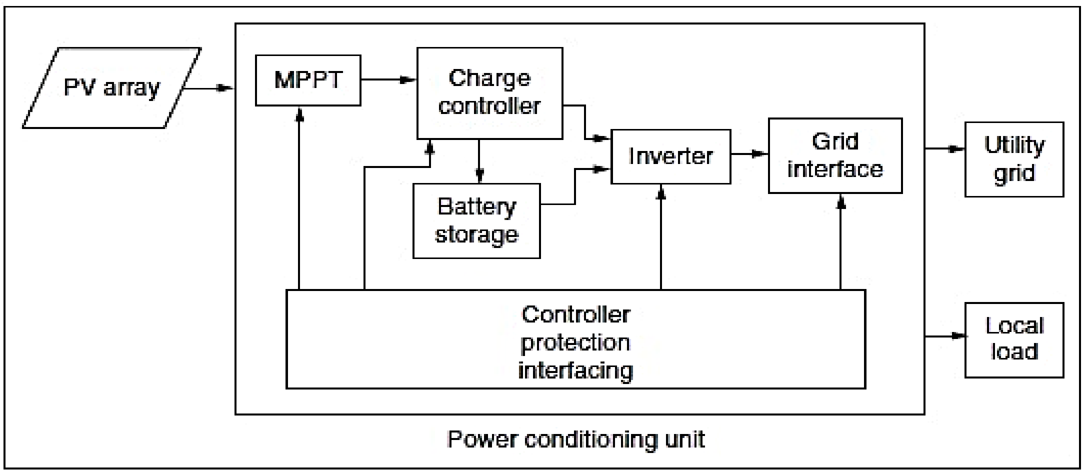


Figure (b) Grid-Connected PV system.

Grid-connected photovoltaic systems are composed of PV arrays connected to the grid through a power conditioning unit and are designed to operate in parallel with the electric utility grid as shown in Fig. (b).

The power conditioning unit may include the MPPT, the inverter, the grid interface as well as the control system needed for efficient system performance.

The major component in both systems is the DC-AC inverter or also called the power conditioning unit (PCU). The inverter is the key to the successful operation of the system, but it is also the most complex hardware. The inverter requirements include operation over a wide range of voltages and currents and regulated output voltage and frequency while providing AC power with good power quality which includes low total harmonic distortion and high power factor, in addition to highest possible efficiency for all solar irradiance levels.

Types of Solar PV Systems:

Photovoltaic power systems can be classified as:

- **Stand-alone PV systems.**
- **Hybrid PV systems.**
- **Grid-connected (integrated) solar PV systems.**

Stand-alone PV systems, shown in Figure 1, are used in remote areas with no access to a utility grid.

Stand-alone photovoltaic systems are usually a utility power alternate. They generally include solar charging modules, storage batteries, and controls or regulators as shown in Figurs-1.

Ground or roof-mounted systems will require a mounting structure, and if ac power is desired, an inverter is also required.

In many stand-alone PV systems, batteries are used for energy storage as they may account for up to 40% of the overall stand-alone PV system cost over its lifetime These batteries cause losses in the PV system due to limited availability of time and energy to recharge the battery in addition to the insufficient battery maintenance.

Hence, a charge controller is then used to control the system and prevent the battery from overcharging and over discharging. Overcharging shortens the battery life and may cause gassing while undercharging may lead to sulphation and stratification, which result in the reduction in battery effectiveness and lifetime.

Batteries are often used in PV systems for storing energy produced by the PV array during daytime and supplying it to electrical loads as needed (during night time or cloudy weather).

Nearly, most of the batteries used in PV systems are deep cycle lead-acid batteries. These batteries have thicker lead plates that make them tolerate deep discharges. The thicker the lead plates, the longer the life span of the batteries. The heavier the battery for a given group size, the thicker the plates and the better the battery will tolerate deep discharges.

All deep cycle batteries are rated in ampere-hour (AH) capacity, a quantity of the amount of usable energy it can store at nominal voltage. A good charge rate is approximately 10% of the total capacity of the battery per hour. This will reduce the electrolyte losses and the damage to the plates.

A PV system may have to be sized to store a sufficient amount of power in the batteries to meet power demand during several days of cloudy weather, known as "days of autonomy."

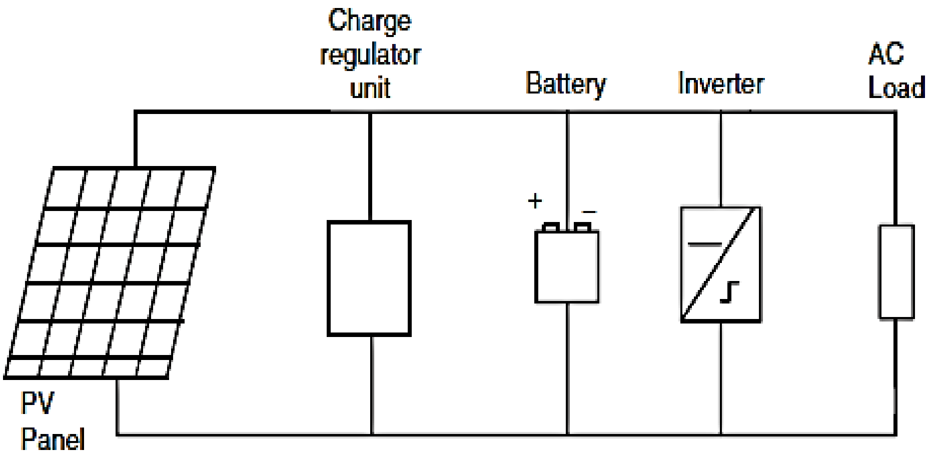


Figure – 1 Stand-alone PV system.

Conventional power systems used in remote areas often based on manually controlled diesel generators operating continuously or for a few hours. Extended operation of diesel generators at low load levels significantly increases maintenance costs and reduces their useful life.

Renewable energy sources such as PV can be added to remote area power systems using diesel and other fossil fuel powered generators to provide 24-hour power economically and efficiently. Such systems are called "hybrid energy systems" Figure 2 shows a schematic of a PV-diesel hybrid system.

In grid-connected PV systems shown in Figure 3, PV panels are connected to a grid through inverters without battery storage.

These systems can be classified as small systems like the residential rooftop systems or large grid-connected systems.

The grid-interactive inverters must be synchronized with the grid in terms of voltage and frequency.

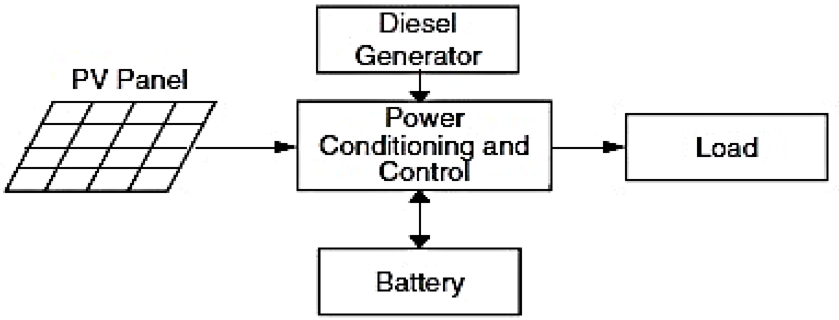


Figure – 2 PV-diesel hybrid systems.

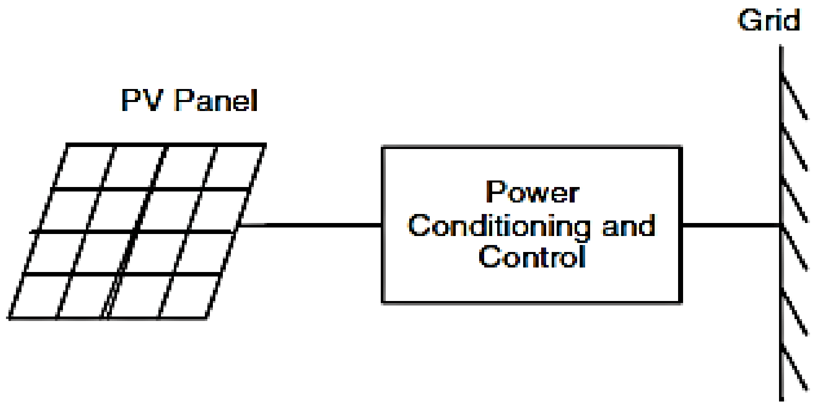


Figure – 3 Grid-connected PV systems.

Stand-alone PV Systems

The two main stand-alone PV applications are:

• Battery charging.

• Solar water pumping.

Battery Charging

Batteries for PV Systems; Stand-alone PV energy system requires storage to meet the energy demand during periods of low solar irradiation and night time.

Several types of batteries are available such as the lead acid, nickel–cadmium, lithium, zinc bromide, zinc chloride, sodium sulfur, nickel–hydrogen, redox, and vanadium batteries.

The provision of cost-effective electrical energy storage remains one of the major challenges for the development of improved PV power systems.

Typically, lead-acid batteries are used to guarantee several hours to a few days of energy storage.

Their reasonable cost and general availability has resulted in the widespread application of lead-acid batteries for remote area power supplies despite their limited lifetime compared to other system components.

Lead-acid batteries can be deep or shallow cycling gelled batteries, batteries with captive or liquid electrolyte, sealed and non-sealed batteries etc. Sealed batteries are valve regulated to permit evolution of excess hydrogen gas (although catalytic converters are used to convert as much evolved hydrogen and oxygen back to water as possible). Sealed batteries need less maintenance.

The following factors are considered in the selection of batteries for PV applications:

- Deep discharge (70–80% depth of discharge).
- Low charging/discharging current.
- Long duration charge (slow) and discharge (long duty cycle).
- Irregular and varying charge/discharge.
- Low self-discharge.
- Long life time.
- Less maintenance requirement.
- High energy storage efficiency.
- Low cost.

PV Charge Controllers

Blocking diodes in series with PV modules are used to prevent the batteries from being discharged through the PV cells at night when there is no sun available to generate energy. These blocking diodes also protect the battery from short circuits. In a solar power system consisting of more than one string connected in parallel, if a short circuit occurs in one of the strings, the blocking diode prevents the other PV strings to discharge through the short circuited string.

The battery storage in a PV system should be properly controlled to avoid catastrophic operating conditions like overcharging or frequent deep discharging. Storage batteries account for most PV system failures and contribute significantly to both the initial and the eventual replacement costs.

Charge controllers regulate the charge transfer and prevent the battery from being excessively charged and discharged.

Three types of charge controllers are commonly used:

- **Series Charge Regulators.**
- **Shunt Charge Regulators.**
- **DC–DC Converters.**

Series Charge Regulators;

The basic circuit for the series regulators is given in Figure 4. In the series charge controller, the switch S1 disconnects the PV generator when a predefined battery voltage is achieved. When the voltage reduces below the discharge limit, the load is disconnected from the battery to avoid deep discharge beyond the limit. The main problem associated with this type of controller is the losses associated with the switches. This extra power loss has to come from the PV power and this can be quite significant.

Bipolar transistors, metal oxide semiconductor field effect transistors (MOSFETs), or relays are used as the switches.

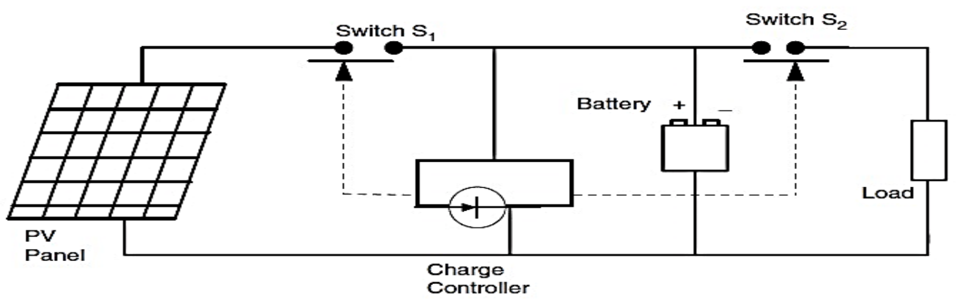


Figure – 4 Series charge regulator.

Shunt Charge Regulators;

In this type, as illustrated in Figure – 5, when the battery is fully charged the PV generator is short-circuited using an electronic switch (S1).

Unlike series controllers, this method works more efficiently even when the battery is completely discharged as the short-circuit switch need not be activated until the battery is fully discharged. The blocking diode prevents short-circuiting of the battery. Shunt-charge regulators are used for the small PV applications (less than 20 A).

Deep discharge protection is used to protect the battery against the deep discharge. When the battery voltage reaches below the minimum set point for deep discharge limit, switch S2 disconnects the load.

Simple series and shunt regulators allow only relatively coarse adjustment of the current flow and seldom meet the exact requirements of PV systems.

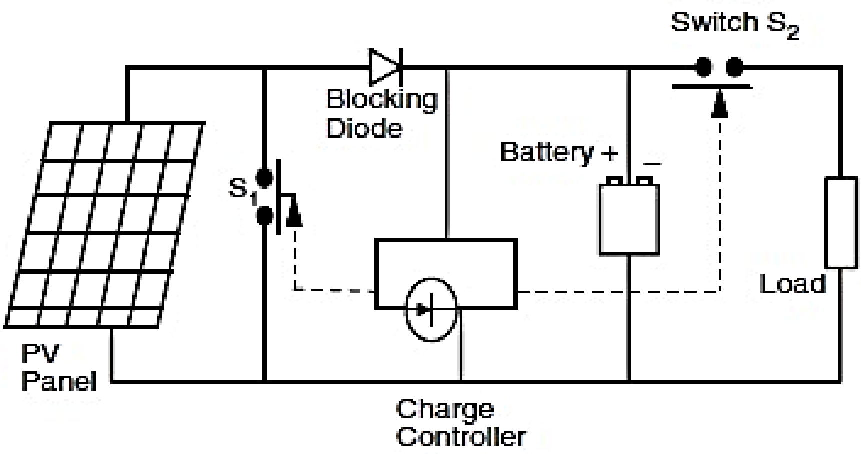


Figure – 5 Shunt charge regulator.

DC–DC Converter Type Charge Regulators

Switch mode DC-to-DC converters are used to match the output of a PV generator to a variable load. There are various types of DC–DC converters such as:

• Buck (step-down) converter.

• Boost (step-up) converter.

• Buck–boost (step-down/up) converter.

Figures 6-8 show simplified diagrams of these three basic types converters. The basic concepts are an electronic switch, an inductor to store energy, and a “flywheel” diode, which carries the current during that part of switching cycle when the switch is off.

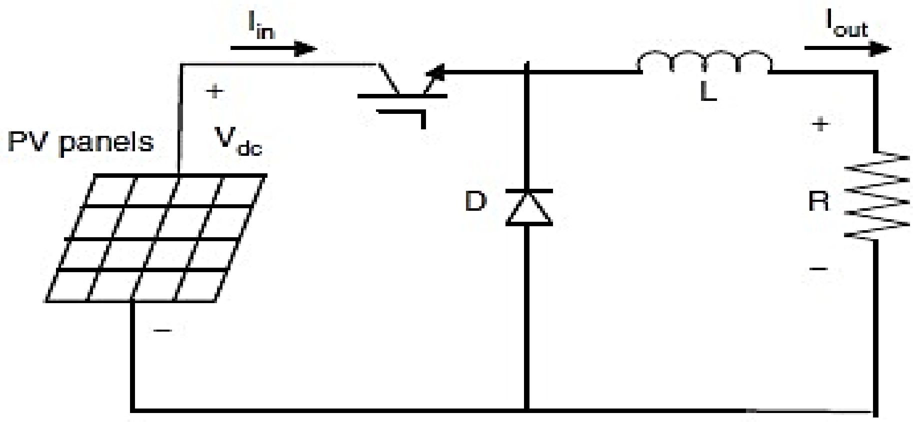


Figure – 6 Buck converter.

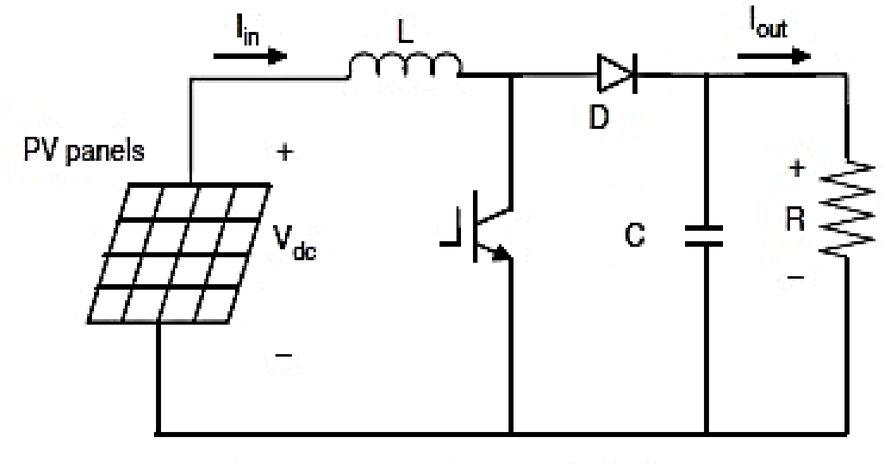


Figure – 7 Boost Converter.

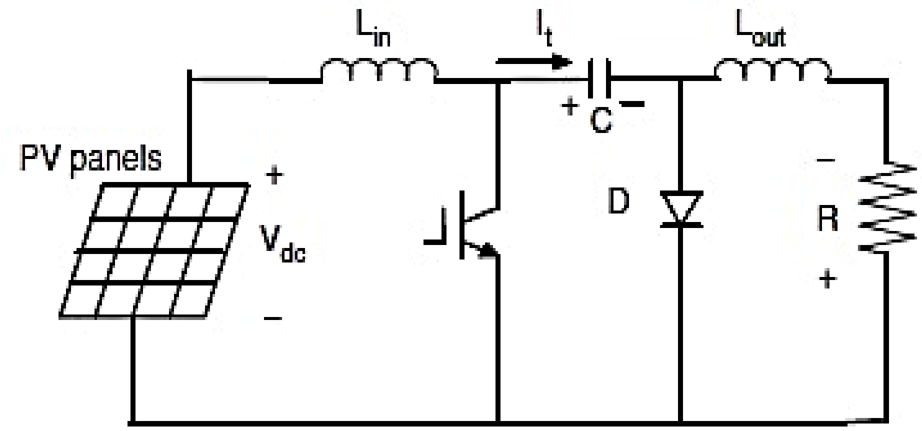


Figure – 8 Boost–buck Converter.

The DC–DC converters allow the charge current to be reduced continuously in such a way that the resulting battery voltage is maintained at a specified value.

Solar water pumping

In many remote and rural areas, hand pumps or diesel driven pumps are used for water supply. Diesel pumps consume fossil fuel, affects environment, needs more maintenance, and are less reliable. Photovoltaic powered water pumps have received considerable attention recently due to major developments in the field of solar cell materials and power electronic systems technology.

Types of Pumps Two types of pumps are commonly used for the water pumping applications: positive and centrifugal displacement. Both centrifugal and positive displacement pumps can be further classified into those with motors that are (a) surface mounted and those which are

(b) Submerged into the water ("submersible").

Displacement pumps have water output directly proportional to the speed of the pump, but, almost independent of head. These pumps are used for solar water pumping from deep wells or bores. They may be piston type pumps, or use diaphragm driven by a cam, rotary screw type, or use progressive cavity system.

The pumping rate of these pumps is directly related to the speed and hence constant torque is desired. Centrifugal pumps are used for low-head applications especially if they are directly interfaced with the solar panels.

Centrifugal pumps are designed for fixed-head applications and the pressure difference generated increases in relation to the speed of pump. These pumps are rotating impeller type, which throws the water radially against a casing, so shaped that the momentum of the water is converted into useful pressure for lifting.

The centrifugal pumps have relatively high efficiency but it reduces at lower speeds, which can be a problem for the solar water pumping system at the time of low light levels. The single-stage centrifugal pump has just one impeller whereas most borehole pumps are multistage types where the outlet from one impeller goes into the center of another and each one keeps increasing the pressure difference.

From Fig. 9, it is quite obvious that the load line is located relatively faraway from *Pmax* line. It has been reported that the daily utilization efficiency for a DC motor drive is 87% for a centrifugal pump compared to 57% for a constant torque characteristics load. Hence, centrifugal pumps are more compatible with PV arrays. The system operating point is determined by the intersection of the *I–V* characteristics of the PV array and the motor as shown in Fig. 9.

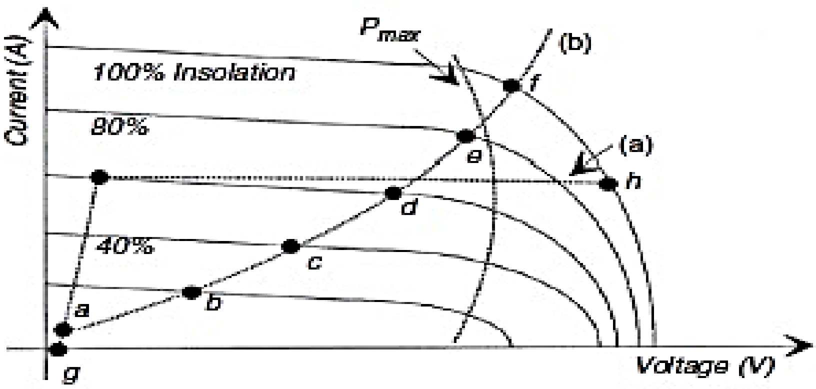


Figure - 9 *I–V* characteristics of a PV array and two mechanical loads: (a) constant torque and (b) centrifugal pump.

The torque speed slope is normally large due to the armature resistance being small. At the instant of starting, the speed and the back emf are zero.

Hence the motor starting current is approximately the short-circuit current of the PV array. By matching the load to the PV source through MPPT, the starting torque increases.

The matching of a DC motor depends upon the type of load being used. For instance, a centrifugal pump is characterized by having the load torque proportional to the square of speed.

The operating characteristics of the system (i.e. PV source, permanent magnet (PM) DC motor and load) are at the intersection of the motor and load characteristics as shown in Fig.10 (i.e. points a, b, c, d, e, and f for centrifugal pump).

From Fig. 10, the system utilizing the centrifugal pump as its load tends to start at low solar irradiation (point a) level.

However, for the systems with an almost constant torque characteristics in Fig. 9, the start is at almost 50% of one sun (full insolation) which results in short period of operation.

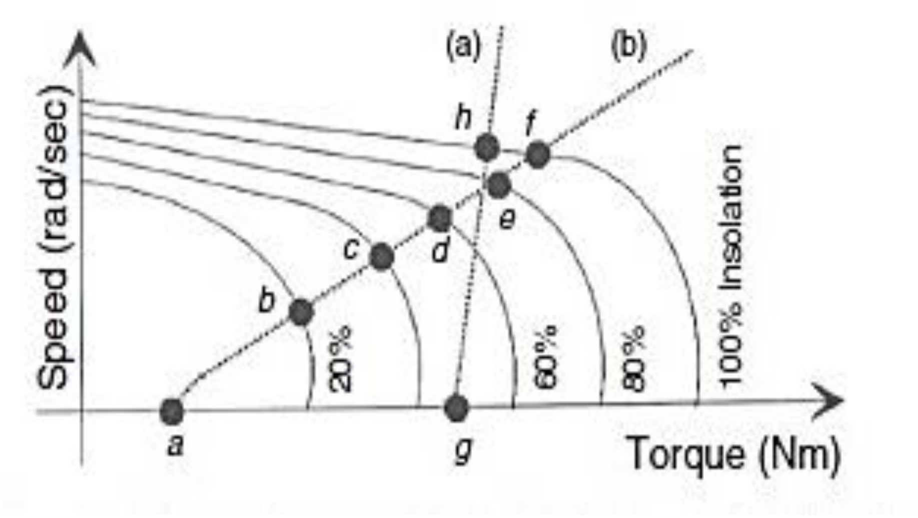


Figure - 10 Speed torque characteristics of a DC motor and two mechanical loads: (a) helical rotor and (b) centrifugal pump.

Types of Motors

There are various types of motors available for the PV water pumping applications:

• DC motors.

• AC motors.

DC motors are preferred where direct coupling to PV panels is desired whereas AC motors are coupled to the solar panels through inverters. AC motors in general are cheaper than the

DC motors and is more reliable but the DC motors are more efficient. The DC motors used for solar pumping applications are:

• Permanent magnet DC motors with brushes.

In DC motors with the brushes, the brushes are used to deliver power to the commutator and need frequent replacement due to wear and tear. These motors are not suitable for submersible applications unless long transmission shafts are used. Brush-less DC permanent magnet motors have been developed for submersible applications.

The AC motors are of the induction motor type, which is cheaper than DC motors and available, worldwide.

However, they need inverters to change DC input from PV to AC power.

A comparison of the different types of motors used for PV water pumping is given in Table.

Types of motor	Advantages	Disadvantages	Main features
Brushed DC	Simple and efficient for PV applications. No complex control circuit is required as the motor starts without high current surge. These motors will run slowly but do not overheat with reduced voltage.	Brushes need to be replaced periodically (typical replacement interval is 2000–4000 hr or 2 years).	Requires MPPT for optimum performance. Available only in small motor sizes. Increasing current (by paralleling PV modules) increases the torque. Increasing voltage (by series PV modules) increases the speed.
Brush-less DC	Efficient. Less maintenance is required.	Electronic computation adds to extra cost, complexity, and increased risk of failure/malfunction. In most cases, oil cooled, can’t be submerged as deep as water cooled AC units.	Growing trend among PV pump manufacturers to use brush-less DC motors, primarily for centrifugal type submersible pumps.
AC induction Motors	No brushes to replace. Can use existing AC motor/pump technology which is cheaper and easily available worldwide. These motors can handle larger pumping requirements.	Needs an inverter to convert DC output from PV to AC adding additional cost and complexity. Less efficient than DC motor-pump units. Prone to overheating if current is not adequate to start the motor or if the voltage is too low.	Available for single or three supply. Inverters are designed to regulate frequency to maximize power to the motor in response to changing insolation levels.

Grid Connection (Integration) Issues in Solar PV Plant

Introduction

Solar-grid integration is a network allowing substantial penetration of Photovoltaic (PV) power into the national utility grid. This is an important technology as the integration of standardized PV systems into grids optimizes the building energy balance, improves the economics of the PV system, reduces operational costs, and provides added value to the consumer and the utility, Solar-grid integration is now a common practice in many countries of the world; as there is a growing demand for use of alternative clean energy as against fossil fuel

The main advantage of a grid connected PV system is its simplicity, relatively low operating and maintenance costs as well as reduced electricity bills. The disadvantage however is that a sufficient number of solar panels need to be installed to generate the required amount of excess power

Major Issues Grid integration on Solar PV Plant

- Voltage fluctuation and regulation
- Short circuit contribution
- Unintentional islanding
- Frequency variation and regulation
- Harmonics & Flickers
- Reactive power Requirement

Voltage fluctuation and regulation

It is considered that electricity is distributed at the consumer's terminal within the tolerable limit. The normal allowable voltage range is ±5% of the nominal value.

Voltage fluctuation in low voltage grid is caused by rapid fluctuation of PV system power output due to cloud transients. This becomes more significant with high penetration of PV systems. These voltage fluctuations may lead to violation of the existing power quality standards. The magnitude of the voltage fluctuations is dependent on the location in the grid, the installed PV capacity and the grid configuration. Voltage fluctuations and flicker can cause damage to electrical appliances connected to the grid and light flicker can cause annoyance and health problems to people exposed to it.

Short circuit contribution

- Identification of fault current contribution by the RES to the grid
- To ascertain the fault level at grid connection point and within the Solar PV plant is within the short circuit rating
- Rated equipment to be used to withstand the maximum subtransient three phase symmetrical short circuit fault levels
- Introduction of the proposed Solar PV plant does not cause the fault levels of Transmission substations should not exceed the short circuit breaker rating.

Unintentional Islanding

(Unintentional islanding refers to the potential for a portion of the distribution system to continue to run even when the larger power system is disconnected by a protection device.)

- PV is becoming pervasive, but there are vital safety considerations that need to be adhered to - and tested thoroughly.
- Islanding of photovoltaic systems is a phenomenon that occurs when the solar inverter and a connected load are disconnected from the main grid and subsequently form an "island".
- In situations where the load circuit inside such an island resonates at the same frequency as the utility grid itself, the solar inverter may not detect the disconnection from the grid, and will continue to power the island.
- It occurs when PV plant delivers power to the network even after circuit breakers have disconnected from main grid.
- This effect can be used intentionally to provide a power back-up system for buildings that normally sell their power to the grid. However, for photovoltaic systems dedicated to supplying power to the grid, this effect is unwanted, and can potentially lead to an unsafe situation and damage to equipment.
- Grid inverter technology has developed to include anti-islanding features as per local regulations and standards.

Frequency variation and regulation

- The frequency of a power system must be preserved near to its nominal value (either 50 Hz or 60 Hz based on the grid). The frequency deviations will only arise when there is a mismatch between generation and load. A stiff power system preserves the frequency subsequent to a contingency even

- The frequency of the power system is maintained at the nominal value only when the active power of generation and demand is balanced

- If the demand is more than the generation, then the frequency decreases from the nominal value. In the case of surplus generation, the system frequency increases.

- As the penetration level of RES increases, the frequency deviations are more frequent. As these RES are connected to the grid through a power electronic inverter, substituting the conventional SG with power electronic inverters will decrease the inertia of the power system.

- To handle the frequency stability issues raised from the low inertia and reserve power, new frequency control techniques need Energies to be employed for RES to participate in a frequency regulation process.

Harmonics & Flickers

- Injection of harmonics lead over heating of equipment's and insulation failures for transformer, cables, switchgears etc.

- The power quality terms and conditions the solar power plant must meet to be eligible to connect to distribution system are as follows: allowed flickers, allowed harmonics currents, voltage fluctuations due to the simultaneous connection and disconnection of the plant, as well as the voltage variation at steady state.

- Photovoltaic power plants contribution to the flicker level in the medium voltage energy network. Connecting them to the energy grid may cause frequency variations or fast voltage variations (flicker), significant problems in terms of power quality

- Effects of flicker depending on the appearing frequency, voltage fluctuations can have the following consequences for electricity distribution networks: visible changes in light output of lighting sources, a visual discomfort sensation (flicker effect), TV image distortion and faults in radios and electronic installations operation.

- Flicker measurement is performed using a flicker-meter. This instrument measures the voltage fluctuation level and simulates both the response of the light source and the reaction of the human eye.

Reactive power Requirement

- Should evaluate the reactive power capability of the PV plant and should check whether PV plant is providing sufficient reactive support according to grid code requirements at the interconnection point.

- Vary the PU Voltage at point of common coupling (PCC) to determine the reactive power required to meet the grid code requirements and identify if additional compensation is required to achieve this

- Poor power factor-increases line losses & makes voltage regulation more difficult.

- Voltage-regulating mode provide power factor correction.

Unit- IV

POWER CONVERTERS FOR WIND SYSTEMS

Introduction

- In rural USA, the first wind mill was commissioned in 1890 to generate electricity.
- At this generation cost, wind energy has become one of the least cost power sources.

Main factors that have contributed to the wind power technology development are:

- High strength fiber composites for manufacturing large low-cost blades.
- Variable speed operation of wind generators to capture maximum energy.
- Advancement in power electronics and associated cost.
- Improved plant operation and efficiency.
- Economy of scale due to availability of large wind generation plants.
- Accumulated field experience improving the capacity factor.

- The technical advancement in power electronics is playing an important part in the development of wind power technology.
- The contribution of power electronics in control of fixed speed/variable speed wind turbines and interfacing to the grid is of extreme importance.
- Because of the fluctuating nature of wind speed, the power quality and reliability of the wind-based power system needs to be evaluated in detail. Appropriate control schemes require power conditioning.

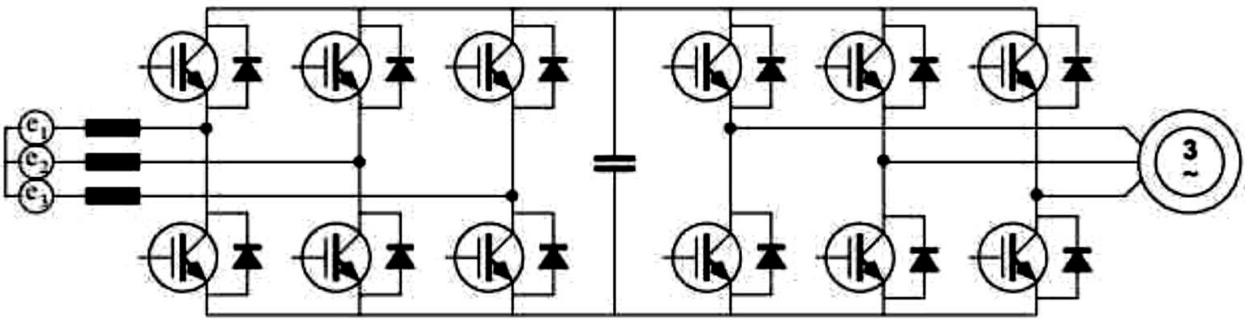
Power Electronic Conditioner (Power Converter)

- The power electronic conditioner is a converter that is mainly used in variable speed applications.
- This converter is connected between the generator machine and the utility grid by an isolating transformer and permits different frequency and voltage levels in its input and output.
- The power converter is connected to the stator voltage or to the rotor of a wound rotor machine.
- This system includes large power switches that can be GTOs, Thyristors, IGCTs, or IGBTs arranged in different topologies.

THREE PHASE AC-DC-AC CONVERTERS (THE BACK-TO-BACK CONVERTER)

The back-to-back converter is consists simply of a force-commutated rectifier and a force-commutated inverter connected with a common dc-link shown in figure. The properties of this combination are well known; the line-side converter may be operated to give sinusoidal line currents, for sinusoidal currents, the dc-link voltage must be higher than the peak main voltage, the dc-link voltage is regulated by controlling the power flow to the ac grid and, finally, the inverter operates on the boosted dc-link, making it possible to increase the output power of a connected machine over its rated power. Another advantage in certain applications is that braking energy can be fed back to the power grid instead of just wasting it in a braking resistor.

An important property of the back-to-back converter is the possibility of fast control of the power flow. By controlling the power flow to the grid, the dc-link voltage can be held constant. The presence of a fast control loop for the dc-link voltage makes it possible to reduce the size of the dc-link capacitor, without affecting inverter performance. In fact, the capacitor can be made small enough to be implemented with plastic film capacitors.



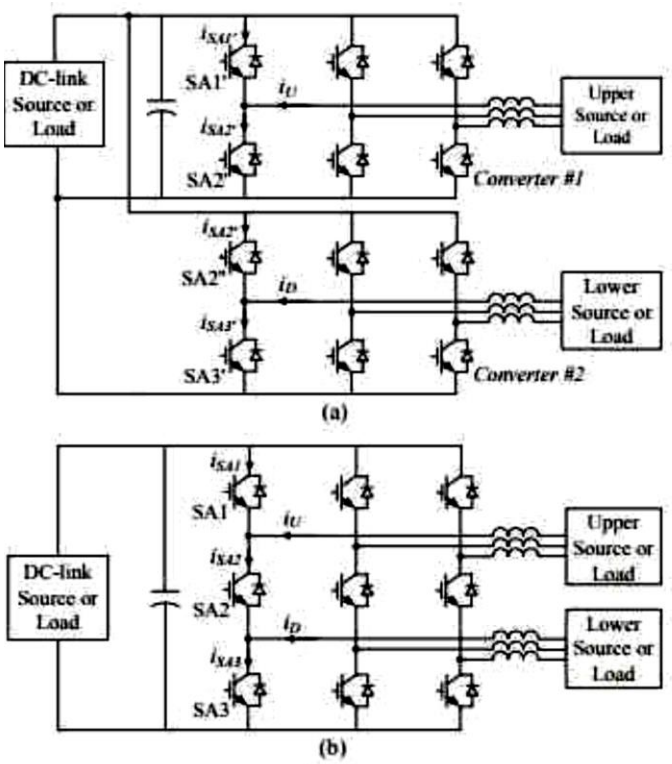
Back-to-back converter

Issues associated with a small DC-link capacitor

Smallest size of the dc-link capacitor is governed by the need to keep the switch-frequent ripple at acceptable (i.e. small) levels. Fluctuations in the load cannot be smoothed in the converter, but must be accommodated by other means. One alternative is to simply transfer such fluctuations to the power grid, but this may re-introduce the line-current harmonics the back to back converter is supposed to eliminate. However, load fluctuations will be random and thus relatively harmless compared to the in-phase harmonics generated by diode rectifiers. Another alternative is to use the load itself. In a typical drive, the mechanical energy stored in the drive is several orders of magnitude larger than the electrical energy stored in the DC-link capacitor in a back-to-back converter. If the application does not need servo-class performance, there is no reason why the rotational speed cannot be allowed to fluctuate slightly.

Application criteria for three-phase nine-switch converters

The nine-switch topology is derived from two converters connected back-to-back (BTB) shown in figure. Two phase legs from converter 1 and 2, respectively, are merged together to compose one phase leg of the nine switch converter, and meanwhile one switch is dismissed. Thus nine-switch converters have only three phase legs and each of them has only three switches.



Nine-switch power converters

With such a topology, nine-switch converters retain the DC-link and can achieve all the functions of twelve-switch BTB even with three switches less.

Electrical/Power Electronics**:** The general configuration is shown in the Fig. 1.

- It consists of the following components:
    - Wind generator.
    - Rectifier.
    - Inverter.

The generator may be:

- DC, synchronous (wound rotor or permanent magnet type)
- squirrel-cage wound rotor, or brushless doubly-fed induction generator.

- The rectifier is used to convert the variable voltage variable frequency input to a DC voltage.
- This DC voltage is converted into AC of constant voltage and frequency of desired amplitude.
- The inverter will also be used to control the active/reactive power flow from the inverter.
- In case of DC generator, the converter may not be required or when a cycloconverter is used to convert the AC directly from one frequency to another.

Types of Generator Options for Variable Speed Wind Turbines Using Power Electronics

Power electronics may be applied to four types of generators to facilitate variable speed operation:

- Synchronous generators.
- Permanent magnet synchronous generators.
- Squirrel-cage induction generators.
- Wound rotor induction generators.
- Doubly Fed Induction Generator.

Synchronous Generator

- In this configuration, the synchronous generator is allowed to run at variable speed, producing power of variable voltage and frequency.
- Control may be facilitated by adjusting an externally supplied field current.
- The most common type of power conversion uses a bridge rectifier (controlled/uncontrolled), a DC link, and inverter as shown in Fig.1.

Uncontrolled Rectifiers: Provide a fixed d.c. output voltage for a given a.c. supply where diodes are used only.

Controlled Rectifiers: Provide an adjustable d.c. output voltage by controlling the phase at which the devices are turned on, where thyristors and diodes are used.

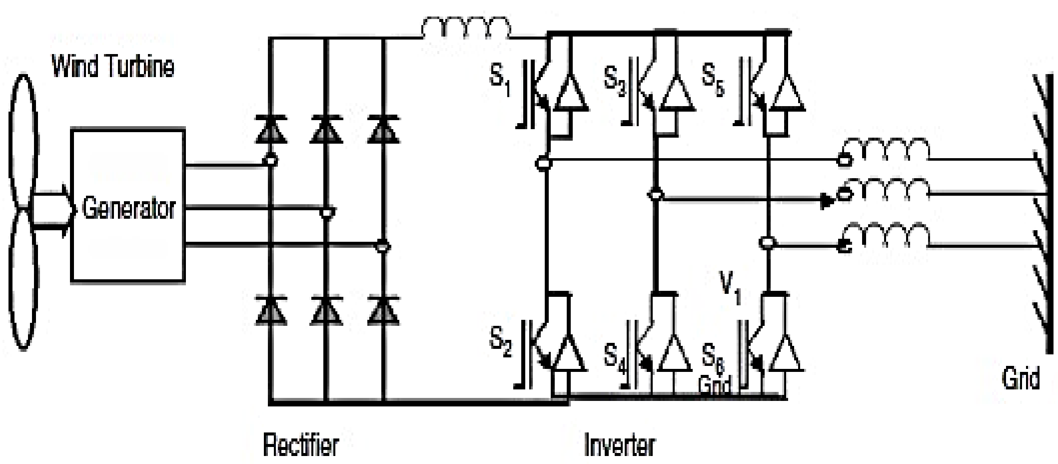


Fig. 1. Grid-connected wind energy system through AC/DC/AC converter.

- The wind turbine directly connected to a generator is referred to as the Direct-Drive concept.
- One advantage of the Direct-Drive concept is the removal of the losses associated to the gearbox.
- Power AC-DC-AC converter system is preferred to transform the energy compatible (well-matched) to the grid in Direct-Drive wind turbines application.

OPERATION PRINCIPLE OF WIND TURBINE POWER CONVERTER

- The power **AC-DC-AC** converter for MW-Level wind turbine grid interface can be separated into two units:
    - One is AC-DC unit that is a diode bridge rectifier with a multiple boost converter.
    - The other is DC-AC unit that is a dual IGBT inverter.

- The electricity generated from the synchronous generator is a variable frequency and variable voltage electricity value, which is altering with the wind speed.

- The diode bridge rectifier is used to transform the variable frequency and variable voltage electricity into a DC power.

- The optimal operating voltage and current for different wind speeds for a rectifier with no DC-DC converter will leads to very large DC link voltage fluctuations, which is unsuitable for the inverter. A Boost converter is then proposed with necessity.

- The boost converter adopts multiple structure, consisting of three boost converters in parallel, which reduces the rating value of the power devices and harmonics content, simultaneity arises the voltage level and keeps it nearly constant over whole wind speed to provide suitable electricity for the following dual VSI.

- Once the AC voltage from a synchronous generator into DC voltage, this power must be converted into AC again, and fed to the utility grid.

- The frequency, voltage and current of the obtained AC waveforms must be compatible (well-matched) with the grid.

Disadvantage

- The disadvantage of this configuration include the relatively high cost and maintenance requirements of synchronous generators and the need for the power conversion system to take the full power generated (as opposed to the wound rotor system).

Permanent Magnet Synchronous Generators

- The permanent magnet synchronous generator (PMSG) has several significant advantageous properties.
- The construction is simple and does not required external magnetization, which is important especially in stand-alone wind power applications and also in remote areas where the grid cannot easily supply the reactive power required to magnetize the induction generator.
- power conversion uses a bridge rectifier (controlled/uncontrolled), a DC link, and inverter as shown in Fig. 2.

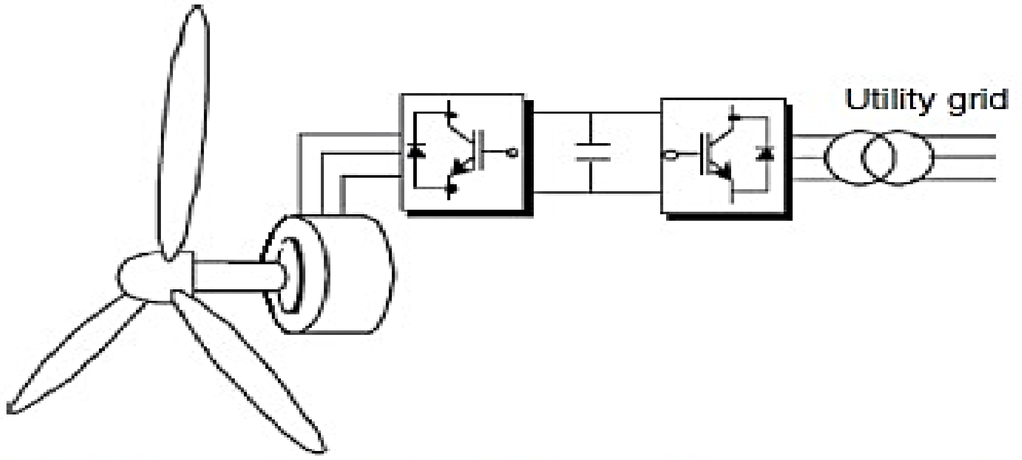


FIGURE. 2. Grid-connected PMSG wind energy system through DC/AC converter.

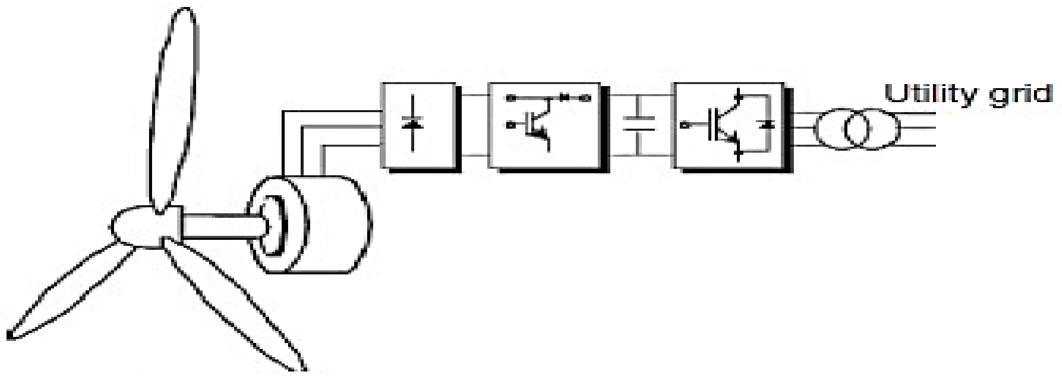


FIGURE. 3. Grid-connected PMSG wind energy system through DC/AC converter with a boost chopper.

- Figure 3 shows a wind energy system where a PMSG is connected to a three-phase rectifier followed by a boost converter.
- In this case, the boost converter controls the electromagnet torque and the supply side converter regulates the DC link voltage as well as controlling the input power factor.

- To extract maximum power at unity power factor from a PMSG and feed this power (also at unity power factor) to the grid, the use of back-to-back connected PWM voltage source converters are proposed.
- Moreover, to reduce the overall cost, reduced switch PWM voltage source converters (four switch) instead of conventional (six switch) converters for variable speed drive systems can be used.
- It is shown that by using both rectifier and inverter current control or flux based control, it is possible to obtain unity power factor operation both at the WTG and the grid.
- Other mechanisms can also be included to maximize power extraction from the VSWT (i.e. MPPT techniques) or sensor-less approaches to further reduce cost and increase reliability and performance of the systems.

Advantages:

- The advantage of the system in Fig. 2 with regardant to the system showed in Fig. 3 is, it allows the generator to operate near its optimal working point in order to minimize the losses in the generator and power electronic circuit. However, the performance is dependent on the good knowledge of the generator parameter that varies with temperature and frequency.

Drawback:

- One drawback of this configuration is the use of diode rectifier that increases the current amplitude and distortion of the PMSG. As a result, this configuration have been considered for small size wind energy conversion systems (smaller than 50kW).
- The main drawbacks, in the use of PMSG, are the cost of permanent magnet that increase the price of machine, demagnetization of the permanent magnet material, and it is not possible to control the power factor of the machine.

Squirrel-cage Induction Generator

- Possible architecture for systems using conventional induction generators which have a solid squirrel-cage rotor have many similarities to those with synchronous generators.
- The main difference is that the induction generator is not inherently self-exciting and it needs a source of reactive power. This could be done by a generator side self-commutated converter operating in the rectifier mode.
- A significant advantage of this configuration is the low cost and low maintenance requirements of induction generators. Another advantage of using the self-commutated double converter is that it can be on the ground, completely separate from the wind machine. If there is a problem in the converter, it could be switched out of the circuit for repair and the wind

machine could continue to run at constant speed. The main disadvantage with this configuration is that, as with the synchronous generator, the power conversion system would have to take the full power generated and could be relatively costly compared to some other configurations.

- There would also be additional complexities associated with the supply of reactive power to the generator.

Wound Rotor Induction Generator

A wound rotor induction rotor has three-phase winding on the rotor, accessible to the outside via slip rings. The possibility of accessing the rotor can have the following configurations:

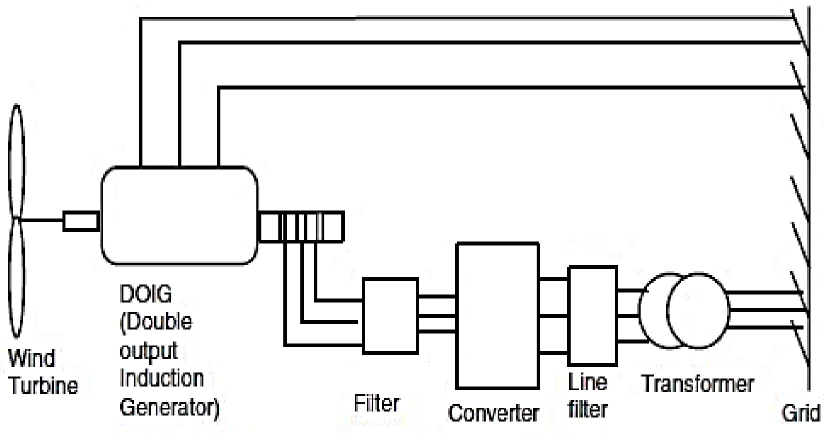
• Slip power recovery.
• Use of cycloconverter.

Slip Power Recovery (Static Kramer System)

The slip power recovery configuration behaves similarly to a conventional induction generator with very large slip, but in addition energy is recovered from the rotor. The rotor power is first carried out through slip rings, then rectified and passed through a DC link to a line-commutated inverter and into the grid. The rest of the power comes directly from the stator as it normally does. A disadvantage with this system is that it can only allow super-synchronous variable speed operation.

In this scheme shown in figure, the stator is directly connected to the grid. Power converter has been connected to the rotor of wound rotor induction generator to obtain the optimum power from variable speed wind turbine. The main advantage of this scheme is that the power-conditioning unit has to handle only a fraction of the total power so as to obtain full control of the generator.

This is very important when the wind turbine sizes are increasing for the grid-connected applications for higher penetration of wind energy and the smaller size of converter can be used in this scheme.



Schematic diagram of doubly-fed induction generator.

Cycloconverter (Static Scherbius System)

A cycloconverter is a converter, which converts AC voltage of one frequency to another frequency without an intermediate DC link. When a cycloconverter is connected to the rotorcircuit, sub- and super-synchronous operation variable speed operation is possible. In super-synchronous operation, this configuration is similar to the slip power recovery.

In addition, energy may be fed into the rotor, thus allowing the machine to generate at sub synchronous speeds. For that reason, the generator is said to be doubly fed. This system has a limited ability to control reactive power at the terminals of the generator, although as a whole it is a net consumer of reactive power. On the other hand, if coupled with capacitor excitation, this capability could be useful from the utility point of view. Because of its ability to rapidly adjust phase angle and magnitude of the terminal voltage, the generator can be resynchronized after a major electrical disturbance without going through a complete stop/start sequence. With some wind turbines, this could be a useful feature.

Doubly Fed Induction Generator

- Wind turbines use a doubly-fed induction generator (DFIG) consisting of a wound rotor induction generator and an AC/DC/AC IGBT-based PWM converter.

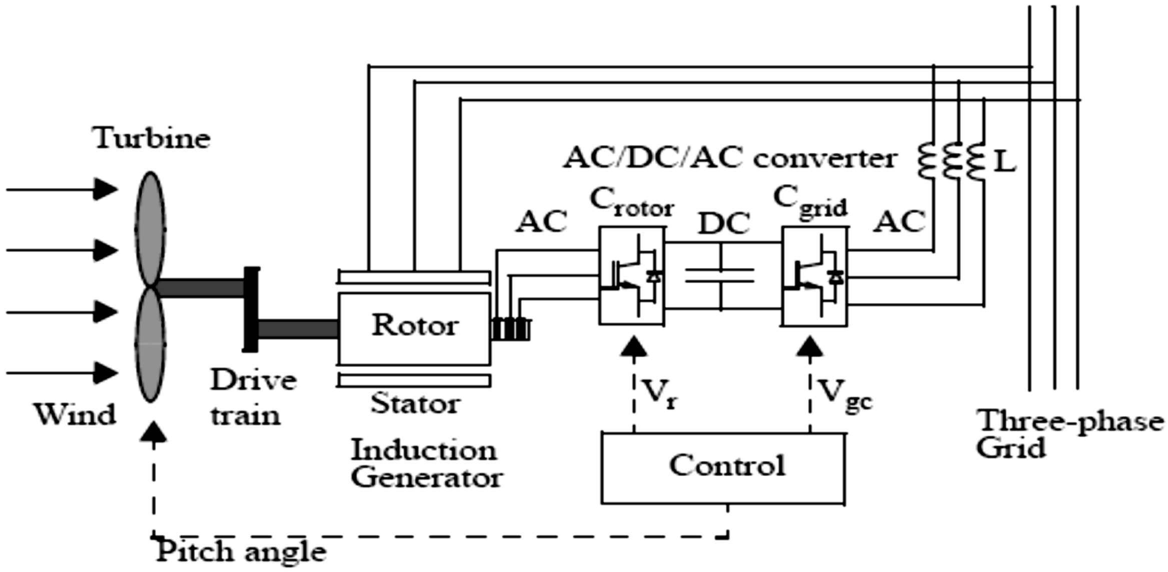


Fig. 4. basic diagram of doubly fed induction generator with converters

- Wind turbines use a doubly-fed induction generator (DFIG) consisting of a wound rotor induction generator and an AC/DC/AC IGBT-based PWM converter.
- The stator winding is connected directly to the 50 Hz grid while the rotor is fed at variable frequency through the AC/DC/AC converter.

- The DFIG technology allows extracting maximum energy from the wind for low wind speeds by optimizing the turbine speed, while minimizing mechanical stresses on the turbine during gusts of wind.
- The optimum turbine speed producing maximum mechanical energy for a given wind speed is proportional to the wind speed.

- Another advantage of the DFIG technology is the ability for power electronic converters to generate or absorb reactive power, thus eliminating the need for installing capacitor banks as in the case of squirrel-cage induction generator.
- Where, Vr is the rotor voltage and Vgc is grid side voltage.
- The AC/DC/AC converter is basically a PWM converter which uses sinusoidal PWM technique to reduce the harmonics present in the wind turbine driven DFIG system.
- Here Crotor is rotor side converter and Cgrid is grid side converter. To control the speed of wind turbine gear boxes or electronic control can be used.

Operating Principle of DFIG

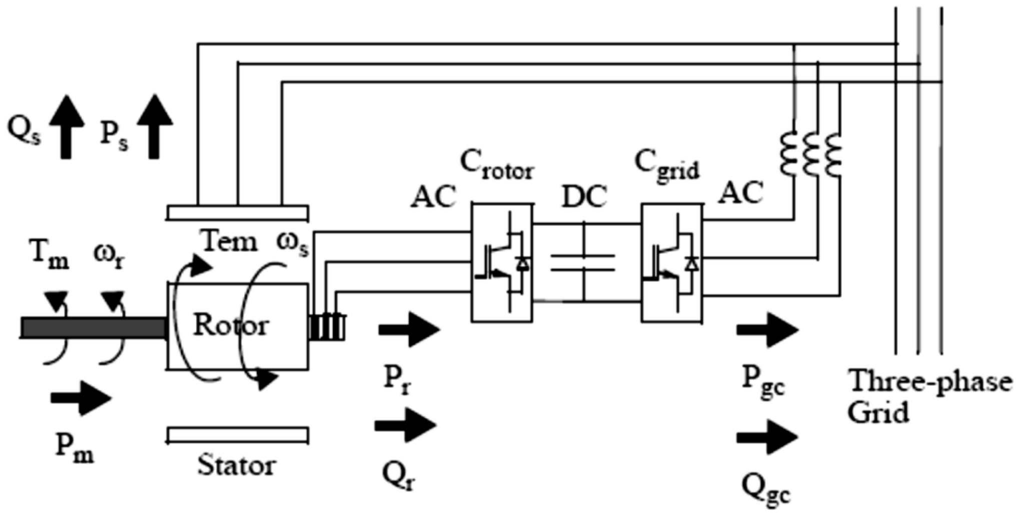


Fig. 5. Power flow diagram of DFIG

Pm → Mechanical power captured by the wind turbine and transmitted to the rotor

Tm → Mechanical torque applied to rotor

ω_r → Rotational speed of rotors

Tem → Electromagnetic torque applied to the rotor by the generator

ω_s → Rotational speed of the magnetic flux in the air-gap of the generator, this speed is named synchronous speed. It is proportional to the frequency of the grid voltage and to the number of generator poles

Qs→ Stator reactive power output

Ps→ Stator electrical power output

Pr→ Rotor electrical power output

Qr→ Rotor reactive power output

Pgc → Cgrid electrical power output

Qgc → Cgrid reactive power output

- The stator is directly connected to the AC mains, whilst the wound rotor is fed from the Power Electronics Converter via slip rings to allow DIFG to operate at a variety of speeds in response to changing wind speed.
- Indeed, the basic concept is to interpose a frequency converter between the variable frequency induction generator and fixed frequency grid.
- The DC capacitor linking stator- and rotor-side converters allows the storage of power from induction generator for further generation.
- To achieve full control of grid current, the DC-link voltage must be boosted to a level higher than the amplitude of grid line-to-line voltage.
- The slip power can flow in both directions, i.e. to the rotor from the supply and from supply to the rotor and hence the speed of the machine can be controlled from either rotor- or stator-side converter in both super and sub-synchronous speed ranges. As a result, the machine can be controlled as a generator or a motor in both super and sub-synchronous operating modes realizing four operating modes.
- Below the synchronous speed in the motoring mode and above the synchronous speed in the generating mode, rotor-side converter operates as a rectifier and stator-side converter as an inverter, where slip power is returned to the stator.
- Below the synchronous speed in the generating mode and above the synchronous speed in the motoring mode, rotor-side converter operates as an inverter and stator side converter as a rectifier, where slip power is supplied to the rotor. At the synchronous speed, slip power is taken from supply to excite the rotor windings and in this case machine behaves as a synchronous machine.

The mechanical power and the stator electric power output are computed as follows:

$P_r = Tm * \omega_r$

$P_s = Tem * \omega_s$

For a loss less generator the mechanical equation is:

$J = \frac{d\omega_r}{dt}$ = $T_m - T_{em}$

In steady-state at fixed speed for a loss less generator

$T_m = T_{em}$ and $P_m = P_s + P_r$

and It follows that:

$P_r = P_m - Ps = T_m \omega_r - T_m \omega_s = -sP_s$

Where**,**

$S= \omega_s - \omega_r / \omega_s$

- Generally the absolute value of slip is much lower than 1 and, consequently, Pr is only a fraction of Ps.
- Since Tm is positive for power generation and since ω*s* is positive and constant for a constant frequency grid voltage, the sign of Pr is a function of the slip sign.
- Pr is positive for negative slip (speed greater than synchronous speed) and it is negative for positive slip (speed lower than synchronous speed). For super synchronous speed operation, Pr is transmitted to DC bus capacitor and tends to rise the DC voltage.
- For sub-synchronous speed operation, Pr is taken out of DC bus capacitor and tends to decrease the DC voltage. Cgrid is used to generate or absorb the power Pgc in order to keep the DC voltage constant.
- In steady-state for a lossless AC/DC/AC converter Pgc is equal to Pr and the speed of the wind turbine is determined by the power Pr absorbed or generated by Crotor.
- The phase-sequence of the AC voltage generated by Crotor is positive for sub-synchronous speed and negative for super synchronous speed.
- The frequency of this voltage is equal to the product of the grid frequency and the absolute value of the slip.
- Crotor and Cgrid have the capability for generating or absorbing reactive power and could be used to control the reactive power or the voltage at the grid terminals.

PWM inverters

PWM inverters: normally use power transistors (IGBTs) or GTOs as the switching elements.

- Modern pulse width modulated (PWM) drives convert the three phases AC line voltage to a fixed-level DC voltage.
- They do this regardless of inverter output speed and power.
- The PWM inverters, therefore, provide a constant power factor regardless of the power factor of the load machine.
- Noise and harmonics problems are to be considered when using PWM inverters.

Grid-interactive inverters

The grid-interactive inverters must be synchronized with the grid in terms of voltage and frequency.

Electrical energy obtained from the WES is preferred to transfer to grid instead of storing energy. In order to transfer energy to the grid, many conditions such as fixed-frequency, continuity of electrical energy, sinusoidal-shaped waveform, being balanced of the phase voltages, to be within certain limits of current harmonics must be carried out. In this sense, the grid interactive inverter and its control technique is fairly important.

Electrical energy's transfer, obtained from the wind energy systems, directly to the grid or load is not possible in terms of efficiency and usability. For these reasons, grid interactive inverters are largely used for wind energy systems.

Grid interactive inverters can be either a current source inverter (CSI) or voltage source inverter (VSI). CSI has some superiority such as showing high resistance to short circuits and blocking reverse voltage, VSI are preferred in many applications due to less conduction losses and easier control. Recently, many methods have been recommended for controlling the three-phase grid interactive VSI.

The power that grid interactive inverters transfer to utility grid can be realized as a controlled voltage or current. In grid interactive inverters controlled by voltage, the obligation of monitoring the grid voltage sensitively makes it both difficult to control algorithm and increases the cost of processor required for controlling. In case of not being monitored the grid voltage precisely, if a small synchronization error occurs, grid interactive inverter will be overloaded and so faults will take place. In current controlled grid interactive inverters, since inverter is much less sensitive to this situation, this method is proposed to control in the practices of power transmission to the utility grid. Moreover, while active and reactive power cannot be controlled in voltage controlled inverter, in current controlled mode, active and reactive power can be controlled independently. Because of this reason, current controlled Grid Interactive inverter can operate to unity power factor. Here both current control method is used in order feed the WECS power to grid.

The power converter is capable of changing both its output voltage magnitude and frequency. However, in many applications these two functions are combined into a single converter by the use of the appropriate switching function; e.g. PWM.

By appropriate control of the stator frequency of AC machines, the speed of rotation of the magnetic field in the machine’s air gap and thus output speed of the mechanical drive shaft can be adjusted. As the magnetic flux density in the machine must be kept constant under normal operation, the ratio of motor voltage over stator frequency must be kept constant.

The input power of the majority of VSD systems is obtained from sources with constant frequency (e.g. AC supply grid or AC generator). In order to achieve a variable frequency output energy an AC/AC converter is needed. Some converters achieve direct power conversion from AC/AC without an intermediate step (e.g. cyclo-converters and matrix-converters).

Matrix-converter

The force-commutated cyclo-converter (better known as a matrix-converter) represents possibly the most advanced state of the art at present, enabling a good input and output current waveform, as well as eliminating the DC link components with very little limitation in input to output frequency ratio.

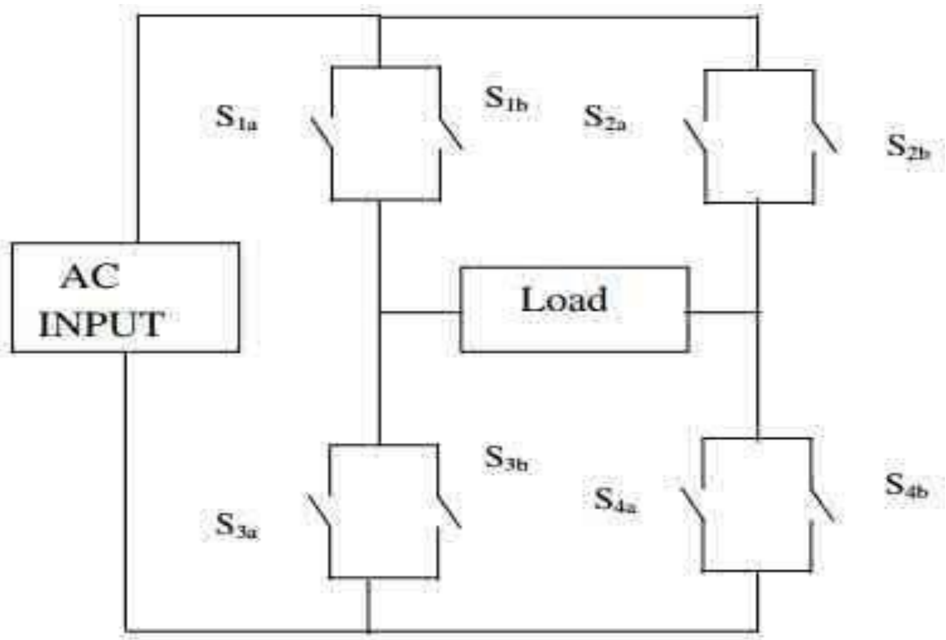
The main advantage of this drive is the ability to convert AC fixed frequency supply input to AC output without DC bus. It is ideal for integrated motor drives with relatively low power ratings.

Major drawbacks include: (a) the increased level of silicon employed (bi-directional switches), (b) its output voltage is always less than its input voltage and (c) complexity of commutation and protection.

Matrix-converters provide direct AC/AC power conversion without an intermediate DC link and the associated reactive components. They have substantial benefits for integrated drives as outlined below:

- Reduced volume due to the absence of DC link components
- Ability to operate at the higher thermal limit imposed by the power devices
- Reduced harmonic input current compared to diode bridge
- Ability to regenerate into the supply without dumping heat in dynamic braking resistors
- Matrix converters have not been commercially exploited because of voltage ratio limitation, device count, and difficulties with current commutation control and circuit protection

Single Phase Matrix Converter

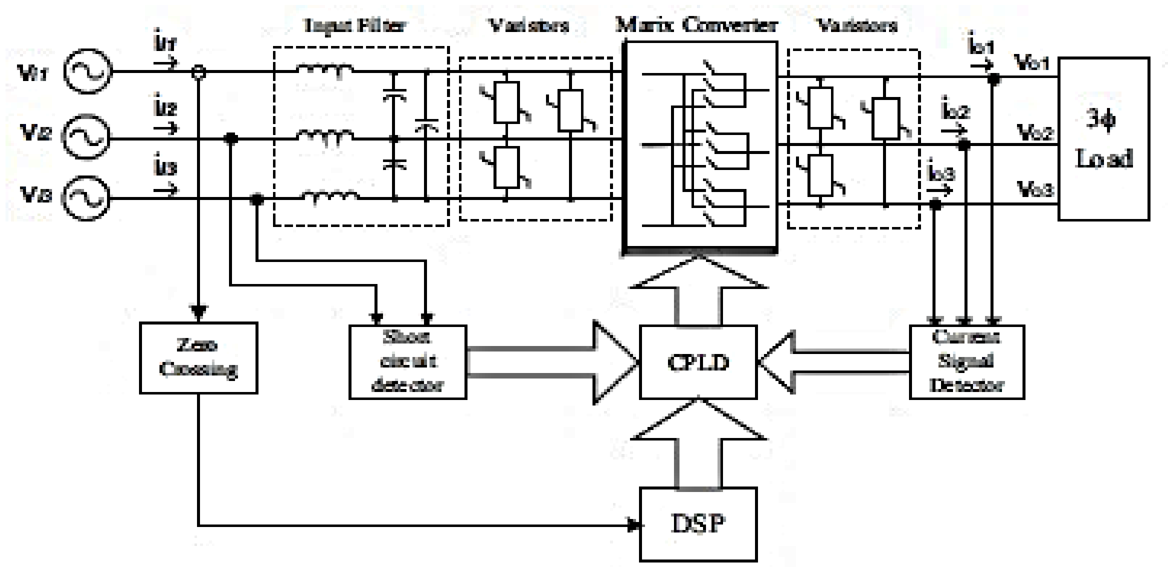


Single Phase Matrix Converter

The AC/AC converter is commonly classified as an indirect converter which utilizes a dc link between the two ac systems and converter that provides direct conversion. This converter consists of two converter stages and energy storage element, which convert input ac to dc and then reconverting dc back to output ac with variable amplitude and frequency. The operation of this converter stages is decoupled on an instantaneous basis by the energy storage elements and controlled independently, so long as the average energy flow is equal. Figure shows the single phase matrix converter switching arrangement.

Three Phase Matrix Converter

Three phase matrix converter consists of nine bidirectional switches. It has been arranged into three groups of three switches. Each group is connected to each phase of the output. These arrangements of switches can connect any input phase. These 3x3 arrangements can have 512 switching states. Among them only 27 switching states are permitted to operate this converter. Here A, B and C are input phase voltage connected to the output phase. Figure shows synchronous operating state vectors of three matrix converter. It shows that the converter switches are switched on rotational basis. In this case no two switches in a leg are switched on simultaneously. These states will not generate gate pulse when one phase of the supply is switched off.



Circuit scheme of a three phase to three phase matrix converter

The matrix converter consists of 9 bi-directional switches that allow any output phase to be connected to any input phase. The input terminals of the converter are connected to a three phase voltage-fed system, usually the grid, while the output terminal are connected to a three phase current-fed system, like an induction motor might be. The capacitive filter on the voltage- fed side and the inductive filter on the current-fed side represented in the scheme are intrinsically necessary. Their size is inversely proportional to the matrix converter switching frequency. It is worth noting that due to its inherent bi-directionality and symmetry a dual connection might be also feasible for the matrix converter: a current-fed system at the input and a voltage-fed system at the output. Taking into account that the converter is supplied by a voltage source and usually feeds an inductive load, the input phases should never be short- circuited and the output currents should not be interrupted. From a practical point of view these rules imply that one and only one bi-directional switch per output phase must be switched on at any instant. By this constraint, in a three phase to three phase matrix converter 27 are the permitted switching combinations.

UNIT V HYBRID RENEWABLE ENERGY SYSTEMS

Hybrid Systems:

A hybrid energy system, or hybrid power, usually consists of two or more renewable energy sources used together to provide increased system efficiency as well as greater balance in energy supply.

A combination of different but complementary energy generation systems based on renewable energies or mixed, is known as a hybrid power system.

Need for hybrid systems:

To meet the load demand during night and cloudy days, battery bank is provided.

During winter, load demand shoots up and solar energy reduces, so designer is compelled to select large size equipment, PV arrays and battery bank.

Similar situation is faced for a stand-alone wind power generating system, when wind speed drops below cut-in speed and Wind Turbine Generator (WTG) stops.

For emergency, loads of hospitals, defense installations and communication services, a backup source (1) diesel generator, (2) gas turbine generator, (3) biogas, (4) small hydro, and (5) fuel cell is required. Two different energy systems installed at a location to ensure continuity of electrical supply is known as hybrid energy system.

Thus, hybrid energy system provides an edge over the stand-alone and even grid interactive systems for reliability of energy supply and lower capital cost.

However, engineer's selection of the backup source is done by maximum capacity of the prime energy source at peak energy demand period.

Advantages of Hybrid Solar Energy Systems

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

Continuous Power Supply

A key advantage of the hybrid solar system over a traditional one is that it delivers continuous power. Because the batteries connected to hybrid solar systems store energy, they provide continuous power without interruption. During power outages, the batteries work as inverters to provide you with backup power for your home and important appliances. When the sun goes down or when there's a power outage, batteries provide backup power to keep things running smoothly.

Utilize the Renewable Sources in the Best Way

Because the batteries are connected to a specially designed system that stores excess solar energy, there is no waste of unused power. So, these systems make use of the renewable energy in the best way, store energy on sunny days and utilize that stored power on cloudy days or at night.

Low Maintenance Cost

Another benefit is the system is cost-effective in the long run. Although the initial cost may be high, you will eventually save money because you will not have to pay for fuel (like you do with generators) and these systems don't require frequent maintenance.

High Efficiency

Unlike traditional generators, which can waste fuel under certain conditions, hybrid solar energy systems work more efficiently and sustainably. Hybrid solar systems generate power efficiently in all types of weather, storing extra energy for later use without wasting fuel.

Load Management

Traditional generators provide high output only when they are turned on. On the other hand, hybrid solar power systems store energy during the day and distribute it at night. A hybrid solar system may have technology that automatically adjusts the energy supply according to the power requirements of specific devices, whether it's an air conditioner or a fan.

Disadvantages of Hybrid Solar Energy Systems

As with many things in life, there can also be some disadvantages to hybrid solar energy systems. Here's a few of them:

Complicated Controlling Process

Because different sources of energy are used, it is helpful to be knowledgeable about those systems. The operation of different energy sources and the interaction between them can become complicated. The great thing is that by working with a trusted contractor, we will handle those complications for you.

High Installation Costs

While the maintenance cost is low, the initial investment for a hybrid solar energy system is higher compared to solar systems alone.

Less Battery Life

Home batteries connected to the system are often exposed to heat, cold or rain, so the system may have a shorter life span. This is less of a challenge if you choose the correct location for installation. (Another reason it's important to work with an experienced installation team!)

RANGE AND TYPE OF HYBRID SYSTEMS

Hybrid System Characteristics

Although hybrid energy systems are open, they can have the characteristics of a closed system if a subsystem with the function of ―monitoring‖ is introduced as a feedback between output (consumer) and input (controller). As inputs of particular hybrid system cannot be changed.

However, the load may be changed. With a backup system as another energy source the system can be designed as a partial closed-loop feedback system. There are various possibly to make combination of different energy sources. Selection of energy source for hybrid system is mainly depends upon availability at the place where it going to stabilized. In general in India solar energy is available almost all the places and infrastructure for power generation is rugged.

Hence need low maintenance so it is smart to choose to have PV one of the energy sources in hybrid system. Wave and tidal energy available only at sea shore and need large capital investment and more maintenance, therefore not compatible for household hybrid system. But can be used in large power hybrid system. Corrosion because of seawater is a major drawback.

Wind energy source is also a good choice but more preferable for open land hybrid system and status of wind throughout the year is also important. India has monsoon climate hence has enough potential of wind energy. Biomass energy is good option but it needs regular feeding to continuously operate. Biomass with grid hybrid system is broadly used in sugar mill in India.

In residential applications, biomass can be used for space heating or for cooking. Businesses and industry use biomass for several purposes including space heating, hot water heating, and electricity generation.

Types of hybrid systems:

PV – Diesel
Wind – PV
Micro hydel – PV
Biomass – Diesel

PV Hybrid with Diesel Generator:

Renewable energy technologies are possible for electrification of remote villages including small hydro, wind, biomass and solar energy, yet solar PV lighting remains the most preferred.

Such systems are used in Orissa, Assam, Sikkim, Jammu and Kashmir, and Uttarakhand.

This power plant contains one PV array with a Diesel electric generator and a battery bank.

Energy generated from PV array feeds load demand and then charges the battery bank.

Diesel generator keeps the battery fully charged and sometime supplies load demand when PV output is not sufficient and battery charge is low to supplement.

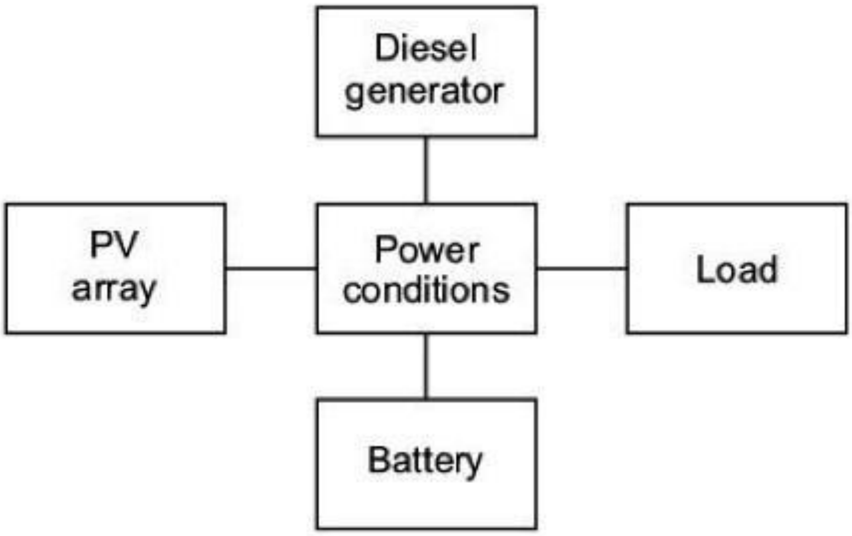


Figure 1 Block diagram of PV – Diesel hybrid power plant.

Figure 1 is a block diagram of such a power plant where Power conditioner performs three functions:

(i) To convert alternating current (ac) diesel generated output into direct current (dc) for charging battery bank.

(ii)To invert direct current (dc) from PV array and battery bank into ac for feeding load.

(iii) To regulate battery current and voltage for input from generator and output for load. Several experiments have been carried out to find where 10 per cent diesel fuel would be required with a given solar PV array area to replace 90 per cent of diesel fuel that would be consumed for a diesel system only. Experimental values have been used to draw a graph.

Figure 2 shows 'life cycle cost' versus array area (10 3 × m2).

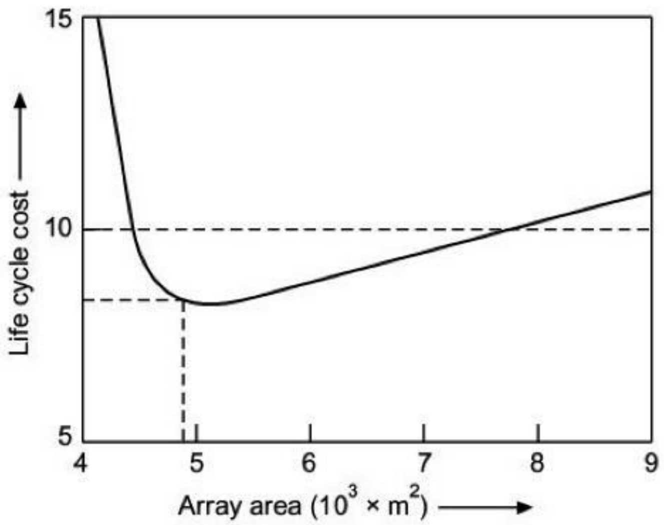


Figure 2 Graph of photo voltaic-diesel system i.e., life cycle cost and array area.

Graph indicates a minimum cost point corresponding to a cost effective design for a PV-diesel hybrid power plant where PV has replaced 90 per cent of the diesel fuel; had it been a diesel system only. Thus, a PV-diesel hybrid power plant ensures continuous power supply and is more cost effective as compared to stand alone PV system or stand-alone diesel.

Wind-PV Hybrid System

Wind and solar hybrid energy systems are located in open terrains away from multistorey buildings and forests. Locations are selected in those areas where the sunshine and wind are favorable for more than 8 months during a year. A schematic wind-PV hybrid system is shown in Figure 5. During the day when sun shines, the solar photovoltaic plant generate dc electric energy conditioner provided, converts dc to ac and supplies power to the load. During favorable wind speed, wind turbine generator produce ac electrical power. It supplies power to the load and excess energy after conversion to dc is stored by the battery bank. The plant may operate as stand-alone load or may be connected to the state grid.

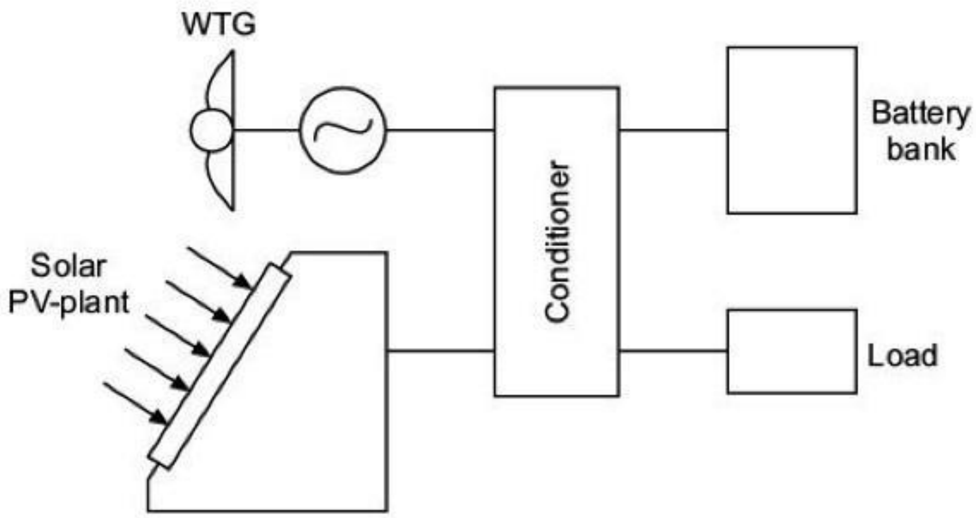
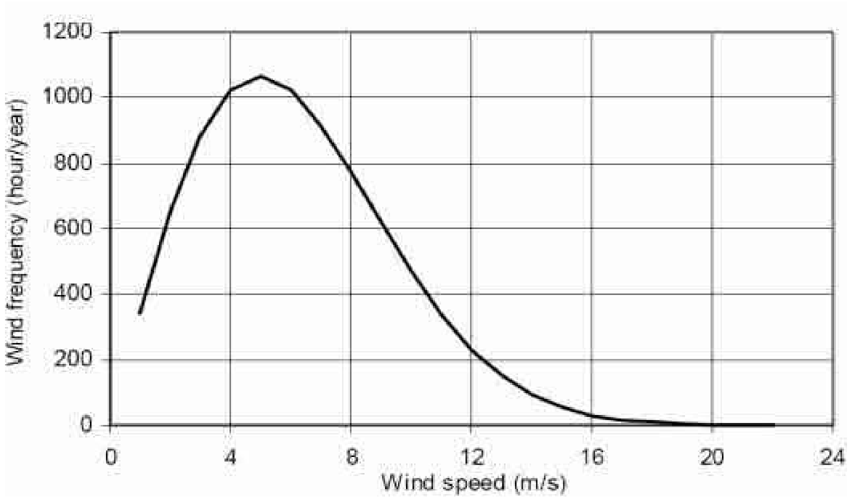


Figure 5 Wind-PV hybrid system.



Micro Hydel-PV Hybrid System

Micro hydel (up to 100 kW) power stations are low head (less than 3 m) installations and provide decentralized power in mountain regions, also in plains on canal falls. In remote areas of J & K, boarder districts of Arunachal Pradesh micro hydro power plants are the only source of energy. With the help of micro hydro power, rural electrification can be achieved besides providing power for pumped irrigation and grinding mills. In Arunachal Pradesh, 425 villages are being electrified by completing 46 small/ micro hydro power projects. However, there are 1058 villages which cannot be illuminated by micro hydel projects as at several locations, head is very low, while at other, quantity of water is small. Solution is to provide micro hydel-PV hybrid system as sunshine is available practically at all locations. Portable micro hydel sets of 15 kW capacities are installed with solar PV panels to complement each other as given in Figure 6.

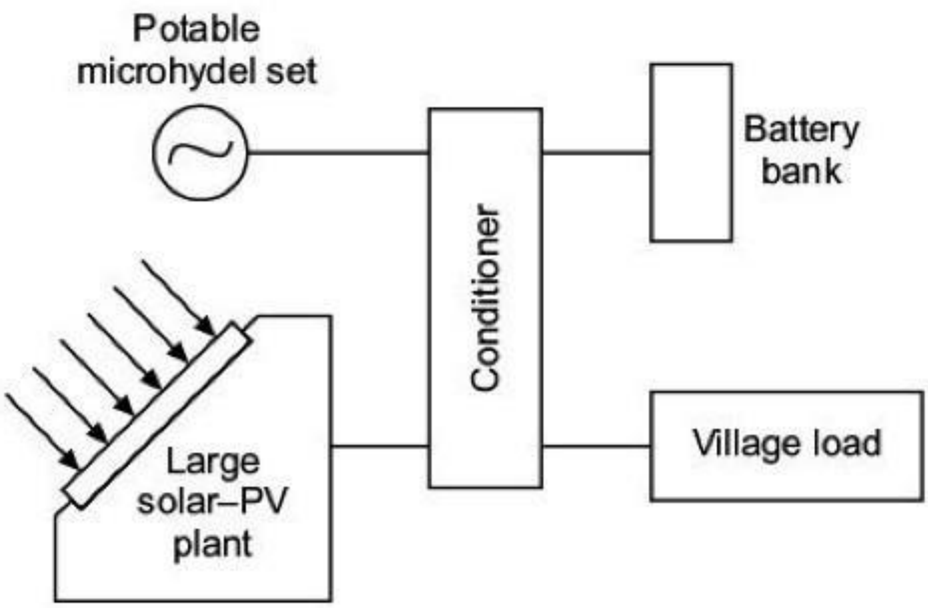


Figure 6 Micro hydel-PV hybrid system.

Biomass-Diesel Hybrid System

Combustion is a common process in biomass conversion technology. Application of combustion process is for solid fuels either from cultivated biomass or waste biomass. Biomass is widely available in hills and remote forest areas but becomes scarce during snowy winter. When its supply stops and stock dwindles, energy route of biomass to electrical energy by incineration suffers a setback. This system needs a backup by diesel power electric generator to meet the known lighting and plug loads of residences, commercial establishments, hospitals and other life sustaining loads. Essential components of this hybrid configuration are:

(a) 25 kW biomass generator.
(b) Battery bank of 1000 Ah capacity
(c) 15 kVA diesel generator.

A biomass-fired steam power plant is made hybrid with a diesel generator along with a controller, battery bank and load is shown in Figure 4.

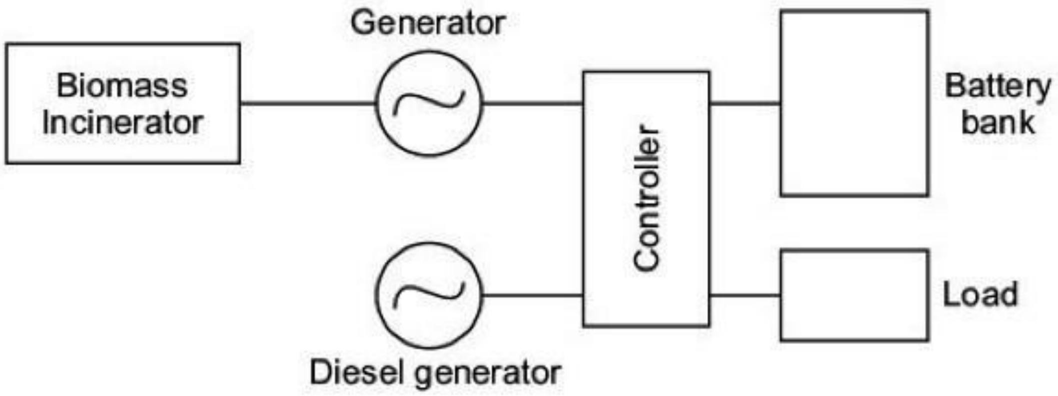


Figure 4 Biomass-diesel hybrid system.

To operate this system, economic viability is necessary by utilizing biomass generator to the full capacity and minimum use of diesel generator, for essential and lifesaving load during crisis period of biomass availability.

Maximum Power Point Tracking (MPPT)

MPPT is a technique used commonly with wind turbines and photovoltaic (PV) solar systems to maximize power extraction under all conditions. Although solar power is mainly covered, the principle applies generally to sources with variable power: for example, optical power transmission and thermo-photovoltaic. PV solar systems exist in many different configurations with regard to their relationship to inverter systems, external grids, battery banks, or other electrical loads. Regardless of the ultimate destination of the solar power, though, the central problem addressed by MPPT is that the efficiency of power transfer from the solar cell depends on both the amount of sunlight falling on the solar panels and the electrical characteristics of the load. As the amount of sunlight varies, the load characteristic that gives the highest power transfer efficiency changes, so that the efficiency of the system is optimized when the load characteristic changes to keep the power transfer at highest efficiency.

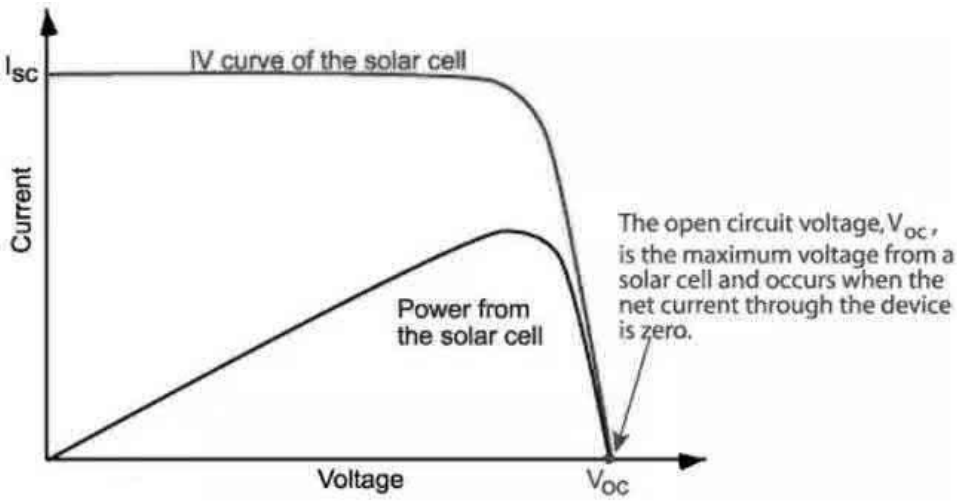
This load characteristic is called the **maximum power point** and **MPPT** is the process of finding this point and keeping the load characteristic there. Electrical circuits can be designed to present arbitrary loads to the photovoltaic cells and then convert the voltage, current, or frequency to suit other devices or systems, and MPPT solves the problem of choosing the best load to be presented to the cells in order to get the most usable power out.

Working of MPPT

Maximum Power Point Tracking (MPPT) is a technology approach used in solar PV inverters to optimize power output in less-than-ideal sunlight conditions. Most modern inverters are equipped with at least one MPPT input.

An MPPT tracker is analogous to a thumb placed over a garden hose. If you put your thumb over part of the opening of the hose (adding resistance to the circuit), the pressure (voltage) goes up and the stream flies faster, but less water (current) is getting through.

If you completely cover the opening, nothing gets through. If you remove your thumb entirely, the maximum flow rate gets through, but the stream falls limply at your feet.



That is the basic mechanism of the MPPT tracker which varies resistance in the circuit to modify current and voltage. Now imagine that there are hundreds of pumps (solar panels) upstream of the hose and they are delivering water (energy) to you. Further complicating things, some of these pumps go offline at certain parts of the day (partial shading of the array). So the force behind the delivery of water will be constantly varying.

MAXIMUM POWER POINT TRACKING ALGORITHMS

MPPT algorithms are necessary in PV applications because the MPP of a solar panel varies with the irradiation and temperature, so the use of MPPT algorithms is required in order to obtain the maximum power from a solar array. Over the past decades many methods to find the MPP have been developed and published. These techniques differ in many aspects such as required sensors, complexity, cost, range of effectiveness, convergence speed, correct tracking when irradiation and/or temperature change, hardware needed for the implementation or popularity, among others. The different MPPT algorithms are discussed below.

Hill-climbing techniques

Algorithms are based on the ―hill-climbing‖ principle, which consists of moving the operation point of the PV array in the direction in which power increases.

Hill-climbing techniques are the most popular MPPT methods due to their ease of implementation and good performance when the irradiation is constant. The advantages of these methods are the simplicity and low computational power they need.

Perturb and observe

The Perturb and observe (P&O) algorithm is also called ―hill-climbing‖, but both names refer to the same algorithm depending on how it is implemented. Hill-climbing involves a perturbation on the duty cycle of the power converter and P&O a perturbation in the operating voltage of the DC link between the PV array and the power converter.

In the case of the Hillclimbing, perturbing the duty cycle of the power converter implies modifying the voltage of the DC link between the PV array and the power converter, so both names refer to the same technique. In this method, the sign of the last perturbation and the sign of the last increment in the power are used to decide the next perturbation.

Incremental conductance

The incremental conductance algorithm is based on the fact that the slope of the curve power vs. voltage (current) of the PV module is zero at the MPP, positive (negative) on the left of it and negative (positive) on the right. It can be written as

$$\frac{\Delta V}{\Delta P} = 0 \left(\frac{\Delta I}{\Delta P} = 0\right) \text{at the MPP}$$
$$\frac{\Delta V}{\Delta P} > 0 \left(\frac{\Delta I}{\Delta P} < 0\right) \text{on the left}$$
$$\frac{\Delta V}{\Delta P} < 0 \left(\frac{\Delta I}{\Delta P} > 0\right) \text{on the right}$$

By comparing the increment of the power versus the increment of the voltage (current) between two consecutives samples, the change in the MPP voltage can be determined.

Fuzzy logic control

The use of fuzzy logic control has become popular over the last decade because it can deal with imprecise inputs, does not need an accurate mathematical model and can handle nonlinearity.

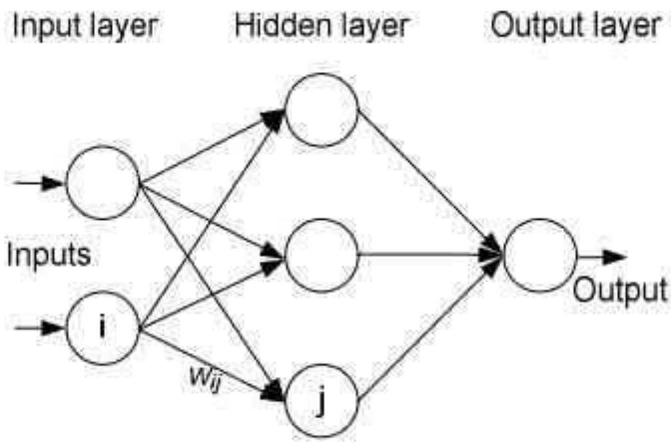
The fuzzy logic consists of three stages: fuzzification, inference system and defuzzification. Fuzzification comprises the process of transforming numerical crisp inputs into linguistic variables based on the degree of membership to certain sets. The number of membership functions used depends on the accuracy of the controller, but it usually varies between 5 and 7. In some cases the membership functions are chosen less symmetric or even optimized for the application for better accuracy The rule base, also known as rule base lookup table or fuzzy rule algorithm, associates the fuzzy output to the fuzzy inputs based on the power converter used and on the knowledge of the user. The last stage of the fuzzy logic control is the defuzzification. In this stage the output is converted from a linguistic variable to a numerical crisp one again using membership functions.

There are different methods to transform the linguistic variables into crisp values. The advantages of these controllers, besides dealing with imprecise inputs, not needing an accurate mathematical model and handling nonlinearity, are fast convergence and minimal oscillations around the MPP.

Neural networks

Another MPPT method well adapted to microcontrollers is Neural Networks [8]. They came along with Fuzzy Logic and both are part of the so called ―Soft Computing. The simplest example of a Neural Network (NN) has three layers called the input layer, hidden layer and output layer, as shown in Figure. More complicated NN‘s are built adding more hidden layers.

The number of layers and the number of nodes in each layer as well as the function used in each layer vary and depend on the user knowledge. The input variables can be parameters of the PV array such as V_{OC} and I_{SC}, atmospheric data as irradiation and temperature or a combination of these. The output is usually one or more reference signals like the duty cycle or the DC-link reference voltage



To execute this training process, data of the patterns between inputs and outputs of the neural network are recorded over a lengthy period of time, so that the MPP can be tracked accurately. The main disadvantage of this MPPT technique is the fact that the data needed for the training process has to be specifically acquired for every PV array and location, as the characteristics of the PV array vary depending on the model and the atmospheric conditions depend on the location.