UNIT V - OTHER ENERGY SOURCES

Tidal Energy: Energy from the tides, Barrage and Non Barrage Tidal power systems. Wave Energy: Energy from waves, wave power devices. Ocean Thermal Energy Conversion (OTEC)- Hydrogen Production and Storage- Fuel cell: Principle of working- various types - construction and applications. Energy Storage System- Hybrid Energy Systems.

Introduction

Tidal power or tidal energy is the form of hydropower that converts the energy obtained from tides into useful forms of power, mainly electricity. The barrage method of extracting tidal energy involves building a barrage across a bay or river that is subject to tidal flow. Turbines installed in the barrage wall generate power as water flows in and out of the estuary basin, bay, or river. Wave energy (or wave power) is the transport and capture of energy by ocean surface waves. The energy captured is then used for all different kinds of useful work, including electricity generation, water desalination, and pumping of water. Ocean Thermal Energy Conversion (OTEC) is a process that can produce electricity by using the temperature difference between deep cold ocean water and warm tropical surface waters. A fuel cell works by passing hydrogen through the anode of a fuel cell and oxygen through the cathode. At the anode site, the hydrogen molecules are split into electrons and protons. 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.

Tidal Energy: Energy from the tides

Tidal power, also called tidal energy is any form of renewable energy in which tidal action in the oceans is converted to electric power. There are three main types of energy that can be captured from the oceans: wave, tidal stream, and tidal range.

Using the power of the tides, energy is produced from the gravitational pull from both the moon and the sun, which pulls water upwards, while the Earth's rotational and gravitational power pulls water down, thus creating high and low tides. This movement of water from the changing tides is a natural form of kinetic energy. The tidal stream devices which utilise these currents are broadly similar to submerged wind turbines and are used to exploit the kinetic energy in tidal currents. Due to the higher density of water the blades can be smaller and turn more slowly, but they still deliver a significant amount of power. To increase the flow and power output from the turbine, concentrators (or shrouds) may be used around the blades to streamline and concentrate the flow towards the rotors.

It can only be installed along coastlines. Coastlines often experience two high tides and two low tides on a daily basis. The difference in water levels must be at least 5 meters high to produce electricity. The various components include, steam generator, tidal turbine or the more innovative dynamic tidal power (DTP) technology to turn kinetic energy into electricity.

The world's first tidal power station was constructed in 2007 at Strangford Lough in Northern

Barrage and Non Barrage Tidal power systems

Tidal electricity can be created from several technologies, the main ones being tidal barrages, tidal turbines and tidal lagoons.

Tidal Barrages

The Tidal Barrage uses long walls, dams, sluice gates or tidal locks to capture and store the potential energy of the ocean. A Tidal Barrage is a type of tidal power generation scheme that involves the construction of a fairly low walled dam, known as a "tidal barrage". It spans across the entrance of a tidal inlet, basin or estuary creating a single enclosed tidal reservoir, similar in many respects to a hydroelectric impoundment reservoir. The bottom of this barrage dam is located on the sea floor with the top of the tidal barrage being just above the highest level that the water can get too at the highest annual tide. The barrage has a number of underwater tunnels cut into its width allowing the sea water to flow through them in a controlled way by using "sluice gates" on their entrance and exit points. Fixed within these tunnels are huge tidal turbine generators that spin as the sea water rushes past them either to fill or empty the tidal reservoir thereby generating electricity.

The water which flows into and out of these underwater tunnels carries enormous amounts of kinetic energy and the job of the tidal barrage is to extract as much of this energy as possible which it uses to produce electricity. Tidal barrage generation using the tides is very similar to hydroelectric generation, except that the water flows in two directions rather than in just one. On incoming high tides, the water flows in one direction and fills up the tidal reservoir with sea water. On outgoing ebbing tides, the sea water flows in the opposite direction emptying it. As a tide is the vertical movement of water, the tidal barrage generator exploits this natural rise and fall of tidal waters caused by the gravitational pull of the sun and the moon.

The tidal energy extracted from tides is a potential energy as the tide moves in a vertical up-down direction between a low and a high tide and back to a low creating a height or head differential. A tidal barrage generation scheme exploits this head differential to generate electricity by creating a difference in the water levels at the side of a dam and then passing this water difference through the turbines. The three main tidal energy barrage schemes that use this water differential to their advantage are:

1. **Flood Generation:** The tidal power is generated as the water enters a tidal reservoir on the incoming Flood tide.
2. **Ebb Generation:** The tidal power is generated as the water leaves a tidal reservoir on the Ebb flow tide.
3. **Two-way Generation:** The tidal power is generated as the water flows in both directions in and out of the reservoir during both the Flood and the Ebb tides.

Tidal Barrage Flood Generation

A Tidal Barrage Flood Generation uses the energy of an incoming rising tide as it moves towards the land. The tidal basin is emptied through sluice gates or lock gates located along the section of the barrage and at low tide the basin is affectively empty. As the tide turns and starts to comes in, the sluice gates are closed and the barrage holds back the rising sea level, creating a difference in height between the levels of water on either side of the barrage dam.

The sluice gates at the entrances to the dam tunnels can either be closed as the sea water rises to allow for a sufficient head of water to develop between the sea level and the basin level before being opened, generating more kinetic energy as the water rushes through, turning the turbines as it passes. Or may remain fully open, filling up the basin more slowly and maintaining the same water level inside the basin as out in the sea.

The tidal reservoir is therefore filled up through the turbine tunnels which spin the turbines generating tidal electricity on the flood tide and is then emptied through the opened sluice or lock gates on the ebb tide. Then a flood tidal barrage scheme is a one-way tidal generation scheme on the incoming tide with tidal generation restricted to about 6 hours per tidal cycle as the basin fills up.

The movement of the water through the tunnels as the tidal basin fills up can be a slow process, so low speed turbines are used to generate the electrical power. This slow filling cycle allows fish or other sea life to enter the enclosed basin without danger from the fast rotating turbine blades. Once the tidal basin is full of water at high tide, all the sluice gates are opened allowing all the trapped water behind the dam to return back to the ocean or sea as it ebbs away.

Flood generator tidal power generates electricity on incoming or flood tide, but this form of tidal energy generation is generally much less efficient than generating electricity as the tidal basin empties, called "Ebb Generation". This is because the amount of kinetic energy contained in the lower half of the basin in which flood generation operates is much less the kinetic energy present in the upper half of the basin in which ebb generation operates due to the effects of gravity and the secondary filling of the basin from inland rivers and streams connected to it via the land.

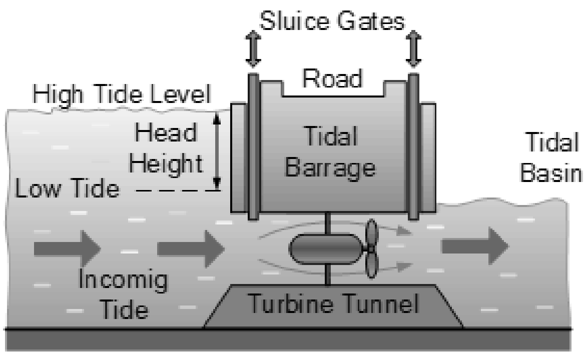


Fig. 1. Tidal Barrage Flood Generation

Tidal Barrage Ebb Generation

A Tidal Barrage Ebb Generation uses the energy of an outgoing or falling tide, referred to as the "ebb tide", as it returns back to the sea making it the opposite of the previous flood tidal barrage scheme. At low tide, all the sluice and lock gates along the barrage are fully opened allowing the tidal basin to fill up slowly at a rate determined by the incoming flood tide. When the ocean or sea level feeding the basin reaches its highest point at high tide, all the sluices and lock gates are then closed entrapping the water inside the tidal basin (reservoir). This reservoir of water may continue to fill-up due to inland rivers and streams connected to it from the land.

As the level of the ocean outside the reservoir drops on the outgoing tide towards its low tide mark, a difference between the higher level of the entrapped water inside the tidal reservoir and the actual sea level outside now exists. This difference in vertical height between the high level mark and the low mark is known as the "head height".

At some time after the beginning of the ebb tide, the difference in the head height across the tidal barrage between the water inside the tidal reservoir and the falling tide level outside becomes sufficiently large enough to start the electrical generation process and the sluice gates connected to the turbine tunnels are opened allowing the water to flow.

When the closed sluice gates are opened, the trapped potential energy of the water inside flows back out to the sea under the enormous force of both the gravity and the weight of the water in the reservoir basin behind it. This rapid exit of the water through the tunnels on the outgoing tide causes the turbines to spin at a fast speed generating electrical power.

The turbines continue to generate this renewable tidal electricity until the head height between the external sea level and the internal basin is too low to drive the turbines at which point the turbines are disconnected and the sluice gates are closed again to prevent the tidal basin from over draining and affecting local wildlife. At some point the incoming flood tide level will again be at a sufficient level to open all the lock gates filling-up the basin and repeating the whole generation cycle over again as shown.

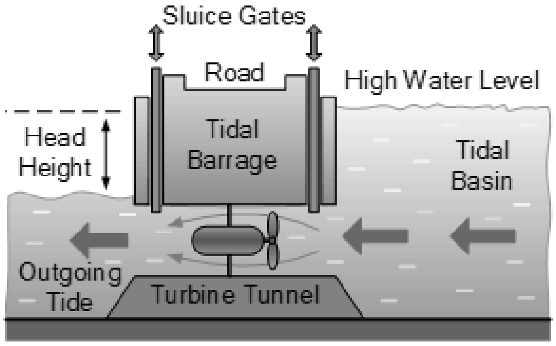


Fig. 2. Tidal Barrage Ebb Generation

According to the estimates of the Indian government, the country has a potential of 8,000 MW of tidal energy. This includes about 7,000 MW in the Gulf of Cambay in Gujarat, 1,200 MW in the Gulf of Kutch and 100 MW in the Gangetic delta in the Sunderbans region of West Bengal.

Two-way Tidal Barrage Generation Scheme

Both Flood Tidal Barrage and Ebb Tidal Barrage installations are "one-way" tidal generation schemes, but in order to increase the power generation time and therefore improve efficiency, we can use special double effect turbines that generate power in both directions. A Two-way Tidal Barrage Scheme uses the energy over parts of both the rising tide and the falling tide to generate electricity.

Two-way electrical generation requires a more accurate control of the sluice gates, keeping them closed until the differential head height sufficient in either direction before being opened. As the tide ebbs and flows, sea water flows in or out of the tidal reservoir through the same gate system. This flow of tidal water back and forth causes the turbine generators located within the tunnel to rotate in both directions producing electricity.

However, this two-way generation is in general less efficient than one-way flood or ebb generation as the required head height is much smaller which reduces the period over which normal one-way generation might have otherwise occurred. Also, bi-directional tidal turbine generators designed to operate in both directions are generally more expensive and less efficient than dedicated uni-directional tidal generators.

Non Barrage Tidal power systems

Tidal turbines

Tidal stream generators are underwater tidal turbines which produce mechanical power by converting the kinetic energy from water currents (the kinetic power component), in a similar way to wind turbines which draw energy from air currents. A tidal stream is a fast-flowing body of water created by tides. A turbine is a machine that takes energy from a flow of fluid. That fluid can be air (wind) or liquid (water). Because water is much more dense than air, tidal energy is more powerful than wind energy. Unlike wind, tides are predictable and stable. Where tidal generators are used, they produce a steady, reliable stream of electricity.

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

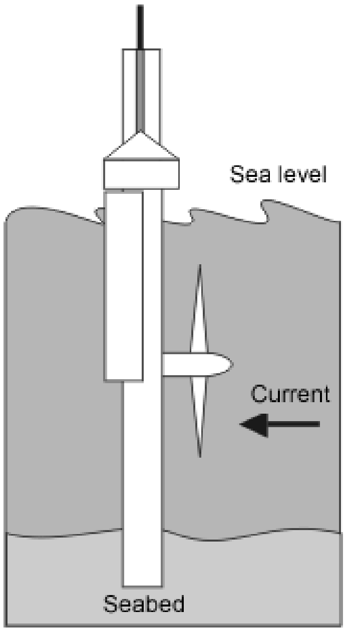


Fig. 3. Tidal turbine

The Bay of Fundy in Canada has the highest tidal ranges in the world, where the height difference between low and high tide water levels can reach 16.3 meters, taller than a three storey building, and therefore brimming with potential for tidal energy production.

Tidal lagoon

A tidal lagoon is a power station that generates electricity from the natural rise and fall of the tides. Tidal lagoons work in a similar way to tidal barrages by capturing a large volume of water behind a man-made structure which is then released to drive turbines and generate electricity. Unlike a barrage, where the structure spans an entire river estuary in a straight line, a tidal lagoon encloses an area of coastline with a high tidal range behind a breakwater, with a footprint carefully designed for the local environment.

As the tide comes in (floods) the water is held back by the turbine wicket gates, which are used to control the flow through the turbine and can be completely closed to stop the water from entering the lagoon. This creates a difference in water level height (head) between the inside of the lagoon and the sea. Once the difference between water levels is optimised, the wicket gates are opened and water rushes into the lagoon through the bulb turbines mounted inside concrete turbine housings in a section of the breakwater wall. As the water turns the turbines, electricity is generated.

The water in the lagoon then returns to closely match the same level as the sea outside. This process also happens in reverse as the tide flows out (ebbs) because the turbines are ‘bi-directional’ and so electricity can be generated from the incoming and outgoing tides. We can hold the tide within the lagoon for approximately 2.5 hours as the sea outside ebbs and the head builds.

The height and time of the tides can be predicted years in advance to a high degree of accuracy, allowing the precise operation of the lagoon on each tidal cycle to be optimised well in advance.

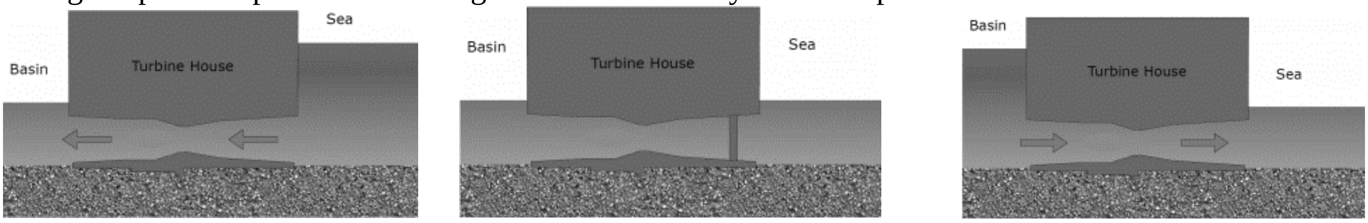


Fig. 4. a. Generating on the flood tide b. Holding period at high or low water c. Generating on the ebb tide

Advantages of Tidal Energy

- **Renewable:** Compared to fossil fuels or nuclear reserves, the gravitational fields from the sun and the moon, as well as the earth's rotation around its axis won't cease to exist any time soon.
- **Green:** Tidal power is an environmentally friendly energy source. In addition to being a renewable energy, it does not emit any climate gases and does not take up a lot of space.
- **Predictable:** Tidal currents are highly predictable. High and low tide develop with well-known cycles, making it easier to construct the system with right dimensions, since we already know what kind of powers the equipment will be exposed to.
- **Effective at Low Speeds:** Water has 1000 times higher density than air, which makes it possible to generate electricity at low speeds. Calculations show that power can be generated even at 1m/s (equivalent to a little over 3ft/s).
- **Long Lifespans:** We have no reason to believe that tidal power plants are not long lived. This ultimately reduces the cost these power plants can sell their electricity, making tidal energy more cost-competitive.

Disadvantages of Tidal Energy

- **Environmental Effects:** Tidal barrages relies on manipulation on ocean levels and therefore potentially have the environmental effects on the environment similar to those of hydroelectric dams.
- **Close to Land:** Tidal power plants needs to be constructed close to land.
- **Expensive:** It is important to realize that the methods for generating electricity from tidal energy is a relatively new technology.

The IEA believes tidal energy could start playing a significant part in the global energy mix by 2030. Tidal energy may produce up to 748 GW of power by 2050, according to Ocean Energy Systems. Although, compared to solar, the predictions are conservative. (Solar power could hit 4,600 GW by

Wave Energy: Energy from waves

Waves form as wind blows over the surface of open water in oceans and lakes. Ocean waves contain tremendous energy. Wave power is produced by the up and down motion of floating devices placed on the surface of the ocean. As the waves travel across the ocean, high-tech devices capture the natural movements of ocean currents and the flow of swells to generate power.

Wave energy or wave power is essentially the power drawn from waves. When wind blows across the sea surface, it transfers the energy to the waves. They are powerful source of energy and the energy output is measured by wave speed, wave height, wavelength and water density. The more strong the waves, the more capable it is to produce power. The captured energy can then be used for electricity generation, powering plants or pumping of water. For example when you look out at a beach and see waves crashing against the shore, you are witnessing wave energy. Wave energy is often mixed with tidal power, which is quite different. When wind blows across the surface of the water strongly enough, it creates waves. This occurs most often and most powerfully on the ocean because of the lack of land to resist the power of the wind. The kinds of waves that are formed, depend on from where they are being influenced.

Long, steady waves that flow endlessly against the beach are likely formed from storms and extreme weather conditions far away. The power of storms and their influence on the surface of the water is so powerful that it can cause waves on the shores of another hemisphere. When you see high, choppy waves that rise and fall very quickly, you are likely seeing waves that were created by a nearby weather system. These waves are usually newly formed occurrences. The power from these waves can then be harnessed through wave energy converter (WEC).

Wave power devices

As an ocean wave passes a stationary position, the surface of the sea changes in height, water near the surface moves as it losses its kinetic and potential energy, which affects the pressure under the surface. The periodic or oscillatory nature of ocean waves means that we can use a variety of different Wave Energy Devices to harness the energy produced by the oceans waves.

The problem lies is that the oscillatory frequency of an ocean wave is relatively slow and is much less than the hundreds of revolutions per minute required for electric power generation. Then a great variety of wave energy devices and designs are available to convert these slow-acting, reversing wave forces into the high speed, unidirectional rotation of a generator shaft.

There are three fundamental but very different wave energy devices used in converting wave power into electric power, and these are:

1. **Wave Profile Devices:** These are wave energy devices which turn the oscillating height of the oceans surface into mechanical energy.
2. **Oscillating Water Columns:** These are wave energy devices which convert the energy of the waves into air pressure.
3. **Wave Capture Devices:** These are wave energy devices which convert the energy of the waves into potential energy.

Tidal turbines are more expensive to build and maintain than wind turbines, but produce more energy. They also produce energy more consistently as the tide is continuous while the wind doesn't always

Wave Profile Devices

Wave profile devices are a class of wave energy device which floats on or near to the sea surface and moves in response to the shape of the incident wave or, for submersible devices, it moves up and down under the influence of the variations in underwater pressure as a wave moves by. Most types of wave profile devices float on the surface absorbing the wave energy in all directions by following the movements of waves at or near the sea surface, just like a float.

If the physical size of the wave profile device is very small compared to the periodic length of the wave, this type of wave energy device is called a “point absorber”. If the size of the device is larger or longer than the typical periodic wavelength, it is called a “linear absorber”, but more commonly they are collectively known as “wave attenuators”. The main difference between the two wave energy devices is how the oscillating system converts the wave energy between the absorber and a reaction point. This energy absorption can be achieved either by a floating body, an oscillating solid member or oscillating water within a buoys structure itself.

The waves energy is absorbed using vertical motion (heave), horizontal motion in the direction of wave travel (surge), angular motion about a central axis parallel to the wave crests (pitch) or angular motion about a vertical axis (yaw) or a combination of all four with the energy being generated by reacting these different movements against some kind of fixed resistance called a reaction point.

To make efficient use of the force generated by the wave, we need some kind of force reaction. In other words, we want the waves force on the float to react against another rigid or semi-rigid body. Reaction points can be inertial masses such as heavy suspended ballast plates, sea-floor anchors or a fixed dead-weight or pile as shown. The pitching and heaving of the waves causes a relative motion between an absorber and reaction point.

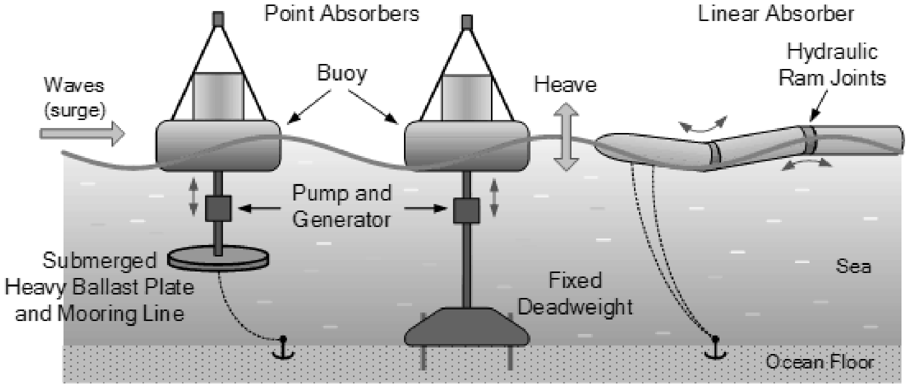


Fig. 5. Wave Profile Devices

The left hand wave energy device above, uses a heavy ballast plate suspended below the floating buoy. The buoy is prevented from floating away by a mooring line attached to a sea-floor anchor. This mooring line allows the point absorber to operate offshore in deeper waters. As the buoy bobs up-and-down in the waves, a oscillatory mutual force reaction is generated between the freely moving absorber and the heavy plate causing a hydraulic pump in between to rotate a generator producing electricity.

The middle wave energy device operates in a similar manner to the previous floating buoy device. The difference this time is that the freely heaving buoy reacts against a fixed reaction point such as a fixed dead-weight on the ocean floor. As this type of point absorber is bottom mounted, it is operated in shallower near shore locations.

The third device is an example of a linear absorber (wave attenuator) which floats on the surface of the water. It to is tethered to the ocean floor so that it can swing perpendicularly towards the incoming waves. As the waves pass along the length of this snake like wave energy device, they cause the long cylindrical body to sag downwards into the troughs of the waves and arch upwards when the waves crest is passing.

Oscillating Water Column

The Oscillating Water Column, (OWC) is a popular shoreline wave energy device normally positioned onto or near to rocks or cliffs which are next to a deep sea bottom. They consist of a partly submerged hollow chamber fixed directly at the shoreline which converts wave energy into air pressure.

The structure used to capture the waves energy could be a natural cave with a blow hole or a man made chamber or duct with a wind turbine generator located at the top well above the waters surface. Either way, the structure is built perpendicular to the waves with part of the ocean surface trapped inside the chamber which itself is open to the sea below the water line. The constant ebbing and flowing motion of the waves forces the trapped water inside the chamber to oscillate in the vertical up-down direction.

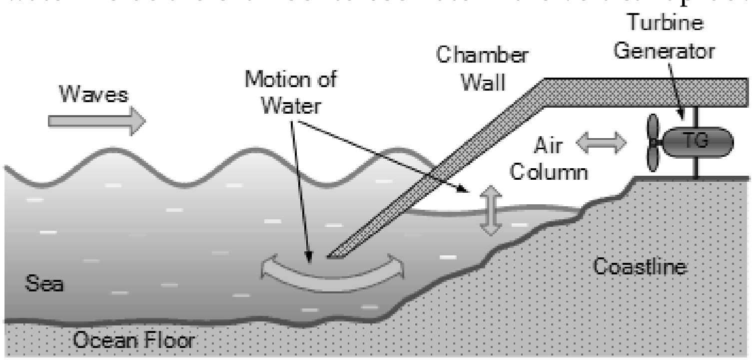


Fig. 6. Oscillating Water Column

As the incident waves outside enter and exit the chamber, changes in wave movement on the opening cause the water level within the enclosure to oscillate up and down acting like a giant piston on the air above the surface of the water, pushing it back and forth. This air is compressed and decompressed by this movement every cycle. The air is channelled through a wind turbine generator to produce electricity as shown.

The type of wind turbine generator used in an oscillating water column design is the key element to its conversion efficiency. The air inside the chamber is constantly reversing direction with every up-and-down movement of the sea water producing a sucking and blowing effect through the turbine. If a conventional turbine was used to drive the attached generator, this too would be constantly changing direction in unison with the air flow. To overcome this problem the type of wind turbine used in oscillating water column schemes is called a Wells Turbine. The Wells turbine has the remarkable property of rotating in the same direction regardless of the direction of air flow in the column. The kinetic energy is extracted from the reversing air flow by the Wells turbine and is used to drive an electrical induction generator. The speed of the air flow through the wells turbine can be enhanced by making the cross-sectional area of the wave turbines duct much less than that of the sea column.

As with other wave energy converters, oscillating wave column technology produces no greenhouse gas emissions making it a non-polluting and renewable source of energy, created by natural transfer of wind energy through a wells turbine. The advantage of this shoreline scheme is that the main moving part, the turbine can be easily removed for repair or maintenance because it is on land. The disadvantage though is that, as with the previous wave energy devices, the oscillating wave columns output is dependent on the level of wave energy, which varies day by day according to the season.

Wave Capture Device

A Wave Capture Device also known as a Overtopping Wave Power Device, is a shoreline to near shore wave energy device that captures the movements of the tides and waves and converts it into potential energy. Wave energy is converted into potential energy by lifting the water up onto a higher level. The wave capture device, or more commonly an overtopping device, elevates ocean waves to a holding reservoir above sea level.

The overtopping wave energy converter works in much the same way as an impoundment type hydroelectric dam works. Sea water is captured and impounded at a height above sea level creating a low head situation which is then drained out through a reaction turbine, usually a Kaplan Turbine generating electricity as shown.

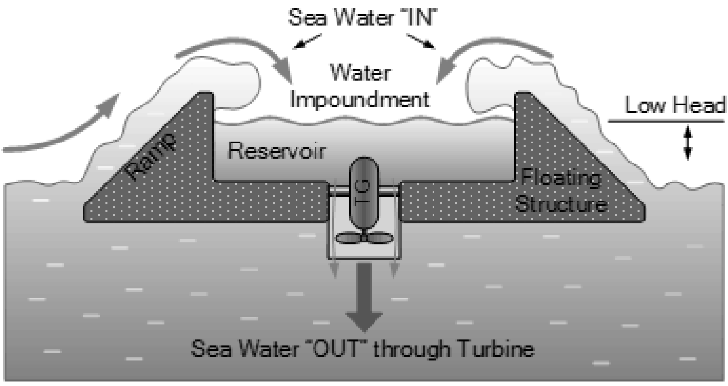


Fig. 7. Wave Capture Device

The basic impoundment structure can be either fixed or a floating structure tethered to the sea bed. The wave overtopping device uses a ramp design on the device to elevate part of the incoming waves above their natural height. As the waves hit the structure they flow up a ramp and over the top (hence the name "overtopping"), into a raised water impoundment reservoir on the device in order to fill it. Once captured, the potential energy of the trapped water in the reservoir is extracted using gravity as the water returns to the sea via a low-head Kaplan turbine generator located at the bottom of the wave capture device.

Ocean Thermal Energy Conversion (OTEC)

Ocean Thermal Energy also called as Ocean Thermal Energy Conversion (OTEC) refers to a method of using the temperature difference between the deep parts of the sea which are cold and the shallow parts of the sea which are cold to run a heat engine and produce useful work. Basically, Ocean thermal energy conversion is an electricity generation system. The deeper parts of the ocean are cooler due to the fact that the heat of sunlight cannot penetrate very deep into the water. Here the efficiency of the system depends on the temperature difference. Greater the temperature difference, greater the efficiency. The temperature difference in the oceans between the deep and shallow parts is maximum in the tropics, 20 to 25^{o} C. Tropics receive a lot of sunlight which warms the surface of the oceans, increasing the temperature gradient.

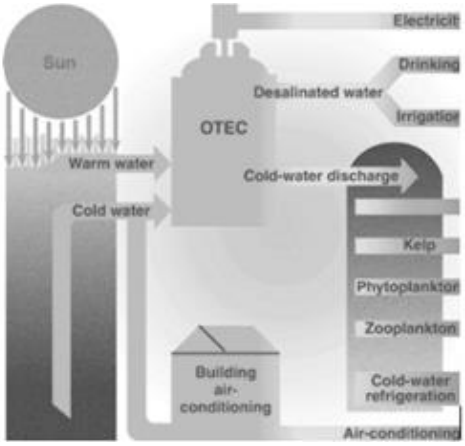


Fig. 8. Ocean Thermal Energy Conversion

The energy source of OTEC is abundantly available, free and will be so, for as long as the sun shines and ocean currents exist. Estimates suggest that ocean thermal energy could contain more than twice the world's electricity demand. This makes it necessary for us to give it a closer look.

Types of Ocean Thermal Energy Conversion Systems

The two types of Ocean Thermal Energy Conversion Systems are closed cycle and open cycle.

Closed Cycle: Closed cycle Ocean Thermal Energy Conversion systems use a working fluid with a low boiling point, Ammonia for example, and use it to power a turbine to generate electricity. Warm seawater is taken in from the surface of the oceans and cold water from the deep at 5^{o} . The warm seawater vaporizes the fluid in the heat exchanger which then turns the turbines of the generator. The fluid now in the vapour state is brought in contact with cold water which turns it back into a liquid. The fluid is recycled in the system so it is called a closed system.

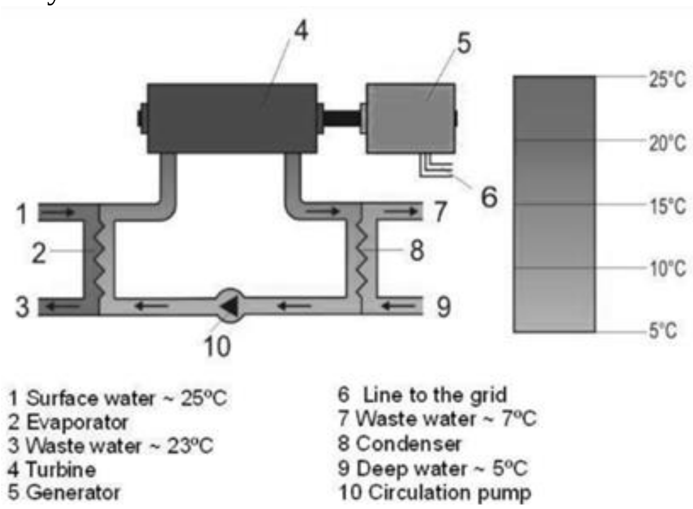


Fig. 9. Closed cycle Ocean Thermal Energy Conversion Systems

Open Cycle: Open cycle OTEC directly uses the warm water from the surface to make electricity. The warm seawater is first pumped in a low-pressure chamber where due to the drop in pressure, it undergoes a drop in boiling point as well. This causes the water to boil. This steam drives a low-pressure turbine which is attached to an electrical generator. The advantage of this system over a closed system is that, in open cycle, desalinated water in the form of steam is obtained. Since it is steam, it is free from all impurities. This water can be used for domestic, industrial or agricultural purposes.

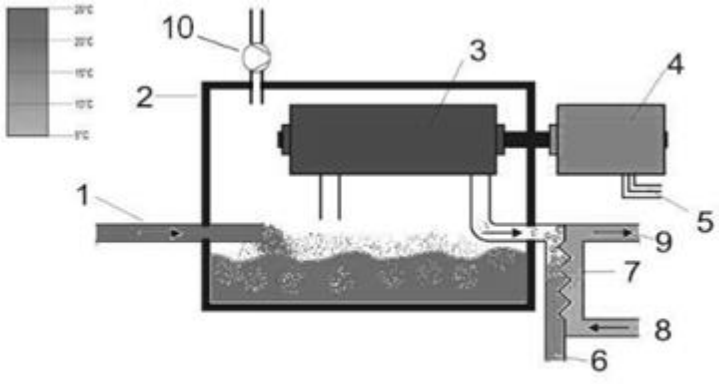


Fig. 10. Open cycle Ocean Thermal Energy Conversion Systems

Land- and sea-based OTEC

Open- and closed-cycle OTEC can operate either on the shore (land-based) or out at sea (sometimes known as floating or grazing). Land-based OTEC plants are constructed on the shoreline with four large hot and cold pipelines dipping down into the sea: a hot water input, a hot water output, a cold-water input, and a cold-water output. Unfortunately, shoreline construction makes them more susceptible to problems like coastal erosion and damage from hurricanes and other storms.

Sea-based OTEC plants are essentially the same but have to be constructed on some sort of tethered, floating platform, not unlike a floating oil platform, with the four pipes running down into the sea; early prototypes were run from converted oil tankers and barges. They also need a cable running back to land to send the electrical power they generate ashore. Hybrid forms of OTEC are also possible.

Advantages:

- Power from OTEC is continuous, renewable and pollution free.
- Unlike other forms of solar energy, output of OTEC shows very little daily or seasonal variation.
- Drawing of warm and cold sea water and returning of the sea water, close to the thermocline, could be accomplished with minimum environment impact.
- Electric power generated by OTEC could be used to produce hydrogen.

Disadvantages:

- Capital investment is very high.
- Due to small temperature difference in between the surface water and deep water, conversion efficiency is very low about 3-4%.
- Low efficiency of these plants coupled with high capital cost and maintenance cost makes them uneconomical for small plants.

Hydrogen Production and Storage - Fuel cell

Although abundant on earth as an element, hydrogen is almost always found as part of another compound, such as water (H_2O), and must be separated from the compounds that contain it before it can be used in vehicles. Once separated, hydrogen can be used along with oxygen from the air in a fuel cell to create electricity through an electrochemical process.

Production

Hydrogen can be produced from diverse, domestic resources including fossil fuels, biomass and water electrolysis with electricity. The environmental impact and energy efficiency of hydrogen depends on how it is produced. Several projects are under way to decrease costs associated with hydrogen production. The current most notable production pathways are the following:

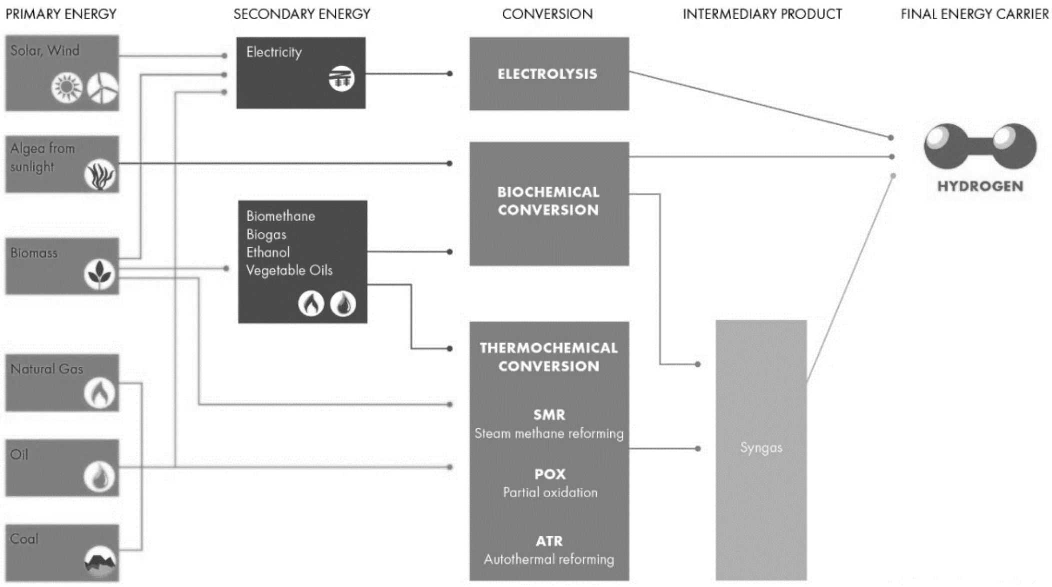


Fig. 11. Methods of producing hydrogen

Electrolysis
Method: Electrolysis
In short: Process where water (H_2O) is split into hydrogen (H_2) and oxygen (O_2) gas with energy input and heat in the case of high temperature Electrolysis.
In Practice: An electric current splits water into its constituent parts. If renewable energy is used, the gas has a zero-carbon footprint, and is known as green hydrogen.

An electric current splits water into hydrogen and oxygen. If the electricity is produced by renewable sources, such as solar or wind, the resulting hydrogen will be considered renewable as well and has numerous emissions benefits. This reaction takes place in a unit called an electrolyzer. Electrolyzers can range in size from small, appliance-size equipment that is well-suited for small-scale distributed hydrogen production to large-scale, central production facilities that could be tied directly to renewable or other non-greenhouse-gas-emitting forms of electricity production.

A DC electrical power source is connected to two electrodes, or two plates (typically made from some inert metal such as platinum or iridium) which are placed in the water. Hydrogen will appear at the cathode (where electrons enter the water), and oxygen will appear at the anode.

At the cathode, hydrogen ions combine with electrons from the external circuit to form hydrogen gas. Anode Reaction: $2H_2O \rightarrow O_2 + 4H^+ + 4e^-$ Cathode Reaction: $4H^+ + 4e^- \rightarrow 2H_2$

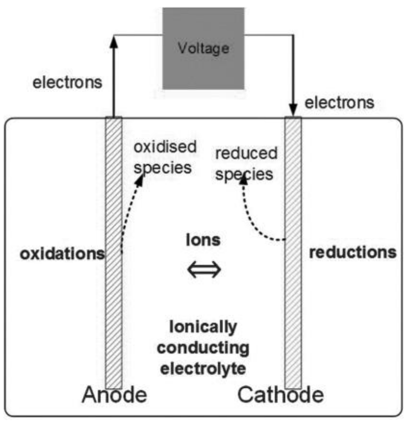


Fig. 12. Electrolysis

Steam Methane Reforming
Method: Reforming - most notably Reforming of natural gas but also biogas
In short: The primary ways in which natural gas, mostly methane, is converted to hydrogen involve reaction with either steam (steam reforming or steam methane reforming SMR when methane is used), oxygen (partial oxidation), or both in sequence (autothermal reforming)

In practice: Steam reforming: Pure water vapour is used as the oxidant. The reaction requires the introduction of heat ("endothermic").
Partial oxidation: Oxygen or air is used in this method. The process releases heat ("exothermic").

Most of the hydrogen produced today, is being produced through the CO_2 intensive process called Steam Methane Reforming.

High-temperature steam (700°C–1,000°C) is used to produce hydrogen from a methane source, such as natural gas. In steam-methane reforming, methane reacts with steam under 3–25 bar pressure (1 bar = 14.5 psi) in the presence of a catalyst to produce hydrogen, carbon monoxide, and a relatively small amount of carbon dioxide. Steam reforming is endothermic, that is, heat must be supplied to the process for the reaction to proceed.

Subsequently, in "water-gas shift reaction," the carbon monoxide and steam are reacted using a catalyst to produce carbon dioxide and more hydrogen. In a final process step called "pressure-swing adsorption," carbon dioxide and other impurities are removed from the gas stream, leaving essentially pure hydrogen. Steam reforming can also be used to produce hydrogen from other fuels, such as ethanol, propane, or even gasoline.

Steam-methane reforming reaction: $CH_4 + H_2O$ (+ heat) $\rightarrow CO + 3H_2$
Water-gas shift reaction: $CO + H_2O \rightarrow CO_2 + H_2$ (+ small amount of heat)

Partial Oxidation

In partial oxidation, the methane and other hydrocarbons in natural gas react with a limited amount of oxygen (typically from air) that is not enough to completely oxidize the hydrocarbons to carbon dioxide and water. With less than the stoichiometric amount of oxygen available, the reaction products contain primarily hydrogen and carbon monoxide (and nitrogen, if the reaction is carried out with air rather than pure oxygen), and a relatively small amount of carbon dioxide and other compounds. Subsequently, in a water-gas shift reaction, the carbon monoxide reacts with water to form carbon dioxide and more hydrogen.

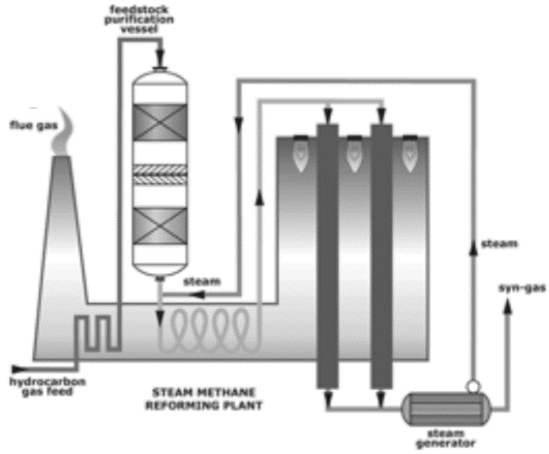


Fig. 13. Steam-methane reforming

Autothermal reforming: This process is a combination of steam reforming and partial oxidation and operates with a mixture of air and water vapour. The ratio of the two oxidants is adjusted so that no heat needs to be introduced or discharged ("isothermal").

Hydrogen as a By-Product or Industrial Residual Hydrogen
Method: Hydrogen from other industrial processes that create hydrogen as a by-product
In Short: Electrochemical processes, such as the industrial production of caustic soda and chlorine produce hydrogen as a waste product.
In Practice: Producing chlorine and caustic soda comes down to passing an electric current through brine (a solution of salt – sodium chloride – in water). The brine dissociates and recombines through exchange of electrons (delivered by the current) into gaseous chlorine, dissolved caustic soda1 and hydrogen. By the nature of the chemical reaction, chlorine, caustic soda and hydrogen are always manufactured in a fixed ratio: 1.1 tonne of caustic and 0.03 tonne of hydrogen per tonne of chlorine.

If the production of hydrogen can be the first objective of the separation process, it can also be that the separation process aims first at producing another molecule and produces hydrogen as a by-product.

Producing chlorine and caustic soda comes down to passing an electric current through brine (a solution of salt – sodium chloride – in water). The brine dissociates and recombines through exchange of electrons (delivered by the current) into gaseous chlorine, dissolved caustic soda and hydrogen. By the nature of the chemical reaction, chlorine, caustic soda and hydrogen are always manufactured in a fixed ratio: 1.1 ton of caustic and 0.03 ton of hydrogen per ton of chlorine. Hydrogen produced by this process can be made available for other applications, such as fuel cell electric vehicles.

Although the technology required to harness tidal energy is well established, tidal power is expensive, and there is only one major tidal generating station in operation. This is a 240 megawatt station at the mouth of the La Rance river estuary in France.

Fermentation

Biomass is converted into sugar-rich feedstocks that can be fermented to produce hydrogen. In fermentation-based systems, microorganisms, such as bacteria, break down organic matter to produce hydrogen. The organic matter can be refined sugars, raw biomass sources such as corn stover and even wastewater. Because no light is required, these methods are sometimes called "dark fermentation" methods.

In direct hydrogen fermentation, the microbes produce the hydrogen themselves. These microbes can break down complex molecules through many different pathways, and the byproducts of some of the pathways can be combined by enzymes to produce hydrogen. Researchers are studying how to make fermentation systems produce hydrogen faster (improving the rate) and produce more hydrogen from the same amount of organic matter (increasing the yield).

Microbial electrolysis cells (MECs) are devices that harness the energy and protons produced by microbes breaking down organic matter, combined with an additional small electric current, to produce hydrogen. This technology is very new, and researchers are working on improving many aspects of the system, from finding lower-cost materials to identifying the most effective type of microbes to use.

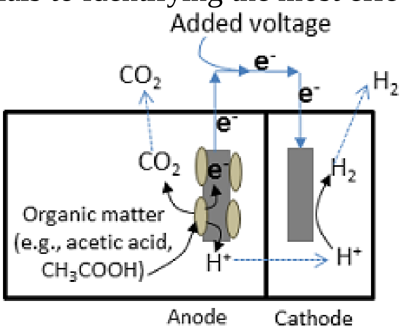


Fig. 14. Fermentation

Hydrogen storage

A major advantage of hydrogen is that it can be produced from (surplus) renewable energies, and unlike electricity it can also be stored in large amounts for extended periods of time. For that reason, hydrogen produced on an industrial scale could play an important part in the energy transition.

The most important hydrogen storage methods, which have been tried and tested over lengthy periods of time, include physical storage methods based on either compression or cooling or a combination of the two (hybrid storage). In addition, a large number of other new hydrogen storage technologies are being pursued or investigated. These technologies can be grouped together under the name materials-based storage technologies. These can include solids, liquids or surfaces.

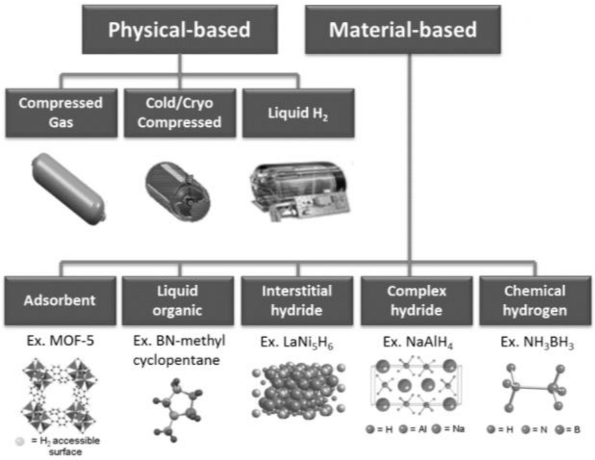


Fig. 15. Methods of hydrogen storage

Liquefied Hydrogen

Apart from the traditional methods of storing gaseous hydrogen under pressure, it is also possible to store cryo-genic hydrogen in the liquid state. Liquid hydrogen (LH_2) is in demand today in applications requiring high levels of purity, such as in the chip industry for example. As an energy carrier, LH_2 has a higher energy density than gaseous hydrogen, but it requires liquefaction at –253°C, which involves a complex technical plant and an extra economic cost. When storing liquid hydrogen, the tanks and storage facilities have to be insulated in order to keep in check the evaporation that occurs if heat is carried over into the stored content, due to conduction, radiation or convection. Tanks for LH_2 are used today primarily in space travel.

Cold- and cryo-compressed Hydrogen

In addition to separate compression or cooling, the two storage methods can be combined. The cooled hydrogen is then compressed, which results in a further development of hydrogen storage for mobility purposes. The first field installations are already in operation. The advantage of cold or cryogenic compression is a higher energy density in comparison to compressed hydrogen. However, cooling requires an additional energy input.

Currently it takes in the region of 9 to 12 % of the final energy made available in the form of H_2 to compress hydrogen from 1 to 350 or 700 bar. By contrast, the energy input for liquefaction (cooling) is much higher, currently around 30%. The energy input is subject to large spreads, depending on the method, quantity and external conditions. Work is currently in progress to find more economic methods with a significantly lower energy input.

Materials-Based H_2 Storage

An alternative to physical storage methods is provided by hydrogen storage in solids and liquids and on surfaces. Most of these storage methods are still in development. Moreover, the storage densities that have been achieved are still not adequate, the cost and time involved in charging and discharging hydrogen are too high, and/or the process costs are too expensive. Material-based hydrogen storage media can be divided into three classes: first, hydride storage systems; second, liquid hydrogen carriers; and third, surface storage systems, which take up hydrogen by adsorption, i.e. attachment to the surface.

Hydride storage systems

In metal hydride storage systems the hydrogen forms interstitial compounds with metals. Here molecular hydrogen is first adsorbed on the metal surface and then incorporated in elemental form (H) into the metallic lattice with heat output and released again with heat input. Metal hydrides are based on elemental metals such as palladium, magnesium and lanthanum, intermetallic compounds, light metals such as aluminium, or certain alloys. Palla-dium, for example, can absorb a hydrogen gas volume up to 900 times its own volume.

Liquid organic hydrogen carriers

Liquid organic hydrogen carriers represent another option for binding hydrogen chemically. They are chemical compounds with high hydrogen absorption capacities. They currently include, in particular, the carbazole derivative N-ethylcarbazole, but also toluene.

Surface storage systems (sorbents)

Finally, hydrogen can be stored as a sorbate by attachment (adsorption) on materials with high specific surface areas. Such sorption materials include, among others, microporous organometallic framework compounds (metal-organic frameworks) microporous crystalline aluminosilicates (zeolites) or microscopically small carbon nanotubes. Adsorption materials in powder form can achieve high volumetric storage densities.

Underground Storage

When it comes to the industrial storage of hydrogen, salt caverns, exhausted oil and gas fields or aquifers can be used as underground stores. Although being more expensive, cavern storage facilities are most suitable for hydrogen storage. Underground stores have been used for many years for natural gas and crude oil/oil products, which are stored in bulk to balance seasonal supply/demand fluctuations or for crisis preparedness.

Gas Grid

Another possibility for storing surplus renewable energy in the form of hydrogen is to feed it into the public natural gas network (Hydrogen Enriched Natural Gas or HENG). Infrastructure elements that were installed at the time, such as pipelines, gas installations, seals, gas appliances etc., were designed for the hydrogen-rich gas and were later modified with the switch to natural gas.

The National Hydrogen Energy Road Map (NHERM) is a program in India initiated by the National Hydrogen Energy Board (NHEB) in 2003 and approved in 2006 for bridging the technological gaps in different areas of hydrogen energy

Fuel cell

A fuel cell can be defined as an electrochemical cell that generates electrical energy from fuel via an electrochemical reaction. These cells require a continuous input of fuel and an oxidizing agent (generally oxygen) in order to sustain the reactions that generate the electricity. Therefore, these cells can constantly generate electricity until the supply of fuel and oxygen is cut off.

Despite being invented in the year 1838, fuel cells began commercial use only a century later when they were used by NASA to power space capsules and satellites. Today, these devices are used as the primary or secondary source of power for many facilities including industries, commercial buildings, and residential buildings.

Construction

A fuel cell is similar to electrochemical cells, which consists of a cathode, an anode, and an electrolyte. In these cells, the electrolyte enables the movement of the protons.

The basic construction of a hydrogen fuel cell consists of two electrodes, an electrolyte, a fuel (hydrogen) and a power supply. An electrolyte that separates the two electrodes is an ion conducting material which facilitates the free passage of ions. In a fuel cell, an oxidizing agent (or oxygen) is made to flow through a fuel (hydrogen). Hydrogen and oxygen combine to form water and generate heat. At the anode, hydrogen is stripped of its electron and its proton is made to pass through the electrolyte. The electron is made to pass through an external DC (direct current) circuit to power devices.

Principle of working

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

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

Cathode Reaction : $O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$
Anode Reaction : $2H_2 + 4OH^- \rightarrow 4H_2O + 4e^-$
Net Cell Reaction : $2H_2 + O_2 \rightarrow 2H_2O$

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

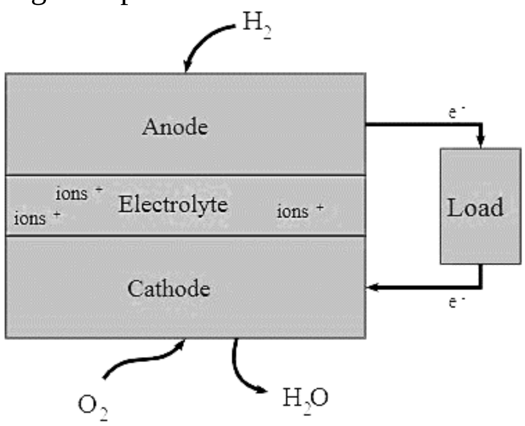


Fig. 16. Operation of fuel cell

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

Types of fuel cells

Despite working in a similar manner, there exist many varieties of fuel cells. Some of these types of fuel cells are discussed here.

The Polymer Electrolyte Membrane (PEM) Fuel Cell

- These cells are also known as proton exchange membrane fuel cells (or PEMFCs).
- The temperature range that these cells operate in is between 50° C to 100° C
- The electrolyte used in PEMFCs is a polymer which has the ability to conduct protons.
- A typical PEM fuel cell consists of bipolar plates, a catalyst, electrodes, and the polymer membrane.
- Despite having eco-friendly applications in transportation, PEMFCs can also be used for the stationary and portable generation of power.

Phosphoric Acid Fuel Cell

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

Solid Acid Fuel Cell

- A solid acid material is used as the electrolyte in these fuel cells.
- The molecular structures of these solid acids are ordered at low temperatures.
- At higher temperatures, a phase transition can occur which leads to a huge increase in conductivity.
- Examples of solid acids include $CsHSO_4$ and $CsH2PO_4$ (cesium hydrogen sulphate and cesium dihydrogen phosphate respectively)

Alkaline Fuel Cell

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

Solid Oxide Fuel Cell

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

Molten Carbonate Fuel Cell

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

More than 10 million metric tons of hydrogen are produced annually in the United States. Most of the hydrogen produced in the United States comes from a process called steam methane reforming.

Applications of fuel cell

Fuel cell technology has a wide range of applications. Currently, heavy research is being conducted in order to manufacture a cost-efficient automobile which is powered by a fuel cell. A few applications of this technology are listed below.

- Fuel cell electric vehicles, or FCEVs, use clean fuels and are therefore more eco-friendly than internal combustion engine-based vehicles.
- They have been used to power many space expeditions including the Appolo space program.
- Generally, the byproducts produced from these cells are heat and water.
- The portability of some fuel cells is extremely useful in some military applications.
- These electrochemical cells can also be used to power several electronic devices.
- Fuel cells are also used as primary or backup sources of electricity in many remote areas.

Energy Storage System

Energy storage systems are an essential part of the renewable power generation system. The renewable power sources like solar, wind, and hydro are fluctuating resources. To supply a smooth output power to the power grid, energy storage systems are installed to the power generation system. Again the renewable sources (wind and solar) are unreliable, and in the case of the wind energy, the wind velocity sometimes drops below the power generation level, and sunlight may only be available 6–8 h per day to generate electricity. When the power generation becomes zero or the energy demand is high, the energy storage systems can deliver power to the consumers. Therefore, an energy storage system can be an important component to improve the reliability of the power network. There are various types of energy storages, such as electric double layer capacitor (EDLC), BESS, superconducting magnetic energy storage (SMES), flywheel (FW), plug in electric vehicle (PEV), etc.

Rechargeable batteries were invented in 1836 by an English chemist. This battery was designed with lead-acid technology and is still the type used for car batteries.

Electric double layer capacitor

Electric double-layer capacitors are based on the operating principle of the electric double-layer that is formed at the interface between activated charcoal and an electrolyte.

The activated charcoal is used as an electrode and activated charcoal is used in its solid form, and the electrolytic fluid is liquid. When these materials come in contact with each other, the positive and negative poles are distributed relative to each other over an extremely short distance. Such a phenomenon is known as an electric double-layer. When an external electric field is applied, the electric double-layer that is formed in the vicinity of the activated charcoal's surface within the electrolytic fluid is used as the fundamental capacitor structure.

EDLC is also known as super capacitor or ultra capacitor. The EDLC enables large power effects per weight having a goal up to 10 kW/kg but a storage capacity around 10 Wh/kg only. The storage time is short or typically up to 30–60s.

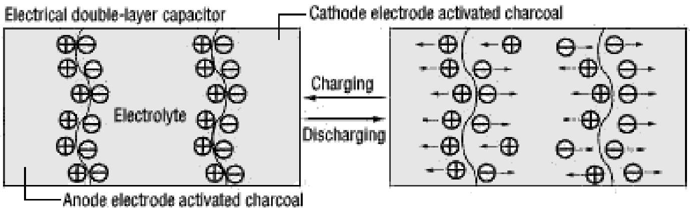


Fig. 17. Electric double-layer capacitors

Battery energy storage system

Batteries are the most common power source for basic handheld devices to large scale industrial applications. A battery can be defined as; it is a combination of one or more electrochemical cells that are capable of converting stored chemical energy into electrical energy. Types of batteries are primary and secondary batteries. Secondary batteries are rechargeable and are used in renewable energy systems. The types of rechargeable batteries are SMF, Lead Acid, Li and Nicd.

SMF Battery

SMF is a Sealed Maintenance Free battery, designed to offer reliable, consistent and low maintenance power for UPS applications. These batteries can be subject to deep cycle applications and minimum maintenance in rural and power deficit areas. These batteries are available from 12V.

Fig. 18. SMF Battery

Lithium (Li) Battery:

The lithium battery has been one of the greatest achievements in portable power in the last decade; with use of lithium batteries we have been able to shift from black and white mobile to color mobiles with additional features like GPS, email alerts etc. These are the high energy density potential devices for higher capacities. And relatively low self-discharge batteries. Also Special cells can provide very high current to applications such as power tools.

Fig. 19. Lithium (Li) Battery

Nickel Cadmium (Nicd) Battery

The Nickel Cadmium batteries have the advantage of being recharged many times and possess a relatively constant potential during discharge and have more electrical and physical withstanding capacity. This battery uses nickel oxide for cathode, a cadmium compound for anode and potassium hydroxide solution as its electrolyte.

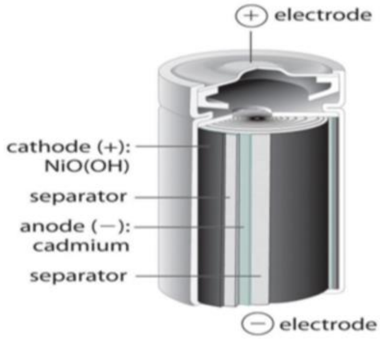


Fig. 20. Nickel Cadmium (Nicd) Battery

Lead Acid Battery

Lead Acid batteries are widely used in automobiles, inverters, backup power systems etc. Unlike tubular and maintenance free batteries, Lead Acid batteries require proper care and maintenance to prolong its life. The Lead Acid battery consists of a series of plates kept immersed in sulphuric acid solution. The plates have grids on which the active material is attached. The plates are divided into positive and negative plates. The positive plates hold pure lead as the active material while lead oxide is attached on the negative plates.

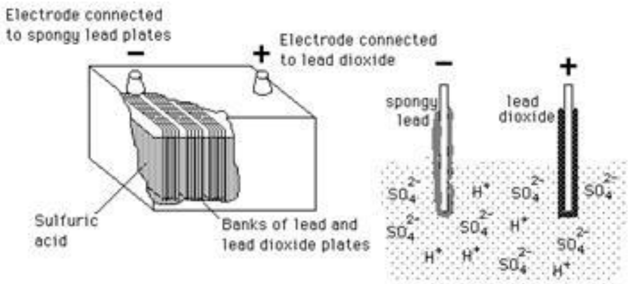


Fig. 21. Lead Acid Battery

Lithium – Ion Battery

Lithium –Ion batteries are now popular in majority of electronic portable devices like Mobile phone, Laptop, Digital Camera, etc due to their long lasting power efficiency. These are the most popular rechargeable batteries with advantages like best energy density, negligible charge loss and no memory effect. Li-Ion battery uses Lithium ions as the charge carriers which move from the negative electrode to the positive electrode during discharge and back when charging.

Fig. 22. Lithium – Ion Battery

Lithium Ion Polymer (Li-ion polymer)

The Lithium Ion Polymer battery offers similar elements to the Li-ion battery in an ultra-slim and simplified packaging form. It is of lithium-ion technology in a pouch format. This makes them lighter, but less rigid. The Li-polymer is different from other batteries in the type of electrolyte used, a dry solid polymer electrolyte. Rather than conducting electricity, this electrolyte allows an exchange of ions (electrically charged atoms or groups of atoms).

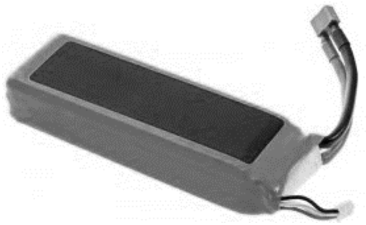


Fig.23. Lithium Ion Polymer

Lithium ion batteries and are not toxic and are smaller and charge faster than NiCd batteries. They are commonly used in tablets, gaming systems, and cell phones.

Superconducting magnetic energy storage

The SMES system is a relatively recent technology. Its operation is based on storing energy in a magnetic field, which is created by a DC current through a large superconducting coil at a cryogenic temperature. The energy stored is calculated as the product of the self-inductance of the coil and the square of the current flowing through it. The response time is very short. The SMES technology has been demonstrated but the price is still very high.

Flywheel

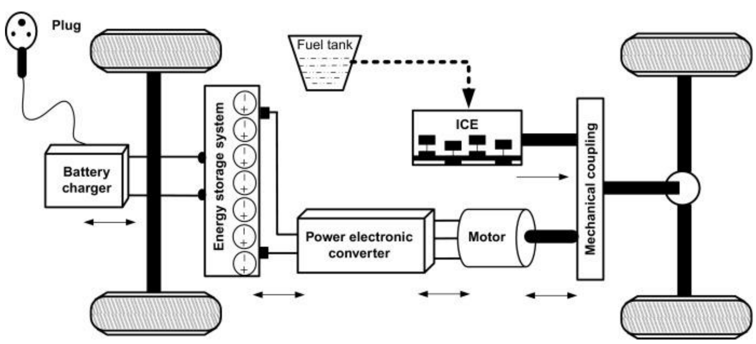
In an FW the storage capacity is based on the kinetic energy of a rotating disc which depends on the square of the rotational speed. A mass rotates on two magnetic bearings in order to decrease friction at high speed, coupled with an electric machine. Energy is transferred to the FW when the machine operates as a motor (the FW accelerates), charging the energy storage device. The FW energy storage system (FESS) is discharged when the electric machine regenerates through the drive (slowing the FW). FESSs have long lifetimes, high energy density, and a large maximum output power. The energy efficiency of an FESS can be as high as 90%. Typical capacities range from 3–133 kWh.

Plug in electric vehicle

Recent PEVs have been increased extensively and usually include a BESS. PEVs may play an important part in balancing the energy on the grid by serving as distributed sources of stored energy, a concept called “vehicle-to-grid”. By drawing on a large number of batteries plugged into the Smart grid (SG) throughout its service region, a utility can potentially inject extra power into the grid during critical peak times, avoiding brownouts and rolling blackouts. Therefore, they can play a vital role to improve the power system reliability and the power quality of the SG.

PEVs can drastically lessen the dependence on oil, and they emit nothing about air pollutants when running in all-electric modes. However, they do rely on power plants to charge their batteries, and conventional fossil-fueled power plants release pollution. To run a PEV as cleanly as possible, it needs to be charged in the hours of the morning when power demand is at its lowest and when wind power is typically at its peak. The SG technologies will help to meet this goal by interacting with the PEV to charge it at the most optimal time.

PHEV is hybrid electric vehicle that contains at least (i) a battery storage system of 4 kWh or more, used to power the motion of the vehicle; (ii) a means of recharging that battery system from an external source of electricity; and (iii) an ability to drive at least 10 mi in all-electric mode, and consume no gasoline”. Conceptually, a PHEV is a HEV with large battery pack that can be recharged from the external source (utility grid or renewable source of energy) to extend the all-electric range (AER) of the vehicles



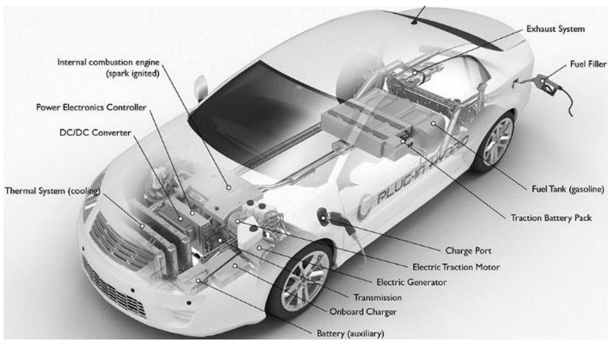


Fig. 24. Plug in electric vehicle

Hybrid Energy Systems

A hybrid energy system 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 hybrid system can combine wind, solar with an additional resource of generation or storage. They may range in size from relatively large island grids of many megawatts to individual household power supplies on the order of one kilowatt.

Hybrid power systems that deliver alternating current of fixed frequency are an emerging technology for supplying electric power in remote locations. They can take advantage of the ease of transforming the AC power to higher voltages to minimize power loss in transferring the power over relatively long distances.

Larger systems, nominally above 100 kW, typically consist of AC-connected diesel generators, renewable sources, loads, and occasionally include energy storage subsystems. Below 100 kW, combinations of both AC and DC-connected components are common as is use of energy storage. The DC components could include diesel generators, renewable sources, and storage. Small hybrid systems serving only DC loads, typically less than 5 kW, have been used commercially for many years at remote sites for telecommunications repeater stations and other low power applications.

In general, a hybrid system might contain AC diesel generators, DC diesel generators, an AC distribution system, a DC distribution system, loads, renewable power sources (wind turbines, or photovoltaic power sources), energy storage, power converters, rotary converters, coupled diesel systems, dump loads, load management options, or a supervisory control system. Hybrid systems might also include biomass or hydroelectric generators. A schematic of the possibilities for hybrid systems is illustrated in the following figure.

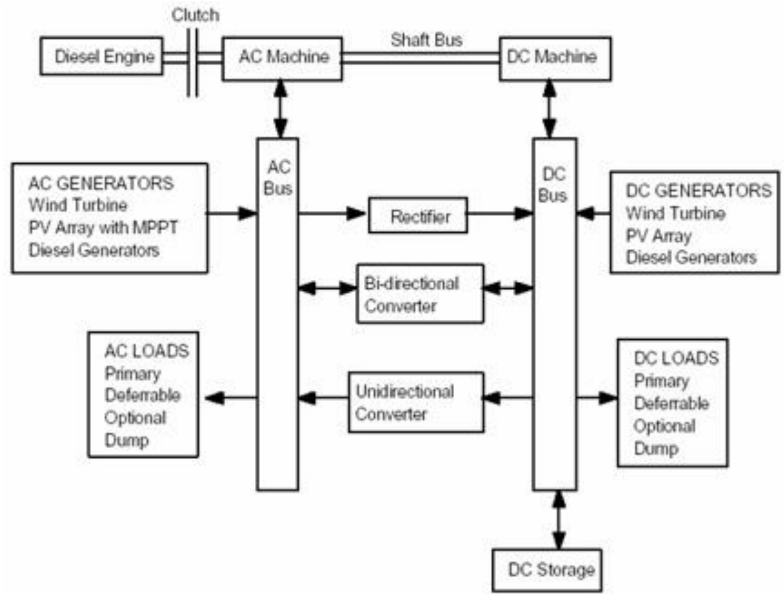


Fig. 25. Hybrid energy storage system

Examples of hybrid systems

Wind-solar hybrid system

As the wind does not blow all the time nor does the sun shine all the time, solar and wind power alone are poor power sources. Hybridizing solar and wind power (min wind speed 4-6m/s) sources together with storage batteries to cover the periods of time without sun or wind provides a realistic form of power generation. The system creates a stand-alone energy source that is both dependable and consistent which is called the solar-wind hybrid system. Generally, these solar wind hybrid systems are capable of small capabilities. The typical power generation capacities of solar wind hybrid systems are in the range from 1 kW to 10 kW.

Major components of solar-wind hybrid power plant are Solar PV modules, Wind turbine Regulation and conversion units, Inverters and electronic controllers, Battery Bank Generator (if required).

Working

- The hybrid solar wind turbine generator uses solar panels that collect light and convert it to energy along with wind turbines that collect energy from the wind.
- Solar wind composite power inverter has inputs for both sources, instead of having to use two inverters and it contains the required AC to DC transformer to supply charge to batteries from AC generators.
- Hence the power from the solar panels and wind turbine is filtered and stored in the battery bank.
- For the times when neither the wind nor the solar system are producing, most hybrid systems provide power through batteries and/or an engine generator powered by conventional fuels, such as diesel.
- If the batteries run low, the engine generator can provide power and recharge the batteries.
- Adding an engine generator makes the system more complex, but modern electronic controllers can operate these systems automatically.
- An engine generator can also reduce the size of the other components needed for the system.
- Keep in mind that the storage capacity must be large enough to supply electrical needs during non-charging periods

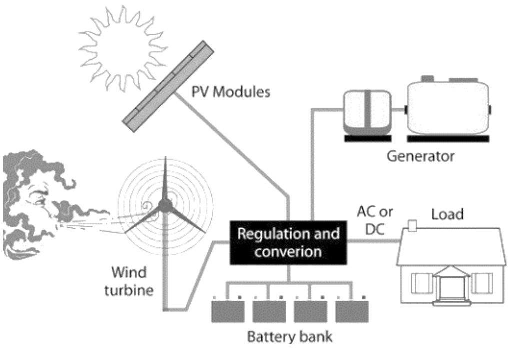


Fig. 26. Wind-solar hybrid system

Wind–hydro hybrid system

Hydropower generation is to convert potential energy in water into electrical energy by means of hydropower generators. As a renewable and clean energy source, hydropower accounts for the dominant portion of electricity generated from all renewable sources. In many locations of the world, hydropower is complementary with wind power, while the seasonal wind power distribution is higher in winter and spring but lower in summer and fall, hydropower is lower in the dry seasons (winter and spring) but higher in the wet seasons (summer and fall). Thus, the integration of wind and hydropower systems can provide significant technical, economic, and systematic benefits for both systems. Taking a reservoir as a means of energy regulation, "green" electricity can be produced with wind–hydro hybrid systems.

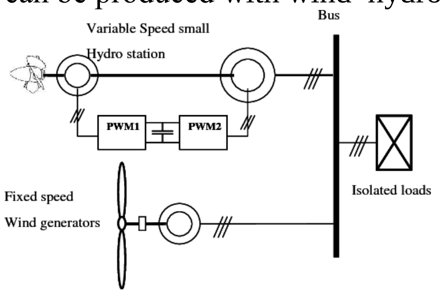


Fig. 27. Wind–hydro hybrid system

Wind–hydrogen system

Hydrogen is an energy carrier and can be produced from a variety of resources such as water, fossil fuels, and biomass. As a fuel with a high energy density, hydrogen can be stored, transported and then converted into electricity by means of fuel cells at end users. It is widely recognized that wind power, solar power and other renewable energy power generation systems can be integrated with the electrolysis hydrogen production system to produce hydrogen fuel. The largest wind to- hydrogen power system in the UK has been applied to a building that is fuelled solely by wind and "green" hydrogen power with the developed hydrogen mini grid system technology. In this system, electricity generated from a wind turbine is mainly used to provide to the building and excess electricity is used to produce hydrogen using a state-of-the-art high-pressure alkaline electrolyser.

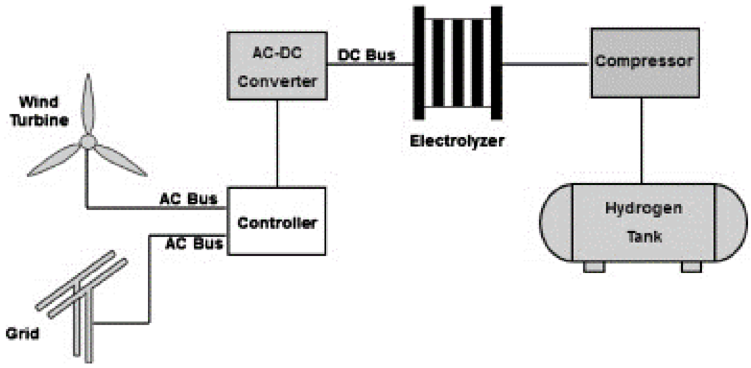


Fig. 28. Wind–hydrogen system

Wind–diesel power generation system

Wind power can be combined with power produced by diesel engine-generator systems to provide a stable supply of electricity. In response to the variations in wind power generation and electricity consumption, diesel generator sets may operate intermittently to reduce the consumption of the fuel. It was reported that a viable wind–diesel stand-alone system can operate with an estimated 50–80% fuel saving compared to power supply from diesel generation alone. Till now, many new techniques have been developed and a large number of wind– diesel power generation systems have been installed all over the world. According to the proportion of wind use in the system, three different types of wind–diesel systems can be distinguished: low, medium, and high penetration wind–diesel systems. Presently, low penetration systems are used at the commercial level, whereas solutions for high penetration wind–diesel systems are at the demonstration level. The technology trends include the development of robust and proven control strategies

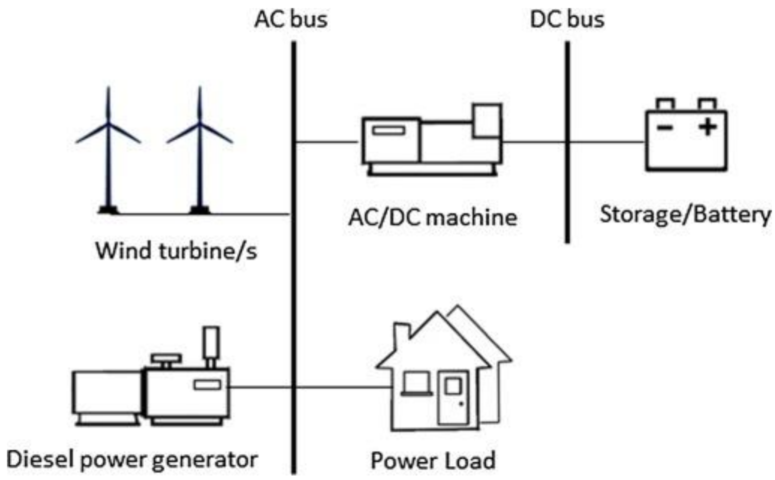


Fig. 29. Wind–diesel power generation system