



KEMENTERIAN PENDIDIKAN TINGGI

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**DEG40023**  
**RENEWABLE**  
**ENERGY**  
**SYSTEM**  
**-SECOND EDITION-**

**DEPARTMENT OF ELECTRICAL ENGINEERING**

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DEG40023  
RENEWABLE  
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*Edisi kedua*

*Terbitan Kedua 2024*

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*Diharapkan kandungan buku ini dapat membantu pelajar untuk menguasai kursus Renewable Energy System serta memudahkan pensyarah dalam proses pengajaran dan pembelajaran.*

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# SOLAR PHOTOVOLTAIC POWER SYSTEMS

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## CHAPTER

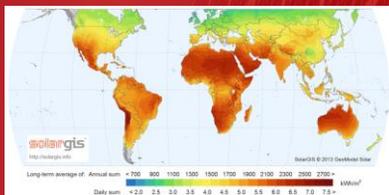
# 01

- ✓ Types of solar photovoltaic system
- ✓ Operation of charge controller and batteries
- ✓ Options for selecting inverters
- ✓ Options for PV array mounting

## 1.1 Types Of Solar Photovoltaic System

### PHOTOVOLTAIC

**Photovoltaic (PV)** is system to convert sunlight directly into electricity and are potentially one of the most useful of the renewable energy technologies. Solar PV systems use cells to convert sunlight to electricity. The PV cell consists of one or two layers of a semi conducting material, usually silicon. When light shines on the cell it creates an electric field across the layers causing electricity to flow.



The availability of solar energy received on the surface of the earth depends on the geography of both the earth and the sun. The rotation on its tilted axis and its revolution around the sun leads to the temporal and spatial variations of solar radiation received by locations on the Earth's motion and relative apparent motion of the sun in the basic geometrical aspect are essential appreciation of sitting a PV system and eventually the design and sizing procedures.

Nowadays there are 4 types of Solar Photovoltaic Systems like:

- Grid-connected PV system (GCPV)
- Grid-connected PV System with Battery Backup
- Off-Grid PV System (OGPV)
- Hybrid PV System



GCPV

A grid-connected PV (GCPV) system is a set of equipment that comprises PV modules, an inverter, BOS and components that are connected to a utility grid

The "Grid - Connected With Battery Backup" PV system incorporates one or more special AC circuits which are not directly connected to the electric grid like the rest of the building, but are always powered through the inverter and/or charge controller



GCPV WITH BATTERY



OGPV

A basic off-grid OR stand-alone system consists of a renewable energy source, which generates DC power, a battery bank that stores the DC power, and an inverter/charger unit.

Hybrid photovoltaic systems most commonly take the form of photovoltaic systems combined with wind turbines or diesel generators



HYBRID

## 1.1 Types Of Solar Photovoltaic System

### GCPV SYSTEM

A **grid-connected PV (GCPV)** system is a set of equipment that comprises PV modules, an inverter, BOS and components that are connected to a utility grid.

The typical BOS components required for PV grid-connected system. Consists of cables, breakers, protection devices and structures for mounting the PV arrays or modules.

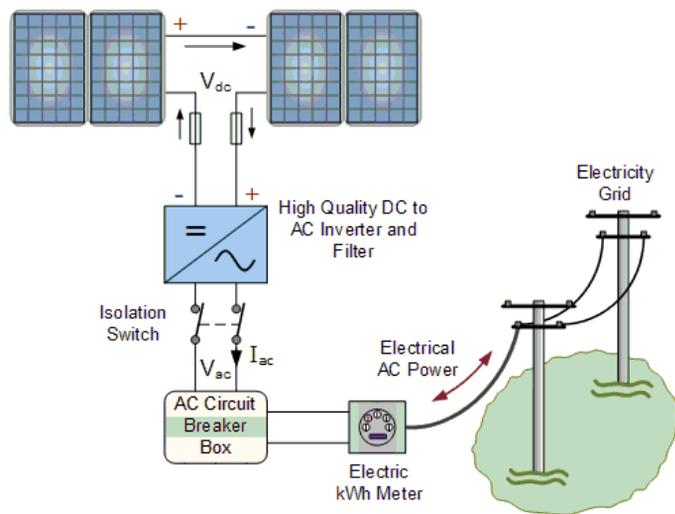
GCPV does not need a battery system as an energy storage as is the stand-alone system and connected to the grid network Fit in Tariff Scheme (for GCPV).

#### Did you know??

This system (GCPV) is popular in Malaysia since 2011 and ended in 2019 where the Feed-in Tariff (FiT) mechanism has been implemented.

The Sustainable Energy Development Authority of Malaysia (SEDA) is the agency under Ministry of Energy, Green Technology and Water (KeTTHA) that responsible for FiT.

Solar PV Panels or Array



Basic Schematic Diagram



**Inverter** – The inverter is the most important part of any grid connected system. The inverter extracts as much DC (direct current) electricity as possible from the PV array and converts it into clean mains AC (alternating current) electricity at the right voltage and frequency for feeding into the grid or for supplying domestic loads.

**AC Breaker Panel and Fuses** – The breaker panel or fuse box is the normal type of fuse box provided with a domestic electricity supply and installation except for additional breakers for inverter and/or filter connections.

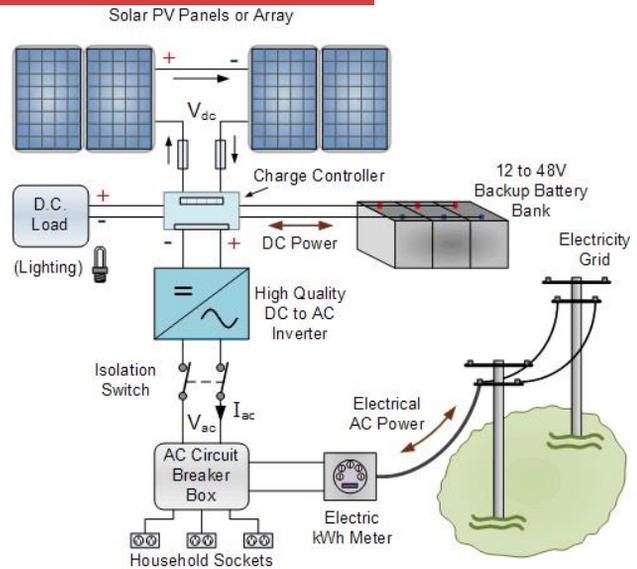


**Electricity Meter** – The electricity meter also called a Kilowatt hour (kWh) meter is used to record the flow of electricity to and from the grid. Twin kWh meters can be used, one to indicate the electrical energy being consumed and the other to record the solar electricity being sent to the grid.

## 1.1 Types Of Solar Photovoltaic System

- It is similar to the grid-connected residential system, but comes with an energy storage system usually in the form of battery backup
- The "Grid - Connected With Battery Backup" PV system incorporates one or more special AC circuits which are not directly connected to the electric grid like the rest of the building but are always powered through the inverter and/or charge controller.
- The charge controller manages the battery voltage, keeping them fully charged when the grid is live, and preventing them from being depleted when the system is drawing power from them.
- The "dual function" inverter can supply the utility grid with any excess power produced by the system like the "grid-tie" inverter, plus the inverter works with the PV modules and battery bank (through the charge controller) to provide AC power to the backup circuits when the grid is down.

### GCPV WITH BATTERY SYSTEM



Photovoltaic System With Battery Backup Diagram



A **charge controller** limits the rate at which electric current is added to or drawn from electric batteries. It prevents overcharging and may protect against overvoltage

A **battery** bank is group of batteries connected using series or parallel wiring. This allows more power to be stored than using a single battery. A battery bank allows you to store electricity generated by solar PV system for use at any time.



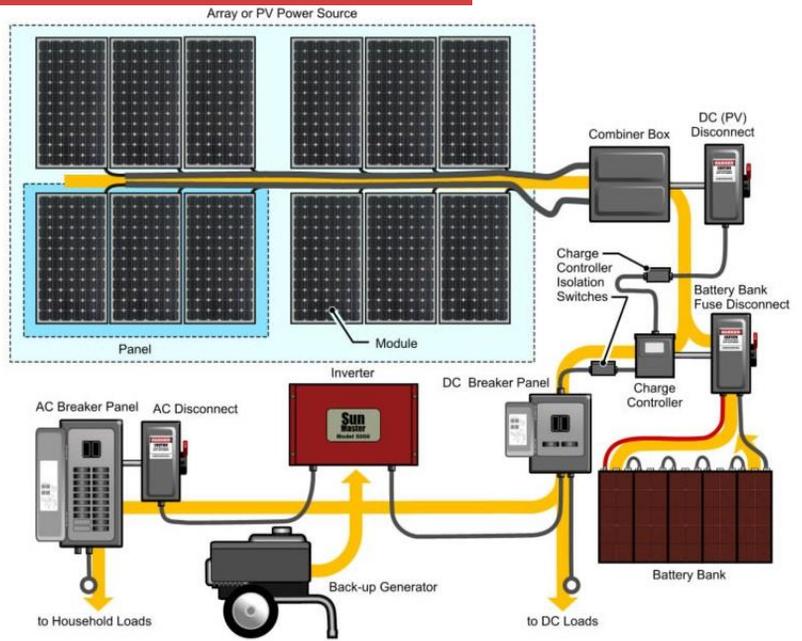
**Safety Switches and Cabling** – A photovoltaic array will always produce a voltage output in sunlight so it must be possible to disconnect it from the inverter for maintenance or testing. Isolator switches rated for the maximum DC voltage and current of the array and inverter safety switches must be provided separately with easy access to disconnect the system.

**The Electricity Grid** – Finally the electricity grid itself to connect too, because without the utility grid it is not a **Grid Connected PV System**

## 1.1 Types Of Solar Photovoltaic System

- The off-grid system is installed in very rural, remote areas, where it is expensive to run a power line to a home.
- The system is more expensive because it is bigger since it's not connected to the electric grid. This requires more solar panels and batteries.
- When the sun is up, the solar panels generate power to charge the battery bank and provide electricity. At night, the inverter/charger automatically runs the electrical equipment from the battery bank.
- The generator provides additional back-up battery charging capability for extended periods of cloudy weather.
- The inverter/charger can automatically start the generator and initiate a recharge cycle when the battery bank is depleted, or if the load is too large for the batteries to supply on their own.

### OGPV WITH BATTERY SYSTEM



### OGPV with Battery System Diagram

A basic off-grid OR stand-alone system consists of a renewable energy source, which generates DC power, a battery bank that stores the DC power, and an inverter/charger unit.

The system is **more expensive** because it is bigger since it's not connected to the electric grid. This requires more solar panels and batteries.



A **backup generator** or an emergency generator adds additional reliability and continuity to your power supply. Generally, the generator should be **around 2 times the size of the inverter's continuous output**. For example, a 4,000-watt inverter should be paired with an 8,000-watt generator

#### ADVANTAGES

**Independence:** One of the best things about this type of solar system is that not depend on the utility company

#### DISADVANTAGES

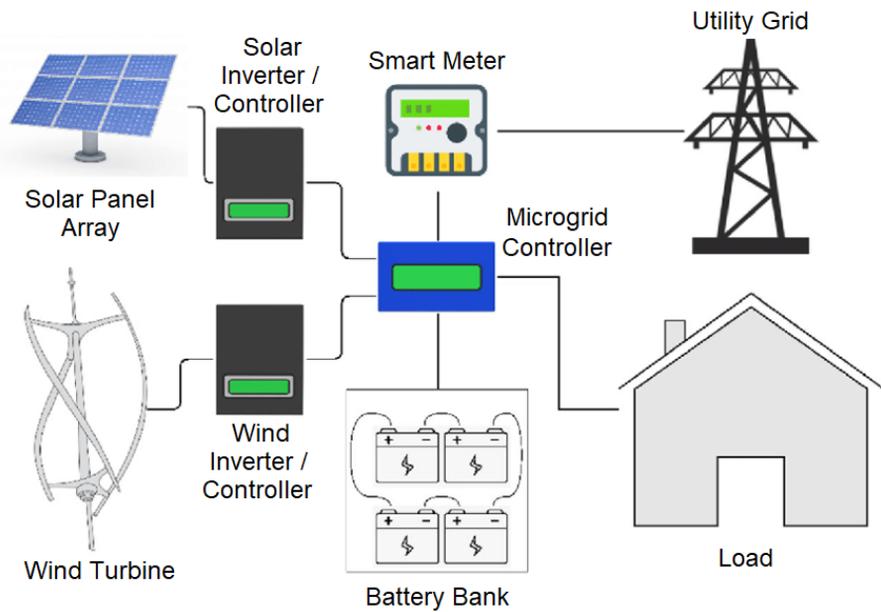
**Higher Initial Cost:** need a backup battery when there is no sun. Adding this source of backup will increase the solar costs.

**\*\*save the money, it can be more feasible to consider a grid-tied photovoltaic system.**

## 1.1 Types Of Solar Photovoltaic System

- Hybrid photovoltaic systems most commonly take the form of photovoltaic systems combined with wind turbines or diesel generators
- Other solar hybrids include solar-wind systems. The combination of wind and solar has the advantage that the two sources complement each other because the peak operating times for each system occur at different times of the day and year.

### HYBRID SYSTEM



Hybrid System Diagram



A **wind turbine** turns wind energy into electricity using the aerodynamic force from the rotor blades

A **wind charge controller** is an electronic device that both ensures that your turbines don't over charge your batteries, as well as limit how fast speed the wind turbine blades are able to spin when the batteries are full or in high wind situations. Having a purpose designed solar charge controller is essential to safely running a wind turbine, unless the wind turbine has a built-in safety system.



1.1 Types Of Solar Photovoltaic System

GRID TIED SYSTEM	
ADVANTAGES	DISADVANTAGES
1. relatively cheaper	1. can't store electricity
2. net metering	2. Utility companies charge monthly fees
3. grid becomes your cost-effective, reliable storage solution	3. not completely independent from the grid (still can blackout)
	4. These are battery-less systems, which provide you no backup.

GRID TIED WITH BATTERY SYSTEM	
ADVANTAGES	DISADVANTAGES
1. Sends excess energy back into power grid for credits	1. Increase in cost
2. Can provide power to designated appliances	2. efficiency is a little lower
3. Stores energy for use during an outage	3. The batteries & charger controller requires additional space
	4. Less battery life.
	5. Increase in maintenance.

OFFGRID SYSTEM	
ADVANTAGES	DISADVANTAGES
1. Independence (remote area)	1. Higher Initial Cost
2. Big Monthly Savings	2. Limited Solar Energy Storage
3. No Blackouts	3. Less battery life
4. No Electricity Bills	4. Energy Efficiency Is A Must

HYBRID SYSTEM	
ADVANTAGES	DISADVANTAGES
1. Continuous power	1. Complicated controlling process
2. Utilize the renewable sources in best way	2. High installation cost
3. Low maintenance cost	3. Less battery life
4. High efficiency	4. The number of instruments connectable is limited
5. Load management	

## 1.2 Operation of Charge Controller and Batteries

### Key Note:

PV solar system consists of three parts:

- i) PV modules or solar arrays,
- ii) Balance Of System [BOS],
- iii) Electrical Load



### Protection Mechanism Of Charge Controller

#### Over Charging

Occurs when the charger keeps the battery at a temperature that is warm to touch while in ready condition.

#### Over Discharge

Batteries can release high power and most packs include protection to safeguard against malfunction. Battery is a fuse that opens on high current.

#### Reverse Current

Flow of direct electric current in a reverse direction or of alternating current in phase opposition to normal

## SOLAR CHARGE CONTROLLER

A **charge controller**, **charge regulator** or **battery regulator** limits the rate at which electric current is added to or drawn from electric batteries. It prevents overcharging and may protect against overvoltage, which can reduce battery performance or lifespan and may pose a safety risk.



### PWM (Pulse Width Modulation)

**PWM** solar charge controllers are a great low-cost option for small 12V systems when one or two solar panels are used, such as simple applications like solar lighting, camping and basic things like USB/phone chargers. Note, if more than one panel is used, they should be connected in parallel, not series.

**MPPT** more advanced than PWM controllers and enable the solar panel to operate at its maximum power point, or to be more precise, the optimum voltage for maximum power output. MPPT solar charge controllers can be up to 30% more efficient, depending on the battery voltage and operating voltage ( $V_{mp}$ ) of the solar panel.



### MPPT (Maximum Power Point Trackers)

#### Ascending Charge

When the battery voltage ascending to the set value in charging course, the solar controller will maintain it at the set value via adjusting the charging current constantly. This step could prevent battery's over-heat and gas generation.

#### Floating stage

Solar controller switches to the floating charge stage when finishing the ascending charge. All the charging current will turn into heat and gas when the battery full charge, no more electrochemical reaction happens. At this time, the floating charge occurs.

#### Equalizing Charge

Equalizing charge boost the battery voltage to let it higher than standard supply voltage and gasify the battery electrolyte

## 1.2 Operation of Charge Controller and Batteries

### Did you know??

The lead-acid battery was invented in 1859 by French physicist Gaston Planté and is the **oldest type of rechargeable battery**.

### Battery Maintenance and Safety

- Wash hand after handling
- Keep sparks, flames and cigarettes away from battery's
- Always disconnect grounded cable first and connect it last to prevent dangerous sparks.
- Wear proper eye protections
- Be sure, load tester is off and battery is disconnected before hook-up to avoid explosive gasses.
- Never attempt to charge a frozen battery to avoid a battery explosion.

### Did you know??

LiFePO4 batteries have much longer life span than lead acid batteries and they can work perfectly for the period of 5-7 years and cycle life can be up to 2500 cycles.

### Type of Batteries



**Flooded lead acid batteries**

- Have the longest track record in solar electric use and are still used in the **majority of stand-alone alternative energy systems**-Longest life
- Require regular maintenance in the form of watering, equalizing charges and keeping the top and terminals clean
- more use in solar electric systems
- Suited for use in grid-tied solar system with battery back-up
- suited to systems that get infrequent use as they typically have less than a 2% self discharge rate during transport and storage.

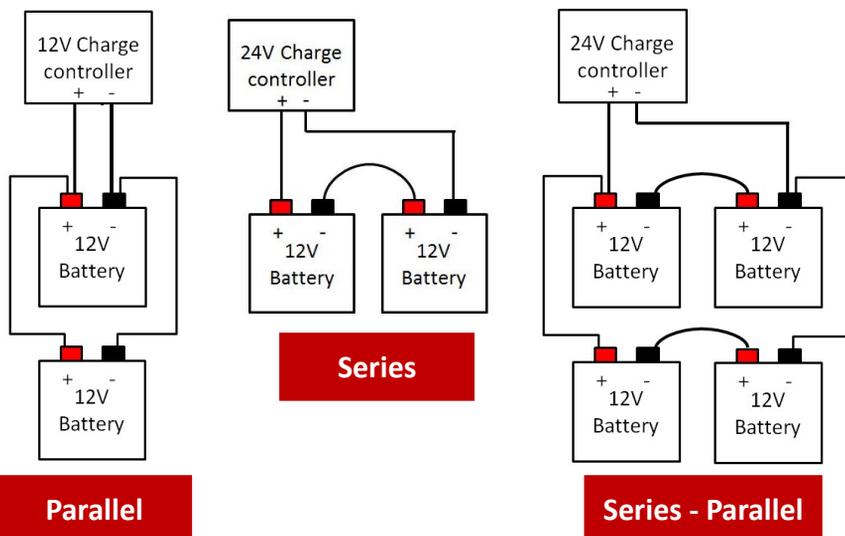


**Sealed lead acid batteries**



**Lithium (LiFePO4) batteries**

LiFePO4 batteries are an **ideal choice for stand-alone PV systems** due to their high efficiencies and long cycle life, provided that they are operated with a charge control algorithm specifically targeted for long charge durations as they are typical in solar PV applications.



1.3 Options For Selecting Inverter

Inverters play a crucial role in any solar energy system and are often considered to be the brains of a project, whether it's a 2-kW residential system or a 5-MW utility power plant. An inverter's basic function is to "invert" the direct current (DC) output into alternating current (AC). AC is the standard used by all commercial appliances, which is why many view inverters as the "gateway" between the photovoltaic (PV) system and the energy off-taker.

INVERTERS



GCPV Inverter

GCPV Inverter is classified based on capacity rating and topology.

- Modular inverter or micro-Inverter
- DC Power Optimiser
- String Inverter
- Central Inverter

Off Grid Inverters are principally meant to be used with solar power systems for a home or business **totally disconnected from the electric utility company.**



OFF-GRID Inverter

**Can operate as Stand-Alone inverters and as Synchronous inverters at the same time!**



MULTIFUNCTION Inverter

In a typical installation, the Trace SW inverter is connected to a battery bank, the utility power lines, a standby generator and the house load center.

RE systems will use one of these three voltages: 12V, 24V, 48V. The **system voltage** of any given installation is usually, though not always, determined by the battery bank required by the application being served; the inverter, if one is used, will influence this decision as well

The **waveform** in commercially available modified-sine-wave inverters is a square wave with a pause before the polarity reversal, which only needs to cycle back and forth through a three-position switch that outputs forward, off, and reverse output at the pre-determined frequency

**Efficiency** is the ratio of power out to power in, expressed as a percentage. If the efficiency is 90 percent, 10 percent of the power is lost in the inverter. The efficiency of an inverter varies with the load.

An inverter's **surge capacity** indicates how it handles short-term overload before "tripping" Surge capacity is essential to start up some large loads, especially motors that need 2-3 times their running power to get going. The start period may be very short – a fraction of a second – but it still needs to be considered..

Selection Criterion For Inverter:

1. System Voltage
2. Output Waveform
3. Conversion Efficiency of
4. Surge Capacity

1.4 Options for PV array mounting

IMPLICATIONS OF TILT ANGLE ON SOLAR ARRAY INSTALLATION

- The tilt angle of a solar energy system is one of the important parameters for capturing maximum solar radiation falling on the solar panels. This angle is site-specific as it depends on the daily, monthly and yearly path of the sun.
- The tilt angles of flat plate type PV module, are generally set to the local latitude of the specific place in collecting the maximum yearly incident solar energy. Sometimes, the installation of PV plates with their optimum angles and orientation becomes hard due to the location and type of applications panels.
- This angle is site-specific as it depends on the daily, monthly and yearly path of the sun

The performance of a PV module has been studied with different varying parameters and conditions. The important factors that affect the operational performance of the PV unit are its orientation and tilt angle. The best Maximum average solar energy has been obtained from 20° to 30°

PV ARRAY MOUNTING

FREE-STANDING(FS) / POLE MOUNT



**Pole Mount** system is ideal for installations with little to no roof space, when shading is an issue, or to achieve maximum power production from the solar array. No roof penetration / liability Flexible positioning for max production. Easy to adjust the tilt angle (potential use for dual axis tracking and small footprint (one pole).it also easy access for maintenance /troubleshooting.

**Rack mounts** can be tailored to fit variety situation, accommodating both ground-mount and roof-mount applications.

Benefit to racks is they can allow variety of specific tilt angles. PV array can be set at optimal tilt angle based on site's latitude or, if adjustable racks are chosen, repositioned seasonally to optimize energy output.

RETROFITTED (RT) – RACK MOUNT



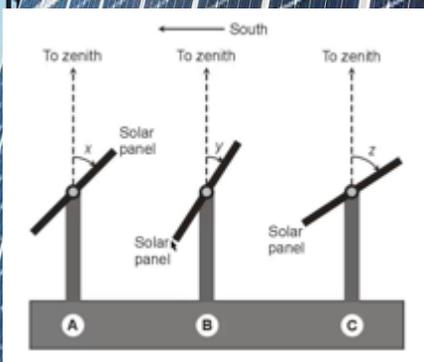
RETROFITTED (RT) – STANDOFF MOUNT



**Standoffs mount** can be installed on almost any style of tile roof, including batten or batten less and curve or flat tile profile . Standoffs attached to rafters typically stand about 4 to 6 inches from the decking on a flat tile roof and approximately 6 to 8 inches on higher profile curved tile roofs. Standoffs mounting allow for the use of virtually any racking system.

**Building integrated photovoltaic (BIPV)** are photovoltaic materials that are used to replace conventional building materials in parts of the building envelope such as the roof, skylights, or facades. They are increasingly being incorporated into the construction of new buildings as a principal or ancillary source of electrical power, although existing building may be retrofitted with similar technology.

BIPV – BUILDING INTEGRATED PHOTOVOLTAIC



## 1.5 Tutorial

**Structure Question**

1. Explain TWO (2) Principle operation of Charge Controller in Solar Photovoltaic Power System.
2. Write and explain the characteristics in the selection of the inverter used in Solar Photovoltaic Power System
3. State the differences of each type of Photovoltaic Array mounting in Solar Photovoltaic Power System.

**CASE STUDY QUESTION**

Detail ONE (1) of the Project must include (for Solar Company)  
(40 MARKS)

1. Recognition the type of Solar Power System Company used. (5 Marks)
2. Investigate the type of PV Modules and quantity and Balance of System (Type of Inverter, Cable, Charge Controller or Batteries) for the project used. (15 Marks)
3. Safety features in the working place. (5 Marks)
4. Understand the concept of solar type and estimate the output power distribution of Solar system. (10Marks)
5. Understand how Solar power plant interfaces to the grid. ( 5Marks)

# WIND ENERGY POWER SYSTEM

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## CHAPTER 02

- ✓ Types of Wind Power System
- ✓ Components of Wind Power System
- ✓ Types of Generator Used In Wind Power System
- ✓ Speed Control Mechanism In Wind Power System
- ✓ Important factors in wind power system selection
- ✓ Tower Options, Assembly and Installation In Wind Power System

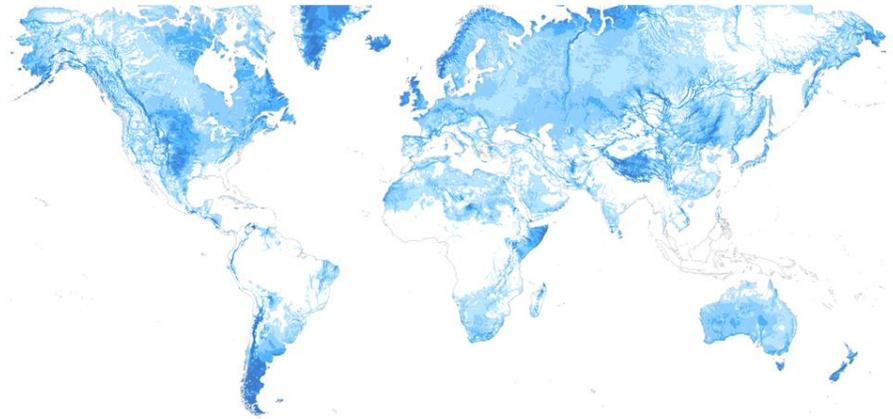
## 2.1 Key concept of Wind Power System

### Wind turbine system

Wind is created by the unequal heating of the Earth's surface by the sun. Wind turbines convert the kinetic energy in wind into clean electricity. When the wind spins the wind turbine's blades, a rotor captures the kinetic energy of the wind and converts it into rotary motion to drive the generator.

Wind speeds (m/s)

6 7 8 9 10+



Wind turbines work on a simple principle: instead of using electricity to make wind—like a fan—wind turbines use wind to make electricity. Wind turns the propeller-like blades of a turbine around a rotor, which spins a generator, which creates electricity.

Wind is a form of solar energy caused by a combination of three concurrent events:

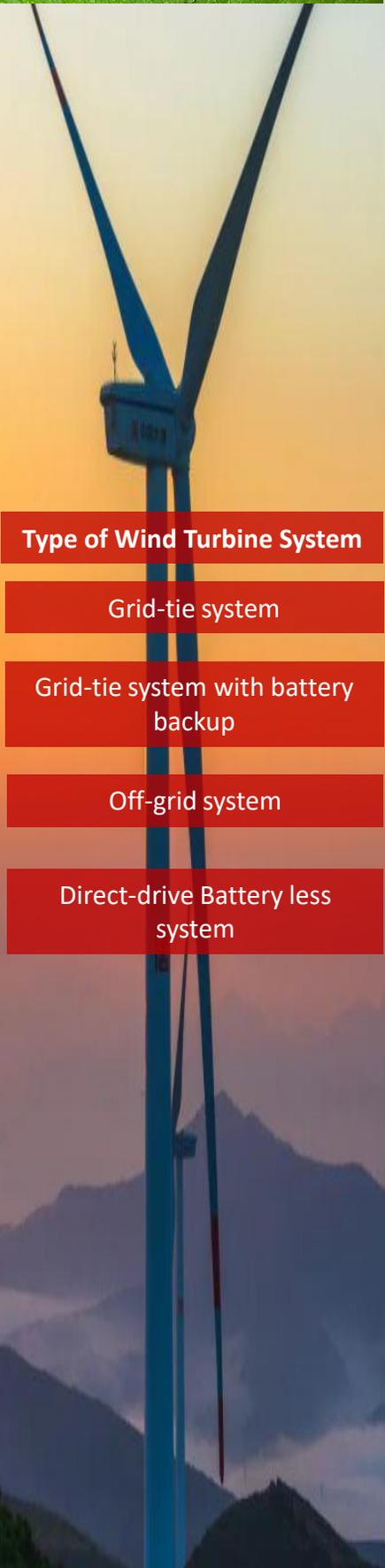
1. The sun unevenly heating the atmosphere
2. Irregularities of the earth's surface
3. The rotation of the earth.

A wind turbine turns wind energy into electricity using the aerodynamic force from the rotor blades, which work like an airplane wing or helicopter rotor blade. When wind flows across the blade, the air pressure on one side of the blade decreases. The difference in air pressure across the two sides of the blade creates both lift and drag. The force of the lift is stronger than the drag and this causes the rotor to spin. The rotor connects to the generator, either directly (if it's a direct drive turbine) or through a shaft and a series of gears (a gearbox) that speed up the rotation and allow for a physically smaller generator. This translation of aerodynamic force to rotation of a generator creates electricity.

#### Key concept:

- ✓ A wind turbine extracts energy from moving air by transferring this energy into a spinning shaft, which usually turns a generator to produce electricity.
- ✓ The power in the wind that's available for harvest depends on both the wind speed and the area that's swept by the turbine blades.

2.1 Type of Wind Power System



Type of Wind Turbine System

Grid-tie system

Grid-tie system with battery backup

Off-grid system

Direct-drive Battery less system

Grid-tie system

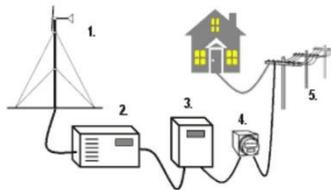


Diagram of a grid-tied wind power system without batteries

Connecting to the grid without batteries is the most cost effective and environmentally friendly way to go. You eliminate batteries, which are costly, require maintenance, and carry a significant efficiency penalty. The only drawback of battery less systems is that when the grid is down, your system shuts down.

Connecting a wind-electric system to the utility grid with battery backup gives you the best of both worlds. You have the unlimited capacity of the grid at your disposal, and you can send your surplus wind energy to the grid. When the grid is down, you can still use your system, within the limitations of the battery bank and turbine.

Grid-tie system with battery backup

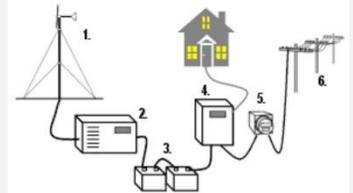


Diagram of a grid-tied wind power system with batteries

Off-grid system

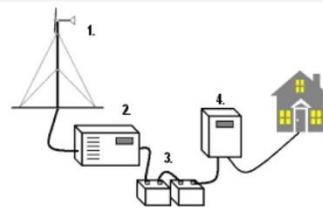


Diagram of an off-grid wind power system

Off-grid wind-electric systems are battery based. People generally choose these systems because their home or other energy use is not connected to the grid, and connection would be expensive. Others prefer the independence of off grid systems, or live where utilities and governments make it difficult to tie a renewable energy system to the grid.

These are the least common wind-electric systems, typically used for water pumping. A turbine is matched to a pump, often through an electronic controller. When the wind blows, water is pumped to an elevated tank, a stock-watering tank, or directly to the land to irrigate. Direct-drive systems are also used for heating.

Direct-drive Battery less system

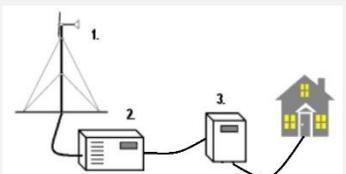
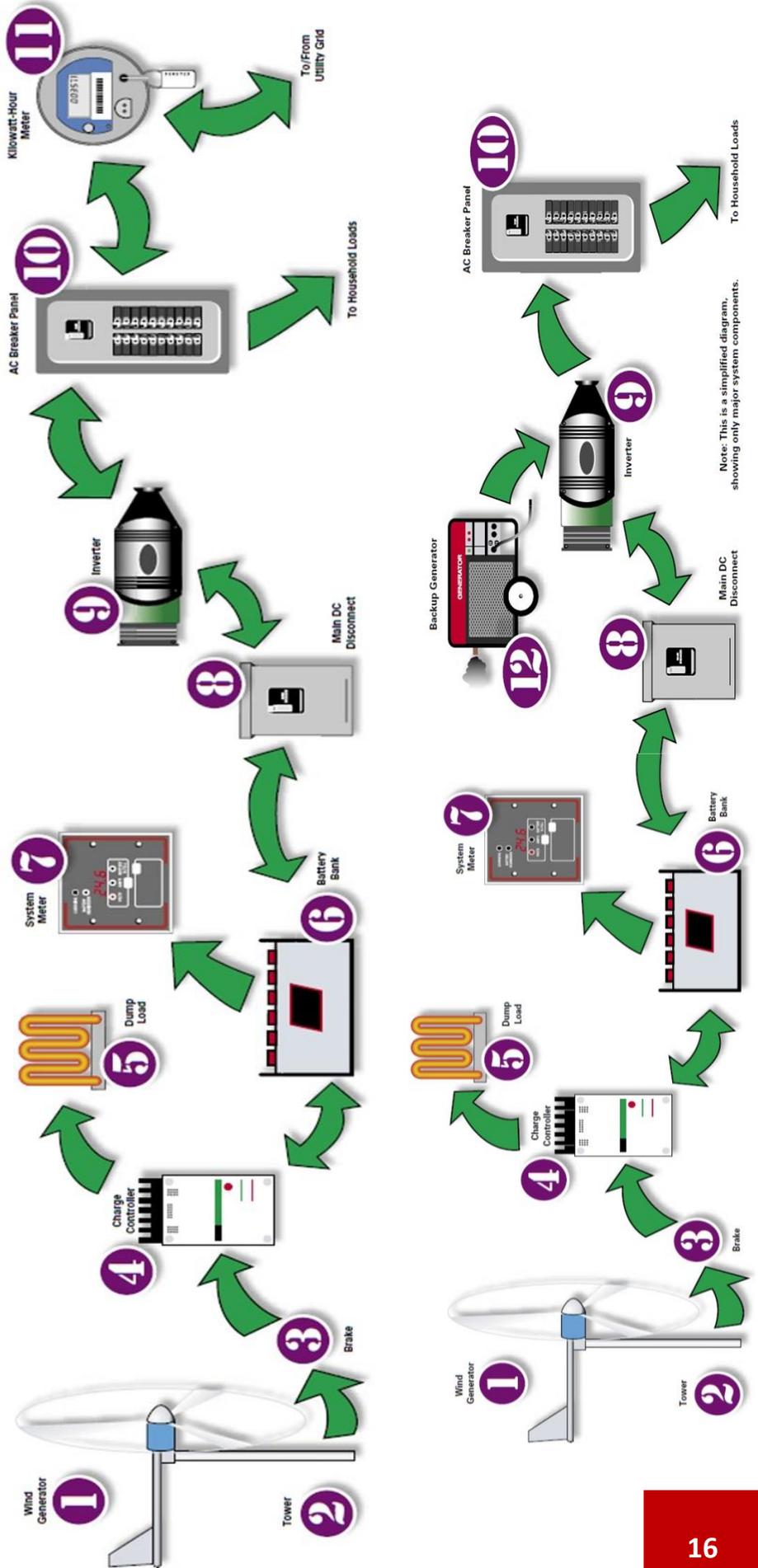


Diagram of a direct drive wind power system

2.1 Type of Wind Power System

Can you differentiate which one Grid-tie system and Off-grid system? Why?



## 2.1 Advantage & Disadvantage of Wind Power System

### Wind Power System advantages:

- ✓ Wind power is cost-effective.
- ✓ Wind creates jobs.
- ✓ It's a clean fuel source.
- ✓ Wind is a domestic source of energy.
- ✓ It's sustainable
- ✓ Wind turbines can be built on existing farms or ranches.
- ✓ Wind turbines are available in a range of sizes
- ✓ Remote areas

## ADVANTAGES

**Wind power is cost-effective.** Land-based utility-scale wind is one of the lowest-priced energy sources available today, costing 1–2 cents per kilowatt-hour after the production tax credit. Because the electricity from wind farms is sold at a fixed price over a long period of time (e.g., 20+ years) and its fuel is free, wind energy mitigates the price uncertainty that fuel costs add to traditional sources of energy.

**Wind creates jobs.** According to the *Wind Vision Report*, wind has the potential to support more than 600,000 jobs in manufacturing, installation, maintenance, and supporting services by 2050.

**It's a clean fuel source.** Wind energy doesn't pollute the air like power plants that rely on combustion of fossil fuels, such as coal or natural gas, which emit particulate matter, nitrogen oxides, and sulfur dioxide—causing human health problems and economic damages. Wind turbines don't produce atmospheric emissions that cause acid rain, smog, or greenhouse gases.

**Wind is a domestic source of energy.** The nation's wind supply is abundant and inexhaustible. Wind turbines have a role to play in both the developed and third world

**It's sustainable.** Wind is a form of solar energy. Winds are caused by the heating of the atmosphere by the sun, the rotation of the Earth, and the Earth's surface irregularities. For as long as the sun shines and the wind blows, the energy produced can be harnessed to send power across the grid.

**Wind turbines can be built on existing farms or ranches.** This greatly benefits the economy in rural areas, where most of the best wind sites are found. Farmers and ranchers can continue to work the land because the wind turbines use only a fraction of the land. Wind power plant owners make rent payments to the farmer or rancher for the use of the land, providing landowners with additional income.

**Wind turbines are available in a range of sizes** which means a vast range of people and businesses can use them. Single households to small towns and villages can make good use of range of wind turbines available today

**Remote areas** that are not connected to the electricity power grid can use wind turbines to produce their own supply.

## 2.1 Advantage & Disadvantage of Wind Power System

### DISADVANTAGES

**Wind power must still compete with conventional generation sources on a cost basis.** Even though the cost of wind power has decreased dramatically in the past several decades, wind projects must be able to compete economically with the lowest-cost source of electricity, and some locations may not be windy enough to be cost competitive.

**Good land-based wind sites are often located in remote locations, far from cities where the electricity is needed.** Transmission lines must be built to bring the electricity from the wind farm to the city. However, building just a few already-proposed transmission lines could significantly reduce the costs of expanding wind energy.

**Wind resource development might not be the most profitable use of the land.** Land suitable for wind-turbine installation must compete with alternative uses for the land, which might be more highly valued than electricity generation.

**Turbines might cause noise and aesthetic pollution.** Although wind power plants have relatively little impact on the environment compared to conventional power plants, concern exists over the noise produced by the turbine blades and visual impacts to the landscape.

**Wind plants can impact local wildlife.** Birds have been killed by flying into spinning turbine blades. Most of these problems have been resolved or greatly reduced through technology development or by properly siting wind plants. Bats have also been killed by turbine blades, and research is ongoing to develop and improve solutions to reduce the impact of wind turbines on these species.

**Large wind farms** are needed to provide entire communities with enough electricity.

**The strength of the wind** is not constant, and it varies from zero to storm force. This means that wind turbines do not produce the same amount of electricity all the time. There will be times when they produce no electricity at all.

**Many people feel that the countryside should be left untouched,** without these large structures being built. The landscape should be left in its natural form for everyone to enjoy.

#### Wind Power System disadvantages:

- ✓ Wind power must still compete with conventional generation sources on a cost basis.
- ✓ Good land-based wind sites are often located in remote locations.
- ✓ Wind resource development might not be the most profitable use of the land.
- ✓ Turbines might cause noise and aesthetic pollution.
- ✓ Wind plants can impact local wildlife.
- ✓ Large wind farms
- ✓ The strength of the wind
- ✓ Many people feel that the countryside should be left untouched

## 2.2 Anatomy of Wind Turbines

### Two Types of Wind Turbine:

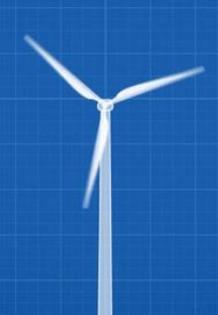
- ✓ Horizontal Axis Wind Turbine (HAWT)
- ✓ Vertical Axis Wind Turbine (VAWT)

### Did you know??

Too expensive  
with added risks



Optimum.  
Not more, not less.



Not very  
cost-effective

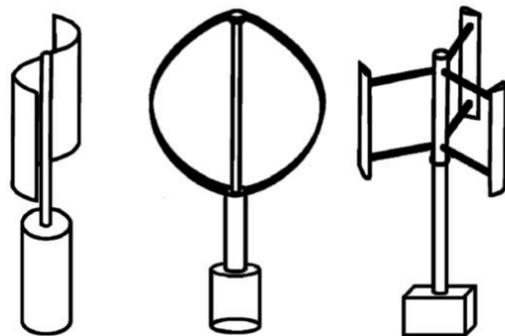


## Horizontal Axis Wind Turbine (HAWT)



**HAWT** (horizontal axis wind turbine) also includes in the famous types of wind turbines. The main shaft of a **HAWT** fixes in the **horizontal direction to the ground**, and this makes it different from a **vertical axis wind turbine**. In simple words, the rotating axis of a **horizontal axis wind turbine** is positioned in a **horizontal direction** to the ground.

## Vertical Axis Wind Turbine (VAWT)



Savonius

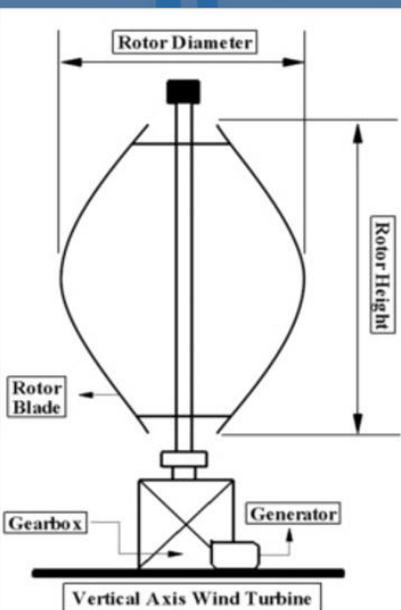
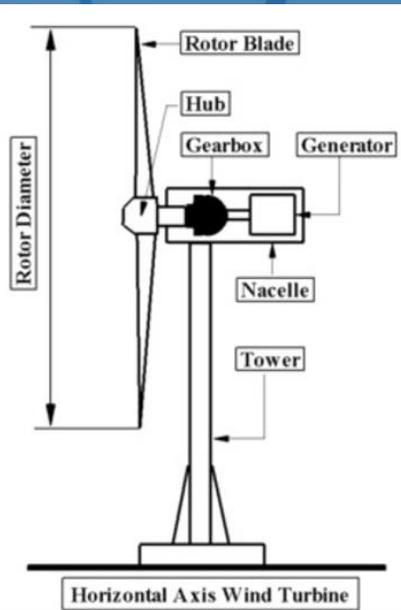
Darrieus

H-Rotor

**VAWT** or **Vertical axis wind turbine** includes in the most famous types of the wind turbine. The **main shaft** of the **VAWT** is fixed in the vertical direction to the ground. While some other major parts place at the turbine base. In simple words, the rotating shaft of the **vertical axis wind turbine** is positioned in a **vertical or perpendicular** direction to the ground. You don't have to turn it into the wind direction for the turbine to work effectively.

## 2.2 Anatomy of Wind Turbines

Did you know??



### Horizontal Axis Wind Turbine

#### Advantages:

- The towers are relatively tall which allows the blades to face much higher velocity winds in high altitude. In some places, the power output of the wind turbine could increase up to 30% every ten meters in altitude because the wind speed is increased by 20%
- High efficiency, the blades always move perpendicular to the wind, receiving power through the whole rotation unlike vertical axis wind turbines.

#### Disadvantages:

- High construction and installation costs. Large Machinery is needed.
- Aesthetically unpleasing. Wind turbines are unappealing to an otherwise beautiful and visually pleasing landscape.

### Vertical Axis Wind Turbine

#### Advantages:

- Does not have to be pointed towards the wind to be effective. This creates a flexible location for placement of the turbine in an area with varying wind direction.
- Capable of operating during minimal wind speed. Long curved propellers are designed to be pushed by a small amount of wind.
- Does not have to be installed at a very high place via a tower. City ordinance regulations do not take effect and lowers cost due to materials needed for construction. Aesthetically more pleasing.
- Easily visible to wildlife. While spinning or at rest, a vertical axis turbine appears as a solid object.
- The generator does not have to be installed on the top of a tower. Important for maintenance considerations.

#### Disadvantages:

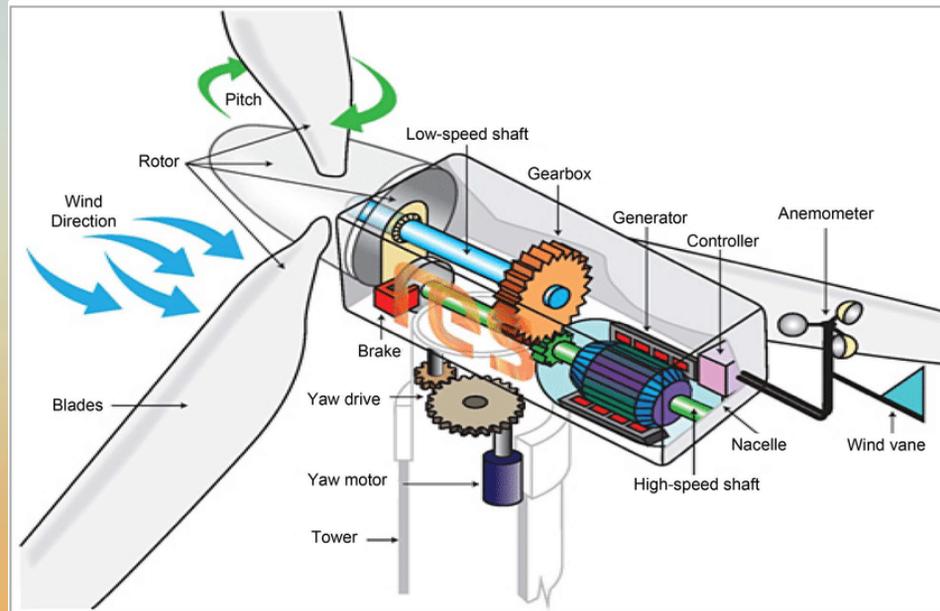
- The lower the place, the slower the wind. This reduces the turbines efficiency which makes it less cost effective

## 2.2 Function of Components in Wind Power System

### Wind Turbine

#### Wind turbine component :

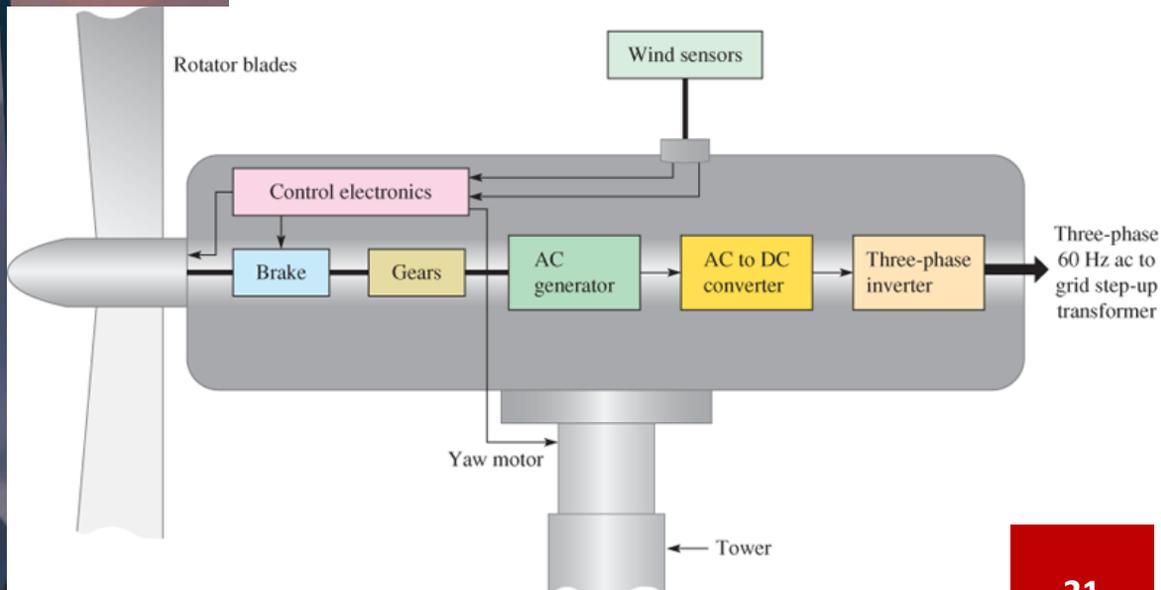
- Wind turbine
- Charge controller
- Dump load
- Battery bank
- System meter
- Main dc disconnect
- Inverter
- Ac breaker panel
- Backup generator
- Kilowatt-hour meter



#### Rotor System

The rotor has one or more blades and a hub. From a performance and total cost perspective, it is considered the essential component. The rotor may have one, two, three, or more blades. The rotor that contains a single blade needs a counterweight to remove vibration, but this design is not applicable in the areas where snow on the blades can unbalance the machine.

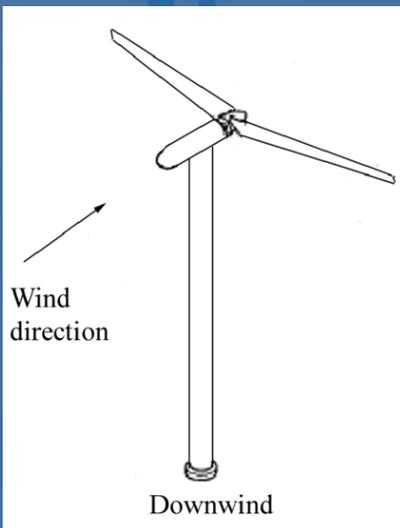
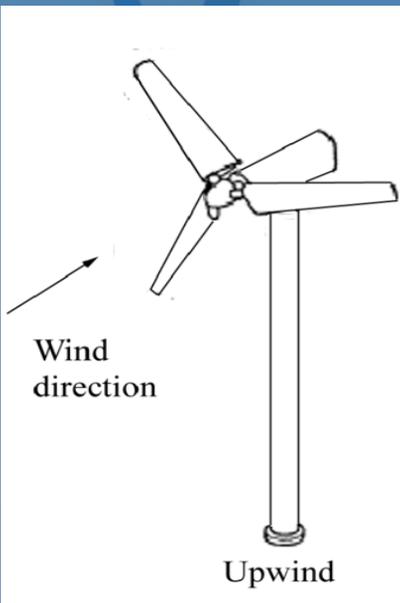
A rotor with two blades uses more often because it is more robust, simpler, and cheaper than the 3-bladed rotor. Still, recently the 3-bladed rotor has been used a lot because the 3-bladed rotor distributes the tension more consistently as the turbine spins, or yaws, during the variations in the wind orientation.



## 2.2 Function of Components in Wind Power System

### Did you know??

The horizontal axis wind turbine has the following major types



### Hub

A hub is the most important and major component of the horizontal axis wind turbine. In the rigid hub, all blades bolt with the hub. This hub severely connects to the turbine shaft. The blades cantilevered from the turbine shaft and transfer their dynamic loads directly to the shaft.

### Power train subsystem

The power train system of the turbine has numerous electrical and mechanical parts that change the mechanical energy absorbed by the rotor hub into electrical energy. The power train of HAWT has an assembly of **turbine shaft** (also known as the main shaft), **lubrication**, **an auxiliary control unit**, **a generator**, **a rotor brake**, **a generator drive shaft**, **a speed gearbox**, and **cooling functions**.

### Gearbox

Wind turbines rotate typically between 40 rpm and 400 rpm. Generators typically rotates at 1,200 to 1,800 rpm. Most wind turbines require a step-up gear-box for efficient generator operation (electricity production).

### Blades

A wind turbine blade uses to obtain Kinetic Energy from the wind and transforms this energy into rotational power (mechanical power). These blades are located on the turbine rotor hub. Wood epoxy or glass fiber reinforced polyester uses to design the wind turbine blades.

The turbine rotor may have one or more blades according to the turbine construction. Maximum horizontal axis wind turbines have three blades. The multi-blade concept was utilized in the past for milling and pumping applications.

### Tower

A tower is a component of the horizontal wind turbine that assists the rotor hub and the nacelle. These towers consist of steel lattice, concrete, or tubular steel. The tower height plays an important role in the HWAT performance. The taller tower enables the turbine to absorb maximum wind kinetic energy and produce maximum electricity. The performance of a typical wind turbine increases with altitude and reduces wind turbulence.

### Foundation

An excellent foundation requires to assist the tower and various components of the turbine, and the tower weight is in many **kgs**.

## 2.2 Function of Components in Wind Power System

### MPPT Charger Controller



### PWM Charger Controller



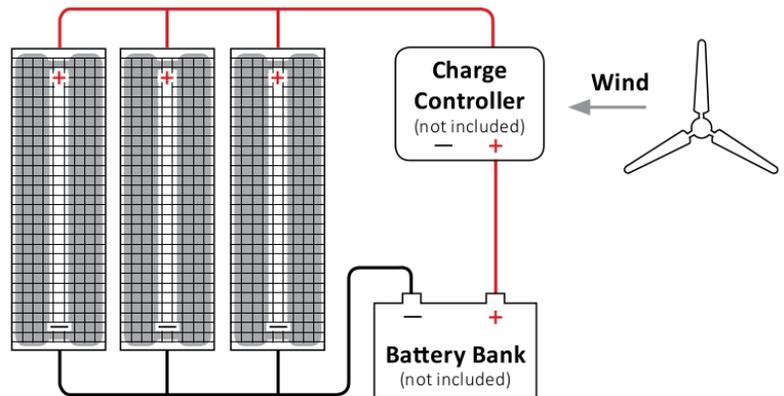
A charge controller, charge regulator or battery regulator **limits the rate at which electric current is added to or drawn from electric batteries**. It prevents overcharging and may protect against overvoltage, which can reduce battery performance or lifespan and may pose a safety risk.

A solar charge controller is available in two different technologies, PWM and MPPT. How they perform in a system is very different from each other. An MPPT charge controller is more expensive than a PWM charge controller, and it is often worth it to pay the extra money.

### Did you know??

Not using a reliable dump load, or no divert load at all, can cause serious heat build up in the wind turbine motor which could ultimately cause the motor to overheat, seize up, and burn out the stator.

### Divert / Dump Load



When your batteries are full, you need **to divert the excess power being generated to a separate load** so your wind turbines will not go into high-speed freewheeling in heavy winds. That is where a dump load (also called a divert load) comes in. The charge controller will switch from battery charging to sending power to the dump load to keep the wind turbine under load.



## 2.2 Function of Components in Wind Power System

### Battery Bank / Storage



These stationary batteries use chemical interactions to safely store electricity from the renewable energy source so that it can be made available later. **The wind turbine charges a bank of batteries, thus enabling efficient wind turbine power distribution throughout the grid.**

**A wind turbine battery storage system utilizes inverters to operate without support from the grid in case of power outages.**

Battery storage doesn't only supply power to the user. The newest standards for inverters requires them to be capable of performing grid services. This is a great benefit of distributed generation because it reinforces the entire electrical grid with innumerable "helper" generators.

Instead of the grid sagging when a big load comes in, the newest inverters can crank up the output to keep the grid stable for everyone.

### Wind System Meter

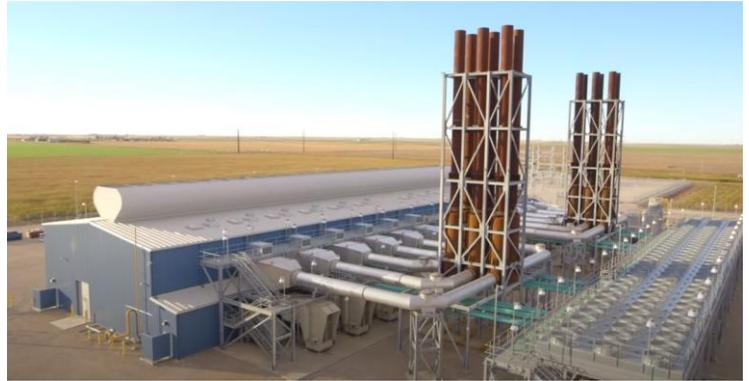


System meters can **measure and display several different aspects of wind-electric system's performance and status.**

Complete system meter include voltage, current, power, energy and win speed.

## 2.2 Function of Components in Wind Power System

### Backup Generator



Off-grid wind-electric systems can be sized to provide electricity during calm periods when the wind doesn't blow.

But for a large utility, wind power do not need a special "backup" generator. Utilities can plan their system to anticipate what additional generation they will need to ensure reliability, and it is very rare that they need a one-for-one generation backup for wind power system.

### Did you know??

Large-scale wind turbines typically start turning in winds minimum speed of 11 to 14 km/h to begin turning and generate electricity and their top speeds are around 80-90 km/h

### Main DC Disconnect



Disconnect between the batteries and inverter is required. This breaker **allows the inverter to be quickly disconnected from the batteries** for service and protects the inverter-to-battery wiring against electrical fires.

### Kilowatt-Hour Meter



A bidirectional KWH meter can simultaneously **keep track of how much electricity you're using and how much your system is producing**. KWH meter come in single phase and 3 phase module.

## 2.2 Function of Components in Wind Power System

### Inverter



Inverters **take direct current (DC) power and change it into alternating current (AC) power**. For most small-scale power generation, the power coming out of the wind turbine is DC power.

Like any inverter, grid tie inverters change DC power into AC power. The grid-tie component of a GTI allows transfer energy from a renewable source into the grid. Being connected to the grid has the obvious benefit for small-scale renewable energy producers of balancing out your load. With a grid tie inverter, you can either tie directly to the grid (without batteries) or elect to charge a battery bank and be connected to the grid

#### Did you know??

Inverter have to types:

1. **Pulse Width Modulated (PWM)**
2. **Maximum Power Point Tracking (MPPT)**

### AC Breaker Panel

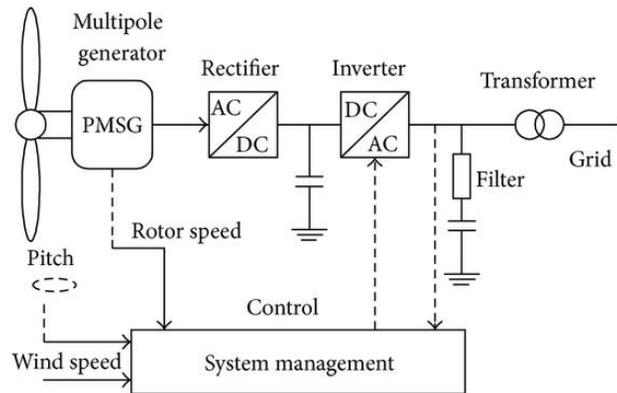


The AC breaker panel or main panel, is the point at which all of a home's electrical wiring meets with the "provider" of the electricity, whether that's the grid or a wind-electric system.

Protection of wind power systems requires an understanding of system faults and their detection, as well as their safe disconnection.

## 2.3 Types of Generator for Wind Power System

### PSMG



•The working of the **Permanent Magnet Synchronous Generator (PMSG)** depends on the field produced by the permanent magnet attached at the rotor of the generator for the conversion of mechanical energy into electrical energy.

•Like synchronous generator in PMSG, there are two types of windings first one is the armature that is wound on the stator and the second one is the field winding that is wound on the rotor.

•At the stator of generator 6 coils of copper, windings are wound and fixed at their respective places.

•The rotor that has a permanent magnet is connected to the bearing rotating on the shaft. In this generator, there are 2 rotors first one is behind the stator and second one is at the exterior side.

•Both relate to each other through the long studs moving by the hole in the stator.

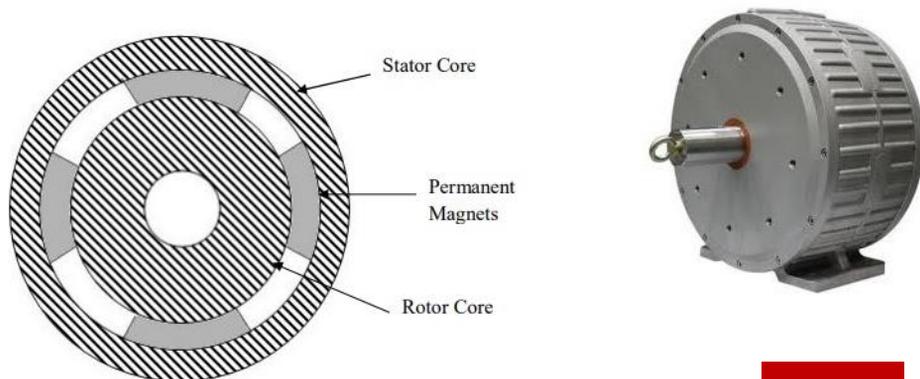
•The blades are also surfaced on these studs that connecting the rotors with each other.

•These blades rotate the rotor for the production of electrical energy.

#### Types of Generator:

1. Permanent Magnet Synchronous Generator (PMSG)
2. Doubly Fed Induction Generator (DFIG)

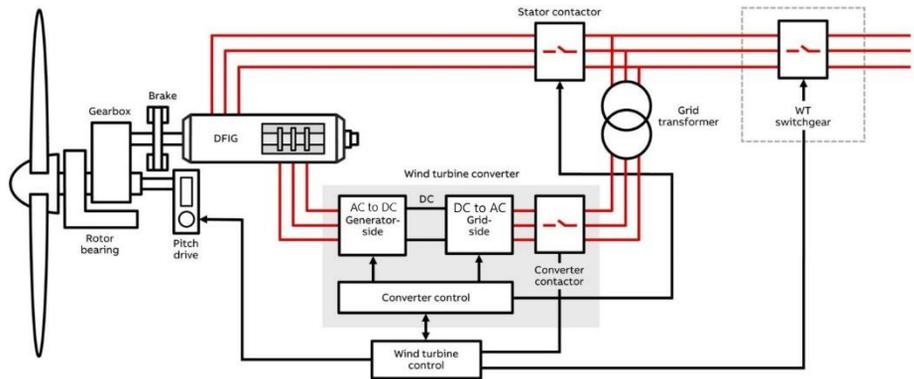
### Permanent Magnet Synchronous Generator



Internal Structure

2.3 Types of Generator for Wind Power System

DFIG

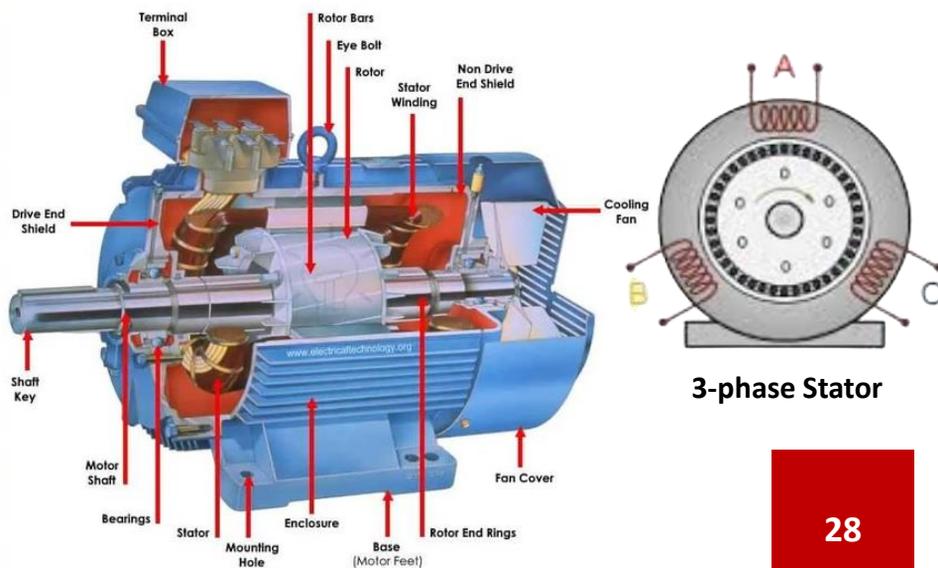


**Double-fed induction generator (DFIG)**, a generating principle widely used in wind turbines. It is based on an induction generator with a multiphase wound rotor and a multiphase slip ring assembly with brushes for access to the rotor windings. It is possible to avoid the multiphase slip ring assembly, but there are problems with efficiency, cost and size. A better alternative is a brushless wound-rotor doubly-fed electric machine

The principle of the DFIG is that stator windings are connected to the grid and rotor winding are connected to the converter via slip rings and back-to-back voltage source converter that controls both the rotor and the grid currents. Thus, rotor frequency can freely differ from the grid frequency (50 or 60 Hz). By using the converter to control the rotor currents, it is possible to adjust the active and reactive power fed to the grid from the stator independently of the generator's turning speed. The control principle used is either the two-axis current vector control or direct torque control (DTC). DTC has turned out to have better stability than current vector control especially when high reactive currents are required from the generator.

Did you know??

A three-phase synchronous motor is a doubly excited machine, whereas an induction motor is a single excited machine.

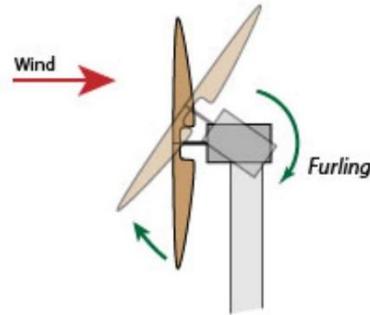


## 2.4 Speed Control Mechanism in Wind Power System

### Furling

Principle: Moving the axis out of the direction of the wind decreases angle of attack and cross-section

**Furling** is one method of preventing a wind turbine from spinning too quickly, simply by turning the blades away from the direction of the wind, either horizontally or vertically.



Standard modern turbines all furl in high wind.

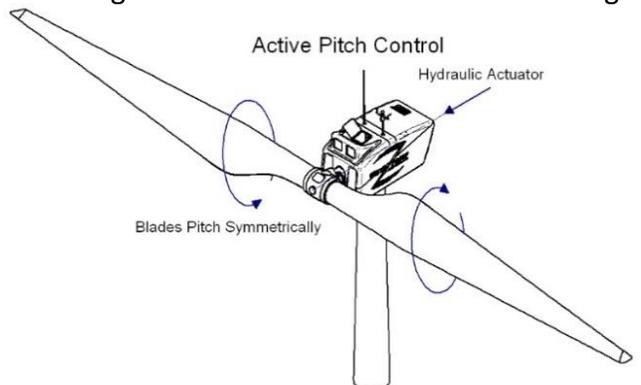
- Requires active pitch control: Pitch angle of the blades needs to be minimized first, otherwise the torque on the rotor would be too big for furling.
- Active: Vertical furling (as diagram) with hydraulic, spring-loaded or electric motor driven.
- Passive: Horizontal furling with yaw

### Speed mechanism:

- Furling
- Blade pitch
- Shut down mechanism
- Constant-speed and variable-speed architectures

### Blade Pitch

Principle: Decrease angle of attack also results in decreasing lift-to-drag ratio.



**Blade Pitch** control is a feature of nearly all large modern horizontal-axis wind turbines. While operating, a wind turbine's control system adjusts the blade pitch to keep the rotor speed within operating limits as the wind speed changes. Feathering the blades stops the rotor during emergency shutdowns, or whenever the wind speed exceeds the maximum rated speed. During construction and maintenance of wind turbines, the blades are usually feathered to reduce unwanted rotational torque in the event of wind gusts.

## 2.4 Speed Control Mechanism in Wind Power System

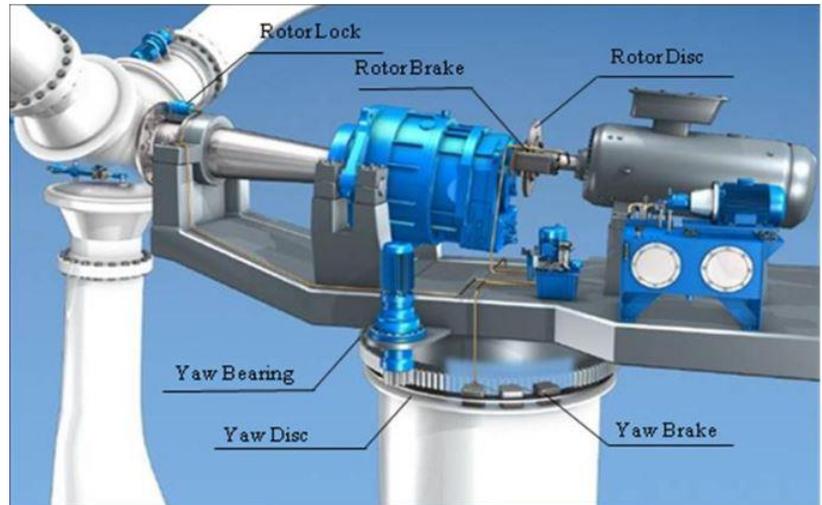
### Shutdown Mechanism

Wind turbines are typically designed to shut down when wind speed reaches a level which could result in damage to the turbine. In high windspeed and gale prone areas this means a regular curtailment of production. New developments allow reduced operation under these conditions rather than complete curtailment, with associated advantages for network stability and energy production.

#### Did you know??

Shut down using any of the mechanisms can have negative effects including:

- *A sudden loss of generating power:* If several windfarms, or a large number of turbines are affected, the sudden loss of output could result in network stability problems.
- *Loss of income from the wind farm:* In high wind speed areas this can be significant.

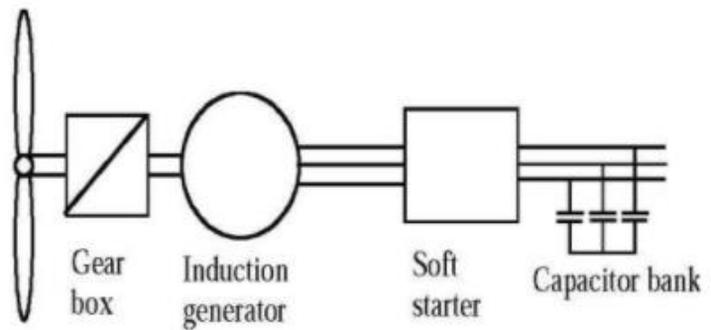


Most wind turbine manufacturers include a shut-down mechanism - a mechanical or electrical device that allows an operator to shut a wind generator off. This is important because it allows the owner to repair or maintain the wind turbine with out fear of injury. It also provides a means to shut the wind turbine down when a violent storm is approaching. Shut-down mechanism come in many varieties, from disc and dynamic brakes to folding tails - tails that fold in such a way that the wind turbine is forced out the wind and the blades stop rotating. The shut-down mechanism of a wind turbine is a key factor to consider when shopping for a wind turbine.

## 2.4 Speed Control Mechanism in Wind Power System

### Fixed-speed Operation

**Most wind turbines operated at fixed speed** when producing power. In a start-up sequence the rotor may be parked (held stopped), and on release of the brakes would be accelerated by the wind until the required fixed speed was reached. At this point, a connection to the electricity grid would be made and then the grid (through the generator) would hold the speed constant. When the wind speed increased beyond the level at which rated power was generated, power would be regulated in either of the ways previously described, by stall or by pitching the blades.

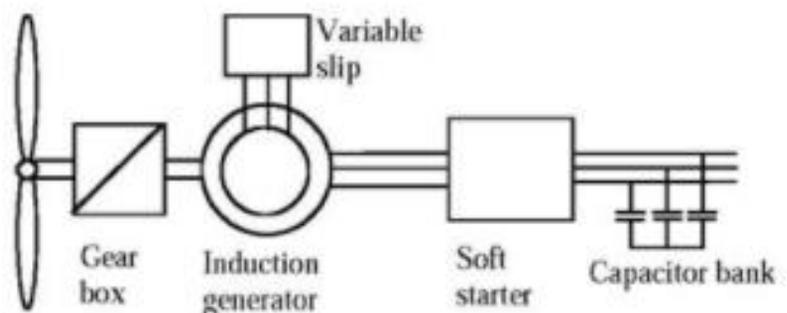


### Did you know??

Variable speed systems could lead to maximize the capture of energy during partial load operation

### Variable-speed Operation

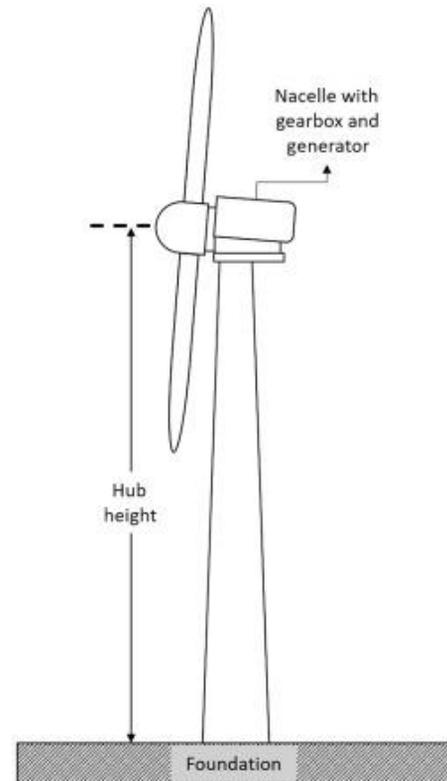
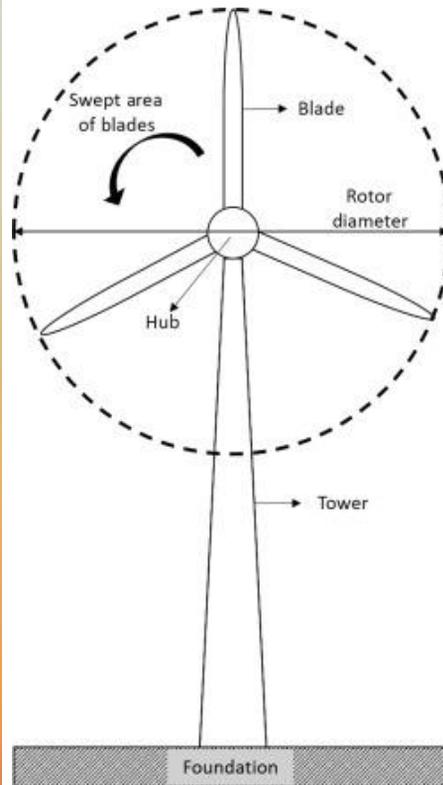
Subsequently, **variable speed operation was introduced**. This allowed the rotor and wind speed to be matched, and the rotor could thereby maintain the best flow geometry for maximum efficiency. The rotor could be connected to the grid at low speeds in very light winds and would speed up in proportion to wind speed. As rated power was approached, and certainly after rated power was being produced, the rotor would revert to nearly constant speed operation, with the blades being pitched as necessary to regulate power.



## 2.5 Factors in Wind Power System Selection

### Swept Area

Principle : The swept area refers to the area of the circle created by the blades as they sweep through the air.



Consideration in wind power system selection:

- Swept area
- Cut-in speed
- Rated power
- Power curves

The power output of a wind turbine is directly related to the area swept by the blades. The larger the diameter of its blades, the more power it is capable of extracting from the wind.

Remember the Power In The Wind Equation:

$$P = 1/2 \times \rho \times A \times V^3$$

P = Power (Watts)

$\rho$  = Air Density (about 1.225 kg/m<sup>3</sup> at sea level)

A = Swept Area of Blades (m<sup>2</sup>) (Area =  $\pi r^2$ )

V = Velocity of the wind

By doing this calculation, you can see the total energy potential in each area of wind. You can then compare this to the actual amount of power you are producing with your wind turbine (you will need to calculate this using a multimeter—multiply voltage by amperage). The comparison of these two figures will indicate how efficient your wind turbine is.

## 2.5 Factors in Wind Power System Selection

### Did you Know??

Malaysia's mean annual wind speed is 1.8 m/s. However, towns in the east coast of Peninsular Malaysia such as Mersing, Kota Baharu, and Kuala Terengganu experience stronger winds. For these places, their mean monthly wind speed could exceed 3 m/s.

Wind speeds during the southwest monsoon are often below 7 m/s, but during the northeast monsoon, wind speeds could reach up to 15 m/s particularly in the east coast of Peninsular Malaysia.

### Cut-in Speed

A turbine's cut-in and cut-out speed (also called 'cut-off' speed) are determined by the manufacturer to protect the turbine from damage. The cut-in speed is simple; it's the point at which the turbine starts generating electricity from turning.

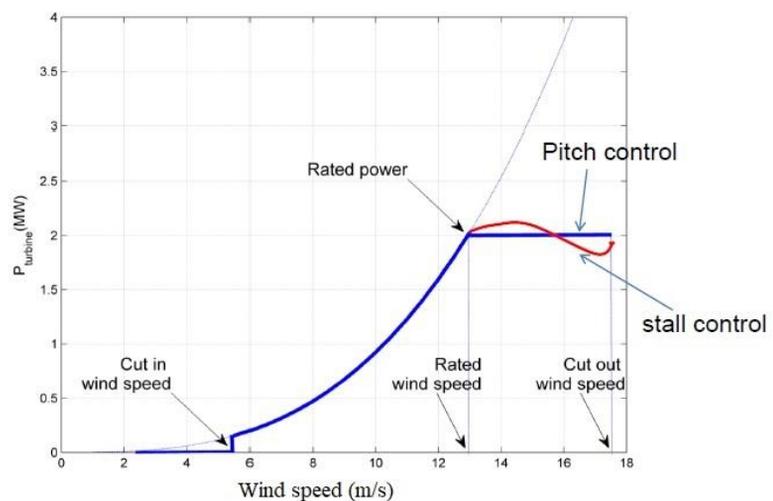
The cut-out point is more important and denotes how fast the turbine can go before wind speeds get so fast that it risks damage from further operation. The primary safety issue with wind turbines comes from over speeding, so some sort of stall or brake mechanism is needed to shut down the turbine before it reaches this danger zone.

### Rated Power

As wind speeds increase, more electricity is generated until it reaches a limit, known as the rated speed. This is the point that the turbine produces its maximum, or rated power. As the wind speed continues to increase, the power generated by the turbine remains constant until it eventually hits a cut-out speed (varies by turbine) and shuts down to prevent unnecessary strain on the rotor.

Power vs wind speed

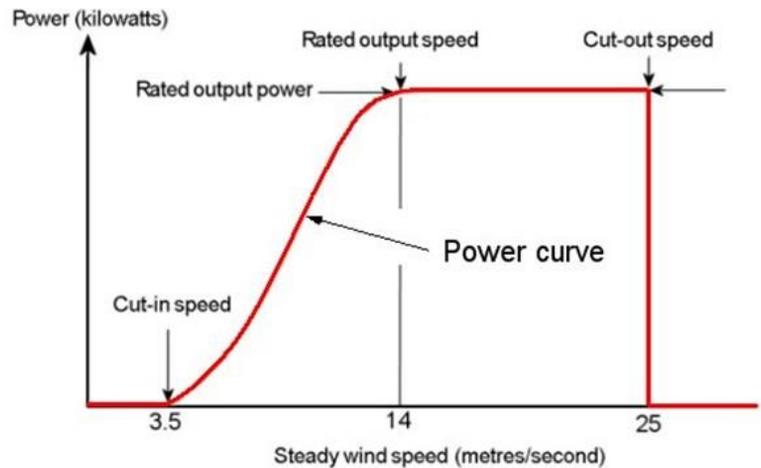
Power output has to be limited according to generator capacity



## 2.5 Factors in Wind Power System Selection

### Power Curve

Power Curve is a graph to show the typical relationship between power output from a wind turbine (power kilowatt) and wind speed (meters/second)



Typical wind turbine power output with steady wind speed.

#### Did you Know??

Most turbines have a rated peak speed - that is, a wind speed at which they'll return the optimal amount of power. Wind speeds both lower and higher than this speed are likely to produce less energy.

#### Cut-in speed

At very low wind speeds, there is insufficient torque exerted by the wind on the turbine blades to make them rotate. However, as the speed increases, the wind turbine will begin to rotate and generate electrical power. The speed at which the turbine first starts to rotate and generate power is called the **cut-in speed** and is typically between 3 and 4 meters per second.

#### Cut-out speed

As the speed increases above the rate output wind speed, the forces on the turbine structure continue to rise and, at some point, there is a risk of damage to the rotor. As a result, a braking system is employed to bring the rotor to a standstill. This is called the **cut-out speed** and is usually around 25 meters per second.

#### Rated output power and rate output wind speed

As the wind speed rises above the cut-in speed, the level of electrical output power rises rapidly as shown. However, typically somewhere between 12 and 17 meters per second, the power output reaches the limit that the electrical generator is capable of.

This limit to the generator output is called the *rated power output* and the wind speed at which it is reached is called the *rated output wind speed*.

At higher wind speeds, the design of the turbine is arranged to limit the power to this maximum level and there is no further rise in the output power.

## 2.6 Towers Options, Assembly and Installation of Wind Power System

Differentiate types of tower:

- Freestanding tower
- Fixed guyed tower
- Tilt-up tower

Did you know??

Lattice or truss type towers generally are climbable, can be assembled onsite, require concrete, a larger base footprint, and possibly guy wires.

Did you know??

Stand-alone (pole) towers are generally more attractive, no guy wires, have height limitations, and require extensive foundation and concrete work prior to installation.

### Free Standing Tower



**Truss tower  
(Lattice)**

### Monopole / Tubular Tower

The Monopole Towers were widely used from our 1kW to 50kW wind turbines. Monopole tower has good appearance, reliable structure and easily to be installed. The survival wind speed is 50m/s. Engineers use the FEM (Finite Element Method) to check the tower strength and vibration. The design lift time is 20 years for a monopole tower.

Small freestanding monopole towers are the sleekest looking towers and with smaller turbines (500W to 2kW) are oftentimes tilt-up type towers. The foundations are several feet deep, however, the surface area of the foundation is the smallest of all towers.

### Lattice / Truss Tower

Self supporting lattice towers are an affordable alternative to guy wired towers. These towers sit atop a large concrete pad measuring anywhere from 8' x 8' to 15' x 15' and secured into the ground as deep as 4' or are anchored to deep pier type foundations, one for each leg of the tower. These towers require use of a crane to be installed but provide access for some maintenance should the tower need to be climbed.



**Tubular tower  
(Pole)**

## 2.6 Towers Options, Assembly and Installation of Wind Power System

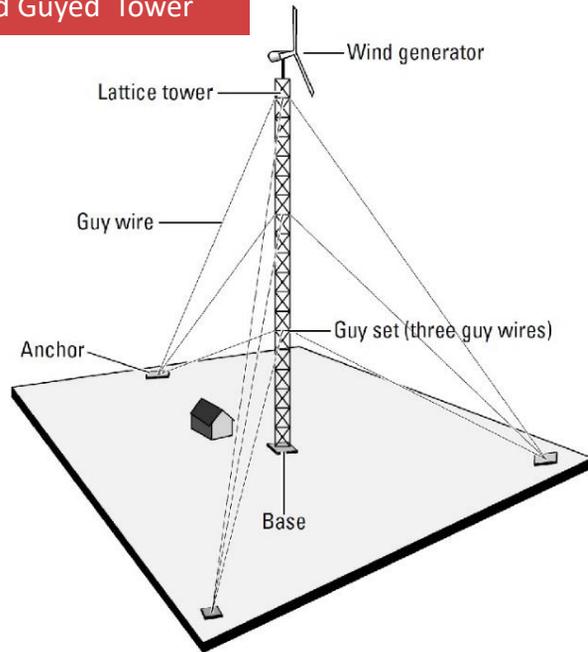
### Did you know??

Guyed masts have been applied within the field of telecommunications for many years.

### Did you know??

Guyed are easier to install than self-supporting towers. However, because the guy radius must be one-half to three-quarters of the tower height, guyed towers require space to accommodate them.

### Fixed Guyed Tower



Guyed towers feature simple tower type, easy construction, and smaller weight of single tower which can reduce steel consumption and construction costs, and they are mostly used in areas where operation and maintenance are convenient, such as shallow hills and deserts.

The most common tower type is a guyed lattice tower. We also see tubular towers, especially in home-built applications.

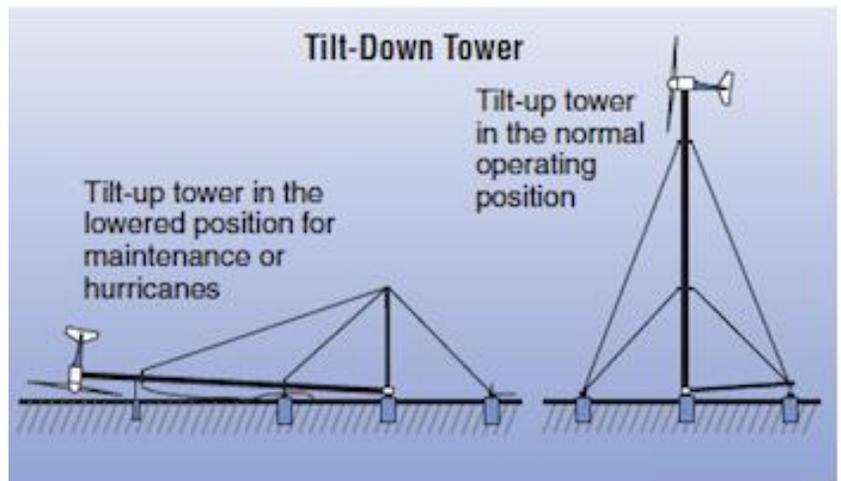


Many small wind turbines are built with narrow pole towers supported by guy wires. The advantage is weight savings, and thus cost. The disadvantages are difficult access around the towers which make them less suitable in farm areas. Finally, this type of tower is more prone to vandalism, thus compromising overall safety.

## 2.6 Towers Options, Assembly and Installation of Wind Power System

### Tilt-up Tower

Tilt-down towers are more expensive, they offer the consumer an easy way to perform maintenance on smaller lightweight turbines (usually 5 kW or smaller). Tilt-down towers can also be lowered to the ground during hurricanes and other hazardous weather conditions. Aluminum towers are prone to cracking and should be avoided. Most turbine manufacturers provide wind energy system packages that include a range of tower options.



#### Did you know??

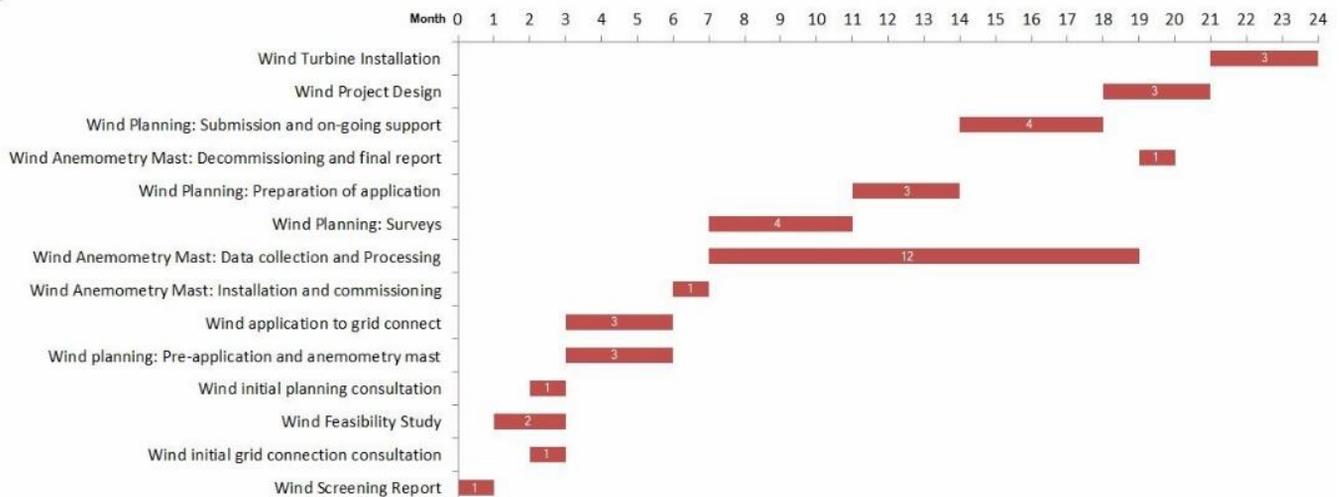
Tilt-down towers provide easy maintenance for turbines, but tilt-down towers are more expensive than regular guyed tower.

Here are two illustrations of a tilt-down wind turbine tower. Four wires extend from the tower, which looks like a pole. Two wires are attached near the top, and the other two are attached a little below the middle of the tower. The first illustration shows the tower tilted down, horizontally. The wind turbine is perpendicular to the ground, touching it, with its tail pointing to the sky. The second illustration shows a wind turbine tower in the upright position, vertical from the ground. All wires are shown taut. At the back of the turbine, a thin pole is shown extending from the tower to two of the wires.

## 2.6 Towers Options, Assembly and Installation of Wind Power System

### Assembling and Installing Towers

The length and complexity of the installation process depends upon the size and type of **wind turbine**. Prior to any installation it is necessary to commission a technical survey the site and monitor local windspeeds over a period (at least 3 months).



You can watch large scale wind tower build from the link below:

[https://www.youtube.com/watch?v=fI6BMVw\\_B-Y](https://www.youtube.com/watch?v=fI6BMVw_B-Y)

<https://www.youtube.com/watch?v=0vE6QkvcV-s>

#### Foundation preparation and installation

Depending on the size and type of turbine system, this may require heavy machinery such as an excavator and crane. It is usually necessary to wait for a period of at least 2 weeks after the laying of foundations to allow the concrete base to cure. If a building-mounted system is being installed, it may be necessary to have your property's roof strengthened so that it can bear the weight of the turbine.

#### Digging of trenches

Trenches need to be dug for the electrical cables which run from the turbine to the control unit and inverter.

#### Erection of tower and turbine

Depending on the turbine size, this may require use of a crane.

## 2.6 Towers Options, Assembly and Installation of Wind Power System

### Electrical wiring

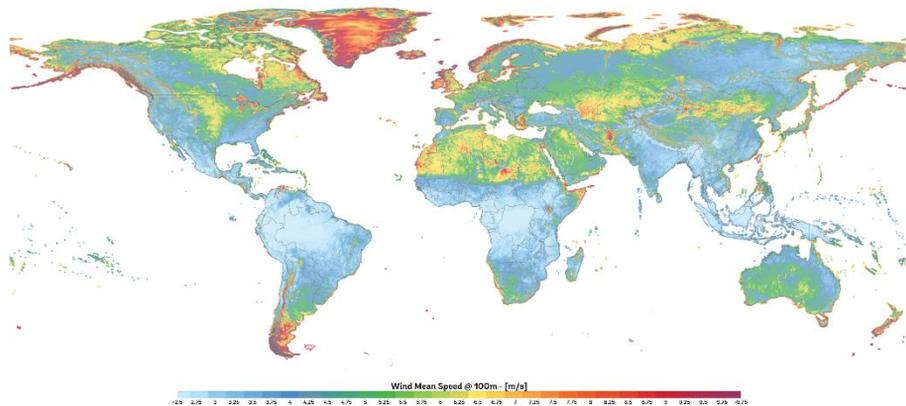
An electrical engineer or electrician will connect the **wind turbines** DC output to the control box and then the inverter. The AC output from the inverter will be connected to your property's electricity supply and the electricity grid. Other electrical components such as isolators are installed for safety, and an approved generation meter will be placed after the inverter.

### Connection to electricity grid

To connect the **wind turbine system** to the grid, your installer will liaise with your local electrical supplier.

### Assessing Wind Site

The wind resource is one of the most critical aspects to be assessed when planning a wind farm. Different approaches on how to obtain information on the wind climate are possible. In most countries where wind energy is used extensively, some form of general information about the wind is available. This information could consist of wind maps showing color coded wind speed or energy at a specific height.



A crucial factor in the development, siting, and operation of a wind plant is the ability to assess and characterize available wind resources.

More accurate prediction and measurement of wind speed and direction allow wind plants to supply clean, renewable power to businesses and homeowners at lower costs.

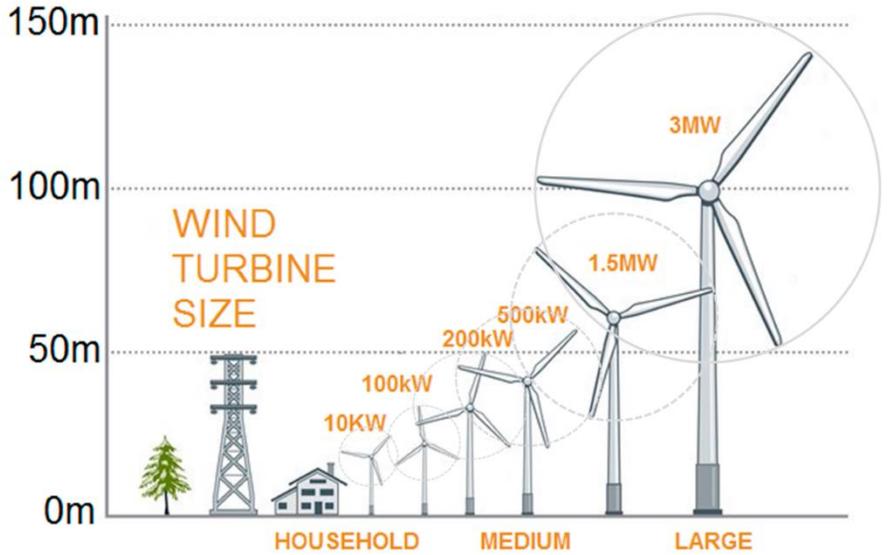
### Did you know??

Modern wind resource assessments have been conducted since the first wind farms were developed in the late 1970s. The methods used were pioneered by developers and researchers in Denmark, where the modern wind power industry first developed.

2.6 Towers Options,  
Assembly and  
Installation of  
Wind Power  
System

Optimum Tower Height

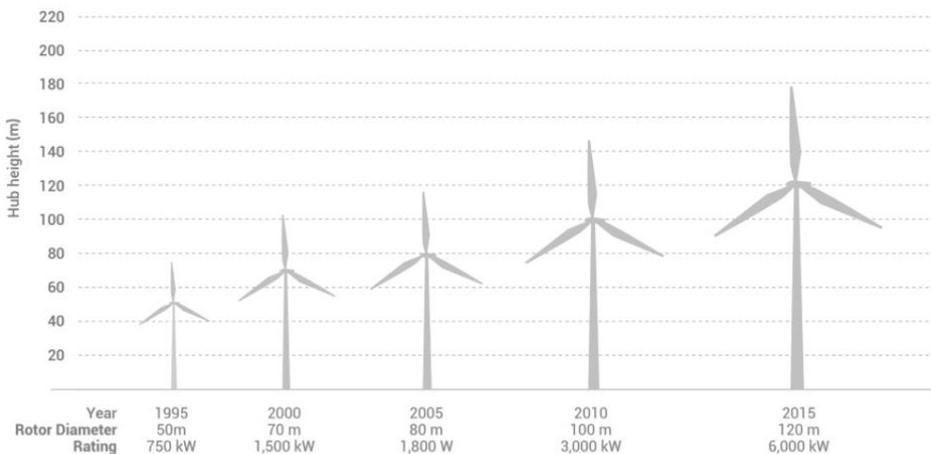
A tall tower is the single most important factor in the economic viability of a small wind system. Tall towers enable turbines to access faster in better quality winds, and even small increases in wind speed translate to exponentially more energy the turbine can generate. In other words, a taller tower means far more – and cheaper – energy.



Did you know??

The world's tallest existing wind turbine is in the German town of Gaildorf, near Stuttgart, with a total height of 246.5m. They would also be 40m taller than the biggest of the 22 turbines in the original Lethans development.

Conventional turbines have grown taller, heavier, and more expensive to generate more power. These large structures are expensive and complex to construct and can only be installed economically where the winds routinely reach speeds of between 5-8 meters per second (20-28 kilometer per hour). Unfortunately, less than 15% of all land around the world meets this criteria.



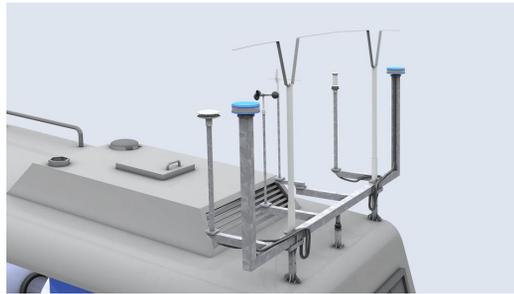
Source: National Renewable Energy Laboratory

## 2.6 Towers Options, Assembly and Installation of Wind Power System

### Solution For Lightning Protection

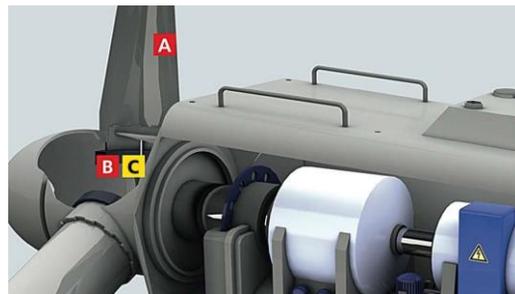
Lightning is particularly likely to strike wind turbines due to their exposed location, height and complexity.

As lightning strikes often cause considerable material and economic damage, it is important to protect your turbines. The chief objective is to prevent lightning from damaging the rotor blades, bearings and electrical systems. Permanent availability is the top priority, both for on- and offshore wind turbines.



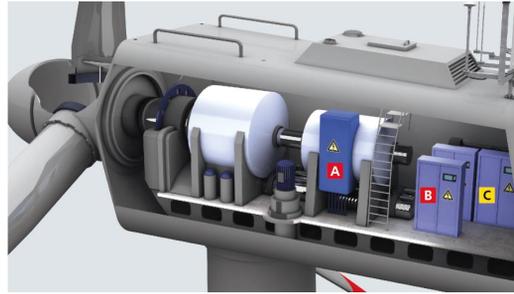
#### Protection of the nacelle - external lightning protection

Safe interception and discharge of direct lightning strikes is decisive to the availability of your wind turbine. The stainless-steel air-termination systems and connection elements fulfil enhanced requirements regarding corrosion resistance.



#### Rotor protection

An integrated protection concept prevents damage to the information and data technology in your wind turbine. In addition, the reliable condition monitoring system keeps you posted about the status of your system - indispensable for operational safety and maximum system availability.



### Protection of the nacelle - surge protection

Lightning currents and surges put the sensitive technology in the nacelle of the wind turbine at risk. Take preventative measures to avoid damage and downtime. Coordinated surge protection maximizes the availability of your turbine.

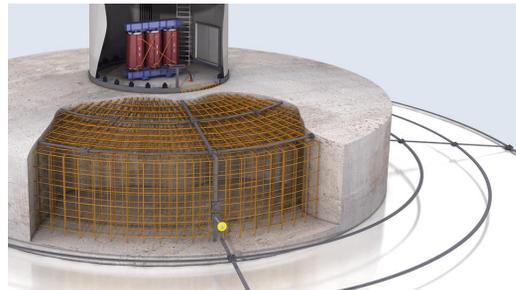


### Surge protective measures in the tower base

Selection of the protective devices for the tower base depends on the end-of-life behavior required of the arrester.

### Generally, you should protect these 3 areas:

- Medium-voltage energy side
- Low-voltage energy side
- Data side



### Earthing and equipotential bonding for a wind turbine

Connection elements which can carry short-circuit current ensure the safe contact of the earth-termination system with metal parts of the foundation and the main earthing busbar.

## 2.7 Tutorial

**Structure Question**

1. Draw the block diagram of Off-grid wind-electric systems system in wind power. (4 Marks)
2. Express the block diagram anatomy of wind turbines for Horizontal Axis Wind Turbine (HAWT) in Wind Power System. (6 Marks)
3. Interpret TWO(2) of the speed control mechanism used in the Wind Power System. (6 Marks)
4. Interpret TWO (2) of important factors consideration used in the wind power system. (6 Marks)

**ESSAY QUESTION**

Generator is a mechanism that converts the rotational kinetic energy into electricity in the Wind Power System. **Permanent Magnet Synchronous Generator (PMSG)** and **Doubly Fed Induction Generator (DFIG)** is a types of generator used in Wind Power System. Based on that, **ILLUSTRATE** the **LABEL** the block diagram of each types generators and **INTERPRET** the operation principle for each generators used in Wind Power System. (20 Marks)

# BIOENERGY POWER SYSTEM

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CHAPTER

03

- ✓ Biomass Preparation
- ✓ Biomass Conversion Technologies.
- ✓ Power Generation Technologies

### 3.1 Biomass Preparation

#### Solid Biomass Fuel Preparation

**Receiving:**  
truck tipper, conveyor, and radial stacker

**Buffer storage:**  
storage bin (24 hours)

**Fuel metering**  
conveyors, meters, and pneumatic transport

**Processing:**  
reclaim feeder, conveyor, metal separator, dryer, screener, and grinder

#### Bioenergy

Bioenergy refers to electricity and gas that is generated from organic matter, known as biomass. This can be anything from plants and timber to agricultural and food waste – and even sewage to create electricity or other form of power.



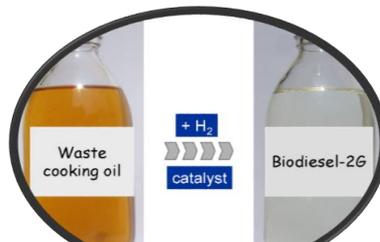
**BIOMASS**

**Biomass** is fuel that is developed from organic materials, a renewable and sustainable source of energy used to create electricity or other forms of power

**Biogas** is formed when microorganisms, especially bacteria, degrade organic material in the absence of oxygen. Biogas consists of 50% to 75% methane (CH<sub>4</sub>), 25–45% carbon dioxide (CO<sub>2</sub>) and small amounts of other gases.

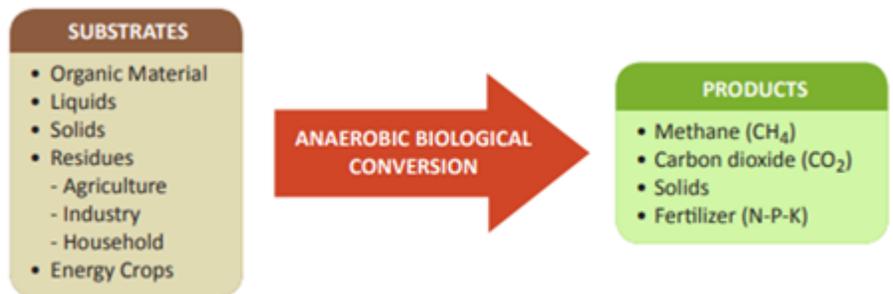


**BIOGAS**



**BIOFUEL**

**Biofuels** are transportation fuels such as ethanol and biomass-based diesel fuel that are made from biomass materials. These fuels are usually blended with petroleum fuels (gasoline and distillate/diesel fuel and heating oil), but they can also be used on their own



Substrates and products in anaerobic biological conversion process

### 3.1 Biomass Preparation

**Key note:**

The processing system treats the biomass prior to charging the energy conversion process. Common steps in processing include separation, sizing, removal of metals and other non combustible materials, and grinding or other size reduction methods. An automated system conveys the correct amount of biomass required by the energy conversion process.

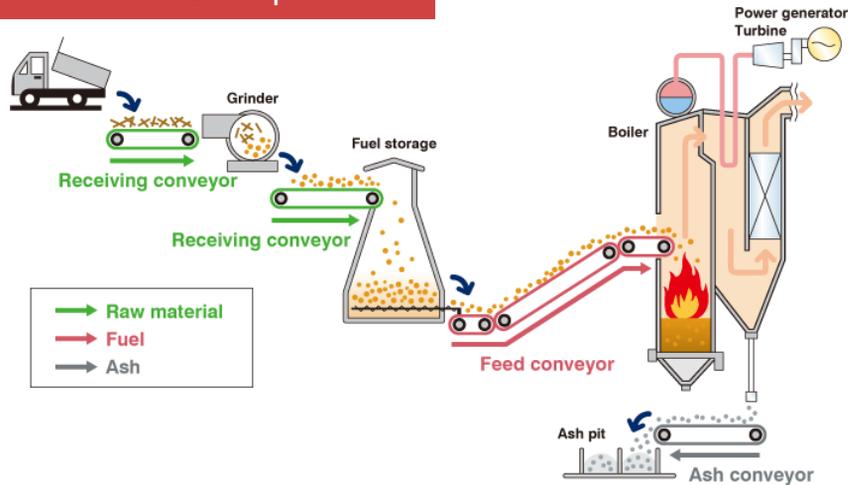
**Did you know??**

The storage area for the options considered in this section is sized for a 30-day supply of biomass. This quantity of biomass can carry the plant through possible supply shortages in the spring or winter seasons.

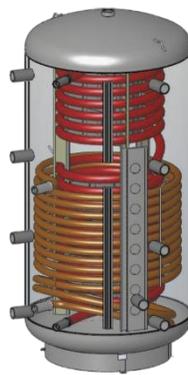
**Did you know??**

For all biomass conversion technologies, the lower the as-fired moisture content of the biomass feedstock, the higher the energy efficiency of the conversion process.

### Biomass Fuel Preparation



### Automatic biomass receiving and preparation system



Buffer Tank

A **buffer tank** is in essence a thermal store; it is a battery or capacitor for your **biomass system**, allowing a burst of heat when your boiler is warming up and its function is to balance the system.

The buffer vessel acts as an energy store that releases its stored hot water into the heating system whilst the boiler gets up to temperature

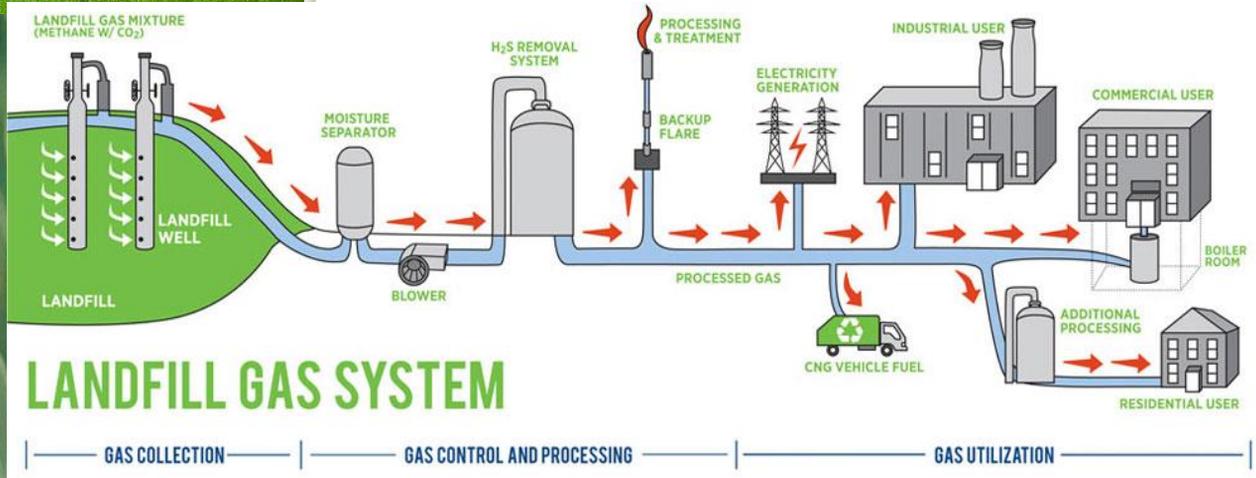
- Fuel metering consists of the controlled delivery of the required amount of biomass to the energy conversion process.
- The biomass is metered as it is discharged from the silo to the collecting conveyor.
- An auger at the base of the silo feeds a conveyor, which then feeds a surge bin.
- The surge bin, the fuel is metered into the boiler or other energy conversion device, passing through a rotary airlock.
- The metering rate is controlled by the boiler control room.
- The fuel is pneumatically transferred to the boiler after passing the airlock.



Heat meter

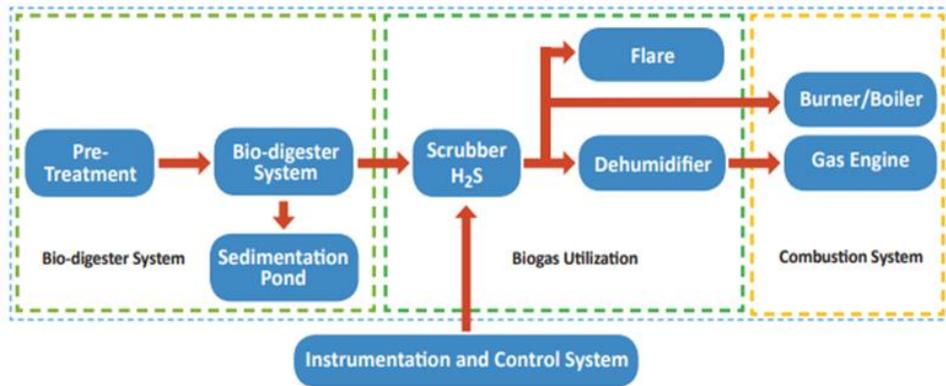
3.1 Biomass Preparation

Biogas Fuel Preparation



Key note:

Biogas is formed when microorganisms, especially bacteria, degrade organic material in the absence of oxygen. Biogas consists of 50% to 75% methane (CH<sub>4</sub>), 25–45% carbon dioxide (CO<sub>2</sub>) and small amounts of other gases. Biogas is about 20% lighter than air and has an ignition temperature between 650°C and 750°C. It is an odourless and colourless gas that burns with a clear blue flame similar to that of liquid petroleum gas (LPG).



Biogas Power Plant Diagram

**Bio-digester System** The bio-digester system consists of a pre-treatment process, the bio-digester itself, and a sedimentation pond. In the pre-treatment component, POME is conditioned to achieve the parameter values needed to enter the digester



Source: Univanich - Krabi, Thailand



Source: Veolia Plant in Malaysia

Covered lagoon and continuously stirred tank reactor

### 3.1 Biomass Preparation

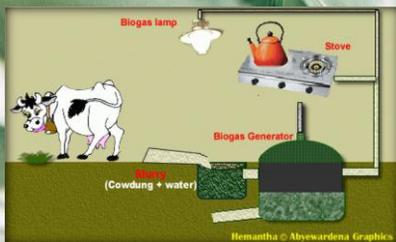
#### Type of Biogas



Pome Palm Oil Mill Effluent



Landfill Management



Cow Dung(waste)

#### Hydrogen Sulfide (H2S) Scrubber

Before biogas can generate power, hydrogen sulfide scrubber must reduce the H2S concentration to permissible levels by gas engine, typically below 200 ppm. This avoids corrosion, optimizes operation, and lengthens the lifetime of biogas engines. H2S in biogas comes from the sulphate (SO4 2-) and other sulphur components in wastewater



Source: PT Austindo Aufwind New Energy

Biogas Flare

#### Biogas Dehumidifier

A gas dehumidifier, can be dryer, chiller, or cyclone; reduces moisture content in biogas to prepare it for use in a gas engine. The dehumidifier extracts water from the biogas. This helps optimize the combustion process in the engine, prevent condensation, and protect the engine from acid formation. Acid forms when water reacts with H2S and oxygen. A high quality, low-moisture biogas with a relative humidity below 80% promotes engine efficiency and reduces fuel gas consumption



Biogas Dehumidifier

**Gas Engine** A gas engine is part of an internal combustion engine that runs on a gas fuel such as natural gas or biogas. After the production process reduces impurities in biogas to specified levels, the biogas feeds into a gas engine to generate electricity.



Gas Engine

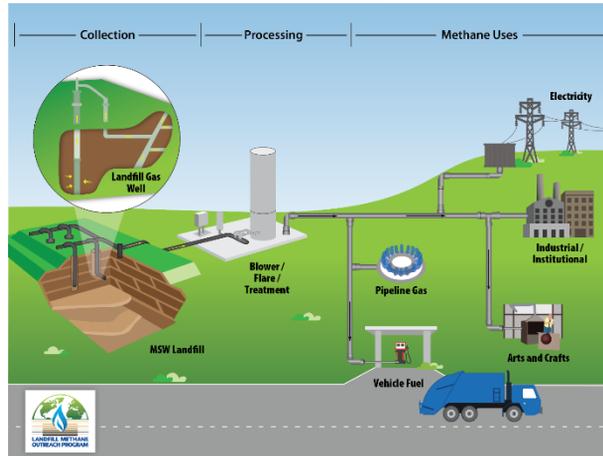


Biogas Flare

**Biogas Flare** burn excess gas in industrial process plants. For safety reasons, biogas plants must have flares installed to burn off excess biogas

3.1 Biomass Preparation

Gas Collection System



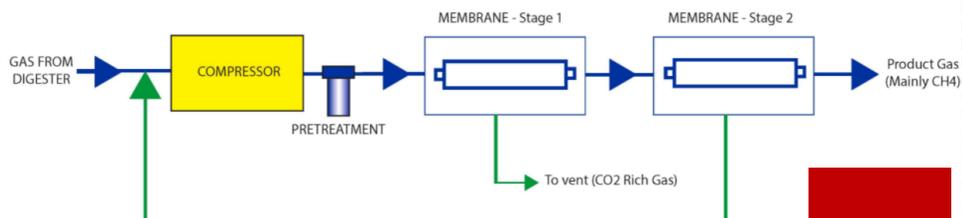
As landfill waste decomposes, it produces methane and other gases. More than 75 percent of this gas is available for use as “green” energy. Landfill gas can be used to generate electricity, or it can be piped directly to a nearby manufacturing plant, school, government building and other facility for heating and cooling.

Trash, buried beneath a layer of soil, decomposes and produces gas. Landfill operators place collection wells that act like straws throughout a landfill to draw out the methane gas. The gas is then piped to a compression and filtering unit beside the landfill. Technicians make sure that the gas is filtered properly before it is sent to its end user. The entire process is carefully managed to prevent odors and leakage of waste material.

Gas Treatment System

In general terms, **biogas treatment** is accomplished by physico-chemical methods, scrubbing being extensively used for H<sub>2</sub>S (hydrogen sulfide) and CO<sub>2</sub>(carbon dioxide) removal to get CH<sub>4</sub> (methane).

During anaerobic digestion or degradation of organic material, in the absence of oxygen, is decomposed by bacteria producing Biogas. Biogas is a mixture of mainly CO<sub>2</sub> and CH<sub>4</sub> with trace amounts of nitrogen, oxygen, H<sub>2</sub>S and H<sub>2</sub>O. The biogas has multiple commercial applications, such as vehicle fuel or R-CNG (Renewable Compressed Natural Gas), injection into the gas distribution grid as RNG (Renewable Natural Gas), conversion of gas to syngas or hydrogen, etc. Biogas needs to be treated before the final product is delivered to the consumer.



Gas Treatment Process Diagram

## 3.2 Biomass Conversion Technologies.

### Type of Boilers:

- **Stoker boilers** employ direct fire combustion of solid fuels with excess air, producing hot flue gases, which then produce steam in the heat exchange section of the boiler. The steam is used directly for heating purposes or passed through a steam turbine generator to produce electric power.
- **Fluidized bed boilers** are the most recent type of boiler developed for solid fuel combustion. The process could efficiently burn biomass and other low-grade fuels that are difficult or impractical to burn with conventional methods

### Modern mechanical stokers consist of four elements:

- ⊙ Fuel Admission System
- ⊙ Stationary or moving grate assembly that supports the burning fuel and provides a pathway for the primary combustion air.
- ⊙ Overfired air system that supplies additional air to complete combustion and minimize atmospheric emission.
- ⊙ Ash discharge system

**Biomass Conversion Technologies** is a process of converting biomass into energy that will in turn be used to generate electricity.

The principal categories of biomass conversion technologies for power and heat production are *direct-fired* and *gasification* systems.

### Direct Fire System

The most common utilization of solid fuel biomass is direct combustion with the resulting hot flue gases producing steam in a boiler—a technology that goes back to the 19<sup>th</sup> century. Boilers today burn a variety of fuels and continue to play a major role in industrial process heating, commercial and institutional heating, and electricity generation. Boilers are differentiated by their configuration, size, and the quality of the steam or hot water produced.

Boiler size is most often measured by the fuel input in **Million Metric British Thermal Units/ hours (MMBtu/hr)**, but it may also be measured by output in pounds of steam per hour. Because large boilers are often used to generate electricity, it can also be useful to relate boiler size to power output in electric generating applications. Using typical boiler and steam turbine generating efficiencies, 100 MMBtu/hr heat input provides about 10 MW electric output.



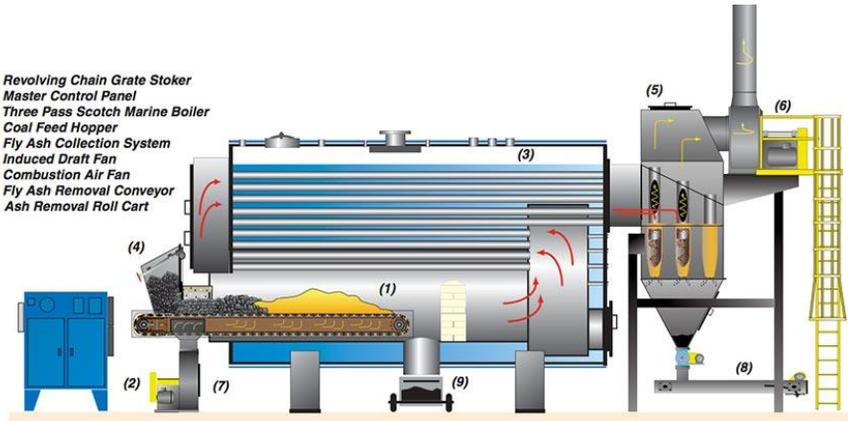
Direct Fire System

3.2 Biomass Conversion Technologies.

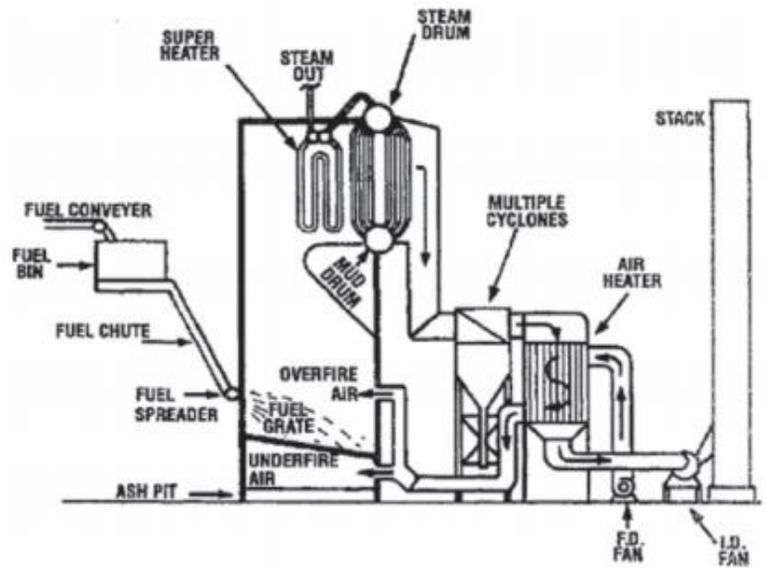
Did you know??

**Stoker boiler types** can be classified based on its type and based on the method of feeding fuel to the furnace. Stoker boiler types are generally classified as chain-gate or traveling-gate stoker boiler and spreader stoker boiler

- (1) Revolving Chain Grate Stoker
- (2) Master Control Panel
- (3) Three Pass Scotch Marine Boiler
- (4) Coal Feed Hopper
- (5) Fly Ash Collection System
- (6) Induced Draft Fan
- (7) Combustion Air Fan
- (8) Fly Ash Removal Conveyor
- (9) Ash Removal Roll Cart



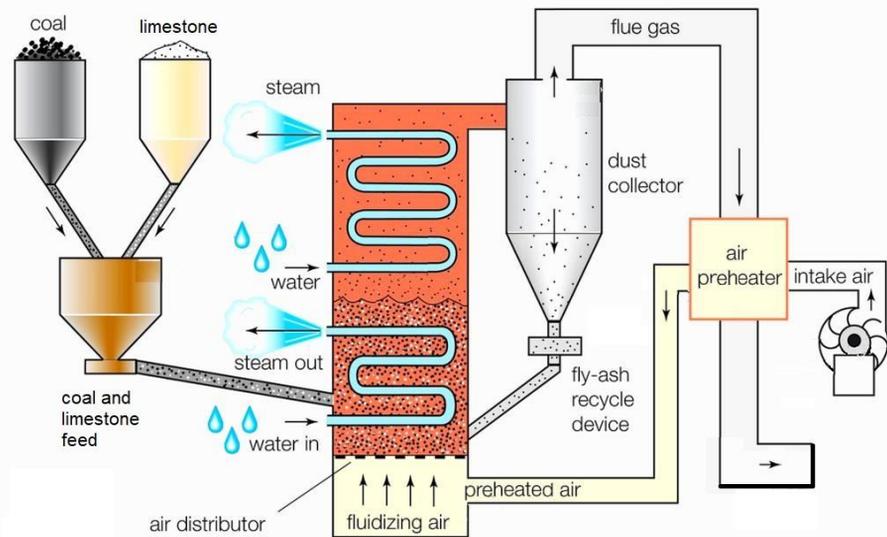
Chain Grate or Travelling Grate Stoker Boiler



Spreader-stoker System

**Fluidized Bed Boiler**

This technology is newer and more complex but offers more flexibility and operating control. Fluidized bed systems offer significant operating flexibility because they can operate under a wide range of load conditions. The thermal inertia of the bed material allows it to withstand changes in moisture and heating content of the fuel without negative impacts.



Fluidized Bed Boiler Diagram

3.2 Biomass Conversion Technologies.

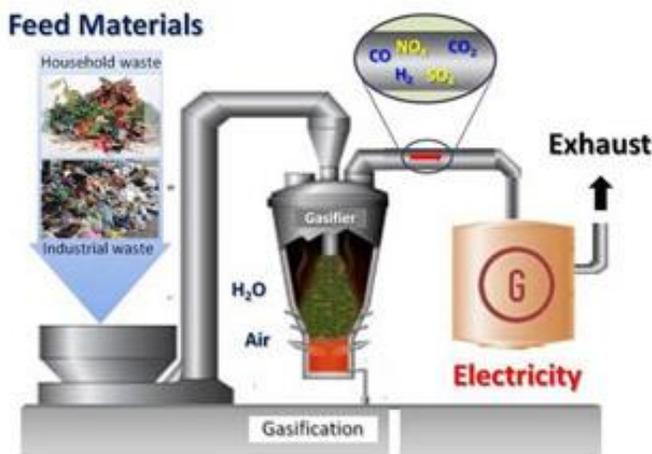
Gasification Technologies

**Gasification** is a technological process that can convert any carbonaceous (carbon-based) raw material such as coal into fuel gas, also known as synthesis gas (syngas for short).

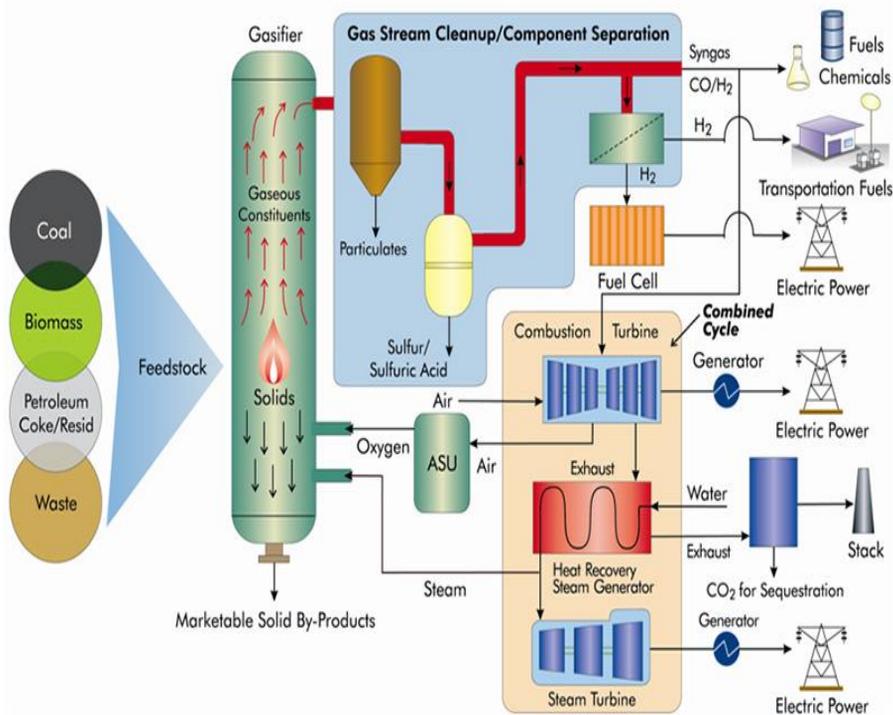
In case of biomass feedstock, this gas is known as wood gas, producer gas or syngas, which composed primarily of carbon monoxide and hydrogen as fuels, together with small amount of methane.

The Concept of Gasification:

- Raw Producer Is Not An End Product, But Requires Further Processing.
- Gasification adds value to low- or negative- value feed stocks by converting them to marketable fuel sand products.
- In utilization of gases from biomass gasification, it is important to understand that gas specifications are different for the various applications.
- Furthermore, the composition of the gasification gas is very dependent on the type of gasification process, gasification agent and the gasification temperature.
- Based on the general composition and the typical applications, two main types of gasification gas can be distinguished as producer gas and syngas.



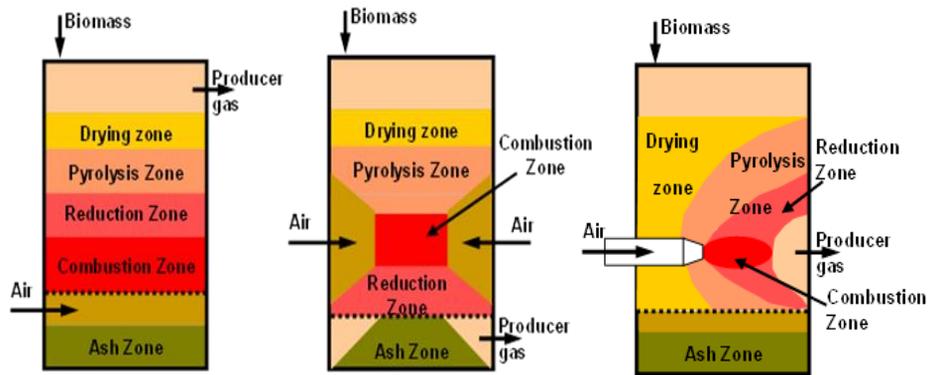
Basic Gasification Diagram



Gasification End Users Diagram

3.2 Biomass Conversion Technologies.

Fixed Bed Gasifiers



UPDRAFT

(air flows up through the grate and biogas is collected above the bed)

DOWNDRAFT

(air flows down through the bed and leaves as biogas under the grate).

CROSS DRAFT

(air flows across the bed, exiting as biogas).

Fixed Gasification Diagram

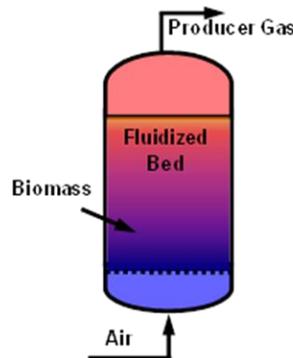
Did you know??

- **Fixed bed gasifiers** are typically simpler, less expensive and produce a lower heat content producer gas.
- **Fluidized bed gasifiers** are more complicate, more expensive, but produce a syngas with a higher heating value.

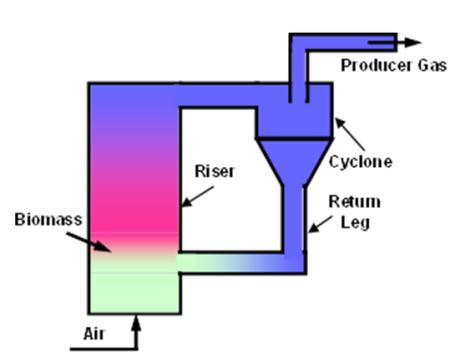
Fluidized Bed Gasifiers

MAIN CLASSIFICATION FLUIDIZED BED GASIFIERS

The fluidized bed gasifiers are categorized into two types as **Bubbling Fluidized Bed** and **Circulating Fluidized Bed**.



Bubbling Fluidized Bed Gasifiers



Circulating Fluidized Bed Gasifiers

3.2 Biomass Conversion Technologies.

There are three stages of fluidization that can occur on the gasifier depending on the design. **(bubbling, recirculating, and entrained flow)**

Fluidized bed gasifiers can be designed to use a portion of the pyrolysis gases to generate the heat to drive the process, or they can be externally fired.

Type of Gasifiers:

1. FIXED BED GASIFIERS

**Fixed bed gasifiers** are usually limited in capacity, typically used for generation systems that are able to produce less than 5 MW.

**Fixed bed gasifiers** are further classified into three types as **updraft, downdraft and cross draft**, depending on the **flow of gas through the fuel bed**.

2. FLUIDIZED BED GASIFIERS

Fluidized bed gasifiers utilize the same gasification processes and offer higher performance than fixed bed systems, but with greater complexity and cost.

Fluidized bed gasifiers can also handle a wider range of biomass feedstock with moisture contents up to 30 percent on average.

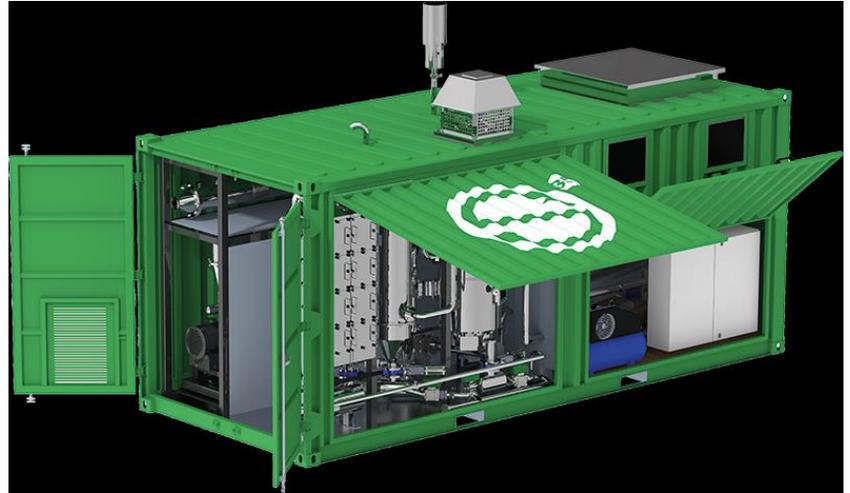
Gasifier	Advantages	Disadvantages
Updraft fixed bed	Mature for small-scale heat applications Can handle high moisture No carbon in ash	Feed size Limits High tar yields Scale limitations Low heating value gas Slagging potential
Downdraft fixed bed	Small-scale applications Low particulates Low tar	Feed size limits Scale limitations Low heating value gas Moisture-sensitive
Bubbling fluid bed	Large-scale applications Feed characteristics Direct/indirect heating Can produce higher heating value gas	Medium tar yield Higher particle loading
Circulating fluid bed	Large-scale applications Feed characteristics Can produce higher heating value gas	Medium tar yield Higher particle loading
Entrained flow fluid bed	Can be scaled Potential for low tar Potential for low methane Can produce higher heating value gas	Large amount of carrier gas Higher particle loading particle size limits

## 3.2 Biomass Conversion Technologies.

Modular biomass-fueled CHP systems are defined as small systems, less than 5 MW, though typically smaller, with the main operating components coming in one or more pre-engineered and packaged modules for simple installation at the user's site. The systems typically include a fuel processor (combustion or gasification), necessary intermediate fuel cleanup, an electric generator, and heat recovery from both the power generation and energy conversion sections. An automatic fuel storage and delivery system must be added for a complete operating system.

Small modular biomass systems can supply electricity to rural areas, farms, businesses, and remote villages. These systems use locally available biomass fuels such as wood, crop waste, animal manure, and LFG. Development of biomass-fueled modular power systems is of great interest internationally as a means to bring power to isolated communities in areas lacking power and fuel infrastructure. In the United States, there is interest in small systems to utilize opportunity fuels from a local area, such as crop wastes or fire control forest thinnings.

### Modular System



Biomass Gasification CHP system by Syngasmart

Modular systems are essentially scaled down versions of larger systems. There are systems that use direct-fired technology with steam power, and systems that use gasification technology and gaseous fuel burning power technologies such as internal combustion engines, micro turbines, and Stirling engines. There are also direct fired systems that use Stirling engines for power production, as well as systems that employ gasification, wherein the hot raw gas is combusted to raise steam.

#### Advantages

- The main operating advantages today are in the use of opportunity biomass fuels of low value such as wood chips or forest things.
- In addition, many of the systems are targeted at remote applications where it would be too costly to connect to grid electricity.

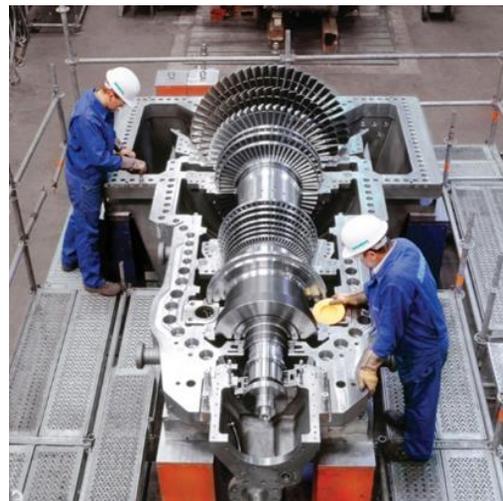
#### Disadvantages

- This equipment also takes up considerable space compared to conventional gas-fired CHP (Combined Heat and Power) system.
- The need for maintenance and repair associated with the many subsystems, particularly the solids handling components and filters.

### 3.3 Power Generation Technologies

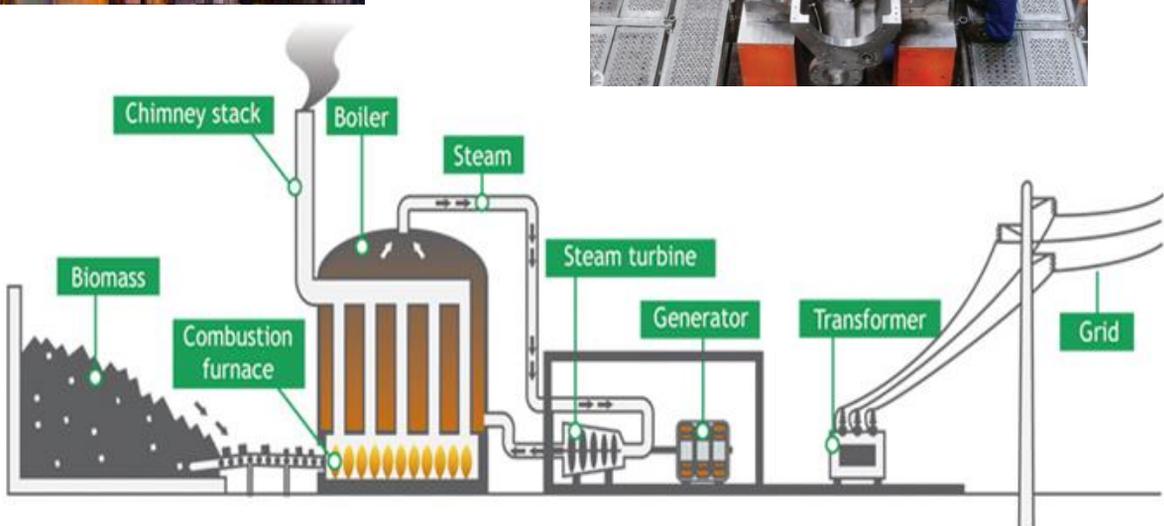
#### Steam Turbines Technologies

**Steam turbines** used in incineration plants harness the steam produced by heat generated from waste materials. Turbines are designed to meet the challenge of variable heating rates from the waste incineration process. Even the substantial variations in generated steam can be handled with ease by the ŠKODA units. Today's incineration plants are built to handle large quantities of waste - plant generating more than 100 MW are not unusual.



#### Type of Power Generation Technologies:

- Steam Turbine Technologies
- Gas Turbines Technologies
- Micro turbine Systems
- Reciprocating Internal Combustion
- Stirling System Generator



3.3 Power Generation Technologies

**Key concept:**

The steam energy is converted mechanical work by expansion through the turbine.

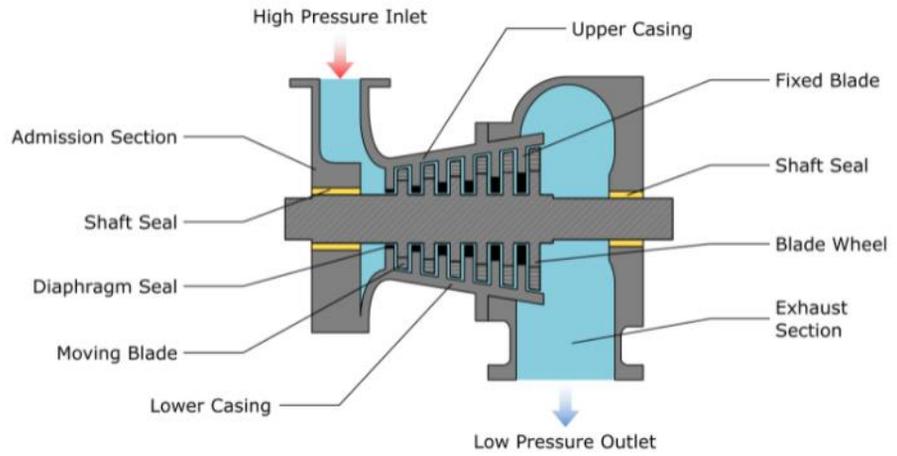
Expansion takes place through a series of fixed blades (nozzles) and moving blade.

In each row fixed blade and moving blade are called stage.

Widely used in CHP (combined heat and power) application

Thermodynamic cycle is the "rankin cycle" that use a boiler.

Steam Turbines Technologies

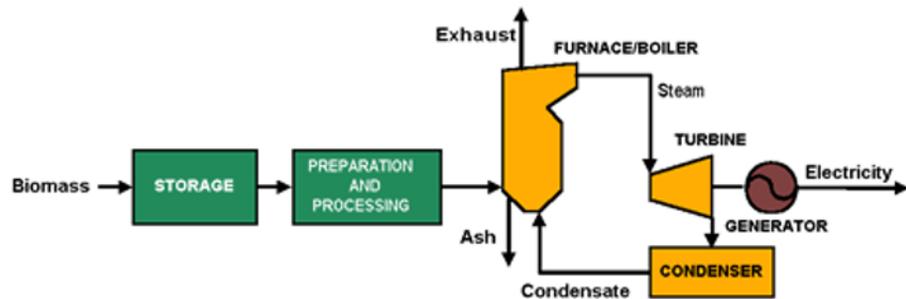


Turbine Construction and Components

Components in Steam Turbines

- Casing
- Rotor
- Blades
- Governor
- Oil pumps
- Stopper and control valve
- Oil befall, stem befall
- Bearing (general and thrust bearing)
- Gear Box (epicyclic gear box)

Direct Combustion / Steam Turbine System



Steam Turbines Block Diagram

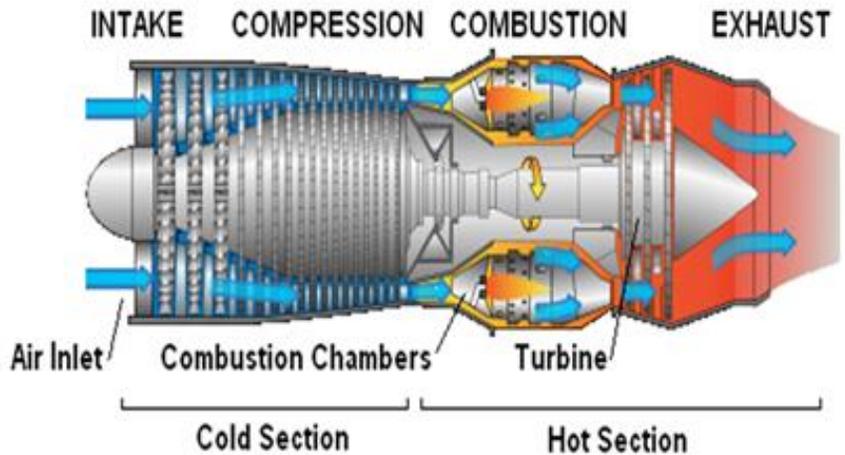
Steam Turbines Genset

### 3.3 Power Generation Technologies

**Key concept:**

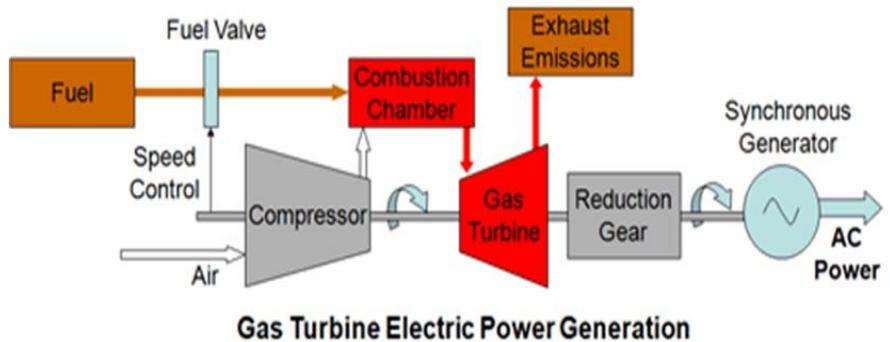
- A gas turbine, also called a combustion turbine, is a type of internal combustion engine. It has an upstream rotating compressor coupled to a downstream turbine, and a combustion chamber in between.
- The basic operation of the gas turbine is similar to that of the steam power plant except that air is used instead of water. Fresh atmospheric air flows through a compressor that brings it to higher pressure.

### Gas Turbines Technologies



#### Components in Gas Turbines

- Air Inlet
- Intake Air
- Compressor
- Combustion
- Combustion Chambers
- Turbines
- Exhaust



#### Gas Turbines Block Diagram



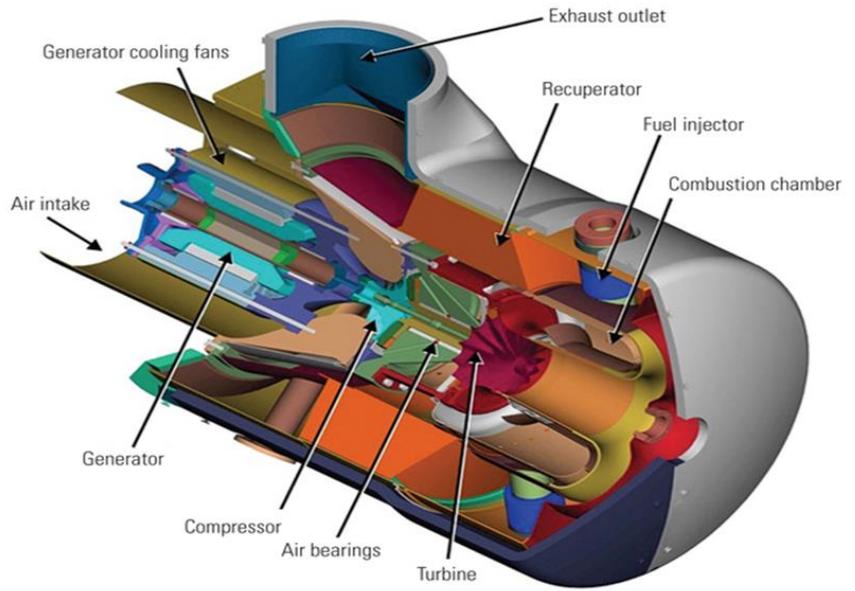
40kW Gas Turbines Block Generator

### 3.3 Power Generation Technologies

Micro turbines are small gas turbines that burn clean gaseous and liquid fuels to create mechanical energy that turns an electrical generator or other load. A technologies that converts the flow of a fluid (air, steam, water, or hot gases) into mechanical motion for generating electricity. It follow then that a Micro Turbine is simply a small device that converts fluid flow into mechanical motion for electric generation processes.

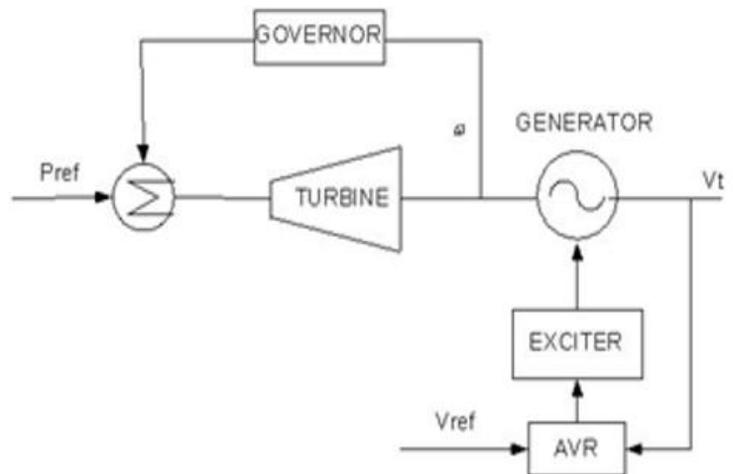
Micro turbines offer several potential advantages compared to other technologies for small-scale power generation, including: a small number of moving parts, compact size, lightweight, greater efficiency, lower emissions, lower electricity costs, and opportunities to utilize waste fuels. Waste heat recovery can also be used with these systems to achieve efficiencies greater than 80%.

### Micro Turbines System



### Components in Micro Turbines

- Generator Cooling Fan
- Intake Air
- Exhaust Outlet
- Generator
- Recuperator
- Compressor
- Air Bearing
- Turbines
- Fuel Injector
- Combustion Chamber



### Micro Turbines Block Diagram



Capstone C65 Micro Turbine that generate up to 390kW of continuous power

3.3 Power Generation Technologies

**Key concept:**

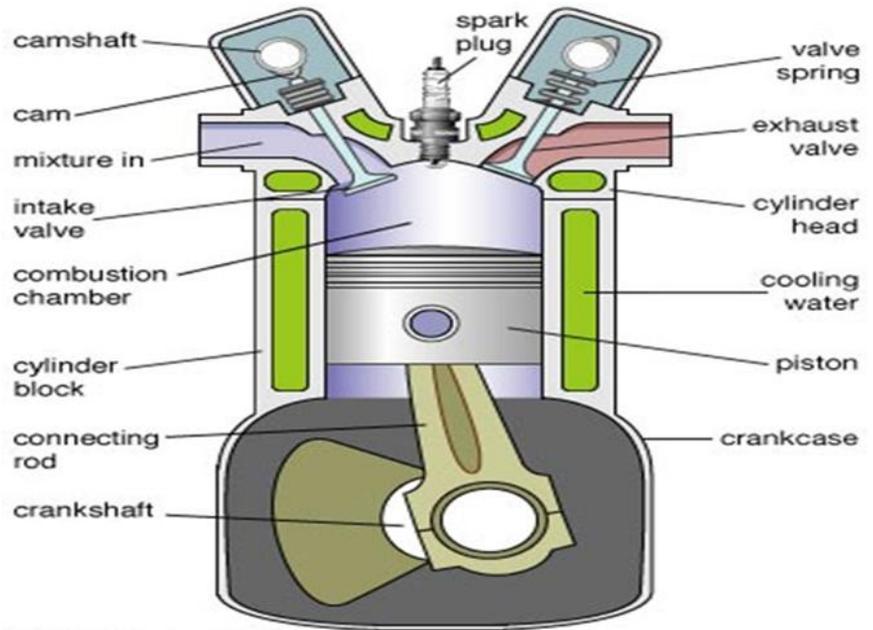
A reciprocating engine, also often known as a piston engine, is typically a heat engine (although there are also pneumatic and hydraulic reciprocating engines) that uses one or more reciprocating pistons to convert pressure into a rotating motion.

The internal combustion engine, used extensively in motor vehicles; the steam engine, the mainstay of the Industrial Revolution and the niche application Stirling engine.

**Internal combustion engines are further classified in two ways:**

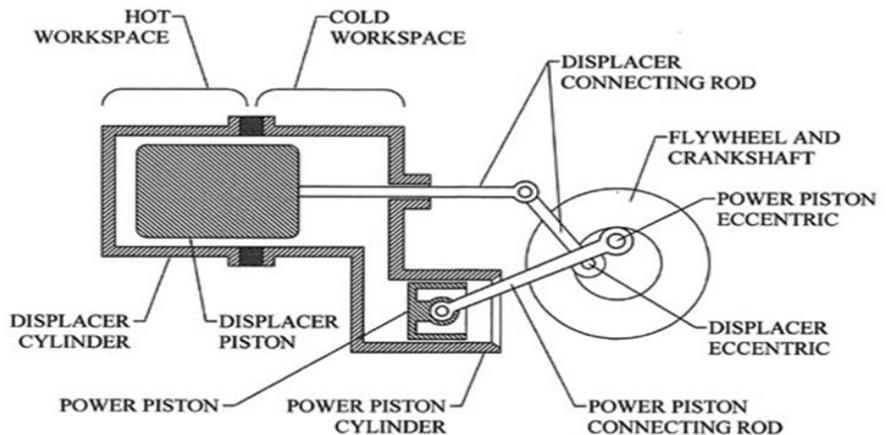
- **Spark-ignition (SI) engine**, where the spark plug initiates the combustion or
- **Compression-ignition (CI) engine**, where the air within the cylinder is compressed, thus heating it, so that the heated air ignites fuel that is injected then or earlier

Reciprocating Internal Combustion



Components in Reciprocating Internal Combustion

- Camshaft
- Cam
- Valve Spring
- Exhaust valve
- Cylinder head
- Cooling Water
- Combustion Chamber
- Cylinder block
- Piston
- Connecting rod
- Crankshaft
- crankcase



Reciprocating Internal Combustion Block Diagram

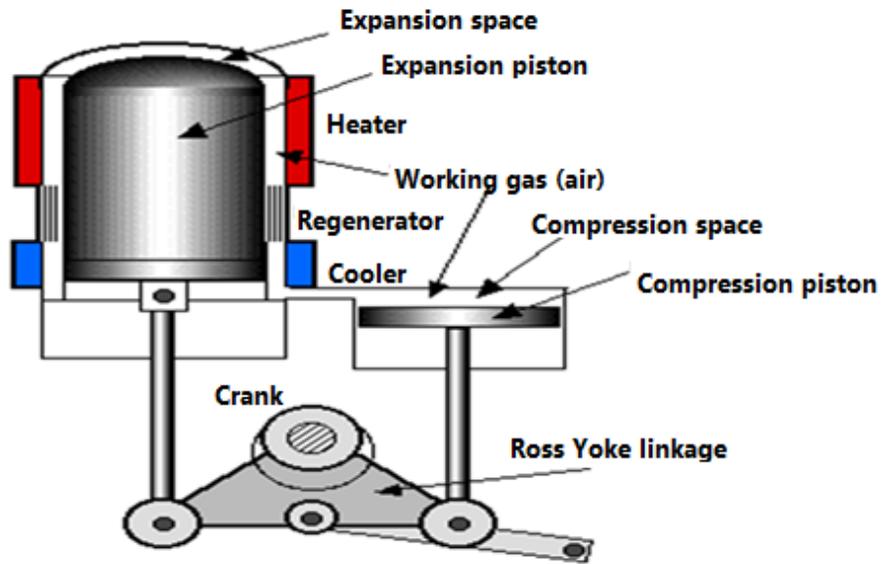


3.3 Power Generation Technologies

Key concept:

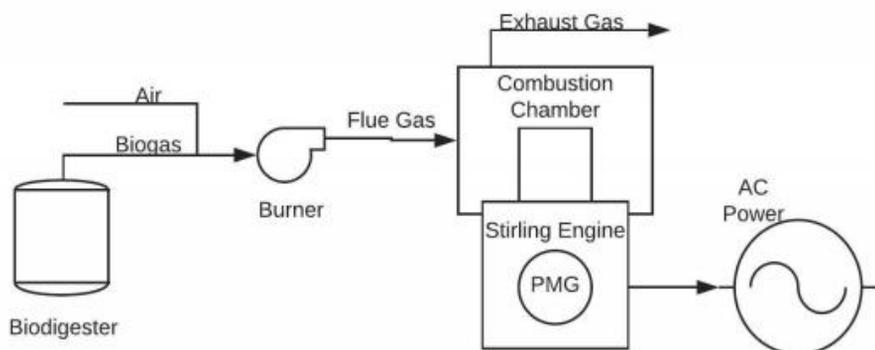
A Stirling engines is a heat engine that operates by cyclic compression and expansion of air or other gas (the working fluid) at different temperatures, such that there is a net conversion of heat energy to mechanical work more specifically, the Stirling engine is a closed-cycle regenerative heat engine with a permanently gaseous working fluid.

Stirling Engine



Components in Stirling Engine

- Expansion Space
- Expansion piston
- Heater
- Regenerator
- Cooler
- Working Gas (Air)
- Compression piston
- Crank
- Ross Yoke linkage
- Compression space



Stirling Engine Block Diagram

A modern Stirling Engine and Generator Set with 55kW Electrical Output For Combined Heat and Power Applications

## Tutorial Question

**CASE STUDY QUESTION 1:**

- ⦿ Identify the various technologies using for **biomass power system**
- ⦿ Discuss type of waste material in **biomass power system** for effective output voltage.
- ⦿ Distinguish the advantages and disadvantages using **biomass and biogas power system** technologies.
- ⦿ Describe the applicability biomass and biogas power system in Malaysia.

**CASE STUDY QUESTION 2:**

Detail ONE (1) of the Project must include (for Biogas or Biomass Company);

(40 MARKS)

1. Recognition the type of fuel used in Biogas/Biomass Power Plant. (5 Marks)
2. Investigate the diagram or process to generate power from the Biogas/Biomass Power Plant. (15Marks)
3. Safety features in the working place. (5Marks)
4. Understand the concept and output distribution of the Biogas/Biomass Power Plant (10Marks)
5. Understand how Biogas/Biomass Power Plant interface to the grid. (5Marks)

**ESEI QUESTION:**

To commercialize renewable energy technologies using the Bioenergy Power System to produce electricity involves various power generation technologies. Micro Turbine Technologies and Stirling Engine Technologies are among Power Generation Technologies used to generate electricity using Bioenergy Power Systems. Classify the main components and illustrate the block diagram for each of the power-generating technology in this question

# FUEL CELL POWER SYSTEM

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## CHAPTER

# 04

- ✓ Fuel cell power systems
- ✓ Fuel processing systems
- ✓ Fuel cell power section systems
- ✓ Fuel cell power conditioning systems and power conversion
- ✓ Application of fuel cells power system

## 4.1 Fuel Cell Power System

### Key concept:

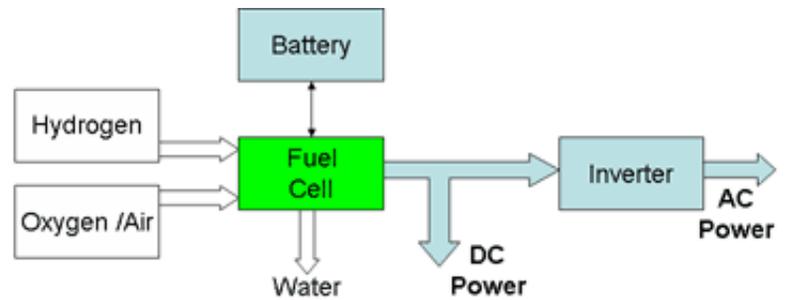
- ✓ A fuel cell is composed of an anode, cathode, and an electrolyte membrane
- ✓ hydrogen and oxygen are combined to generate electricity, heat, and water.

### Did you know??

- ✓ The first fuel cells were invented in 1838
- ✓ The first commercial use of fuel cells came more than a century later in **NASA** space programs to generate power for satellites and space capsules.

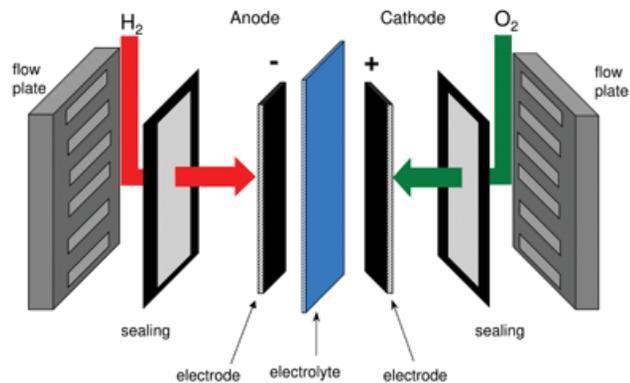
## Fuel Cell

A fuel cell uses the chemical energy of hydrogen or other fuels to cleanly and efficiently produce electricity. If hydrogen is the fuel, the only products are electricity, water, and heat. Fuel cells are unique in terms of the variety of their potential applications; they can use a wide range of fuels and feedstocks and can provide power for systems as large as a utility power station and as small as a laptop computer.



Fuel Cells

Fuel Cell Block Diagram



Fuel Cell Main Components

There are many types of fuel cells, but they all consist of an **anode**, a **cathode**, and an **electrolyte that allows ions**, often positively charged hydrogen ions (protons), to move between the two sides of the fuel cell.

Due to their high efficiency, fuel cells are very clean, with their only by-products being electricity, excess heat, and water. In addition, as fuel cells do not have any moving parts, they operate near-silently.

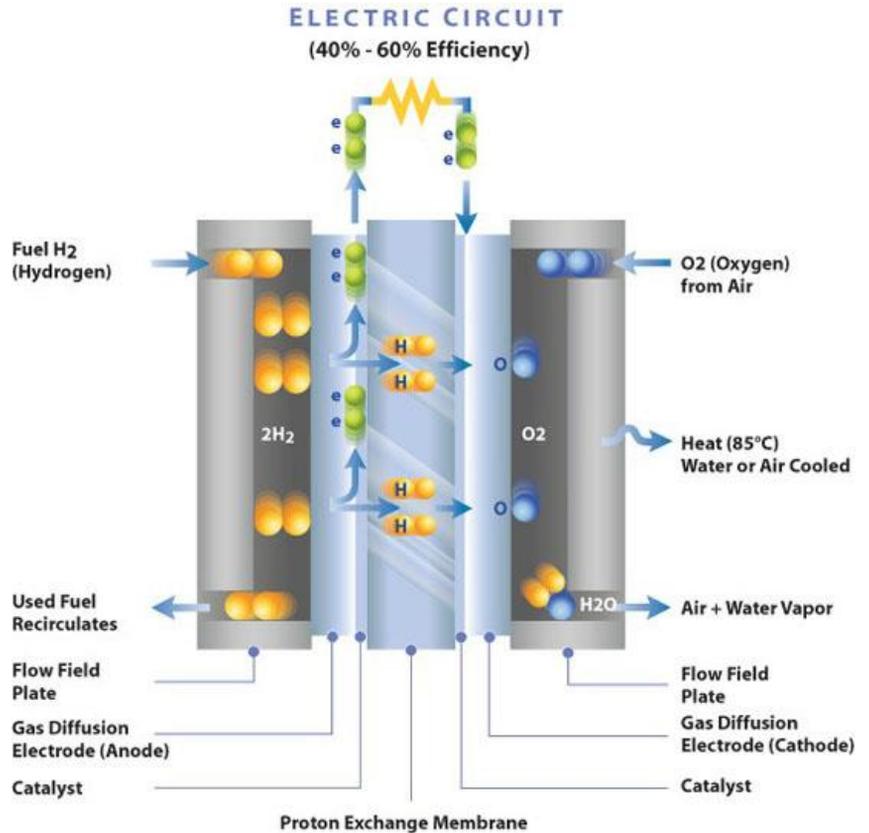
## 4.1 Fuel Cell Power System



### Benefit of Fuel Cell:

- Low-to-Zero Emissions
- High Efficiency
- Reliability
- Fuel Flexibility
- Energy Security
- Durability
- Scalability
- Quiet Operation

Hydrogen  
ENERGY  
Fuel cell



•The anode and the cathode are electrodes which carry a positive or negative charge; also known as Gas Diffusion Layers (GDL). The anode is negatively charged, and cathode is positively charged. They are placed on opposite sides of the fuel cell, so that the proton exchange membrane and the catalyst layers are sandwiched in-between.

•The catalyst is made of microscopic particles of platinum are placed on a carbon support and mixed with an ion-conducting polymer (known as an ionomer). The layer next to the anode separates hydrogen atoms into electrons and protons while the layer next to the cathode reacts with oxygen and the protons that traveled through the PEM to form water.

•In a fuel cell, hydrogen is fed into the system next to the anode, where the catalyst separates the electron from the rest of the hydrogen molecule. The hydrogen molecule, which no longer has any electrons and is thus positively charged, travels through the PEM where it meets up with the oxygen that has entered near the cathode. The hydrogen and oxygen combine to make a water byproduct. Meanwhile, the free electron, not attached to any molecule, is channeled through an external circuit, creating a flow of electricity. As long as hydrogen and oxygen are being pumped into the fuel cell, it will continue to produce electricity.

## 4.2 Fuel Processing System

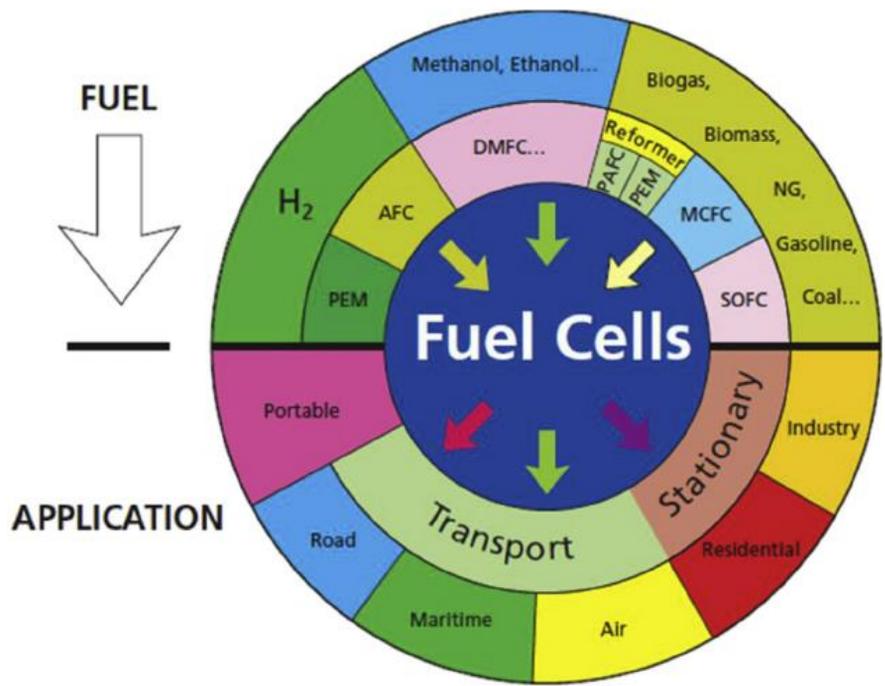
### Two category of fuel cells:

#### Low-temperature fuel cells:

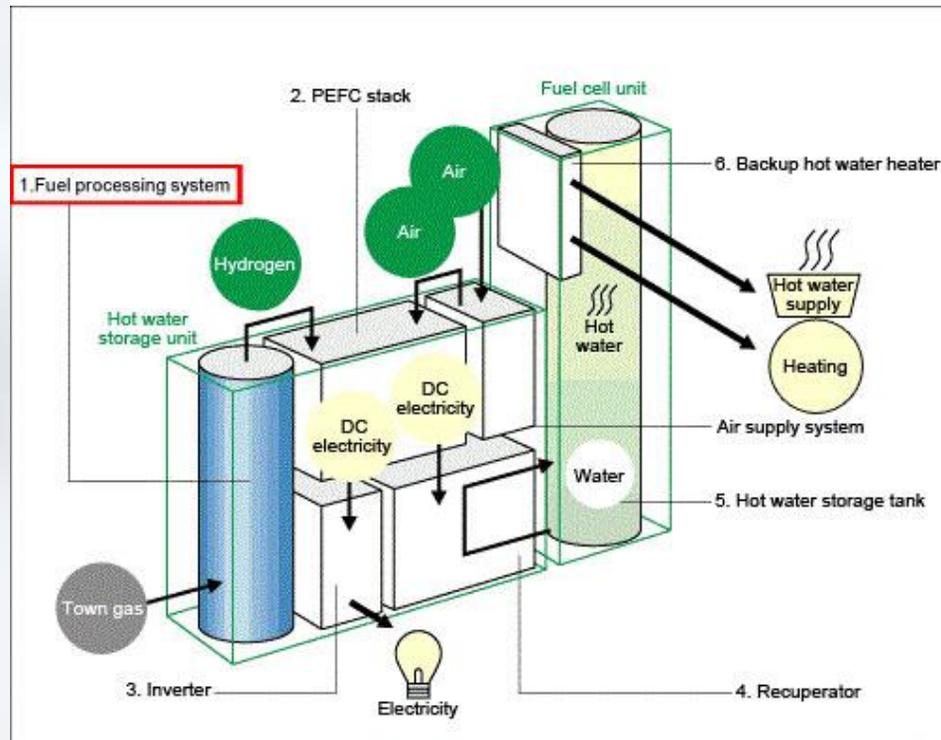
- ✓ **Proton Exchange Membrane (PEMFCs)**, comprising a proton exchange membrane, working between 60°C and 120°C depending on the pressure used.
- ✓ **Direct methanol fuel cells (DMFCs)**, which are PEMFCs fed by methanol directly oxidized at the anode.
- ✓ **Alkaline fuel cells (AFCs)** with a hydroxide conducting electrolyte, working between 70°C and 120°C.
- ✓ **Phosphoric acid fuel cells (PAFCs)**, with an electrolyte containing concentrated phosphoric acid, working between 150°C and 210°C.

#### High-temperature fuel cells:

- ✓ **Molten carbonate fuel cells (MCFCs)**, with a molten carbonate eutectic as electrolyte, working between 600°C and 650°C.
- ✓ **Solid Oxide Fuel Cell (SOFCs)**, with an oxide conducting membrane. The operational temperature of SOFC membrane ranges between 550 and 1000 °C depending on the electrolyte type



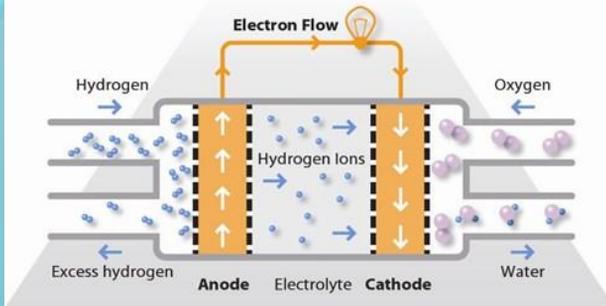
A fuel processing system is a system for producing hydrogen from city gas to be used as fuel for fuel cells. It is made up of a desulfurizer, to remove the sulfur used as an odorant in city gas, and a fuel processor for producing and purifying hydrogen gas. The aim of desulfurizer development has been the creation of a low-cost desulfurization system.



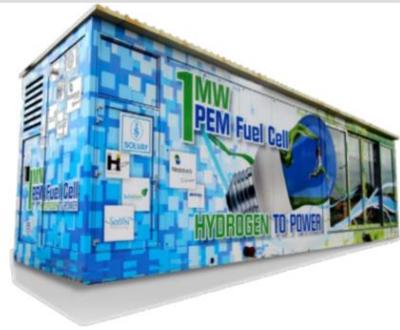
## 4.2 Fuel Processing System

### Proton Exchange Membrane Fuel Cells (PEMFCs)

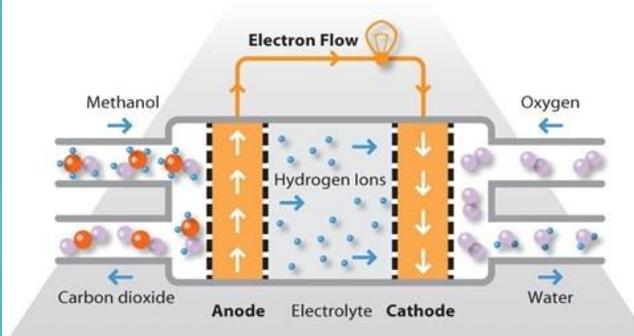
Proton Exchange Membrane Fuel Cells (PEMFCs) use a polymer membrane for its electrolyte and a precious metal, typically platinum, for its catalyst. What distinguishes these fuel cells from others is PEMFC's ability to operate at cooler temperatures relative to other types of fuel cells, between 80 to 200 degrees Fahrenheit. Pure hydrogen gas is the typical fuel for PEMFCs. Due to their use of precious metals and lower operating temperatures.



PEMFCs operate between 40% to 60% efficiency and are capable of handling large and sudden shifts in power output. PEMFCs are well-suited for cars and other specialty vehicles such as forklifts that need to quickly start up or accelerate. Additionally, PEMFC's can be scaled in stationary applications for use in telecommunications, data centers, and residential markets.



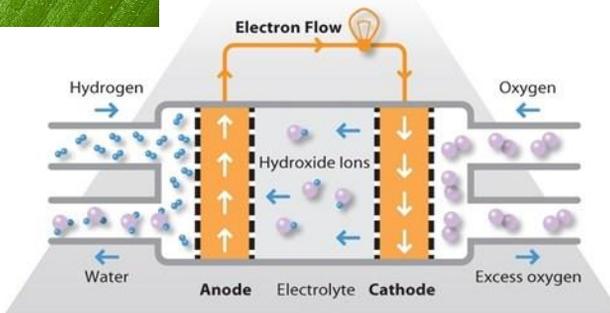
### Direct Methanol Fuel Cell (DMFC)



Much like PEMFCs, Direct Methanol Fuel Cells (DMFCs) use a polymer membrane as an electrolyte and commonly a platinum catalyst as well. However, unlike PEMFCs, DMFCs draw hydrogen from liquid methanol, rather than use direct hydrogen fuel. DMFCs also run at relatively cool temperatures, between 125 and 250 degrees Fahrenheit. Applications of DMFCs range from small electronics, such as battery chargers and laptops, to larger applications like stationary power for telecommunications backup.

## 4.2 Fuel Processing System

### Alkaline Fuel Cell (AFC)

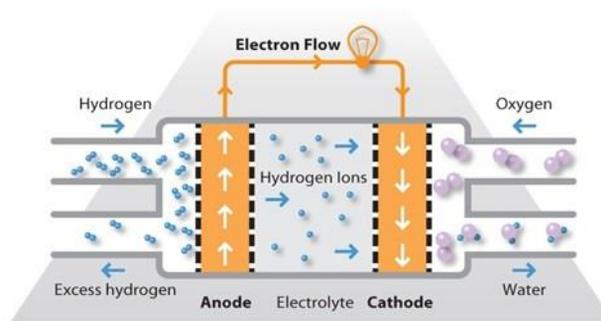


AFCs are best known for their roles in the NASA Apollo mission to provide both water and electricity to the crew. These fuel cells use porous electrolytes saturated with an alkaline solution and have an alkaline membrane as the name suggests. The AFC is one of the most efficient types of fuel cells, with a potential of 60% electrical efficiency, and 80% to 90% in CHP applications. AFCs use hydrogen as a fuel source, though are highly sensitive and can fail when exposed to carbon dioxide, which is why they are primarily used in controlled aerospace and underwater applications.



### Phosphoric Acid Fuel Cell (PAFC)

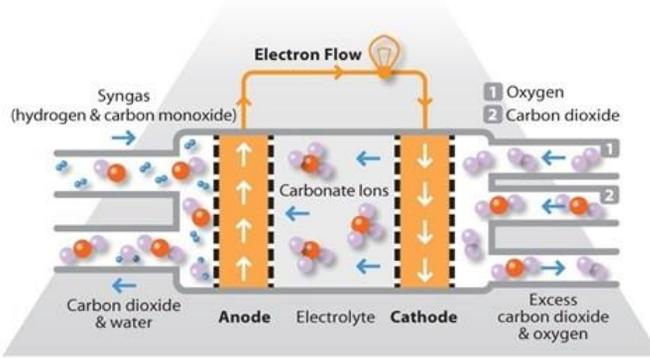
PAFCs use a liquid phosphoric acid and ceramic electrolyte and a platinum catalyst. These fuel cells operate physically similar to the PEM fuel cell and at similar efficiency level. However, PAFCs run at a higher temperature, allowing them to handle small amounts of fuel impurities. PAFCs are typically used in a cogeneration mode to not only produce electricity, but also heat to be captured to assist heating and cooling. PAFCs are often seen in high-energy demand applications, such as hospitals, schools and manufacturing and processing centers.



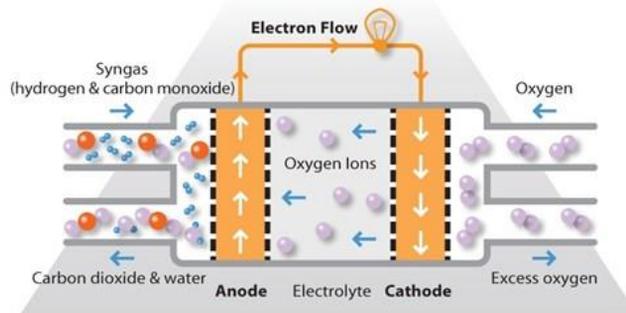
## 4.2 Fuel Processing System

### Molten Carbonate Fuel Cells (MCFCs)

Molten Carbonate Fuel Cells (MCFCs) operate at temperatures upwards of 1200-degree Fahrenheit, utilizing a molten carbonate-salt mixture suspended in a ceramic matrix as an electrolyte. This high temperature allows for MCFCs to utilize non-platinum catalysts through a process called 'internal reforming,' decreasing overall system cost. MCFCs can also use natural gas directly as its fuel source, as its high temperatures allow internal reforming of the natural gas into hydrogen within the system itself. MCFCs can reach efficiencies of 50-60%, and 70% - 80% in CHP applications. These fuel cells are typically deployed in stationary applications, providing high-quality primary and back-up power to utilities and businesses.



### Solid Oxide Fuel Cell (SOFC)



SOFCs are the highest temperature fuel cells, operating at about 1800 degrees Fahrenheit. SOFCs use a dense layer of ceramic as an electrolyte, which at high temperatures allows for the conductivity of oxygen ions. Similar to the MCFCs, SOFCs also use a non-platinum catalyst utilizing internal reformation and are commonly fueled by natural gas. Through this process, SOFCs can achieve electrical efficiencies of 50% to 60%, and 70%-80% in CHP applications. SOFCs are being used in a range of applications, from small residential auxiliary power units supplying heat and power to homes, to large-scale stationary power generators for larger buildings and businesses

## 4.2 Fuel Processing System



### Advantages of Fuel Cell

- High efficiency
- Clean. Carbon free when using H<sub>2</sub> and O<sub>2</sub>.
- Can use renewable fuels
- Do not need recharging.
- Can run continuously (as long as fuel is available)
- Provides base load power (good complement to renewables)
- No moving parts
- No noise
- Certain types are well suited to CHP applications
- Fuel can be made from water which is abundant or many other things
- Highly scalable--cell phones to power plants.
- Well suited for distributed generation, eliminating distribution losses.
- Can be run in reverse for energy storage, producing hydrogen from electricity and water

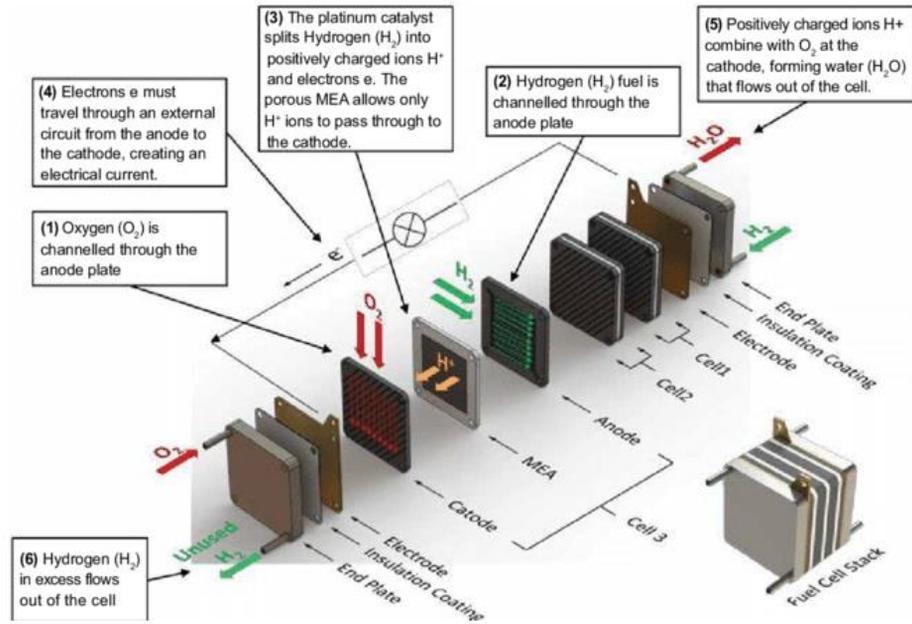
### Disadvantages of Fuel Cell

- High cost due to expensive materials like platinum
- Requires fuel
- Reliability still evolving.
- Durability, particularly at high temperatures.
- Robustness. Many are sensitive to temperature and contamination.
- Hydrogen fuel not readily available
- Little (but growing) infrastructure for hydrogen delivery
- Safety concerns with hydrogen (though it is less dangerous than gasoline)
- Low density of fuel, compared to gasoline
- Could become irrelevant if batteries got good enough

### 4.3 Fuel Cell Power Section Systems

#### PEMFC

**Proton exchange Membrane (PEM) fuel cells**, also known as **Polymer exchange membrane fuel cells** typically operate on pure (99.999%) hydrogen fuel. The PEM fuel cell combines the hydrogen fuel with the oxygen from the atmosphere to produce Water, heat (up to 90°C) and electricity.



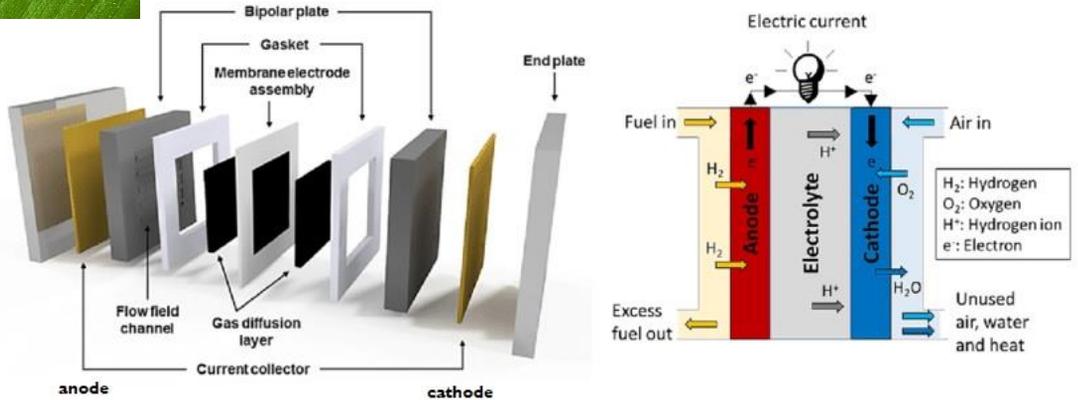
Proton exchange membrane (PEM) fuel cells provide high power density and the advantages of low weight and volume compared to other types of fuel cells. In a PEM cell, hydrogen and oxygen gas are fed to catalytic electrodes at opposite sides of a special membrane. This special membrane is porous to protons but not electrons. The protons and electrons are separated by the action of a platinum catalyst in the electrodes. The protons can diffuse directly through the membrane, but the electrons have to make their way through an external circuit to reach the other side, providing power for an electric motor in the process.

PEM fuel cells are considered to have the highest energy density of all the fuel cells, and due to the nature of the reaction have the quickest start up time (less than 1 sec) so they have been favored for applications such as vehicles, portable power and backup power applications.

The intolerance of the catalysts to impurities such as carbon monoxide has led to developments of high temperature membranes which operate at 150°C +. This enables the catalysts to tolerate greater impurities in the hydrogen supply.

4.3 Fuel Cell Power Section Systems

PEMFC Components



PEM Fuel cells typically utilize **platinum-based catalysts** on the **Anode** to split the **Hydrogen** into positive ions (protons) and negative electrons. The ions pass through the membrane to the **cathode** to combine with oxygen to produce water. The electrons must pass round an external circuit creating a current to rejoin the H<sub>2</sub> ion on the cathode.

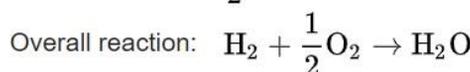
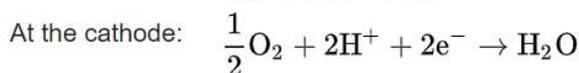
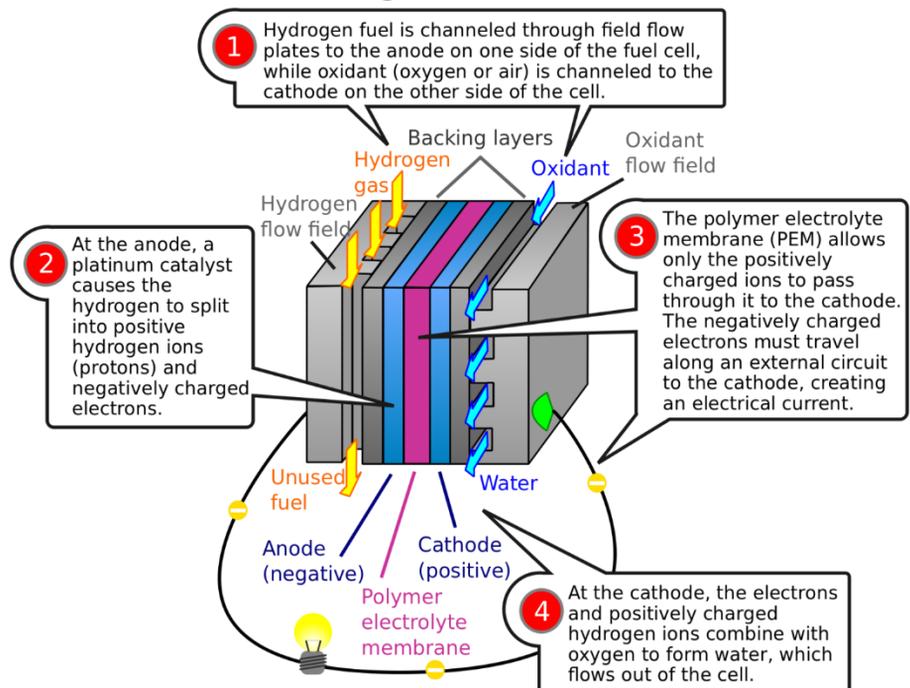
PEMFC Components:

- Anode
- Cathode
- Catalyst / Electrolyte
- Hydrogen
- Oxygen

Chemical reaction create heat, electricity and water

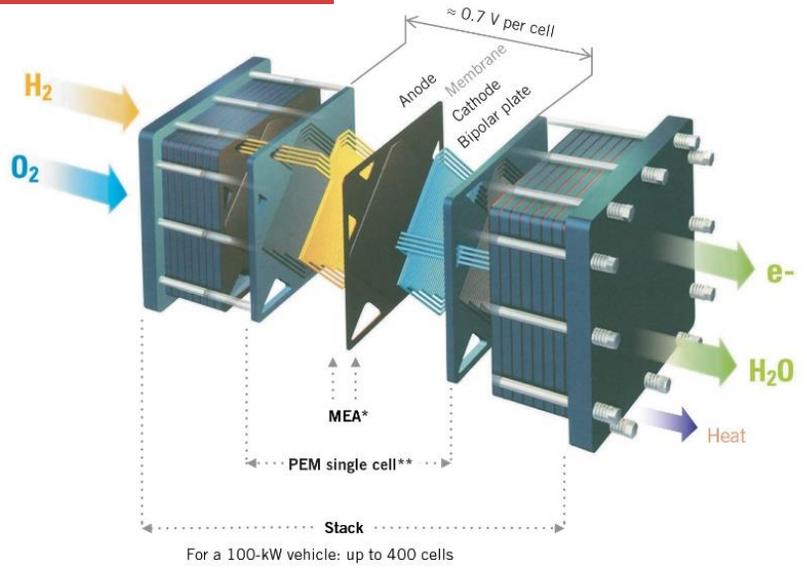
PEMFC Operation Diagram

Proton exchange membrane fuel cell



4.3 Fuel Cell Power Section Systems

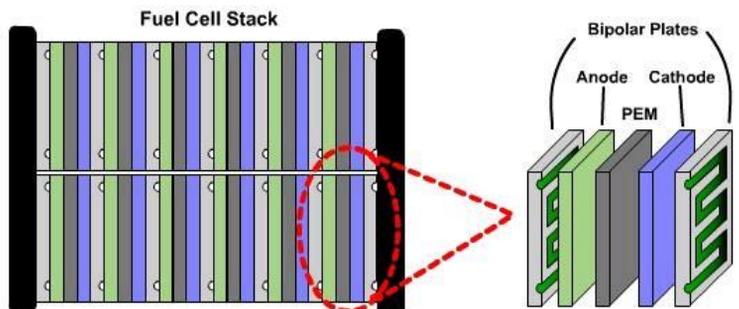
Fuel Cell Stack Design



\*MEA: Membrane Electrode Assembly  
 \*\*PEMFC: Proton Exchange Membrane Fuel Cell

Fuel Cell Stack, PEM Fuel Cell Stack, Polymer Electrolyte Membrane Fuel Cells Proton exchange membrane fuel cells, also known as polymer electrolyte membrane (PEM) fuel cells (PEMFC), are a type of fuel cell being **developed for transport applications** as well as **for stationary fuel cell applications and portable fuel cell applications**.

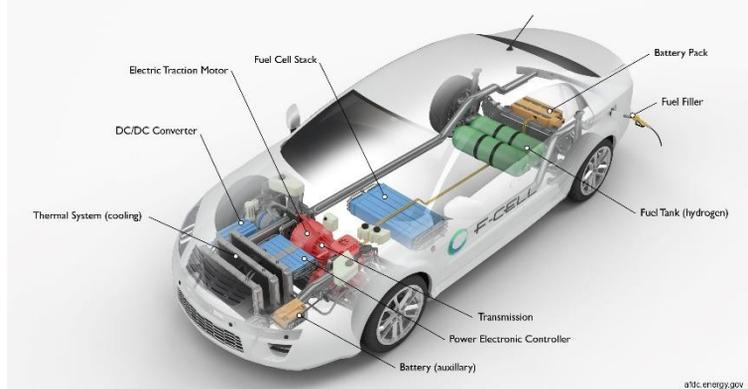
The fuel cell stack is the heart of a fuel cell power system. It generates electricity in the form of direct current (DC) from electrochemical reactions that take place in the fuel cell. A single fuel cell produces less than 1 V, which is insufficient for most applications. Therefore, individual fuel cells are typically combined in series into a fuel cell stack. A typical fuel cell stack may consist of hundreds of fuel cells. The amount of power produced by a fuel cell depends upon several factors, such as fuel cell type, cell size, the temperature at which it operates, and the pressure of the gases supplied to the cell. Learn more about the parts of a fuel cell.



## 4.5 Application of Fuel Cells Power System

### Automotive Application

Hydrogen Fuel Cell Electric Vehicle



- A fuel cell vehicle (FCV) or fuel cell electric vehicle (FCEV) is a type of vehicle which uses a fuel cell to power its on-board electric motor.
- Fuel cells in vehicles create electricity to power an electric motor, generally using oxygen from the air and compressed hydrogen.
- A fuel cell vehicle that is fueled with hydrogen emits only water and heat, but no tailpipe pollutants, therefore it is considered a zero-emissions vehicle.
- Depending on the process, however, producing the hydrogen used in the vehicle creates pollutants. Currently, the primary alternative for clean hydrogen production without CO<sub>2</sub> emissions is **water electrolysis**.
- Fuel cells have been used in various kinds of vehicles including forklifts, especially in indoor applications where their clean emissions are important to air quality, and in space applications.

In conventional electric vehicles batteries provide power to the electric motor, in the FCHEVs batteries and fuel cell are connected in a parallel system and together provide power.

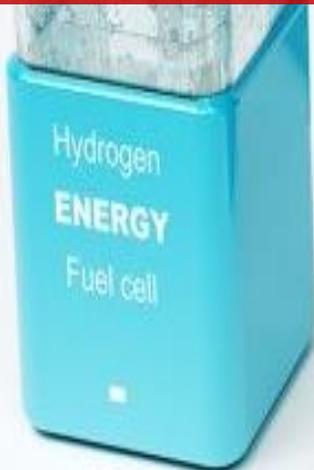
Capable of traveling 300-400 miles on a tank of hydrogen and refueling in three-five minutes, FCVs combine the emissions-free driving of an electric vehicle with the range and convenience of a traditional internal combustion engine. FCVs are up to three times more efficient than conventional vehicles, and when natural gas is used as a source for hydrogen, FCVs are the most efficient way to use this resource in cars. Having no internal moving parts, fuel cells also are quiet and highly reliable.

Conversely, the lower operating temperature fuel cells like PEMFCs and PAFCs are particularly well suited for transportation applications where the heat is neither usable nor desirable.



Fuel Cell Today categories the use of fuel cells into three broad areas:

- portable power generation,
- stationary power generation,
- power for transportation.



## 4.5 Application of Fuel Cells Power System

### Fuel Cell in Automotive



Toyota Mirai



Mercedes Benz



Yamaha FC



Boeing

#### Did you know??

A fuel cell vehicle (FCV) or fuel cell electric vehicle (FCEV) is an electric vehicle that uses a fuel cell



Hyundai Truck



Toyota Forklift



Hydra Boat



Alstom Coradia LINT

## 4.5 Application of Fuel Cells Power System

### Stationary Power System



Stationary fuel cells generate electricity through an electrochemical reaction, not combustion, providing clean, efficient, and reliable off-grid power to homes, businesses, telecommunications networks, utilities, and others.

Stationary fuel cells are quiet and have very low emissions, so they can be installed nearly anywhere. These systems provide power on-site directly to customers, without the efficiency losses of long-range grid transmission.

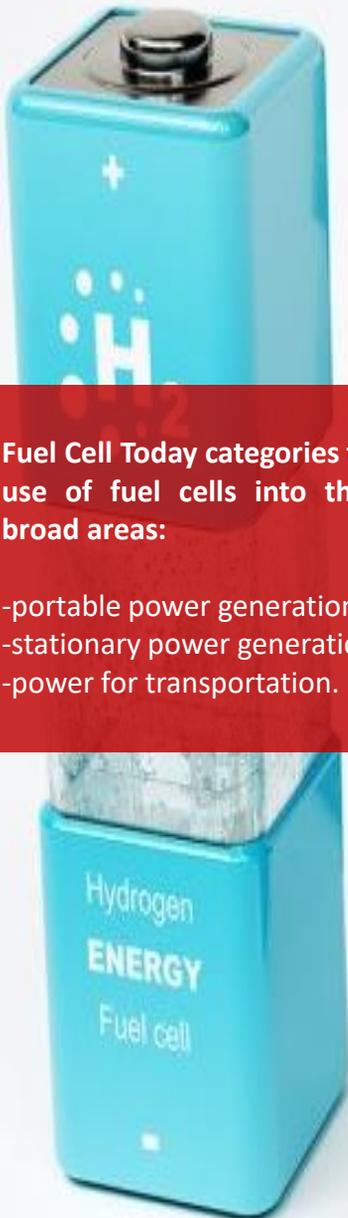
Stationary fuel cell systems also take up much less space in proportion to other clean energy technologies. For instance, a 10 MW fuel cell installation can be sited in about an acre of land. This is compared to about 10 acres required per MW of solar power and about 50 acres per MW of wind.

Fuel cells are highly efficient, typically reaching fuel to electricity efficiency of 60 percent, nearly double the efficiency of today's electric grid. Fuel cells also generate heat which, if captured, can increase overall energy efficiency to more than 90 percent. The heat produced by fuel cells can generate additional electricity through a turbine, provide heating directly to nearby buildings or facilities, and even cooling with the addition of an absorption chiller.

Unlike combustion-based power generation, stationary fuel cells provide virtually emission-free power. Fuel cells do not produce particulate pollutants, unburned hydrocarbons, or the gases that produce acid rain. They emit less carbon dioxide than other, less efficient technologies, and when using fuel generated from renewable sources such as biomass, fuel cells are completely carbon neutral.

Fuel Cell Today categorizes the use of fuel cells into three broad areas:

- portable power generation,
- stationary power generation,
- power for transportation.

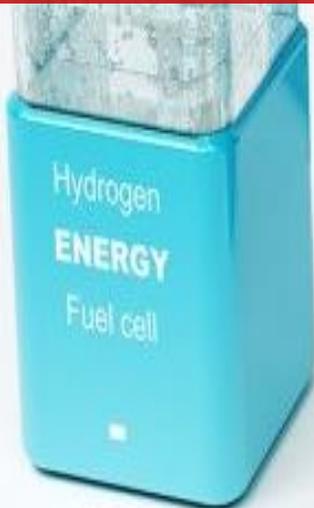


## 4.5 Application of Fuel Cells Power System



Stationary has been divided into three categories:

1. Micro-CHP
2. Emergency Power System
3. UPS



### Micro-CHP



**Micro combined heat and power or micro-CHP** is an extension of the idea of cogeneration to the single/multi family home or small office building in the range 0.3 - 50 kW. Local generation has a higher efficiency as it lacks the 8-10 % energy losses when transporting electricity over long distances and the 10-15 % energy losses on long distance heat transfer due to the difference between the hot energy carrier (water) and the colder external environment. The most common systems use some form of methane as their energy source and emit carbon dioxide.

### Emergency Power System



An **emergency power system** is an independent source of electrical power that supports important electrical systems on loss of normal power supply. A standby power system may include a standby generator, batteries and other apparatus. Emergency power systems are installed to protect life and property from the consequences of loss of primary electric power supply. They find uses in a wide variety of settings from homes to hospitals, scientific laboratories, data centers, telecommunication equipment and ships. Emergency power systems can rely on generators, deep cycle batteries, flywheel energy storage or hydrogen fuel cells

## 4.5 Application of Fuel Cells Power System

### UPS Fuel Cell



An **uninterruptible power supply**, also **uninterruptible power source**, **UPS** or **battery/flywheel backup**, is an electrical apparatus that provides emergency power to a load when the input power source, typically mains power, fails. A UPS differs from an auxiliary or emergency power system or standby generator in that it will provide near-instantaneous protection from input power interruptions, by supplying energy stored in batteries, super capacitors, or flywheels. The on-battery runtime of most uninterruptible power sources is relatively short (only a few minutes) but sufficient to start a standby power source or properly shut down the protected equipment.



## 4.5 Application of Fuel Cells Power System

### Portable Power Application



#### Fuel Cell Power Packs

Fuel cell power packs refer to battery replacement type applications. Examples would be fuel cells packaged into portable devices such as lap[top of page] computers, cellular phones, digital cameras, camcorders, and power tools. Portable devices are seen as employing up to 100 watt hours of energy, with supplemental energy available through refueling cartridges. Examples include:

- Cellular Phones (1 - 3 W)
- Computers (5 - 50 W)
- Camcorders (2 - 5 W)
- Cordless Tools (20 - 200 W)

Portable has been divided into two categories:

1. Fuel Cell Power Packs
2. Small Portable Power Generators



#### Small Portable Power Generators

Small Portable Power Generators refer to units up to about 20 pounds in weight, up to 3 - 5 kW power, with fuel for up to 1 to 2 kWhr energy. Examples of applications include power for camping and other recreational activity, or short-term power in an emergency.

## 4.6 Application of Fuel Cells Power System

### Transportation Application

#### Hydrogen Fuel Cell Cars

##### Pros

- Greenest power source
- Use of renewable energy
- Efficient power source
- Quiet means of transportation
- Short fueling time
- Long range
- No harmful fumes
- No air pollution
- No greenhouse gas emissions
- Perfect for commuting
- Hedge against increasing gas prices

##### Cons

- High costs for new cars
- High depreciation in the first years
- Charging may be an issue
- Lack of infrastructure related to hydrogen cars
- Limited selection of vehicles
- Technology not mature yet
- Large investments in R&D necessary
- High fuel costs
- Safety concerns
- Hydrogen production may not be eco-friendly

#### Fuel cell power system used in :

1. Automotive application is for power up the vehicles by charging up battery in the vehicles itself
2. Stationary power system used as a backup system or to supply power to remote area
3. Portable fuel cell power application used for low power equipment such as laptop, mobile phone and for recreational activity.

## 4.6 Application of Fuel Cells Power System

### Stationary Power Application

Type of fuel cell	Advantages	Disadvantages
<b>Alkaline Electrolyte Fuel Cell (AFC)</b>	<ul style="list-style-type: none"> <li>➤ Faster cathode reaction in alkaline electrolyte, higher performance</li> </ul>	<ul style="list-style-type: none"> <li>➤ Expensive removal of CO<sub>2</sub> from fuel and air streams required (CO<sub>2</sub> degrades the electrolyte)</li> </ul>
<b>Proton Exchange Membrane Fuel Cells (PEMFC)</b>	<ul style="list-style-type: none"> <li>➤ Solid electrolyte reduces corrosion &amp; electrolyte management problems</li> <li>➤ Low temperature quick start up</li> </ul>	<ul style="list-style-type: none"> <li>➤ Requires expensive catalyst</li> <li>➤ High sensitivity to fuel impurities</li> <li>➤ Low temperature waste heat</li> <li>➤ Waste heat temperature not suitable for combined heat and power(CHP)</li> </ul>
<b>Phosphoric Acid Fuel Cell (PAFC)</b>	<ul style="list-style-type: none"> <li>➤ Higher overall efficiency with CHP</li> <li>➤ Increased tolerance to impurities in hydrogen</li> </ul>	<ul style="list-style-type: none"> <li>➤ Requires expensive platinum catalyst</li> <li>➤ Low current and power</li> <li>➤ Large size and weight</li> </ul>
<b>Molten Carbonate Fuel Cell (MCFC)</b>	<ul style="list-style-type: none"> <li>➤ High efficiency</li> <li>➤ Fuel flexibility</li> <li>➤ Can use variety of catalysts</li> <li>➤ Suitable for CHP</li> </ul>	<ul style="list-style-type: none"> <li>➤ High temperature speeds up corrosion and breakdown of cell components</li> <li>➤ Complex electrolyte management</li> <li>➤ Slow start up</li> </ul>
<b>Solid Oxide Fuel Cells (SOFC)</b>	<ul style="list-style-type: none"> <li>➤ High efficiency</li> <li>➤ Fuel flexibility</li> <li>➤ Can use variety of catalysts</li> <li>➤ Solid electrolyte reduces electrolyte management problems</li> <li>➤ Suitable for CHP</li> <li>➤ Hybrid/GT cycle</li> </ul>	<ul style="list-style-type: none"> <li>➤ High temperature enhances corrosion and breakdown of cell components</li> <li>➤ Slow start-up</li> <li>➤ Brittle of ceramic electrolyte with thermal cycling</li> </ul>

## 4.7 Tutorial

**Structure Question**

1. There are six type of fuel cell power system. Explain **TWO (2)** type of fuel cell power system. [5 marks]
2. Elaborate the automotive applications of the fuel cells power system. [5 marks]
3. Show the difference between the stationary and portable power applications of fuel cells power system. [10 marks]

**ESSAY QUESTION**

Using suitable diagram and sketching, explain how fuel cell can generate electricity. (20 Marks)



# GREEN TRANSPORTATION SYSTEM

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## CHAPTER

# 05

- ✓ Key concepts of green transportation
- ✓ Types of alternative vehicles
- ✓ Architecture of alternative vehicles
- ✓ Powertrain component sizing for electric vehicles
- ✓ Energy storage solution in Electric Vehicles

## 5.1 Key concept of Green Transportation

### Key concept:

- ✓ Transportation contributes significantly to global climate change.
- ✓ It is responsible for over a quarter of all global carbon dioxide emissions from fossil fuel combustion.
- ✓ Road travel contributes for 75% of all CO<sub>2</sub> emissions, and this percentage is increasing every day.

### Challenges To Implement Green Transportation

- ✓ More expensive
- ✓ Higher preventive maintenance
- ✓ Fewer trained mechanics
- ✓ Battery concerns
- ✓ Public awareness and participation.
- ✓ Impact on grid.
- ✓ Smart charging infrastructure.

### The Most Eco-Friendly Ways to Travel

<https://www.goredmond.com/blog/april-2-2019-212pm/most-eco-friendly-ways-travel>

Walking

Biking

Transit

Carpool

Drive alone

## Types of green transportation

Green transportation is for reducing the environmental damage originated due to individual's use of vehicles like cars and trucks. These green transportation options make our lives easier, reduce congestion, reduce our dependence on cars & foreign oil, are safer & less costly, and help save the plane



Train

Electric trains emit 20-35% less carbon than diesel trains. A train is environmentally friendly especially Electric trains that are powered by renewable energy and offer carbon-free journeys.

Bicycling is an environmentally beneficial mode of transportation. It does not contribute to environmental pollution. Hence, it is an excellent mode of short-distance transportation.



Bicycles



Scooter

Electric scooters offer no pollutants and do not require you to visit a petrol station to top up your tank because they are powered by a rechargeable battery. A ride on an electric scooter is far more environmentally beneficial than a ride on a gas-powered scooter.

Walking is the best and most convenient way to travel short distances. Otherwise, it encourages individuals to exercise more in terms of healthcare.



Walking



Hybrid Car

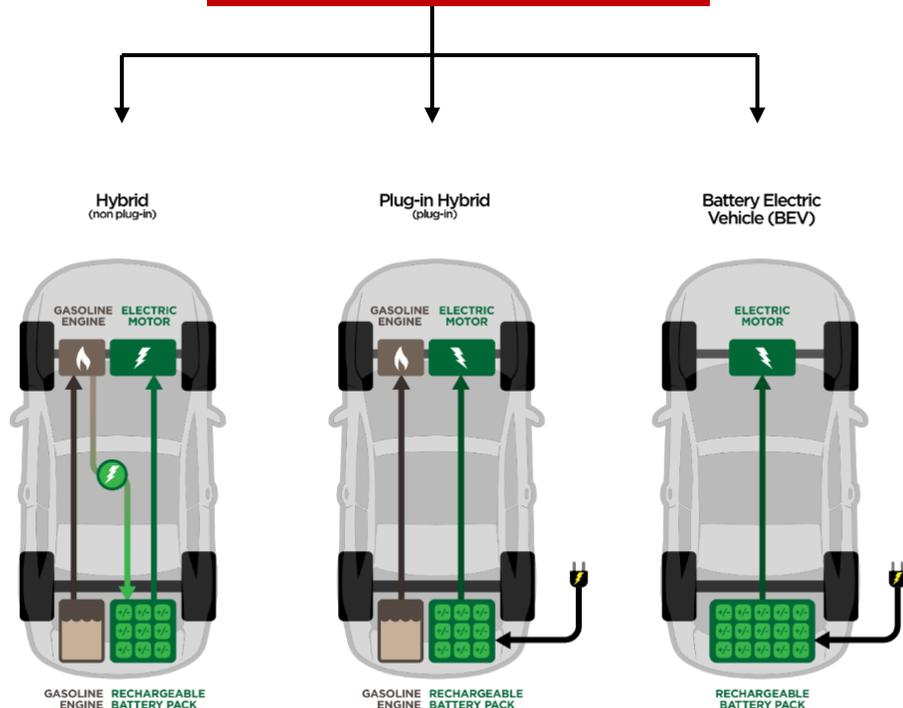
The great majority of hybrid cars are intended to recharge their batteries automatically by converting energy when braking. Hybrid automobiles have extremely low greenhouse gas emissions, ranging from 26 percent to 90 percent lower than regular cars.

## 5.2 Types Of Alternative Vehicles

### What is an alternative green vehicles:

- ✓ Other types of green vehicles include those that run entirely or partially on renewable energy sources rather than fossil fuels.
- ✓ Green vehicles refer to any engine-powering technology that does not rely entirely on petroleum (e.g. electric car, hybrid electric vehicles, solar powered).
- ✓ Another possibility is to use alternate fuel compositions (such as biofuels) in conventional fossil-fuel cars, allowing them to run on renewable energy sources in part.
- ✓ BIODIESEL is an alternative fuel that is a clean-burning renewable fuel generated by converting natural vegetable oils and fats into a non-toxic and renewable form of energy through a chemical process. It can be used as a replacement for regular diesel, but it can also be blended with diesel fuel in any amount.

### TYPES OF ALTERNATIVE VEHICLES



#### 1. Hybrid Electric Vehicle (HEV)

- ✓ combines a conventional internal combustion engine (ICE) propulsion system with an electric propulsion system.

#### 2. Plug-in Hybrid Electric Vehicle (PHEV)

- ✓ A PHEV having an electric motor and an internal combustion engine (ICE), and of an all-electric vehicle, having a plug to connect to the electrical grid.
- ✓ uses rechargeable batteries that can be recharged by plugging it in to an external source of electric power.

#### 3. Electric Vehicle (EV)

- ✓ EV operates with the help of an electric motor and a battery.
- ✓ The rechargeable batteries can be recharged by plugging it in to an external source of electric power.

5.2 Types Of Alternative Vehicles



EV: BMW i3S



EV: Renault Twizy

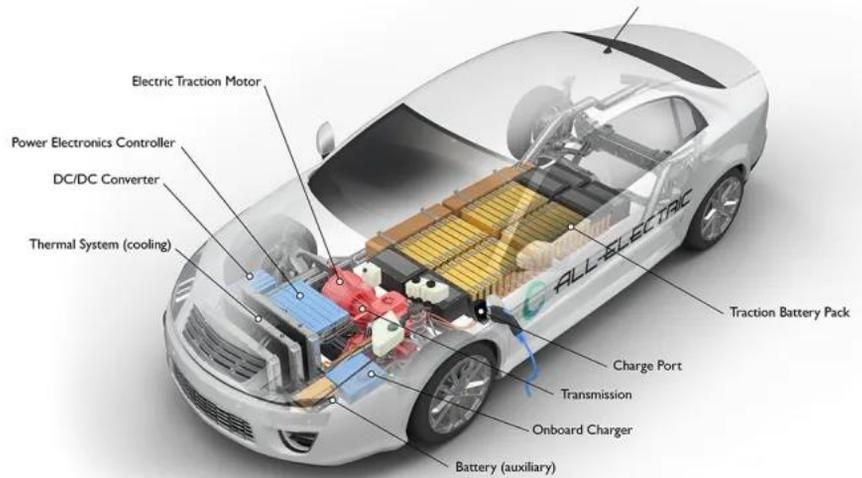


HEV: Toyota Prius C



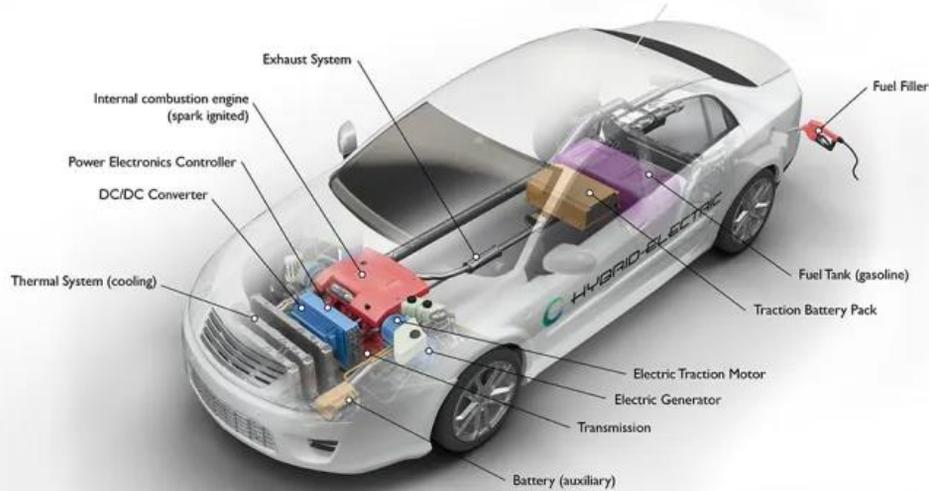
PHEV: BMW X5

1. ELECTRIC VEHICLES



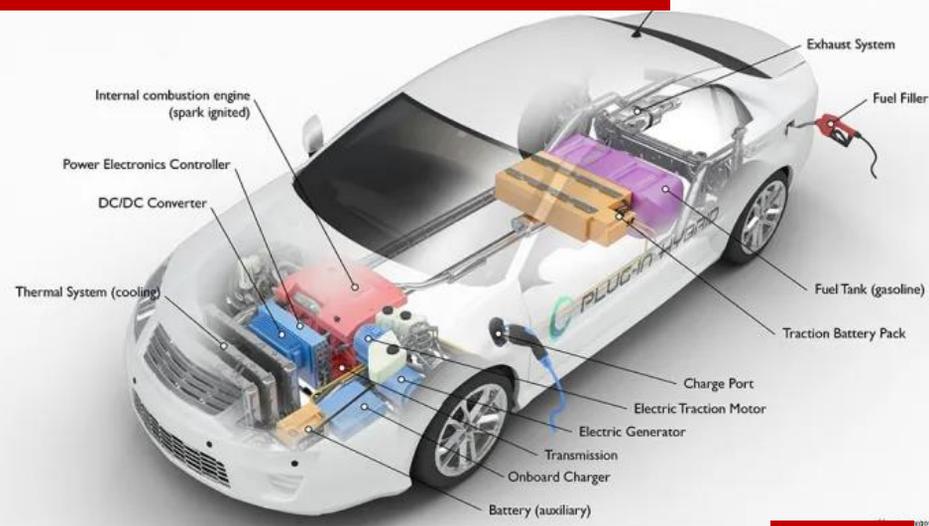
afdc.energy.gov

2. HYBRID ELECTRIC VEHICLES



afdc.s

3. PLUG-IN HYBRID ELECTRIC VEHICLES



afdc.gov

## 5.2 Types Of Alternative Vehicles

### Component used in Hybrid vehicle system:

Regardless of the type of hybrid vehicle system, the propulsion system mainly comprises the following components: **prime mover; electric motor with DC/DC converter, DC/AC inverter, and controller; energy storage system; and transmission system.**

The prime mover of a hybrid vehicle is its main **energy source**, which generally is one of gasoline, diesel, or fuel cells. The electric motor is one of the most important components in a hybrid vehicle. The energy storage system, one of the most important sub systems in an hybrid electric vehicle (HEV), consists of an **energy storage pack**; a voltage, current, and temperature measurement module; a cell balancing circuit; and a cooling system. In addition, battery-related estimation algorithms play key roles. Transmission is another important subsystem on the drivetrain.

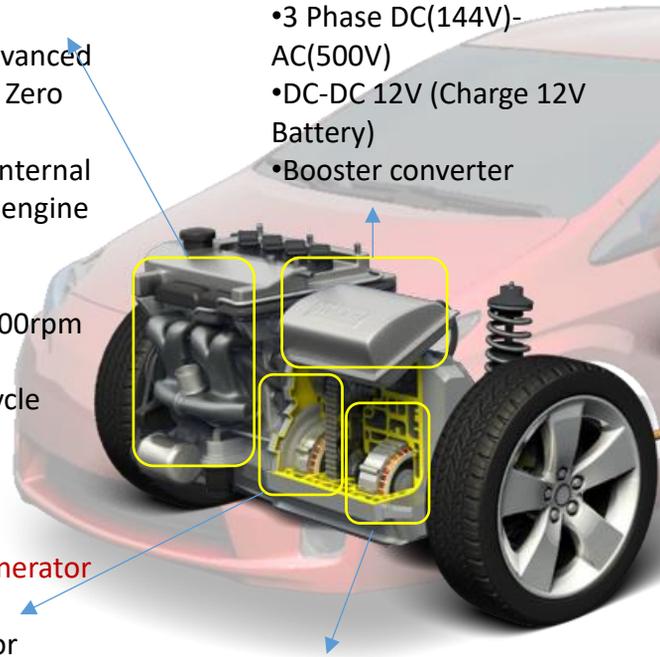
### COMPONENT USED IN HYBRID VEHICLE SYSTEM (refers to TOYOTA Prius)

#### 1. ICE – Internal Combustion Engine

- AT-PZEV Advanced Tech. Partial Zero Emission
- 1.5L Small internal combustion engine
- VVTi
- 54kW  
111Nm@4800rpm  
Max output
- Atkinson Cycle

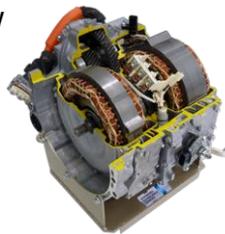
#### 5. Inverter

- 3 Phase DC(144V)-AC(500V)
- DC-DC 12V (Charge 12V Battery)
- Booster converter



#### 2. MG1 – Motor Generator 1

- Generator or starter.
- AC Synchronous Motor
- 30kW



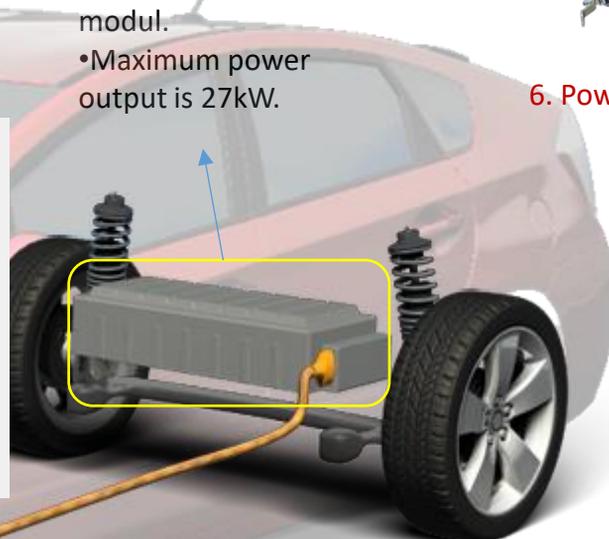
#### 3. MG2 – Motor Generator 2 / Electric Traction Motor

- Motor/Three phase Generator.
- AC Synchronous Motor
- 60kW 650Vmax
- Torque 169Nm



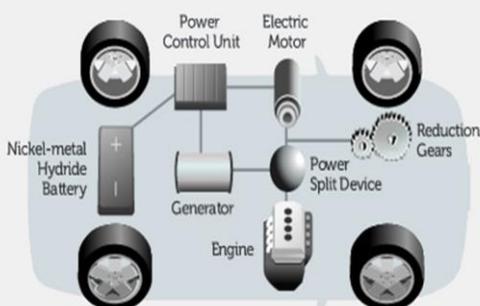
#### 4. HV Battery

- Nickel–metal hydride
- DC 144V, 20 cell
- $144/20=7.2V$  per modul.
- Maximum power output is 27kW.



#### 6. Power split device

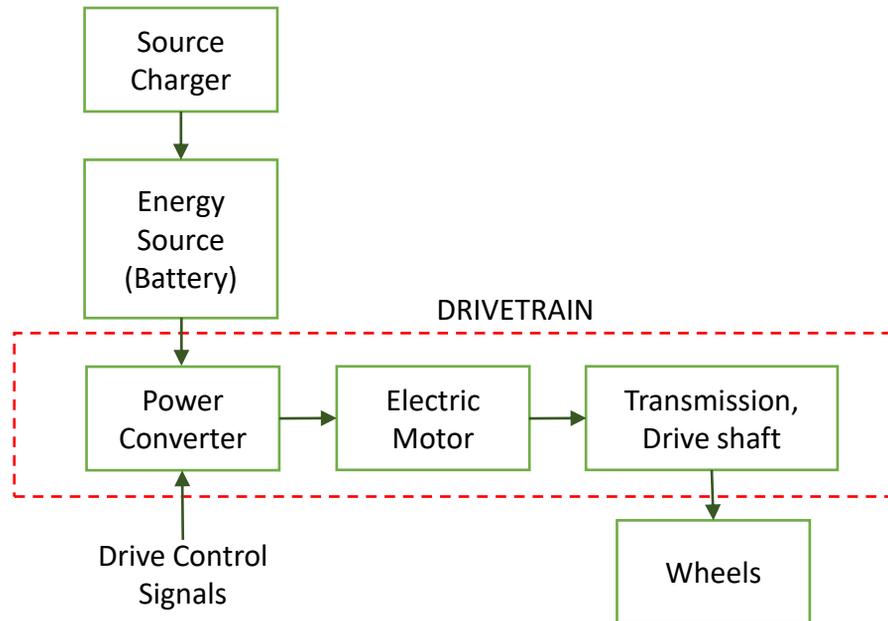
- Connector of three components;
- ICE, carrier gear
- MG1, sun gear
- MG2, ring gear, wheels
- ECVT



## 5.3 Architecture Of Alternative Vehicles

- ✓ Electric Vehicles (EVs) such as battery electric vehicles (BEV), hybrid electric vehicles (HEV), plug-in hybrid electric vehicles (PHEV), and fuel cell electric vehicles (FCEV) have become more widespread in the transportation sector.
- ✓ EVs can run entirely on electricity or in conjunction with an internal combustion engine. The most basic type of EV is one that uses solely batteries as an energy source, however there are others that can use various energy sources. These are known as hybrid electric vehicles (HEVs).
- ✓ BEVs are electric-only vehicles that do not have an internal combustion engine, a fuel tank, or an exhaust pipe. It contains one or more electric motors instead, which are driven by a larger onboard battery. An external outlet is used to charge the battery.
- ✓ HEVs are vehicles that use two or more types of energy sources, storage, or converters, as long as at least one of them provides electrical energy.

### ARCHITECTURE OF ELECTRIC VEHICLES



### COMPONENTS OF ELECTRIC VEHICLES

1. **Battery:** It powers the electric motor.
2. **Power Converter:** The electrical energy stored in the battery is fixed DC, and it must be converted to variable DC or variable AC, depending on the type of electric motor used to drive the wheels.
3. **Electric Motor:** In the beginning, DC series induction motors were employed. The focus has now switched to specialized electrical machinery.
4. **Clutch:** The engine must be decoupled from the wheels to shift from low speed to high speed gears or vice versa.
5. **Transmission:** The gearbox is also called as transmission which allows transfer of power from engine to wheels.
6. **Drivetrain:** The combination of electric motor, Clutch, Gearbox is referred to as drivetrain.

## 5.3 Architecture Of Alternative Vehicles

### What is HYBRID vehicles?

- ✓ Work with two or more power sources.
- ✓ Fuel + Battery = Hybrid EV

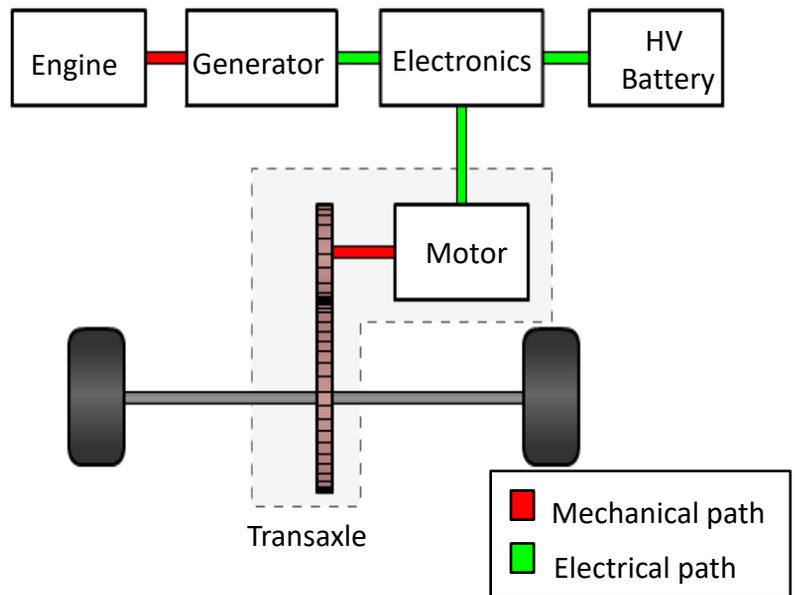
### SERIES HYBRID SYSTEM

- In a series hybrid system, the combustion engine drives an electric generator instead of directly driving the wheels.
- The electric motor is the only means of providing power to the wheels.
- The generator both charges a battery and powers an electric motor that moves the vehicle.
- When large amounts of power are required, the motor draws electricity from both the batteries and the generator.
- In a series hybrid, there is no mechanical connection between the ICE and the wheels.

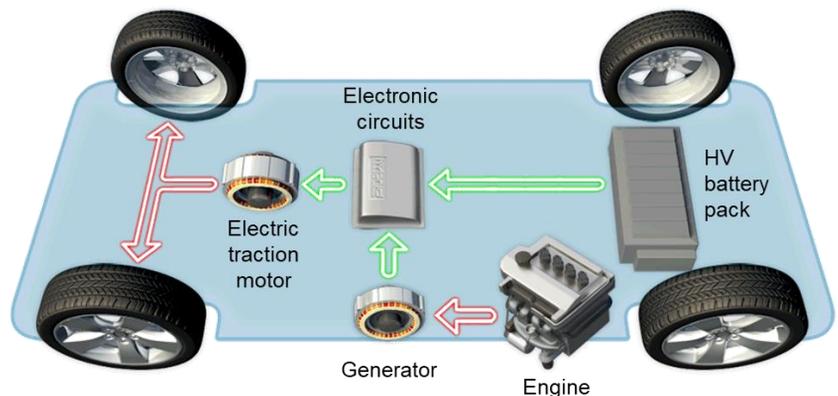
### The key feature of:

- ✓ Series hybrid is to **couple the ICE and the generator** to generate electricity for pure electric propulsion.

### 1. Series Hybrid System



1. **IC Engine:** Series hybrid use gasoline or diesel ICE, coupled with a generator, to generate electricity but not to drive the car. The engine sends an electric current to the electric motor directly or charge a large battery that stores and distributes electricity to the electric motor upon request.
2. **Electric Motor:** An electric motor drives the vehicle, using the power to rotate a driveshaft or a set of drive axes that turn the wheels. Suitable for use in moving and stopping conditions. At the stop condition, the engine generates electricity.
3. **Battery:** Regenerative braking reduces the operating time of the engine to charge the "HV Battery" while saving fuel and reducing emissions.



Series System Operation

## 5.3 Architecture Of Alternative Vehicles

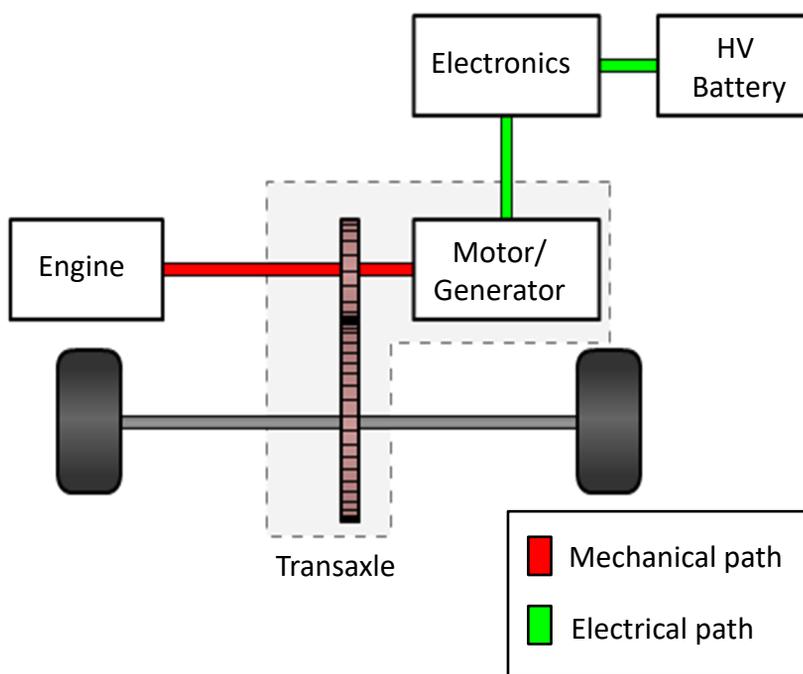
### PARALLEL HYBRID SYSTEM

- ✓ The parallel HEV (Figure 4b) allows both the internal combustion engine (ICE) and the electric motor (EM) to send power to the wheels.
- ✓ Because both the ICE and the EM are connected to the drive shaft of the wheels through two clutches, the propulsion power can come from either the ICE or the EM.
- ✓ When the ICE's output is greater than that required to move the wheels, the EM can be employed as a generator to charge the battery via regenerative braking or by absorbing power from the ICE.
- ✓ Due to its compact characteristics, small vehicles use parallel configuration. Most passenger cars employ this configuration

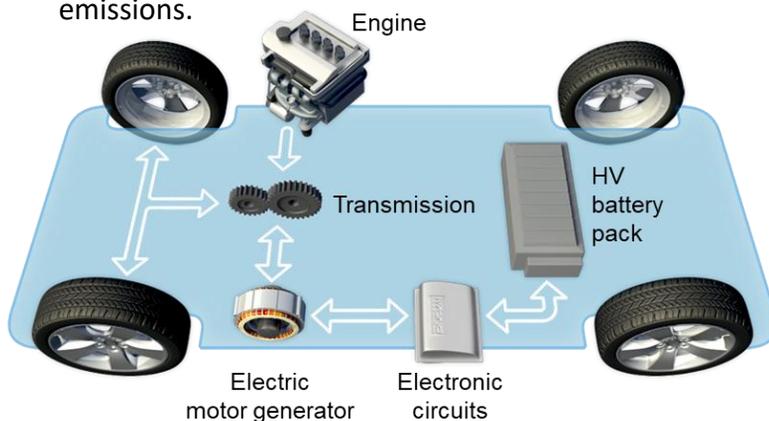
The key feature of:

- ✓ **Parallel hybrid** is to couple both the ICE and electric motor with the transmission via the same drive shaft to propel the vehicle.

### 2. Parallel Hybrid System



1. **IC Engine:** A parallel hybrid uses both an electric motor and an ICE. The engine does not function efficiently during constant start-stop driving.
2. **Electric Motor:** They can run in parallel, or one can be used as a main power source by kicking in to assist when additional power is needed to start, climbing hills, and accelerating to pass another vehicle. Because both are connected to the drive train, they're said to run "in parallel."
3. **Electronics (Power Converter):** It is tuned to work efficiently at higher speeds to reduce fuel consumption and emissions.



### Parallel System Operation

## 5.3 Architecture Of Alternative Vehicles

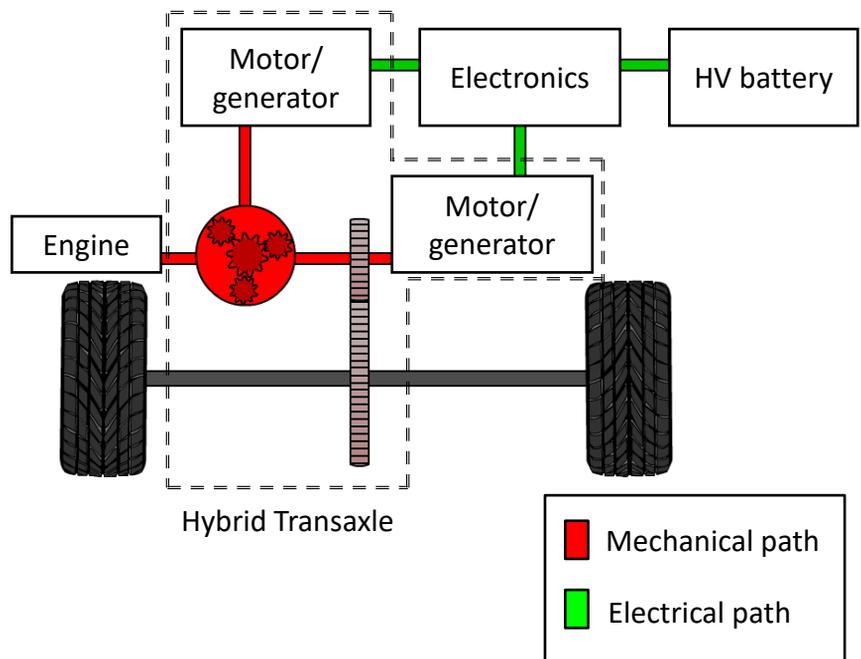
### SERIES/PARALLEL HYBRID SYSTEM

- In a power-split hybrid electric drive train there are two motors: an electric motor and an internal combustion engine.
- The power from these two motors can be shared to drive the wheels via a power splitter, which is a simple planetary gear set.
- The ratio can be from 100% for the combustion engine to 100% for the electric motor, or anything in between, such as 40% for the electric motor and 60% for the combustion engine.
- The combustion engine can act as a generator charging the batteries.

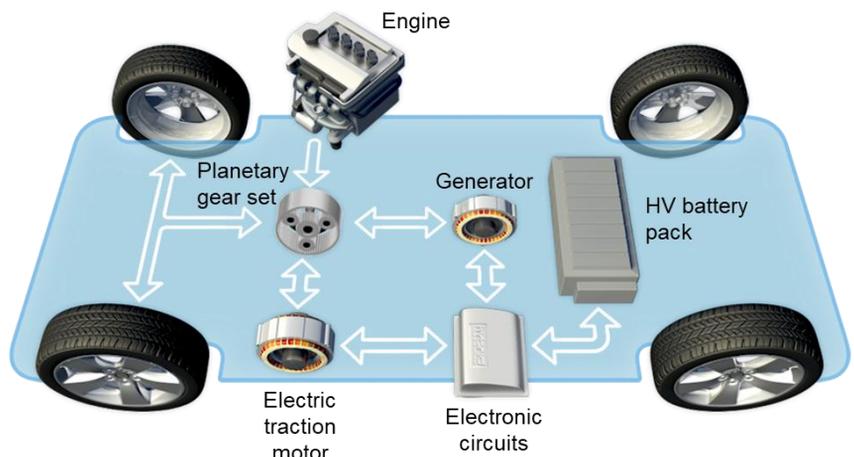
#### The key feature of:

- ✓ Series/Parallel Hybrid is the configuration incorporates the features of both the series and parallel HEVs. However, this configuration needs an additional electric machine and a planetary gear unit making the control complex.

### 3. Series/Parallel Hybrid System



1. **IC Engine:** These vehicles can operate using the electric motor alone or with assist of the ICE. They combine both functions of series and parallel design.
2. **Electric Motor:** It has two motors, and depending on the driving conditions, uses only the electric motor or the driving power from both the electric motor and the engine, in order to achieve the highest efficiency level. At high speeds, a fuel-efficient engine produces very low emissions. Whereas at low speeds, the engine does not run until a target speed is reached, which reduces fuel consumption and emission levels.



### Series/Parallel System Operation

## 5.4 Powertrain Component Sizing For Electric Vehicles

- ✓ Powertrain Component Sizing For Electric Vehicles is a very important part of the design when it comes to achieve the performance targets.
- ✓ Many of the world's biggest companies in the automotive industry have been investing heavily in the development of new powertrains and technology in order to make their vehicles more energy efficient.
- ✓ The sizing of a vehicle's powertrain components is directly affecting its energy efficiency and dynamic performance.
- ✓ The automakers must deal with a trade-off problem including considerations of energy efficiency and specific dynamic performance like acceleration and speed.
- ✓ The performance of a vehicle is determined by the following factors; Acceleration, Maximum cruising speed and Grade ability.

### POWER REQUIREMENT FROM PROPULSION SYSTEM

The power train of EVs and HEVs consists of Electric EM and the ICE. The first step towards the design of the power train is to determine the power ratings of the motor used in the EV and HEV drivetrain is to ascertain the motor specifications.

#### 1. Initial acceleration

A vehicle's acceleration is defined by the time and distance it takes to go from zero to a specific high speed on a terrain level. From 800 seconds onwards, the vehicle is subjected to high acceleration. During these times, the power required to accelerate the vehicle can be obtained from a combination of ICE and EM in the case of HEVs.

#### 2. Rated vehicle velocity

Velocity of the EV is defined as the best mileage that can be reached with the constant battery energy if the EV is moving at a specific speed. The combination of route information and vehicle conditions is required to determine the energy-time optimal velocity trajectories. The motor is in driving mode when the total of the rolling resistance force and the climbing resistance force is greater than zero.

#### 3. Maximum velocity

The maximum speed of a vehicle is defined as the constant cruising speed that the vehicle can accomplish with full power plant load on a flat road. The maximum speed of a vehicle is regulated by the ratio between the vehicle's tractive effort and the resistance, maximum speed of the power plant and the transmission gear ratios.

#### 4. Maximum grad ability

Grade ability is defined as the grade angle that the vehicle can negotiate at a specific steady speed. The grade ability of heavy commercial vehicles is commonly described as the highest-grade angle that the vehicle can withstand over its entire speed range. The tractive effort and resistance equilibrium are achieved when the vehicle is driving on a road with a reasonably low grade and constant speed.

## 5.4 Powertrain Component Sizing For Electric Vehicles

- ✓ Powertrain provides power to the vehicle.
- ✓ Powertrain refers to the set of components that generate the power required to move the vehicle and deliver it to the wheels.
- ✓ Powertrain of an electric vehicle (EV) is a simpler system compared to internal combustion engine (ICE).

### THE CHARACTERISTIC OF BATTERY ENGINE AND GAS/PETROL ENGINE IN DIFFERENT DRIVING CONDITION.

Battery electric vehicles (BEVs) are propelled by an electric motor which uses electric energy stored on board in batteries. In some cases, the car is equipped with a so-called range extender to charge the batteries on road. The range extender can be a small ICE or some other machine that converts another energy form to electric energy while driving.

The BEVs does not have the characteristics of a conventional ICE, whose efficiency is significantly more reliant on load and engine speed than the electric motor. In comparison to an internal combustion engine, the electric motor has a very high efficiency across all loads and engine speeds.

The BEVs may offer instant torque right after the engine starts turning. This means that an electric motor can use only one gear instead of a complete gearbox and that increases efficiency and reduces drivetrain complexity.

BEVs may use their electric motors as brakes and generate electricity to charge the batteries rather than converting that energy to heat through friction brakes. This is known as regenerative braking, and it can only be done up to a specific brake power before the friction brakes have to take over the deceleration process.

As a result, the driving behavior of people who use BEVs has a significant impact on the car's total energy usage and range. This is also true for ICE vehicles, but due to regenerative braking, it will have a much greater impact on BEVs.

The lower energy density of batteries in BEVs compared to gas or petrol is a disadvantage. A huge battery pack is required to get the same energy density as a typical gas/petrol tank. When compared to a conventional gas or petrol tank carrying the same amount of energy, the battery pack is both enormous in volume and bulk.

## 5.5 Energy Storage Solution In Electric Vehicles



Lithium-ion Batteries



Nickel-metal Hydride Batteries



Lead-acid Batteries



Ultracapacitors

### BATTERY FOR ELECTRIC VEHICLES

The following energy storage systems are used in HEVs, PHEVs, and EVs.

#### LITHIUM-ION BATTERIES

Lithium-ion batteries are currently used in most portable consumer electronics such as cell phones and laptops because of their high energy per unit mass relative to other electrical energy storage systems. They also have a high power-to-weight ratio, high energy efficiency, good high-temperature performance, and low self-discharge. Most of today's plug-in hybrid electric vehicles and all-electric vehicles use lithium-ion batteries.

#### NICKEL-METAL HYDRIDE BATTERIES

Nickel-metal hydride batteries have a much longer life cycle than lead-acid batteries and are safe and abuse tolerant. These batteries have been used successfully in all-electric vehicles and are widely used in hybrid electric vehicles. The main challenges with nickel-metal hydride batteries are their high cost, high self-discharge and heat generation at high temperatures, and the need to control hydrogen loss.

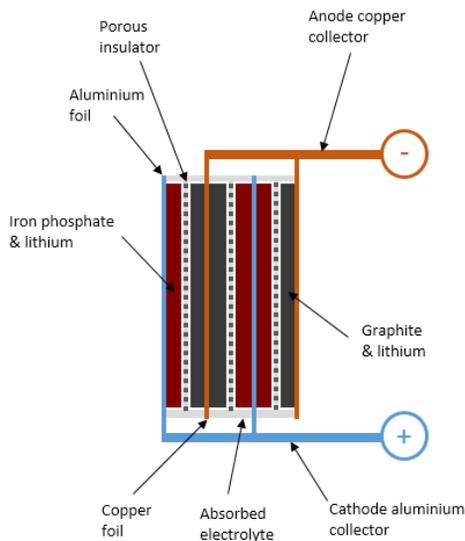
#### LEAD-ACID BATTERIES

Lead-acid batteries can be designed to be high power and are inexpensive, safe, and reliable. Their application is limited by their low specific energy, poor cold-temperature performance, and short calendar and cycle life. Advanced high-power lead-acid batteries are being developed, but these batteries are only used in commercially-available electric drive vehicles for ancillary loads.

#### ULTRACAPACITORS

Ultra capacitors store energy in a polarized liquid between an electrode and an electrolyte. Energy storage capacity increases as the liquid's surface area increases. Ultra capacitors can provide vehicles additional power during acceleration and hill climbing and help recover braking energy.

## 5.5 Energy Storage Solution In Electric Vehicles



### Lithium-ion Battery cell Structure

- ✓ A Lithium-ion battery cell is made up of positive plates (cathode), negative plates (anode), porous insulating separators to keep them from shorting out, and a conductive liquid (electrolyte) around them, similar to a lead-acid cell.
- ✓ The differences are due to the materials employed and the fact that a lead-acid battery works by converting its components through chemical reactions, whereas a Lithium-ion battery does not.
- ✓ A lithium battery only moves lithium ions during charge and discharge, leaving the rest of the battery mostly unchanged.

## BATTERY CELLS STRUCTURE USED IN ELECTRIC VEHICLES



Battery cell



Battery module



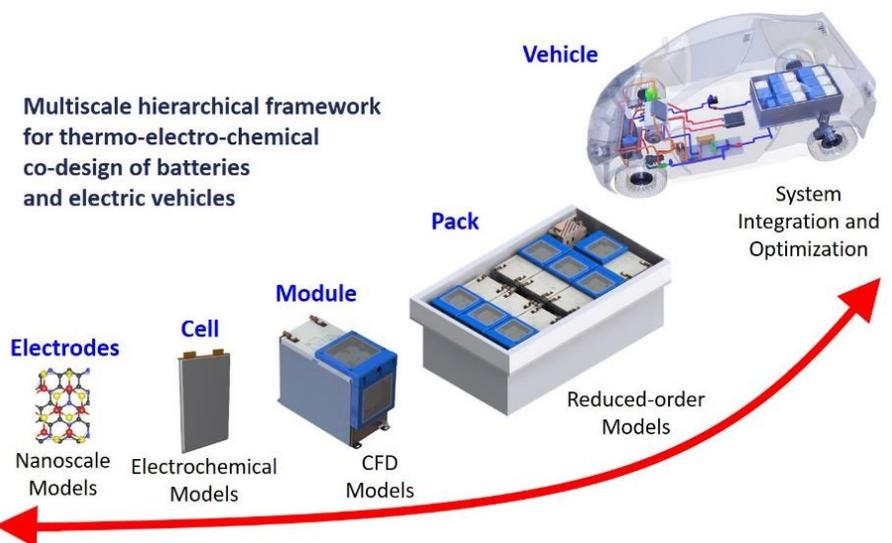
Battery pack

A cell is a single unit that performs the functions of a battery.

A module is made by connecting multiple cells, encasing them in a metal case, and then connecting them with terminals.

A pack is made up of several connected modules containing sensors and a controller, which are then housed in a case.

### Multiscale hierarchical framework for thermo-electro-chemical co-design of batteries and electric vehicles



## 5.5 Energy Storage Solution In Electric Vehicles

### Why Lithium-ion is the most common battery type use in electric vehicles?

because of their higher energy density, lithium-ion batteries can be discharged and recharged daily and at any state of charge.

### How they work?

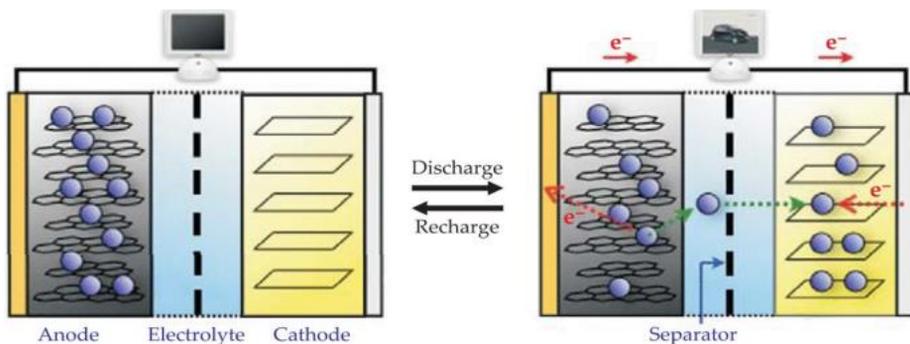
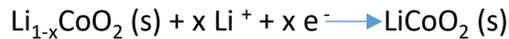
- ✓ Lithium-ion batteries work by transferring lithium ions between a cathode and an anode.
- ✓ The neutral lithium is oxidized and transformed to  $\text{Li}^+$  at the anode.
- ✓ These  $\text{Li}^+$  ions then move to the cathode, where they combine with  $\text{LiCoO}_2$  to form  $\text{LiCoO}_2$ .
- ✓ When electrons from the anode reaction reach the cathode, they reduce  $\text{Co(IV)}$  to  $\text{Co(III)}$ .
- ✓ The battery can be recharged by conducting the reactions in reverse because lithium is involved in both electrode processes.
- ✓ Primary batteries (single-use) most commonly use a reaction between  $\text{Li}$  and  $\text{MnO}_2$  to produce electricity while
- ✓ secondary batteries (rechargeable) use a reaction in which lithium from a lithium/graphite anode is incorporated into  $\text{LiCoO}_2$  at the cathode.

## CHEMICAL REACTION IN ELECTRIC VEHICLES BATTERY CELLS (Lithium-ion)

During discharge, lithium in lithium-graphite anode is oxidized from  $\text{Li}$  to  $\text{Li}^+$  (0 to +1 oxidation state) by the following reaction:



These lithium ions move to the cathode through the electrolyte medium, where they are integrated into lithium cobalt oxide by the reaction below, which reduces cobalt from a +4 to a +3 oxidation state:



To recharge the cell, execute these reactions backwards. In this situation, lithium ions move from the lithium cobalt oxide cathode to the anode, where they are reduced to neutral lithium and reincorporated into the graphite network.

### Anode:

Lithiated graphite ( $\text{Li}_x\text{C}_6$ ), which is composed of graphene sheets intercalated with lithium, is one of the most prevalent anode materials used today.

### Electrolyte:

Electrolytes can be made from a variety of different materials. They're all based on a lithium-containing substance that enables for easy lithium diffusion. Liquid electrolyte ( $\text{LiPF}_6$  or similar lithium salt and Ethylene Carbonate) are the most often used.

### Cathode:

The most prevalent cathode material is lithiated metal oxide. There are three major types:

- i. Layered oxide like  $\text{Li}_x\text{CoO}_2$
- ii. Polyanion materials such as  $\text{LiFePO}_4$  and  $\text{Li}_2\text{FeSiO}_4$
- iii. Spinel oxides like  $\text{LiMn}_2\text{O}_4$

## 5.5 Energy Storage Solution In Electric Vehicles

### BATTERY PARAMETERS RELATED TO ELECTRIC VEHICLES

#### What is the energy density of a lithium-ion battery?

They have one of the highest energy densities of any battery technology today (**100-265 Wh/kg or 250-670 Wh/L**). In addition, Li-ion battery cells can deliver up to 3.6 Volts, 3 times higher than technologies such as Ni-Cd or Ni-MH.

#### What is a 2C discharge rate?

A 2C discharge rate means it will discharge twice as fast (**30 minutes**). A 1C discharge rate on a 1.6 Ah battery means a discharge current of 1.6 A. A 2C rate would mean a discharge current of 3.2 A.

#### What does 500 cycles mean for batteries?

A 500-cycle life means that a manufacturer has achieved about 625 recharge times at a constant discharge depth (such as 80%) and reached 500 charging cycles.

- 1. Energy density** - Energy density is the measure of how much energy a battery contains in proportion to its weight. This measurement is typically presented in Watt-hours per kilogram (Wh/kg). A system with a high energy density may store a large quantity of energy in a small amount of mass.
- 2. Power density** – Power density is the measure of how quickly the energy can be delivered, rather than how much stored energy is available. If a system's power density is high, it can produce large amounts of energy based on its mass.
- 3. Gravimetric energy density** (Specific energy) at cell and pack level - The amount of energy in a system in relation to its mass, measured in watt-hours per kilogramme (Wh/kg) or Megajoules per kilogramme (MJ/kg).
- 4. Battery C-rate** - The maximum charge or discharge current in relation to the battery's energy is described by the C-rate (in 1/h). It's important to distinguish between charging and discharging C-rates, as the latter is usually higher than the former. The higher power with a higher discharge rate (C-rate). 1C means that the battery is fully charged and discharged within one hour, 2C is 30 minutes, and so on 10C=6mins, 100C=6 seconds.
- 5. Number of Battery cycles** – The number of Battery cycles is the maximum number of cycles a battery can withstand before its usable energy reduces to 80% of its initial value.

## 5.5 Energy Storage Solution In Electric Vehicles

### What Is BMS In Electric Vehicle?

Battery Management Systems (BMS) are used to monitor and control power storage systems, as well as to ensure the health of battery cells and to supply power to vehicle systems.

### What is the function of BMS?

The battery management system (BMS) is a complex hardware and software system that is an essential component of any high-voltage battery pack. The common functions of the BMS include cell voltage measurement and control.

### What is the objective of BMS?

The purpose of the BMS is to protect, increase the lifespan, and maintain the stability of the batteries in the energy storage system. The BMS should have monitoring, computation, control, and communication features in order to complete the tasks.

To protect the batteries from damage and maintain them in good condition, the BMS needs to monitor the temperature, voltage and current in the batteries.

## BATTERY MANAGEMENT SYSTEM (BMS) IN ELECTRIC VEHICLES

The BMS is responsible for managing the system during the EV/HEV vehicle's complete operational cycle and ensuring the following functions;

- ✓ **Collecting data from the battery's sensors**, such as current, voltage, and temperature. The BMS analyses the data to ensure that the battery is operating properly.
- ✓ **Controlling the charger** to ensure that the battery is properly charged. The charger can be located inside or outside the vehicle. The control is programmed to respond to data from the sensors on each battery module.
- ✓ **Managing cell balance** to provide the battery's best performance. In multi-cell batteries, balancing is required because the weakest cell lowers the battery's overall performance.
- ✓ **Safety control: prevents overcharging or discharging**, as well as other serious anomalies that may arise if the battery, auxiliary equipment, or surrounding environment fail. The electronic system's action can be physical (emergency battery shutdown) or informative (reporting trouble to the user).
- ✓ **Reporting the battery state**: communication of information (alarms, gauge, etc.) to the user and to other on-board equipment via the communication bus.
- ✓ The BMS **monitors the temperature of the cells** in all modes of operation (drive, charge, etc.) and manages the pump, fans, and heater to keep the battery at a comfortable temperature.
- ✓ **Communication with the vehicle**: Data is exchanged between the vehicle computer and the BMS via the communication bus (CAN 2.0B).
- ✓ **Maintenance via the BMS**: Users will be able to connect maintenance and diagnostic tools to the BMS to perform necessary battery maintenance procedures.
- ✓ **Data transfer to a laptop PC**, which can monitor and store the battery measurement data collected by the BMS.

## 5.5 Energy Storage Solution In Electric Vehicles

Figure 5.5 shows a block diagram of a BMS for a Li-ion battery, but a similar approach can be used for any battery system. The BMS, as indicated in the diagram, not only monitors and controls the battery, but also communicates with the vehicle controller via the CAN bus. As a result, the BMS can be linked to other vehicle systems, such as anti-theft devices that disconnect the battery. In a HEV, determining the battery level of charge is particularly important. For start or acceleration, these batteries require both high-power charge (regenerative braking) and high-power discharge capabilities.

### BATTERY MANAGEMENT SYSTEM (BMS) IN ELECTRIC VEHICLES

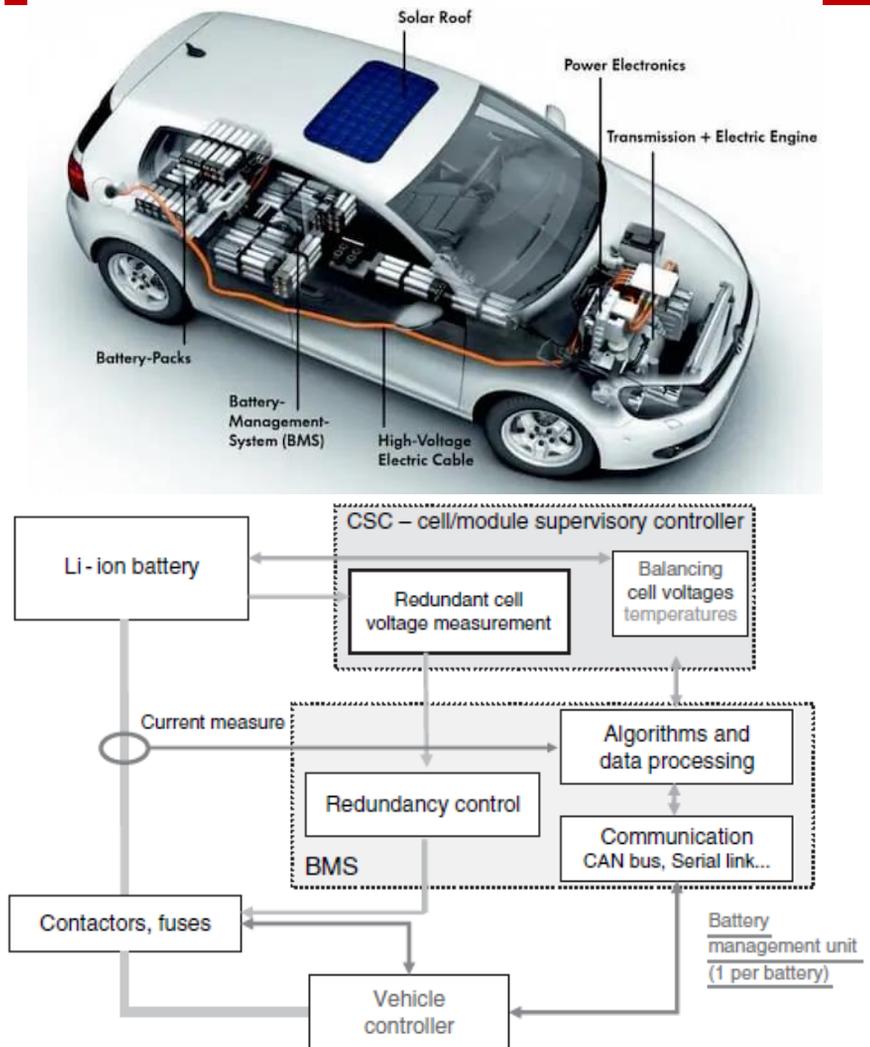
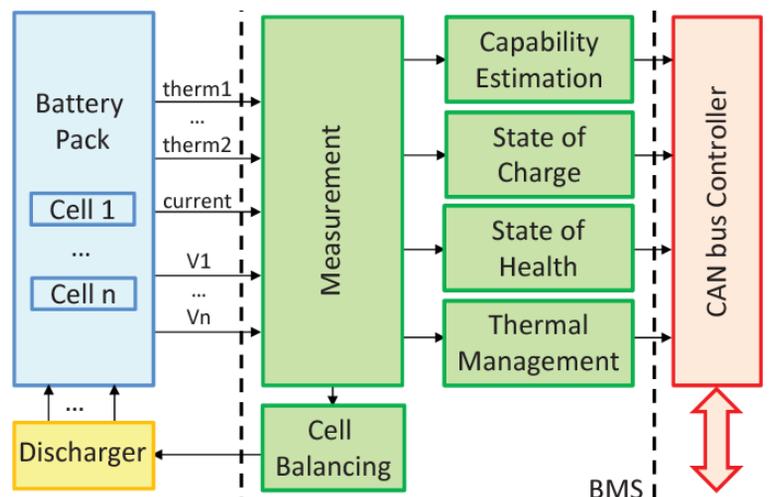


Figure 5.5 BMS developed by Johnson Controls – Saft for an electric vehicle using a Li-ion battery pack.



BMS Interface controller



Block diagram of a BMS

## 5.6 Tutorial

**Structure Question**

1. List types of Alternative Vehicles used in Green Transportation Systems.

[3 marks]

2. Compare the architecture diagram for parallel hybrid system and series/parallel hybrid systems in alternative vehicle using for green transportation.

[6 marks]

3. Explain the internal structure of Battery pack using in hybrid and Plug-in Electric Vehicles using an appropriate diagram.

[6 marks]

**Essay Question**

Based on the type of alternative vehicle, discuss the components used in hybrid and show the **series hybrid system** of hybrid vehicles using an appropriate diagram.

[20 Marks]

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