



ST. ANNE'S COLLEGE OF ENGINEERING AND TECHNOLOGY

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ANGUCHETTYPALAYAM, PANRUTI – 607 106.

EE3014 - POWER ELECTRONICS FOR RENEWABLE ENERGY RESOURCES

(REGULATION 2021- Professional Elective paper)



prepared by

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St.Annes college of engineering and technology

Anguchetypalayam

COURSE OBJECTIVES:

- To learn the various types of renewable sources of energy.
- To understand the electrical machines to be used for wind energy conversion systems..
- To learn the principles of power converters used in solar PV system.
- To study the principle of power converters used in Wind system.
- To simulate the AC-DC, AC-AC Converters, Matrix Converters and PWM Inverters

UNIT I INTRODUCTION TO RENEWABLE ENERGY SYSTEMS 6

Classification of Energy Sources – Importance of Non-conventional energy sources – Advantages and disadvantages of conventional energy sources - Environmental aspects of energy - Impacts of renewable energy generation on the environment - Qualitative study of renewable energy resources: Ocean energy, Biomass energy, Hydrogen energy, - Solar Photovoltaic (PV), Fuel cells: Operating principles and characteristics, Wind Energy: Nature of wind, Types, control strategy, operating area.

UNIT II ELECTRICAL MACHINES FOR WIND ENERGY CONVERSION SYSTEMS (WECS) 6

Construction, Principle of operation and analysis: Squirrel Cage Induction Generator (SCIG), Doubly Fed Induction Generator (DFIG) - Permanent Magnet Synchronous Generator (PMSG).

UNIT III POWER CONVERTERS AND ANALYSIS OF SOLAR PV SYSTEMS 6

Power Converters: Line commutated converters (inversion-mode) - Boost and buck-boost converters- selection of inverter, battery sizing, array sizing. Simulation of line commutated converters, buck/boost converters. Analysis: Block diagram of the solar PV systems - Types of Solar PV systems: Stand-alone PV systems, Grid integrated solar PV Systems - Grid Connection Issues

UNIT IV POWER CONVERTERS FOR WIND ENERGY SYSTEMS 6

Power Converters: Three-phase AC voltage controllers- AC-DC-AC converters: uncontrolled rectifiers, PWM Inverters, Grid-Interactive Inverters - Matrix converter.

UNIT V CASE STUDIES FOR HYBRID RENEWABLE ENERGY SYSTEMS 6

Need for Hybrid Systems- Range and type of Hybrid systems- Case studies of Diesel-PV, WindPV, Micro hydel-PV, Biomass-Diesel systems - Maximum Power Point Tracking (MPPT).

TOTAL : 30 PERIODS

LAB COMPONENT:

30 PERIODS

1. Simulation on modelling of Solar PV System- V I Characteristics
2. Simulation on Modelling of fuel cell- V I Characteristics
3. Simulation of self- excited Induction Generator.
4. Simulation of DFIG/ PMSG based Wind turbine.
5. Simulation on Grid integration of RES.

TOTAL: 30+30 = 60 PERIODS

COURSE OUTCOMES: Upon completion of the course, students will be able to:

COURSE OUTCOMES: At the end of the course, students should be able to:

CO1: Examine the available renewable energy sources.

CO2: Demonstrate the working principles of electrical machines and power converters used for wind energy conversion system

CO3: Demonstrate the principles of power converters used for solar PV systems

CO4: Examine the available hybrid renewable energy systems.

CO5: Simulate AC-DC converters, buck/boost converters, AC-AC converters and PWM inverters.

REFERENCES:

1. S.N.Bhadra, D. Kastha, & S. Banerjee "Wind Electrical Systems", Oxford University Press, 2009, 7th impression.
2. Rashid .M. H "Power electronics Hand book", Academic press, 2nd Edition, 2006 4th Edition, 2017
3. Rai. G.D, "Non-conventional energy sources", Khanna publishers, 6th Edition, 2017. 145
4. Rai. G.D," Solar energy utilization", Khanna publishers, 5th Edition, 2008.
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6. H.Khan "Non-conventional Energy sources ",Tata McGraw-hill Publishing Company, New Delhi, 2017, Edition.

UNIT-I

INTRODUCTION TO RENEWABLE ENERGY SYSTEMS

Definition for hybrid energy:

Renewable energy is energy derived from natural sources that are replenished at a higher rate than they are consumed. Sunlight and wind, for example, are such sources that are constantly being replenished. Renewable energy sources are plentiful and all around us..

Renewable Energy Systems in INDIA

Renewable energy systems can be of different types:

SOLAR ENERGY

WIND ENERGY

GEOTHERMAL ENERGY

HYDROPOWER

OCEAN ENERGY

BIOENERGY

Advantage of Hybrid Energy System:

- **Environmental Protection:** Drastically reduces greenhouse gas emissions and air pollutants, improving public health and mitigating climate change.
- **Inexhaustible Resource:** Sun, wind, and water are naturally replenished, ensuring a long-term, reliable energy supply that will not run out.
- **Economic Growth & Stability:**
Creates jobs in the green sector and provides stable, often lower, energy prices compared to volatile fossil fuel markets
- **Energy Independence:** Reduces reliance on imported fuels, improving national security by diversifying energy sources and utilizing local resources.
- **Low Maintenance Costs:** Technologies like solar panels and wind turbines typically have lower operating and maintenance costs over their lifespans.
- **Scalability & Access:** Suitable for both large-scale power grids and small-scale, off-grid, or rural applications.

Dis Advantage of Hybrid Energy System:

- **Intermittency and Reliability:** Solar is unavailable at night, and wind is not constant, leading to inconsistent power generation. These sources rely on weather, making them less reliable than fossil fuels.
- **High Initial Costs:** Although operational costs are low, the initial investment for technology like solar panels and wind turbines is high.
- **Storage Challenges:** Because they are intermittent, renewable energy requires expensive, large-scale battery storage to ensure a consistent supply.

- **Geographical and Spatial Limitations:** Renewable energy projects often need large amounts of space (land-intensive). They are also dependent on specific locations (e.g., sunny or windy areas).
- **Environmental Impact of Infrastructure:** Manufacturing, installing, and disposing of solar panels and wind turbines can create pollution, with some components being hard to recycle.
- **Grid Integration Issues:** Existing electrical grids are not always designed for the, at times, volatile nature of renewable energy, leading to stability challenges.
- **Lower Energy Density:** Renewable sources generally produce less energy per unit of space compared to conventional fossil fuels.

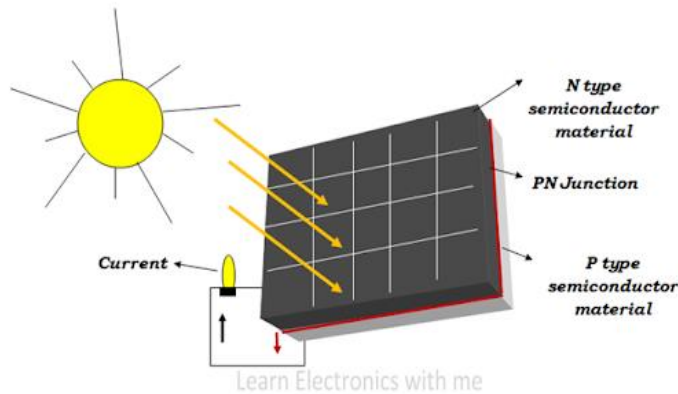
Need For Hybrid Energy

- **Combating Climate Change & Environmental Protection:** Fossil fuels cause ~75% of global greenhouse gas emissions. Switching to renewables is essential to keep global temperature rises below 1.5⁰c, reducing air pollution, and mitigating climate change impacts like extreme weather, melting ice, and biodiversity loss
- **Energy Security and Independence:** Unlike fossil fuels, which are often imported and concentrated in specific regions, renewable energy can be generated locally. This reduces dependence on foreign, volatile, or unreliable energy supplies, bolstering national security.
- **Economic Viability and Cost Efficiency:** In most parts of the world, renewable energy is now the most affordable source of power. The industry is a major driver of economic growth, creating new jobs in manufacturing and installation.
- **Sustainability and Resource Conservation:** Conventional energy sources are finite and will eventually run out. Renewable sources (sun, wind, water) are, by definition, inexhaustible.
- **Health Benefits:** Reduced reliance on fossil fuels leads to better air quality and lower healthcare costs associated with pollution-related illnesses.

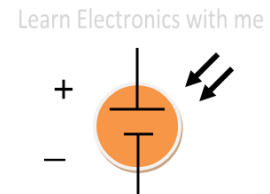
SOLAR PANEL WORKING AND OPERATING CHARACTERISTICS

Solar cell is also called as photovoltaic cell and this is a device which converts light energy into electrical energy by using photovoltaic effect. Solar cell is basically a normal PN Junction diode

CONSTRUCTION OF SOLAR CELL:

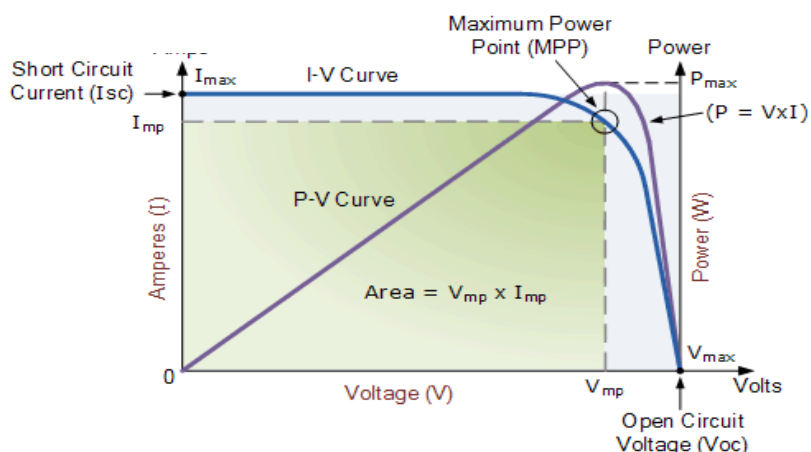


SYMBOL



- It consists of N type and P type semiconductor material.
- N type is highly doped and P type is lightly doped.
- Top and bottom is of conducting electrode to collect the current.
- The bottom is fully covered with the conductive layer and top layer is not fully covered because the sun rays should not be fully blocked.
- Since semiconductors are reflective in nature, antireflective coating is used. The whole arrangement is kept inside a thin glass to avoid mechanical shock.
- Solar cell is the basic building module and it is in octagonal shape and in bluish black colour.
- Each cell produces 0.5 voltage. 36 to 60 solar cells in 9 to 10 rows of solar cells are joined together to form a solar panel.
- For commercial use upto 72 cells are connected. By increasing the number of cells, the wattage and voltage can be increased.
- The thickness of solar panel is in the range 2.5 to 4cm. Many modules together form the solar array.

Solar Cell I-V Characteristic Curve



The above graph shows the current-voltage (I-V) characteristics of a typical silicon PV cell operating under normal conditions.

VOC = open-circuit voltage – This is the maximum voltage that the array provides when the terminals are not connected to any load (an open circuit condition). This value is much higher than Vmp which relates to the operation of the PV array which is fixed by the load. This value depends upon the number of PV panels connected together in series.

ISC = short-circuit current – The maximum current provided by the PV array when the output connectors are shorted together (a short circuit condition). This value is much higher than Imp which relates to the normal operating circuit current.

MPP = maximum power point – This relates to the point where the power supplied by the array that is connected to the load (batteries, inverters) is at its maximum value, where $MPP = I_{mp} \times V_{mp}$. The maximum power point of a photovoltaic array is measured in Watts (W) or peak Watts (Wp).

FF = fill factor – The fill factor is the relationship between the maximum power that the array can actually provide under normal operating conditions and the product of the open-circuit voltage multiplied by the short-circuit current, (VOC x ISC)

%eff = percent efficiency – The efficiency of a photovoltaic array is the ratio between the maximum electrical power that the array can produce compared to the amount of solar irradiance hitting the array.

Application of Photovoltaic Cell

- It may be used to charge batteries.
- Used in light meters.
- It is used to power calculators and wrist watches.
- It can be used in spacecraft to provide electrical energy.

Advantages of Solar Cell

- No pollution associated with it.
- It must last for a long time.
- No maintenance cost.

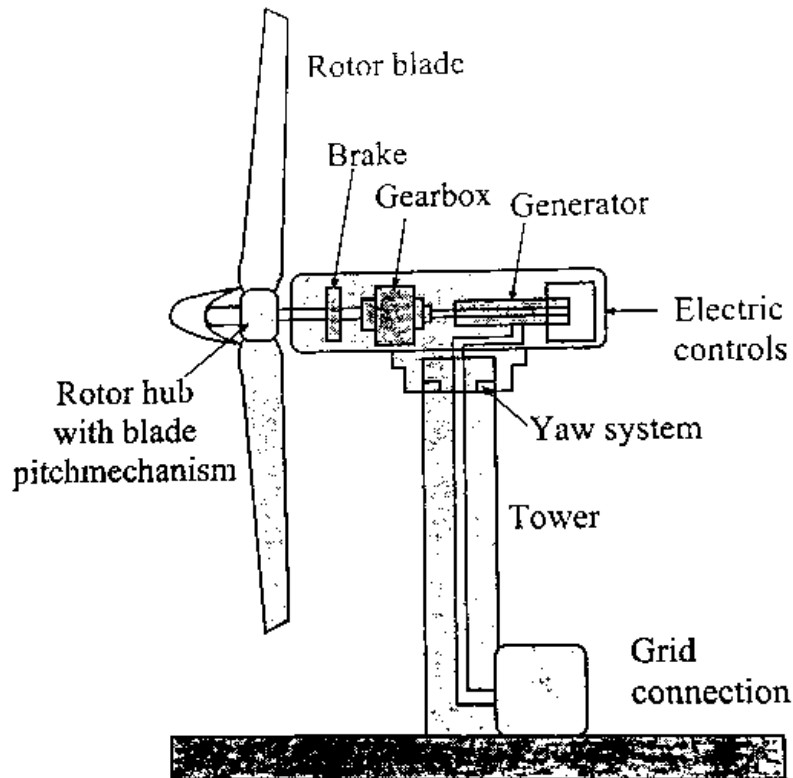
Disadvantages of Solar Cell

- It has high cost of installation.
- It has low efficiency.
- During cloudy day, the energy cannot be produced and also at night we will not get solar energy.

WIND ENERGY WORKING AND OPERATING CHARACTERISTICS

The wind mill works on the principle of converting kinetic energy of the wind into mechanical energy. Wind energy is energy obtained from the force of the wind. wind turbine that transforms the kinetic energy of air currents into electrical energy

CONSTRUCTION OF WIND MILL:



(i) Tower:

At 100 feet or more above the ground, the tower allows the turbine to take advantage of faster wind speeds found at higher altitudes. All the blades of the propeller are aligned at a specific angle and are connected to a rotor. The rotor, propeller blades, and hub are collectively known as the rotor tower. The material used for the construction of a rotor tower includes concrete, tubular steel, or steel lattice.

(ii) Nacelle:

The inner structure of the blades contains a pitch system. The main purpose of a pitch system is to tilt the propeller blades. Nacelle sits at the top of the tower and contains the gear box, low- and high-speed shafts generator, controller, and brake. It is essentially the cover for the machinery that translates wind power into electrical power.

(iii) Brake:

Brake is a disc that can be applied aerodynamically, electrically, or hydraulically to stop the rotor in emergencies. A brake shuts down the turbine if the winds become strong enough to impact the turbine's internal components.

(iv) Gear box mechanism:

The rotor turns the low-speed shaft at about 15 to 30 rotations per minute. Gear box connect the low-speed shaft to the high-speed shaft and increases the rotational speeds from about 15 to 30 rotations per minute (rpm) to about 1000 to 1800 rpm, the rotational speed required by most generators (alternators) to produce electricity. This is an expensive and heavy part of wind turbines.

(v)Generator:

Generator is usually an induction generator that produces 50-cycle AC electricity.

Most of the wind mill uses Squirrel cage Induction Motor(SGIM),Doubly fed Induction motor(DFIG),Permanent Magnet Synchronous Generator(PMSG).

The generated electric power output is given to the Grid through Transformer.

(vi)Controller:

Wind vane measures wind direction and communicates with the yaw drive to orient the turbine properly with respect to the wind.

Anemometer: It measures the wind speed and transmits the data to the controller. The controller then corrects the turbine's direction, pitch, and yaw to best available wind energy.

The main purpose of yaw control mechanism is to move the nacelle and blades according to the wind direction. It enables the wind turbine to capture the maximum available wind.

WORKING OF WIND TURBINE

- When the wind strikes the rotor blades, blades start rotating.
- The turbine rotor is connected to a high-speed gearbox.
- Gearbox transforms the rotor rotation from low speed to high speed. The high-speed shaft from the gearbox is coupled with the rotor of the generator and hence the electrical generator runs at a higher speed.
- An exciter is needed to give the required excitation to the magnetic coil of the generator field system so that it can generate the required electricity.
- The generated voltage at output terminals of the alternator is proportional to both the speed and field flux of the alternator.

CHARACTERISTICS OF WIND TURBINE

Power contained in wind is given by the kinetic energy of the flowing air mass per unit time.

Kinetic Energy= $\frac{1}{2} (m v^2)$ joules

Mass flow rate is given by $m = \rho A V$

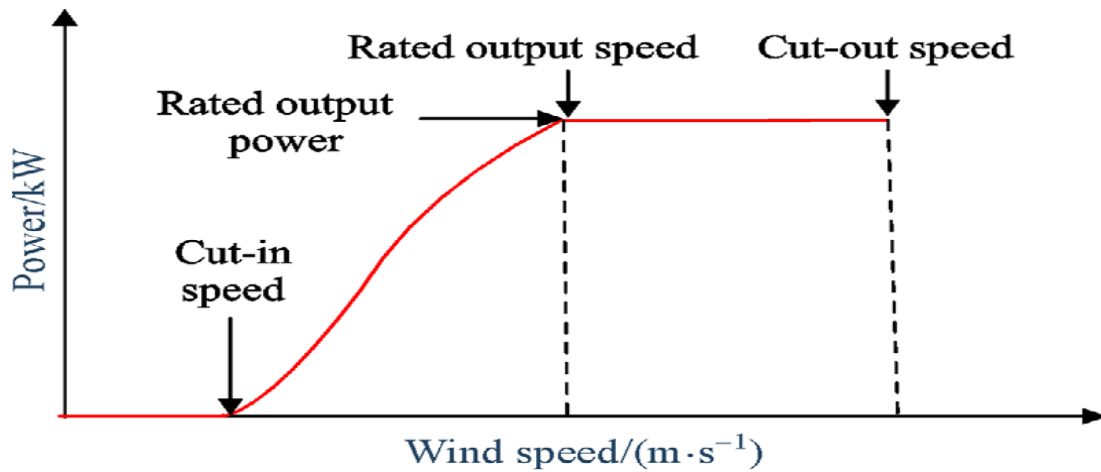
Where, ρ = air density, kg/m³

A = area swept by the rotor blades, m²

V = velocity of the air, m/s.

The wind power is given as $P_w = \frac{1}{2} \rho A V^3$

The power generated is directly proportional to the cube of the velocity of air.($P_w \propto V^3$).



- **Cut-in wind speed:**
The cut-in speed is the point at which the wind turbine is able to generate power. The speed of the wind is (8 to 16mph). Between the cut-in speed and the rated speed, where the maximum output is reached, the power output will increase cubically with wind speed.
- **Rated wind speed:**
where the generator delivers 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.
- **Cut-out or furling wind speed:**
The cut-out speed is the point at which the turbine must be shut down to avoid damage to the equipment. Above the rated speed (55 mph) when the wind flow rate is high the turbine must be shut down.

ADVANTAGES OF WIND POWER

- 1) clean energy,
- 2) cost-effectiveness,
- 3) low-maintenance requirements and
- 4) high efficiency.

DISADVANTAGES OF WIND POWER

- 1) unreliability,
- 2) noise and aesthetic pollution, and
- 3) harm to wildlife.

CONSTRUCTION AND WORKING OF FUEL CELLS (or) HYDROGEN GAS

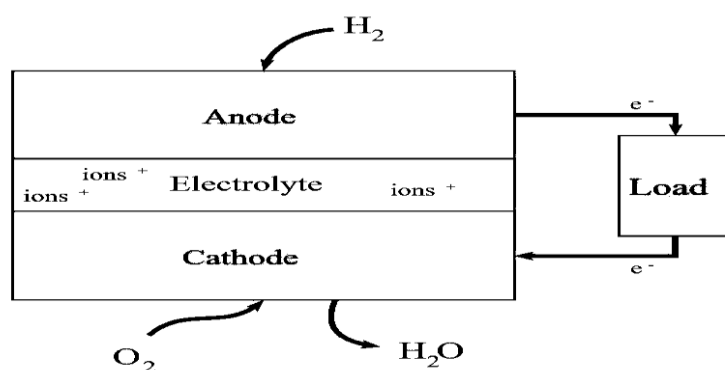
A fuel cell can be described as an electrochemical cell which, through an electrochemical reaction, generates electrical energy from the fuel.

CONSTRUCTION

A fuel cell, which consists of a cathode, an anode, and an electrolyte, is similar to electrochemical cells. The electrolyte makes the motion of the protons possible in these cells.

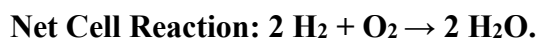
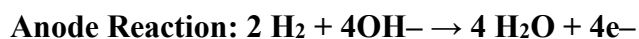
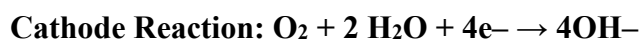
- **The Anode** is the negative or reducing electrode that releases electrons to the external circuit and oxidizes during an electrochemical reaction
- **The Cathode** is the positive or oxidizing electrode that acquires electrons from the external circuit and is reduced during the electrochemical reaction.
- **The Electrolyte** is the medium that provides the ion transport mechanism between the cathode and anode of a cell. Electrolytes are often liquids, such as water or other solvents, with dissolved salts, acids, or alkalis that are required for ionic conduction.

Diagram:



WORKING OF FUEL CELL:

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



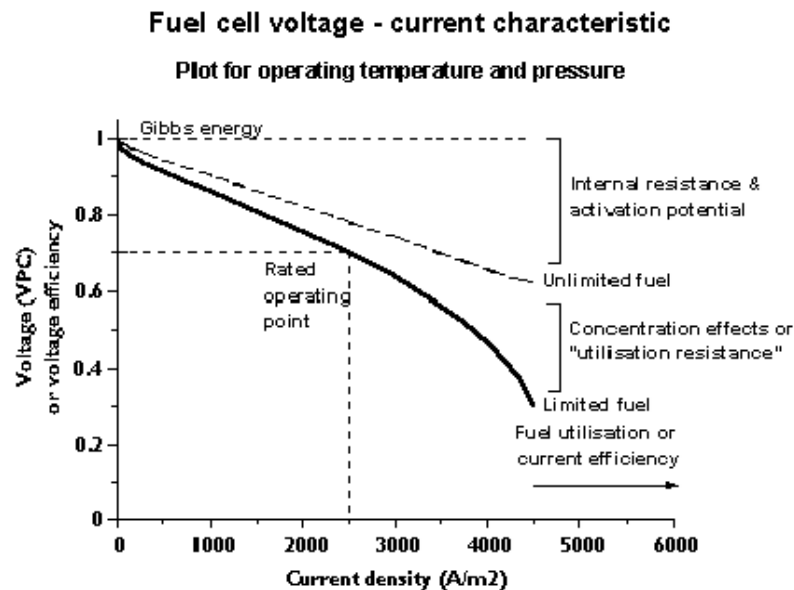
However, the reaction rate of this electrochemical reaction is quite low. In order to increase the effective surface area, the catalyst is finely divided before being incorporated into the electrodes. The efficiency of the fuel cell described above in the generation of electricity generally approximates to 70%.

Types of Fuel Cells

- 1) The Polymer Electrolyte Membrane (PEM) Fuel Cell
- 2) Phosphoric Acid Fuel Cell
- 3) Solid Acid Fuel Cell

- 4) Alkaline Fuel Cell
- 5) Solid Oxide Fuel Cell
- 6) Molten Carbonate Fuel Cell

Characteristics of fuel cell



At near zero currents the conditions approach the constant theoretical conditions. Pressure losses, concentration changes, and temperature variations are small as the fuel passages are large compared with the fuel flows, and the reaction is small.

Hence the voltage efficiency remains high at low currents. However, for a finite fuel flow rate the fuel utilisation or current efficiency will be very low.

As current increases, the voltage reduces due to the internal resistance, over-potentials, and concentration effects. Provided that excess fuel is supplied, the voltage decreases approximately linearly with current.

If the fuel flow is regulated proportional to the current, current efficiency will be constant. Hence the voltage efficiency and overall efficiency is higher at low loads.

ADVANTAGE

- 1) High Efficiency
- 2) Good reliability
- 3) No Noise
- 4) Environmentally beneficial

DISADVANTAGE

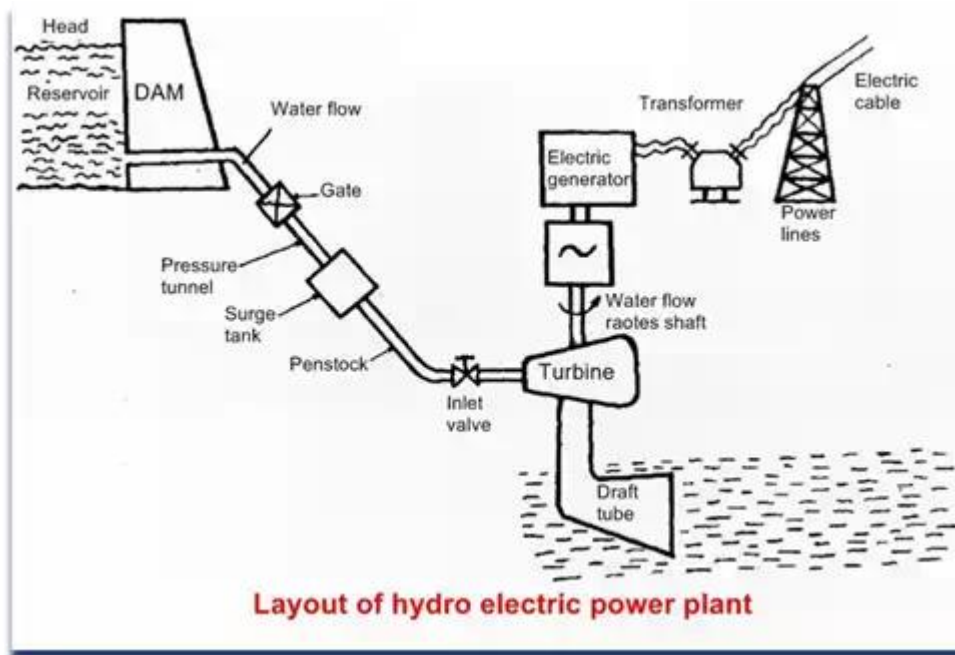
- 1) Expensive to manufacture due the high cost of catalysts
- 2) Hydrogen is expensive to produce and not widely available
- 3) Lack of infrastructure to support the distribution of hydrogen

APPLICATION

- 1) primary and backup power for commercial
- 2) used to power fuel cell vehicles, automobiles, buses, trains, boats, motorcycles.

CONSTRUCTION AND WORKING OF HYDRO POWER PLANT

The process of utilizing hydropower to generate energy is referred to as hydroelectricity. A hydroelectric power plant transform water's potential energy into electrical energy by the turbine coupled with generator.



The above image shows the typical layout of a hydroelectric power plant and its basic components.

Dam and Reservoir: The dam is constructed on a large river in hilly areas to ensure sufficient water storage at height. The dam forms a large reservoir behind it. The height of water level (called as water head) in the reservoir determines how much of potential energy is stored in it.

Control Gate: Water from the reservoir is allowed to flow through the penstock to the turbine. The amount of water which is to be released in the penstock can be controlled by a control gate. When the control gate is fully opened, maximum amount of water is released through the penstock.

Penstock: A penstock is a huge steel pipe which carries water from the reservoir to the turbine. Potential energy of the water is converted into kinetic energy as it flows down through the penstock due to gravity.

Surge Tank: Surge tanks are usually provided in high or medium head power plants when considerably long penstock is required. A surge tank is a small reservoir or tank which is open at the top. It is fitted between the reservoir and the power house. The water level in the surge tank rises or falls to reduce the pressure swings in the penstock. When there is sudden reduction in load on the turbine, the governor closes the gates of the turbine to reduce the water flow. This causes pressure to increase abnormally in the penstock. This is prevented by using a surge tank, in which the water level rises to reduce the pressure. On the other hand, the surge tank provides excess water needed when the gates are suddenly opened to meet the increased load demand.

Water Turbine: Water from the penstock is taken into the water turbine. The turbine is mechanically coupled to an electric generator. Kinetic energy of the water drives the turbine and consequently the generator gets driven. There are two main types of water turbine; (i) Impulse turbine and (ii) Reaction turbine.

Generator: A generator is mounted in the power house and it is mechanically coupled to the turbine shaft. When the turbine blades are rotated, it drives the generator and electricity is generated which is then stepped up with the help of a transformer for the transmission purpose.

Advantages of Hydroelectric Power Plant

1. No fuel is required as potential energy is stored water is used for electricity generation
2. Neat and clean source of energy
3. Very small running charges - as water is available free of cost
4. Comparatively less maintenance is required and has longer life
5. Serves other purposes too, such as irrigation

Disadvantages of Hydroelectric Power Plant

1. Very high capital cost due to construction of dam
2. High cost of transmission – as hydro plants are located in hilly areas which are quite away from the consumers.

OCEAN ENERGY

Ocean energy refers to all forms of renewable energy derived from the sea. There are three main types of ocean technology: wave, tidal and ocean thermal.

Tidal Energy:

Tide or wave is periodic rise and fall of water level of the sea. Tidal energy is a form of renewable energy which is created by converting energy from tides into electricity.

Working

The arrangement of this system is shown in figure. The ocean tides rise and fall and water can be stored during the rise period and it can be discharged during fall. A dam is constructed separating the tidal basin from the sea and a difference in water level is obtained between the basin and sea.

During high tide period, water flows from the sea into the tidal basin through the water turbine. The height of tide is above that of tidal basin. Hence the turbine unit operates and generates power, as it is directly coupled to a generator.

During low tide period, water flows from tidal basin to sea, as the water level in the basin is more than that of the tide in the sea. During this period also, the flowing water rotates the turbine and generator power.

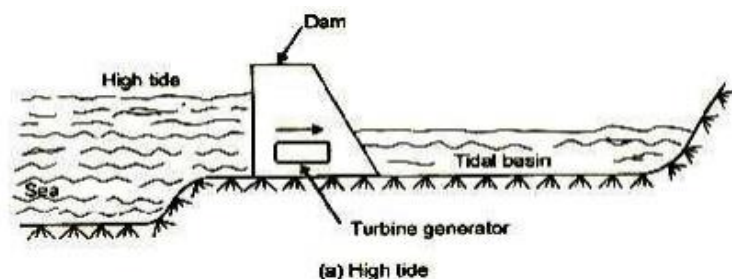
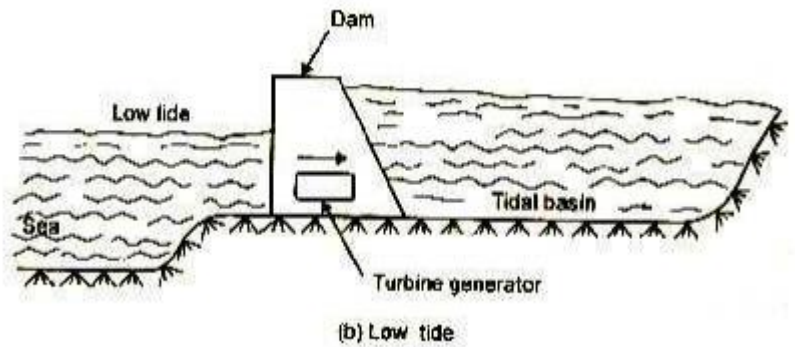


Figure: High tide

The generation of power stops only when the sea level and the tidal basin level are equal. For the generation of power economically using this source of energy requires some minimum tide height and suitable site. (Kislaya power plant of 250 MW capacity in Russia and Rance power plant in France are the only examples of this type of power plant.)



Advantages of tidal power plants.

1. It is free from pollution as it does not use any fuel.
2. It is superior to hydro-power plant as it is totally independent of rain.
3. It improves the possibility of fish farming in the tidal basins and it can provide recreation to visitors and holiday makers.

Disadvantages of tidal power plants.

1. Tidal power plants can be developed only if natural sites are available on the bay.
2. As the sites are available on the bays which are always far away from load centres, the power generated has to be transmitted to long distances. This increases the transmission cost and transmission losses.

Ocean thermal energy (OTEC):

Ocean thermal energy conversion (OTEC) is a process or technology for producing energy by harnessing the temperature differences (thermal gradients) between ocean surface waters and deep ocean waters.

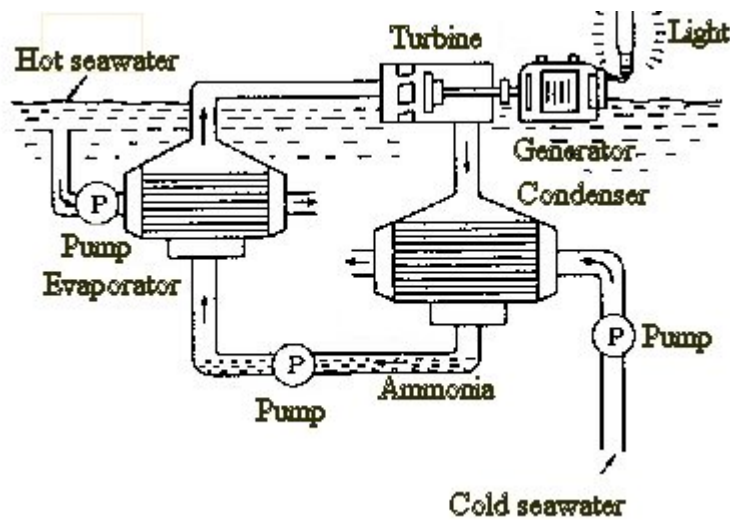
1.Collection of warm surface water: The OTEC plant is typically located in a tropical or subtropical region where there is a significant temperature difference between the surface and deep ocean waters. Large-diameter pipes called “cold water pipes” or “seawater intake pipes” are deployed to depths of around 1,000 meters (3,280 feet) or more. These pipes collect warm surface water, usually with temperatures around 20 to 25 degrees Celsius (68 to 77 degrees Fahrenheit).

2.Evaporation process: The warm surface water is pumped through a heat exchanger called the “evaporator.” In the evaporator, a low-pressure liquid (often ammonia) with a low boiling point is circulated in a separate closed-loop system. As the warm surface water passes through the evaporator, it heats the working fluid, causing it to evaporate into steam.

3.Power generation: The high-pressure steam produced from the evaporator is directed toward a turbine. The steam expands in the turbine, spinning its blades and driving a generator, which converts the mechanical energy into electrical energy. This process is similar to conventional power plants that use steam turbines.

4.Cold water condensation: After passing through the turbine, the now low-pressure and cooler steam enters a condenser. Cold deep ocean water, usually with temperatures around 5 to 10 degrees Celsius (41 to 50 degrees Fahrenheit), is pumped through another set of pipes called “warm water pipes” or “sea water discharge pipes.” The cold water circulates inside the condenser, causing the steam to condense back into a liquid state.

5.Heat rejection: The heat extracted from the steam is transferred to the cold water from the deep ocean, which absorbs the excess heat. The cold water is then discharged back into the ocean, completing the cycle.

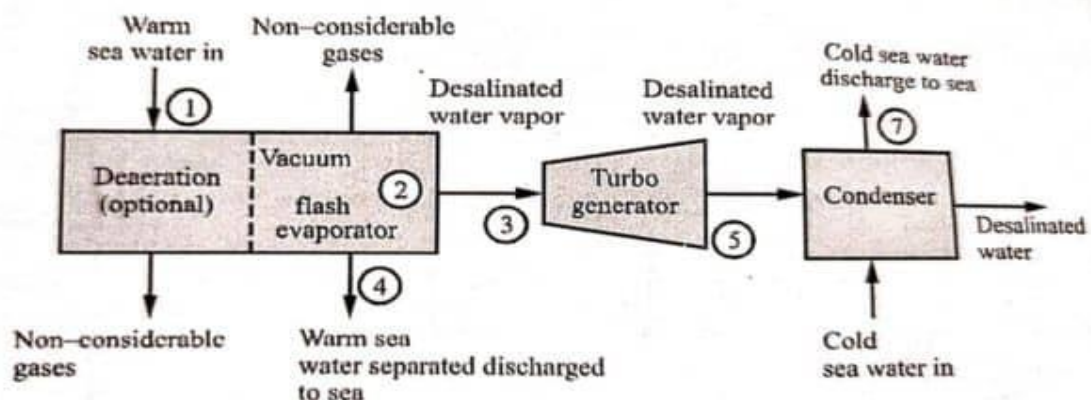


Different types of OTEC:

- a. Open cycle OTEC
- b. Closed cycle OTEC
- c. Hybrid OTEC

Open cycle OTEC:

In an open-cycle OTEC plant, there is no intermediate working fluid involved. Instead, the warm surface water directly enters a vacuum-flashed evaporator, where it is transformed into low-pressure vapor in a vacuumed environment. This process requires a significant vacuum pump to create the necessary conditions.



1.Warm surface water intake: The warm seawater from the ocean surface is pumped into the flash evaporator, denoted as step (1-2) in the process.

2.Flash evaporation: In the flash evaporator, the warm sea water is subjected to low pressure and vacuum conditions, causing it to rapidly vaporize and form steam. This step is represented as (1-2) in the process.

3.Steam production: The depressurization process continues from (2) to (3), resulting in the complete vaporization of the seawater and the production of steam. This steam is then directed to the low-pressure turbine, represented as (3-5) in the process.

4.Power generation: The steam generated in the previous step is used to drive a large-diameter low-pressure turbine (around 12 m/MW of the steam plant). The turbine is connected to a generator, which converts the mechanical energy of the turbine into electrical energy.

5.Warm water discharge: The warm water separated from the evaporator, depicted as (4) in the process, is discharged back into the ocean at the bottom. This step completes the cycle for the warm water.

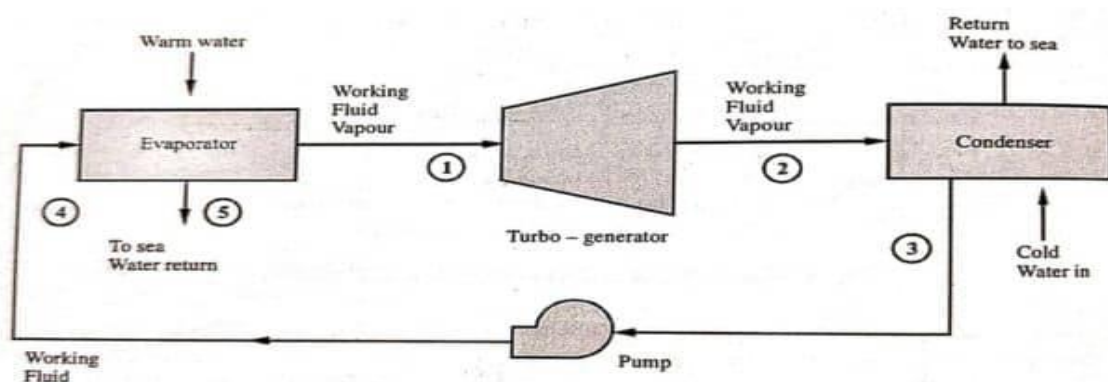
6.Steam condensation: After leaving the turbine, the steam enters a contact-type condenser, represented as (5-7) in the process. Cold water from the depths of the ocean is pumped into the condenser to facilitate the condensation of the steam back into liquid form.

7.Desalination and utilization: The condensed water obtained from the condenser is desalinated water, which can be utilized for various purposes. This water is typically free of salt and can be used for drinking, agriculture, or other applications.

8.Cold water intake: The cold deep water from the ocean, after being used in the condenser, is discharged back into the sea, where it meets the low-temperature seawater. This step is denoted as (6) in the process.

Closed Cycle or (Anderson Cycle)

In a closed-cycle OTEC system, the warm surface water does not directly vaporize. Instead, it heats an intermediate working fluid with a low boiling point, such as ammonia or freon, in the evaporator (heat exchanger). Here's a breakdown of the closed-cycle OTEC process:



1.Warm surface water intake: The warm seawater is directed into the evaporator, where it transfers heat to the intermediate working fluid (ammonia or freon).

2.Heat transfer and vaporization: The warm surface water in the evaporator raises the temperature of the intermediate working fluid, causing it to vaporize into a high-pressure gas.

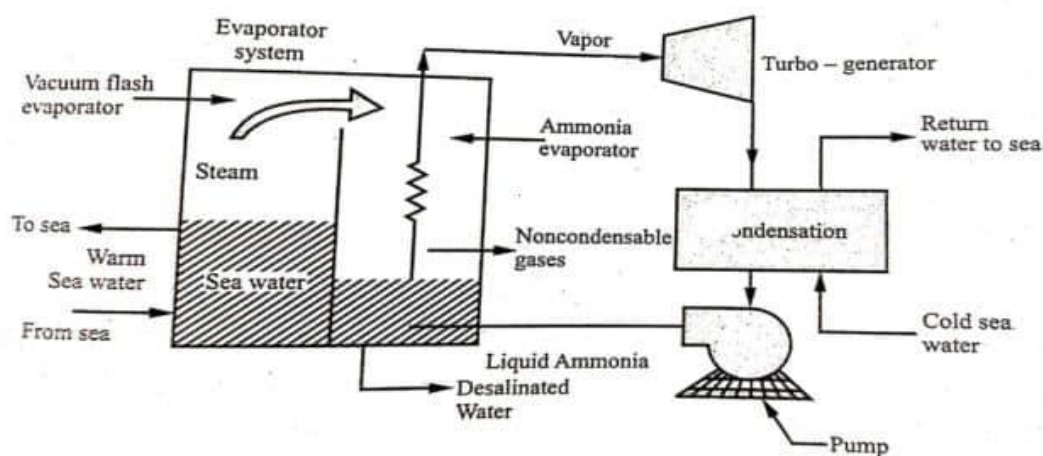
3.Power generation: The high-pressure gas from the evaporator is directed to drive the turbines, which are connected to generators to produce electricity.

4.Condensation: After passing through the turbine, the high-pressure gas (now at a lower pressure) enters the condenser. Cold water from the deep sea is used to cool the gas, causing it to condense back into a liquid state.

5.Heat rejection and circulation: The condensed liquid working fluid is pumped back to the evaporator to restart the cycle. At all times, the working fluid remains in a closed system and is continuously circulated by a pump.

3. Hybrid Cycle

This cycle is a combination of open and closed cycles. The overall thermal efficiency of a hybrid system is higher than the other two systems. The hybrid systems are used to produce electricity as well as desalinated water.



There are two concepts of the hybrid system. The first one is to use a closed-cycle OTEC to generate electricity and produce desalinated water. The necessary low-pressure environment for the open cycle OTEC is produced in the flash evaporator to flash the water vapour. The water gets evaporated in a vacuum chamber and is condensed back in the second ammonia evaporator to produce desalinated water as in an open cycle. The intermediate secondary fluid (ammonia) gets evaporated in this chamber and enters the turbine as in a closed cycle to produce turbine work to generate electricity. The non- condensable gases are removed from the ammonia evaporator and are discharged into the atmosphere.

Advantages of OTEC Plant

1. Renewable energy
2. Baseload power:
3. Environmentally friendly
4. Integrated desalination: It produce fresh water.

Disadvantages of OTEC Plant

1. Limited scalability: Does not have large scale production
2. Energy transmission: Difficult transmit generated power to grid
3. More expense

BIOMASS ENERGY CONSTRUCTION AND WORKING

Biomass serves as the primary raw material for the production of bioenergy. Biomass energy itself refers to the energy produced from organic matter, such as plants, agricultural crops, wood, and waste materials. It is a renewable energy source that can be converted into heat, electricity, and biofuels.

Biomass Conversion Process:

For bioenergy production from biomass, multiple biomass conversion processes are used:

1.Combustion:

Feedstock is burnt in the presence of air to release heat. Eg: heating wood, and steam heating to generate electricity

2.Gasification:

It is the process of using heat, pressure and partial combustion to convert feedstock into combustible gas mixture called syngas (can be used as natural gas/electricity/other uses).

3.Pyrolysis:

The process of heating feedstock in high temperature in the absence of oxygen. As oxygen is not present, organic material does not combust and it converts into 3 forms: Bio-oil (solid), Bio-char (solid) and Syngas.

4.Anaerobic Digestion or Biodigestion:

Here, the feedstock is burnt which then gets converted into biogas with the help of bacteria in the absence of oxygen. The residue is called digestate and is a great fertilizer.

5.Fermentation:

The process of converting feedstock or the plant glucose into an alcohol called ethanol by utilization of yeast. Ethanol produced is a biofuel that can be used in the automotive industry.

The usage of the specific process for a specific feedstock depends upon the availability of the resources and desired form of energy. Prior to the industrial revolution, biomass was the primary source of our energy. Now, it is a small percentage of the total energy usage. However, for approx 2.5 billion people, it still remains the primary source of energy for cooking and heating. As earlier stated, resources availability, availability of technology and economic viability are drivers of biomass use.

Some of the advantages of biomass energy are:

1. Biomass is always and widely available as a renewable source of energy.
2. It is carbon neutral. No air pollution
3. It reduces the overreliance of fossil fuels.
4. Is less expensive than fossil fuels.
5. Biomass production adds a revenue source for manufacturers.
6. Less garbage in landfills.

Disadvantages of Biomass Energy:

1. Biomass energy is not as efficient as fossil fuels
2. It is not entirely clean
3. Can lead to deforestation.
4. Biomass plants require a lot of space.

Present Indian and international energy scenario of conventional and RE Sources:

Overview of Renewable energy in India:

India's population of more than 1028 million is growing at an annual rate of 1.58%. As fossil fuel energy becomes scarcer, India will face energy shortages significantly due to increase in energy prices and energy insecurity within the next few decades. Increased use of fossil fuels also causes environmental problems both locally and globally.

The 2022 electrical power targets include achieving 227GW (earlier 175 GW) of energy from renewable sources,

- Nearly 113 GW through solar power,
- 66 GW from wind power,
- 10 GW from biomass power,
- 5GW from small hydro and
- 31GW from floating solar and offshore wind power.
- The bidding process for the further additional 115 GW

Or thereabouts to meet these targets of installed capacity from January 2018 levels will be completed by the end of 2019-2020. The government has announced that no new coal-based capacity addition is required beyond the 50 GW under different stages of construction likely to come online between 2017 and 2022.

Ministry of Non-conventional Energy Sources is focused on nation-wide resource assessment, setting up of commercial projects, renovation and modernization, development and up-gradation of water mills and industry based research and development.

BIOMASS:

In recent years, the interest in using biomass as an energy source has increased and it represents approximately 14% of world final energy consumption. Estimates have indicated that 15–50% of the world's primary energy use could come from biomass by the year 2050. Biomass power generation in India is an industry that attracts investments of over Rs. 600 crores every year, generating more than 5000 million units of electricity and yearly employment of more than 10 million man-days in the rural areas.

HYDROPOWER:

Hydro-power is another source of renewable energy that converts the potential energy or kinetic energy of water into mechanical energy in the form of watermills, textile machines, etc., or as electrical energy (i.e., hydroelectricity generation). It refers to the energy produced from water (rainfall flowing into rivers, etc.). Hydro-power is the largest renewable energy resource being used for the generation of electricity. Only about 17% of the vast hydel potential of 150,000 MW has been tapped so far.

In India, hydropower projects with a station capacity of up to 25 Megawatts (MW) fall under the category of Small Hydropower (SHP). India has an estimated SHP potential of about 15,000 MW, of which about 11% has been tapped so far. The Ministry of New and Renewable Energy (MNRE) supports Small Hydropower project development throughout the country.

WIND ENERGY:

Wind energy is being developed in the industrialized world for environmental reasons and it has attractions in the developing world as it can be installed quickly in areas where electricity is urgently needed. In many instances it may be a cost-effective solution if fossil

fuel sources are not readily available. In addition there are many applications for wind energy in remote regions, worldwide, either for supplementing diesel power (which tends to be expensive) or for supplying farms, homes and other installations on an individual basis.

Wind power accounts for nearly 10% of India's total installed power generation capacity and generated 2.67 TWh in the fiscal year 2017-18, which is nearly 3% of total electricity generation.

The capacity utilization factor is nearly 16% in the financial year 2017-18 (19.62% in 2016-17 and 14% in 2015-16). 70% of wind generation is during the five months duration from May to September coinciding with Southwest monsoon duration. In India, solar power is complementary to wind power as it is generated mostly during the no monsoon period in daytime.

SOLAR ENERGY:

Solar energy is the most abundant permanent energy resource on earth and it is available for use in its direct (solar radiation) and indirect (wind, biomass, hydro, ocean, etc.) forms. Solar energy, experienced by us as heat and light, can be used through two routes: the thermal route uses the heat for water heating, cooking, drying, water purification, power generation, and other applications the photo voltaic route converts the light in solar energy into electricity, which can then be used for a number of purposes such as lighting, pumping, communications, and power supply in unelectrified areas.

The Ministry of New and Renewable Energy (MNRE) has planned a detailed trajectory so as to meet the target of 100 GW by 2022. A capacity of 23.12 GW was installed up to July 2018. Projects of around 10 GW are under implementation and tenders for additional 24.4 GW are issued. India has a good level of solar radiation, receiving the solar energy equivalent of more than 5000 trillion kWh/yr.

GEO THERMAL ENERGY:

Geothermal is energy generated from heat stored in the earth, or the collection of absorbed heat derived from underground. Immense amounts of thermal energy are generated and stored in the Earth's core, mantle and crust. Geothermal energy is at present contributing about 10,000 MW over the world and India's small resources can augment the above percentage.

Future of renewable energy in India:

- India, faced with twin challenges on energy and environmental front, has no option but to work towards increasing the role of renewable in the future energy systems.
- Renewable energy technologies vary widely in their technological maturity and commercial status.
- In India, renewable energy is at the take- off stage and businesses, industry, government and customers have a large number of issues to address before these technologies could make a real penetration.
- India with large renewable energy resources (solar PV, wind, solar heating, small hydro and biomass) is to set to have large-scale development and deployment of renewable energy projects

UNIT II

ELECTRICAL MACHINES FOR WIND ENERGY CONVERSION SYSTEMS (WECS)

SQUIRREL CAGE INDUCTION GENERATOR (SCIG)

Induction generators are often used in wind turbine due to the ability to produce power at variable rotor speed. The two primary assemblies within an induction motor are the stator and rotor;

CONSTRUCTION, PRINCIPLE OF OPERATION AND ANALYSIS

Stator

Stator windings are usually manufactured from copper

Each winding is energised in pairs and in sequence to produce a rotating magnetic field

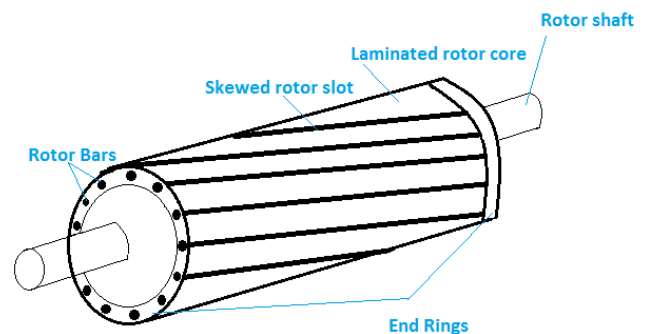
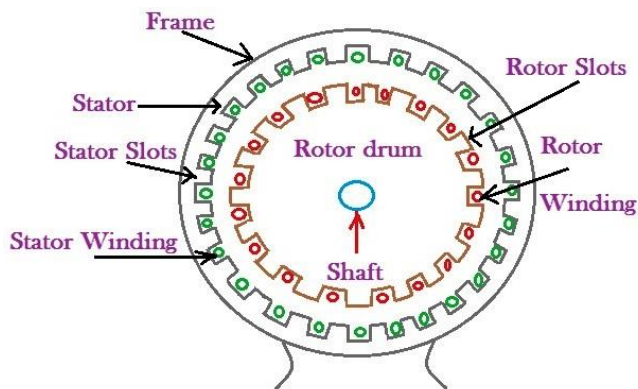
Rotor

The rotor shaft usually has a long and thin cylindrical shape, but this is design dependent. The squirrel cage is a cylindrical shaped cage that fits around the shaft with bars extending between its two ends. At either end of the squirrel cage, end rings are attached to create a short-circuit that induced current will flow through. Squirrel cages are typically made from copper or aluminium.

Thin steel laminations are slid onto the squirrel cage bars and compressed between the end rings; the rotor lamination materials involved are similar to those used for the stator laminations.

The laminations do not follow a perfectly straight orientation, but are slightly skewed in order to increase the torque produced. There is a maximum degree of 'skewedness' these laminations can adopt, and this is dependent on the design of the motor.

Skewing of the laminations also reduces the risk of the motor rotor 'locking' in a position between magnetic fields; this scenario causes the rotor to remain stationary and not rotate even when current is supplied to the stator windings.



Squirrel Cage Rotor

Working of Squirrel cage induction generator

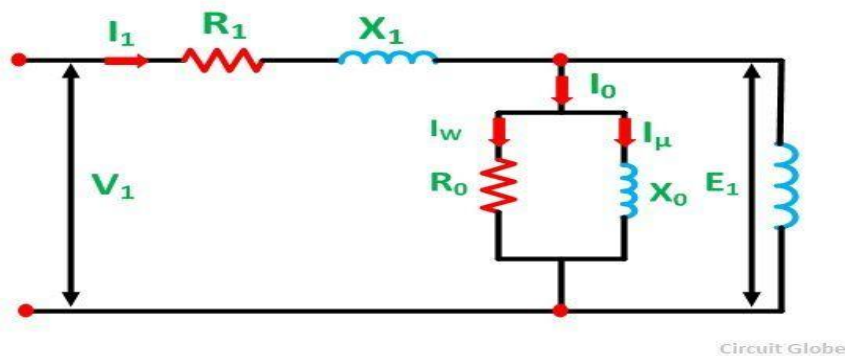
- Consider, an AC supply is connected to the stator terminals of an induction machine. The rotating magnetic field produced in the stator pulls the rotor to run behind it (in this phase, the machine is acting as a motor).
- Now, if the rotor is accelerated to the synchronous speed using one of the prime movers we mentioned above, the slip will be zero and hence the net torque will be zero. The rotor current will become zero when the rotor is running at synchronous speed.
- If the rotor is made to rotate at a speed more than the synchronous speed, the slip becomes negative. A rotor current is generated in the opposite direction, due to the rotor conductors cutting the stator magnetic field.
- In the last step, this generated rotor current produces a rotating magnetic field in the rotor that forces in the opposite way to the stator field. This causes a stator voltage which pushes current flowing out of the stator winding against the applied voltage. Thus, the machine is now working as an induction generator or as it is usually known an asynchronous generator.

EQUIVALENT CIRCUIT OF SQUIRREL CAGE INDUCTION GENERATOR

The Equivalent Circuit of an Induction Generator enables the performance characteristics which are evaluated for steady-state conditions. An induction Generator is based on the principle of induction of voltages and currents. The voltage and current are induced in the rotor circuit from the stator circuit for the operation. The equivalent circuit of an induction motor is similar to that of the transformer.

Stator circuit

The stator circuit model of an induction motor consists of a stator phase winding resistance R_1 , stator phase winding leakage reactance X_1 as shown in the circuit diagram below:



The no-load current I_0 is simulated by a pure inductive reactor X_0 taking the magnetizing component (I_μ) and a non-inductive resistor R_0 carrying the core loss current (I_w). Thus,

$$I_0 = I_\mu + I_w \dots \dots \dots (1)$$

I_0 No Load Current

I_μ Magnetising component

I_w Core loss Or Copper Loss

Rotor Circuit Model

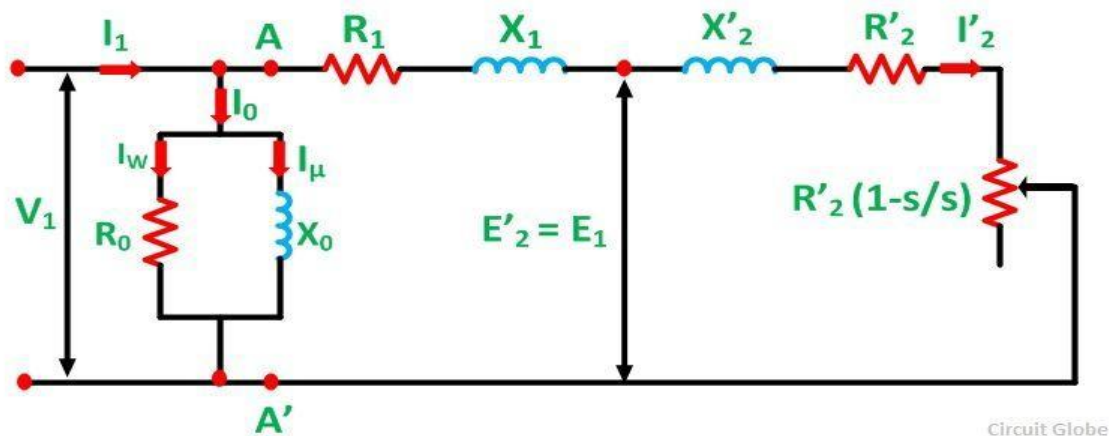
When a three phase supply is applied to the stator windings, a voltage is induced in the rotor windings of the machine.

The greater will be the relative motion of the rotor and the stator magnetic fields, the greater will be the resulting rotor voltage. The largest relative motion occurs at the standstill condition. This condition is also known as the locked rotor or blocked rotor condition. If the induced rotor voltage at this condition is E_{20} then the induced voltage at any slip is given by the equation shown below:

$$E_{2s} = sE_{20} \dots \dots \dots (2)$$

The rotor resistance is constant and is independent of the slip. The reactance of the induction motor depends upon the inductance of the rotor and the frequency of the voltage and current in the rotor.

Approximate Equivalent Circuit of an Induction Motor



Slip

Slip in Induction Generator is the relative speed between the rotating magnetic flux in stator and rotor.

$$\text{Slip (s)} = (N_s - N_r) / N_s$$

N_s — Rotating magnetic field in stator

N_r ----- Rotating magnetic field in Rotor

Case (i): $s = 0$ (Zero Slip)

Zero slip means that rotor speed is equal to synchronously rotating magnetic flux. Under this condition, there will not be any relative motion between the rotor coils and rotating magnetic flux.

Case (ii): $s=1$ (Slip equal to 1)

Slip = 1, means that rotor is stationary.

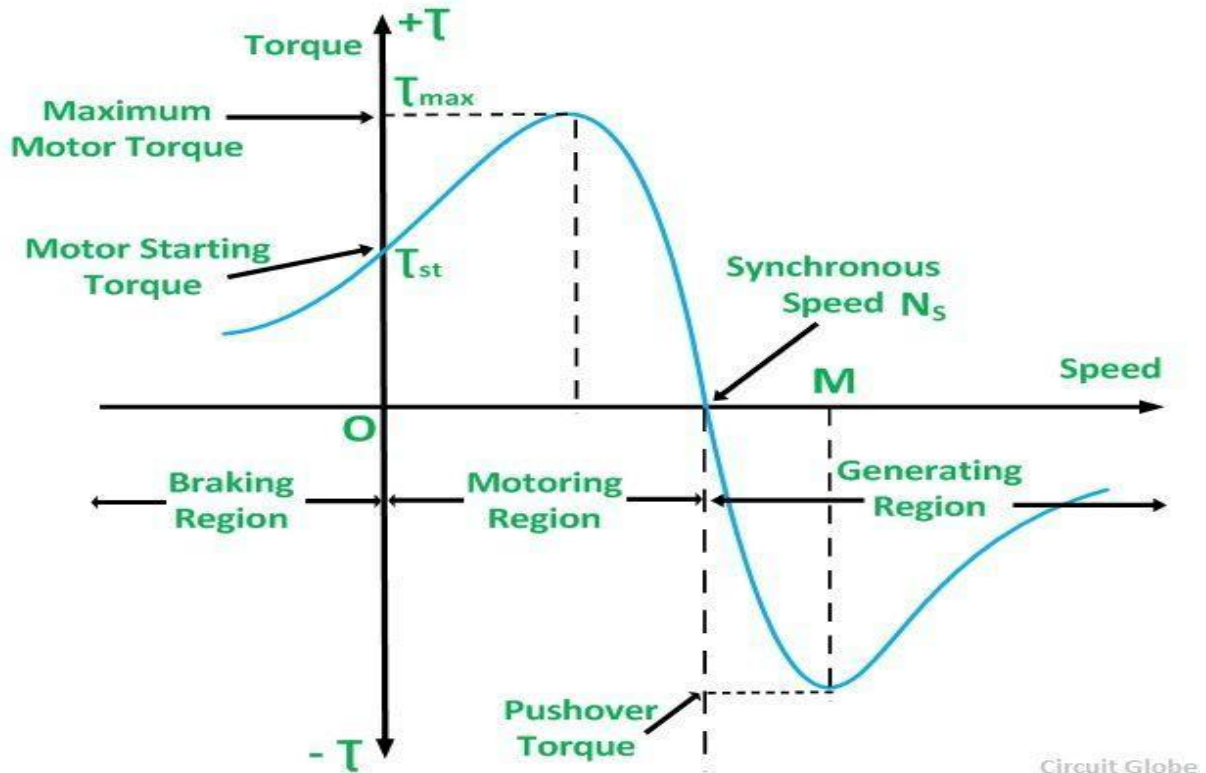
Case (iii): $s > 1$ (Slip greater than 1)

Slip more than 1 implies that, rotor is rotating in a direction opposite to the direction of rotation of magnetic flux. This means if magnetic flux is rotating in clockwise direction, then rotor is rotating in anticlockwise direction or vice versa.

Case (iv): $s < 1$ (Slip greater than 1)

Negative value of slip in induction motor can be achieved when the rotor speed is more than the synchronously rotating magnetic flux. Under this condition, the machine operates as an Induction Generator

Speed Torque characteristics:



Doubly Fed Induction Generator Working [DFIG]

DFIGs are variable speed generators used in Wind turbines due to their several advantages.

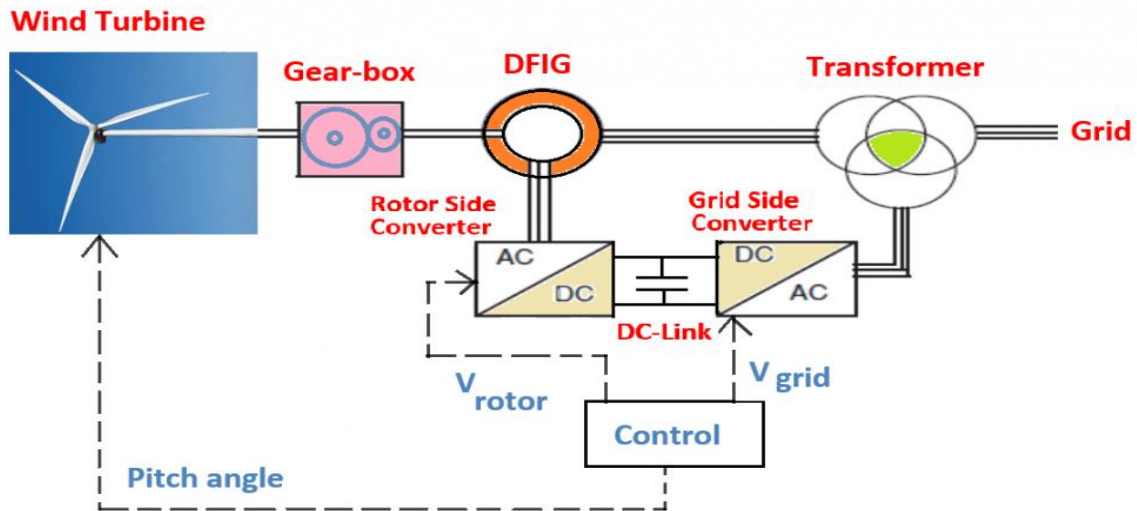
Operation of Doubly Fed Induction Generator:

Doubly fed Induction generators fed ac currents into both stator and rotor windings. The wind power captured by the turbine is converted into electric power by the generator and is transferred to the grid by stator and rotor windings.

The major advantage of DFIG is that it allows the amplitude and frequency of their output voltages to be maintained at a constant value, irrespective of the speed of the wind turbine rotor. Hence DFIG can be directly connected to the ac power network and remained synchronized at all times. Parts of Doubly Fed Induction Generator:

1. Three-phase Wound rotor Induction Machine:

The Doubly fed Induction generator is a three-phase wound rotor induction machine. The rotor windings of the DFIG-based wind turbines are connected with the use of two back-to-back converters, while the stator windings are connected directly to the network via a power transformer.



2. Back to Back converters:[AC/DC/AC Converter]:

The two back-to-back converters are namely RSC- Rotor Side Converter and GSC- Grid Side Converter. These converters are used to control the terminal voltage and power factor by injecting reactive power into the system.

Rotor Side Converter-RSC: [AC/DC]

The generator slip rings are connected to the rotor side converter, which shares a DC link with the grid side converter.

By receiving Pitch angle and Voltage commands RSC is used to control the torque/speed of the generator and also control the power factor at the stator terminals. RSC controls the rotor currents. Controlling the rotor currents and their frequency controls the slip and hence the speed of the machine.

Grid Side Converter-GSC: [DC/AC]

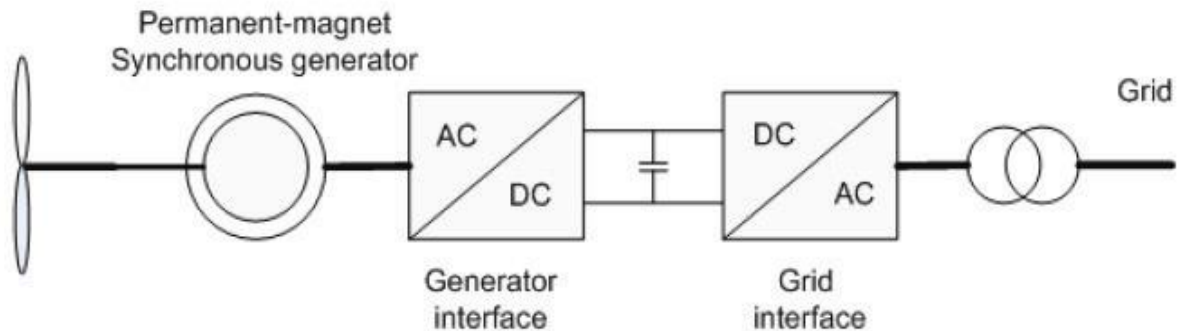
By receiving voltage command keeps the DC-link voltage constant and controls the reactive power or voltage at grid terminals.

3. DC-link Capacitor:

A DC-link capacitor is placed between the two converters. It acts as a DC voltage source in order to keep the voltage variations in the DC-link.

PERMANENT MAGNET SYNCHRONOUS GENERATOR

A Permanent Magnet Synchronous Generator (PMSG) is a type of electrical generator that uses permanent magnets instead of traditional field windings in the rotor. Its rotor consists of the permanent magnet that generates a field for excitation and replaces the external supply source for the generator.

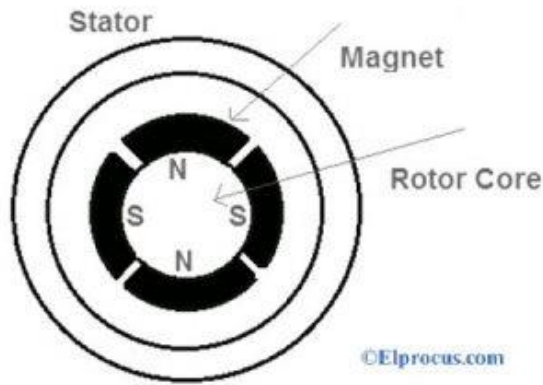


Stator

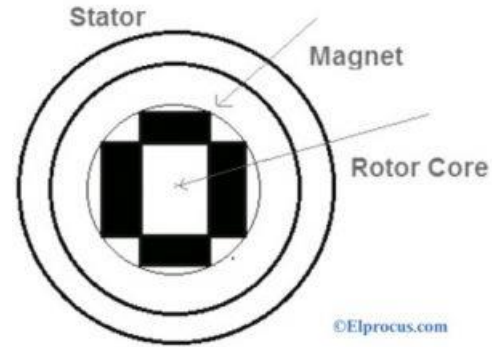
- The stator frame may be made up of cast iron for small-size machines and of welded steel for large-size machines.
- The stator core is assembled with high-grade silicon content steel laminations. These silicon steel laminations reduce the hysteresis and eddy-current losses in the stator core.
- The slots are cut on the inner periphery of the stator core. A 3-phase armature winding is put in these slots.
- The armature winding of the alternator is star connected. The winding of each phase is distributed over several slots. When current flows through the distributed armature winding, it produces an essential sinusoidal space **distribution of EMF**.

Rotor

- The rotor doesn't have any field winding, but the permanent magnets are used to create field poles.
- The most widely used permanent magnet is neodymium-boron-iron because of its effective cost and ease of availability.
- In this type, the permanent magnets are mounted on the rotor. Based on the mounting of the permanent magnet on the rotor, the construction of a permanent magnet synchronous motor is divided into two types.
 - Surface-mounted PMSM
 - Buried PMSM or Interior PMSM



Surface-mounted PMSM



Buried PMSM or Interior PMSM

Working of PMSG

- The operation of a PMSG is based on Faraday's law of electromagnetic induction.
- When the rotor, embedded with permanent magnets, rotates, it creates a moving magnetic field. T
- his motion induces an electromotive force (EMF) in the stator windings, generating electricity.
- Notably, the produced EMF and, consequently, the output frequency directly depend on the rotor's rotational speed.

$$N_s = \frac{120 \times f}{P}$$

Advantages of Permanent Magnet Synchronous Generator

1. High efficiency
2. Less noise and vibration
3. size and lightweight
4. Different speed range
5. Reliable operation

Disadvantages of Permanent Magnet Synchronous Generator

1. Higher initial cost
2. Susceptibility to demagnetize
3. Need for a controller
4. Limited availability
5. Poor voltage regulation
6. Sensitive to load changes

UNIT III

POWER CONVERTERS AND ANALYSIS OF SOLAR PV SYSTEMS

Solar photovoltaic (SPV) systems can be used to harvest the energy of sunlight in the form of direct current. These power converters need to be selected and designed optimally in order to provide maximum energy efficiency, ensuring reliability and safety of the overall solar PV system, required for different applications. For low-power DC/DC conversion-based applications, most modern power conversion is accomplished using three major types of power converters – buck, boost, and buck-boost.

Line commutated converter under inversion mode:

- Rectifiers or AC to DC converters means the same which convert the Alternating Current (AC) to Direct Current (DC). The power flows from AC side (source) to DC side (load).
- Inverters are the power electronic converters which convert DC to AC, i.e. the power flow is from DC side (source) to AC side (load).

Now, in rectifiers by somehow if you have an active source of energy in DC bus (load side) and with proper polarity then there may be a situation arises that the power can flow from DC bus (load) to AC side (source) which is just the opposite of rectifier action and sometimes called as converters operating in inverter mode or inversion mode of converters.

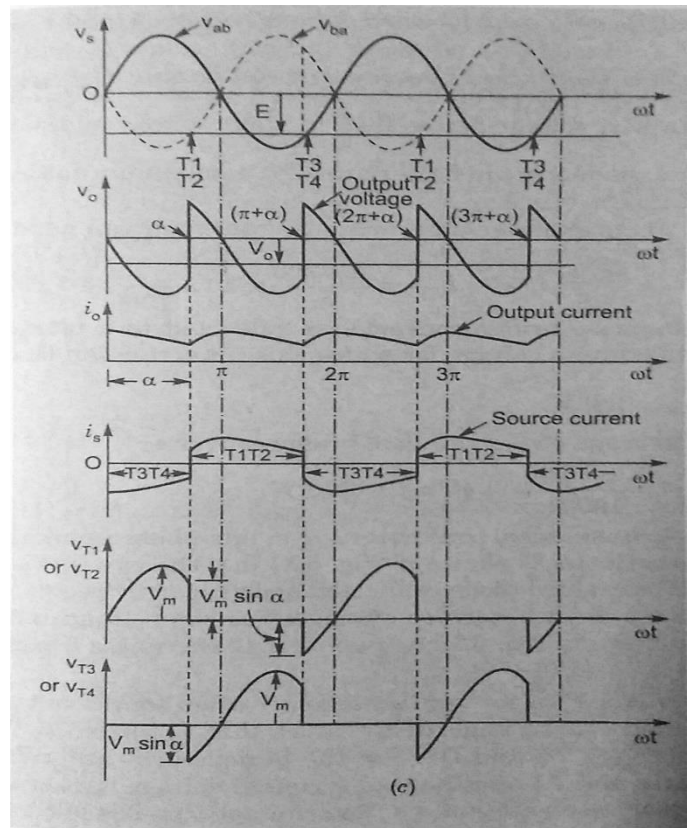
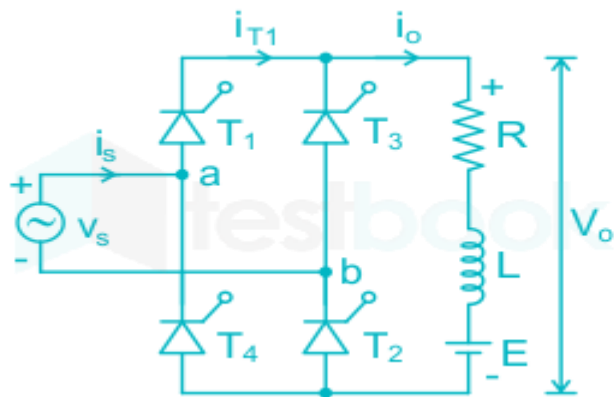
To operate the converter in inversion mode the following conditions need to be met.

- The converter firing angle (in case of controlled rectifiers using thyristors) must be more than 90 degrees whereas for rectification it is less than 90 degrees.
- There must be an active source of energy in DC bus with proper polarity so that current flows through the thyristors in the forward direction only. (e.g. a battery connected with its polarity reversed to the normal rectification mode bus voltage polarity.)

Converter working in inversion mode:

The circuit diagram of a single phase fully controlled bridge converter is shown in the figure with a highly inductive load and a dc source in the load circuit so that the load current is continuous and ripple free (constant load current operation). The fully controlled bridge converter consists of four thyristors T1, T2, T3 and T4 connected in the form of full wave bridge configuration as shown in the figure. Each thyristor is controlled and turned on by its gating signal and naturally turns off when a reverse voltage appears across it.

During the positive half cycle when the upper line of the transformer secondary winding is at a positive potential with respect to the lower end the thyristors T1 and T2 are forward biased during the time interval $\omega t = 0$ to π . As soon as the thyristors T3 and T4 are triggered a reverse voltage appears across the thyristors T1 and T2 and they naturally turn-off and the load current is transferred from T1 and T2 to the thyristors T3 and T4.



During (α to π) the voltage and current is positive. The power flow from AC source to load.

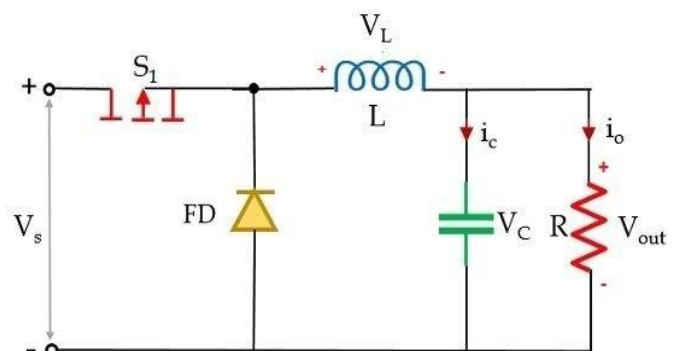
During the interval π to $(\pi + \alpha)$, the voltage is negative but the current is positive. The load transfers the energy to supply. so the net power flow is from load to supply. The fully controlled converter operated in firing angle delay greater than 90° is known as inversion mode converter.

DC-DC converters

For low-power DC/DC conversion-based applications, most modern power conversion is accomplished using three major types of power converters – buck, boost, and buck-boost.

Buck Converter

The operation of the buck converter is based on the principle of storing energy in an inductor. The voltage drop across an inductor is proportional to the change in the electric current flowing through the device. A switching transistor is used in between input and output for continuous switches on and off at high frequency. To maintain a continuous output, the circuit uses the energy stored in the inductor.



Buck Converter Circuit diagram

How2Electronics

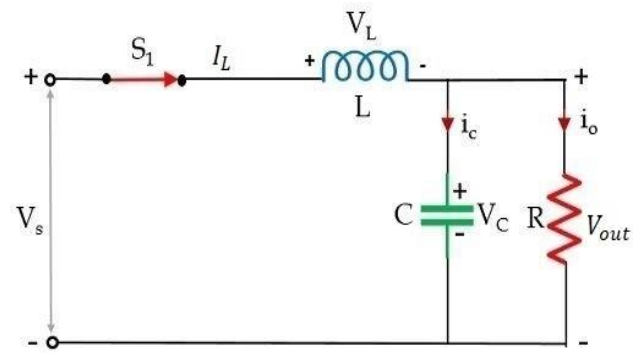
There are two modes of operation of the Buck converter. They are:

1. Mode I: Switch1 is ON and Diode FD is OFF
2. Mode II: Switch1 is OFF and Diode FD is ON

Mode I: Switch S_1 is ON and Diode FD is OFF

In this mode of operation, switch S_1 is in closed condition i.e. ON state, and diode FD is in open condition i.e. OFF state. Thus, switch S_1 allows the flow of current through it.

Due to this the diode FD is in reverse biased condition. The current flow through inductor " L " store energy in the form of a magnetic field. The capacitor is connected as shown in the circuit diagram. The current flows through the capacitor also and hence the capacitor store the charge. The voltage across the capacitor appears across the load and is equal to the output voltage V_o .

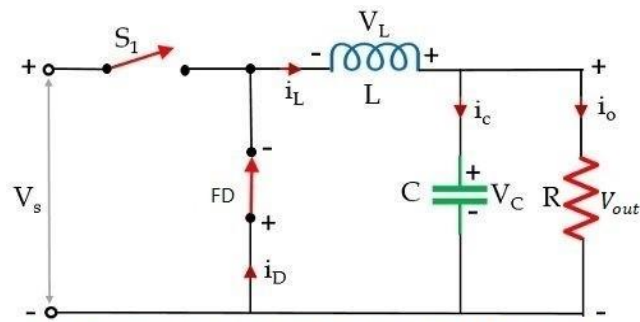


Buck Converter circuit when S_1 is closed

How2Electronics

Mode II: Switch S_1 is OFF and Diode FD is ON

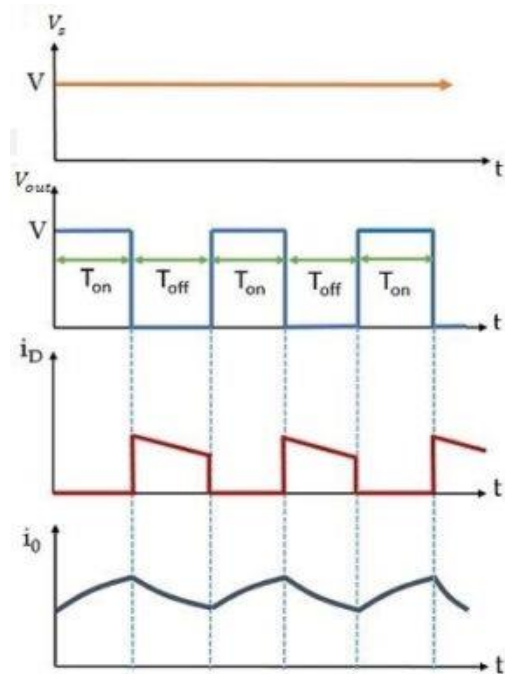
In this mode of operation, the switch S_1 is in open condition i.e. OFF state and diode FD is in closed condition i.e. ON state. Thus switch diode FD allows the flow of current through it, whereas switch S_1 blocks the current flow through it. The circuit diagram for this mode is shown in the above figure.



Buck Converter circuit when S_1 is open and FD is closed

How2Electronics

We know that the inductor in the circuit store energy in the form of a magnetic field. When S_1 is open, then the inductor acts as the source. Hence diode FD becomes closed. In this mode of operation, the inductor releases the energy stored in the previous mode when switch S_1 was closed. During releasing of energy stored in the inductor, the polarity of the inductor gets reversed which causes the freewheeling diode (FD) to come in forward biased condition. So it allows the flow of current in the circuit through diode FD . The way of current flow is shown in the above figure. The flow of current in the circuit will continue until the stored energy in the inductor gets completely collapsed. When the inductor gets completely discharged, the freewheeling diode (FD) comes in reverse biased condition and hence diode FD will be open. Instantly, the switch S_1 will get closed. In this way, the cycle will be continuing.

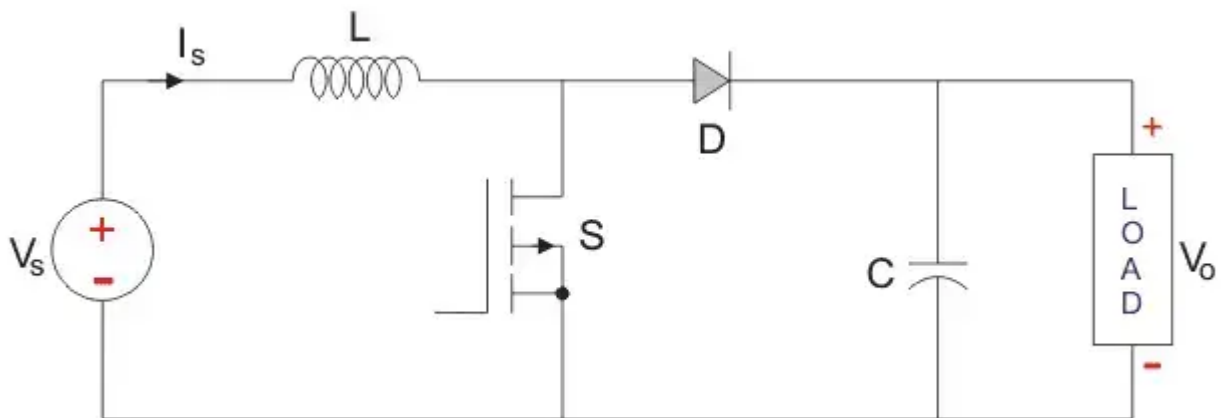


Waveform representation of Buck Converter

How2Electronics

Boost converter

Chopper or Boost converter which increases the input DC voltage to a specified DC output voltage.

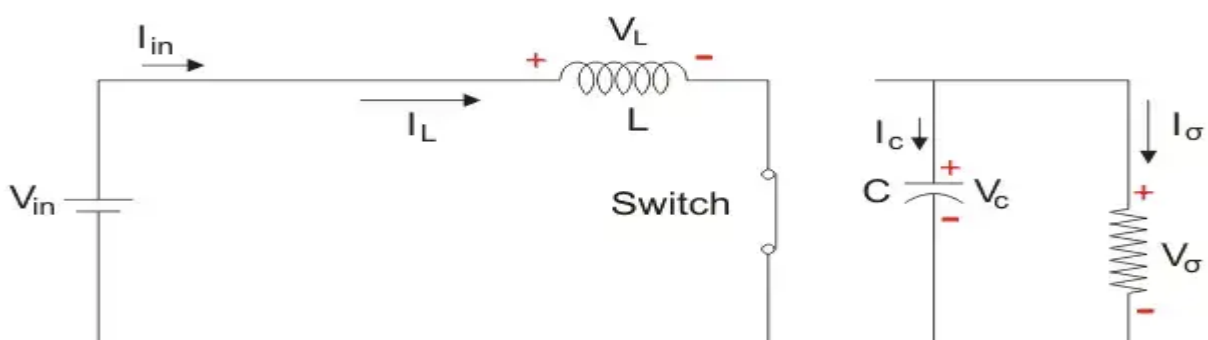


The input voltage source is connected to an inductor. The solid-state device which operates as a switch is connected across the source. The second switch used is a diode. The diode is connected to a capacitor, and the load and the two are connected in parallel.

The inductor connected to input source leads to a constant input current, and thus the Boost converter is seen as the constant current input source. And the load can be seen as a constant voltage source. The controlled switch is turned on and off by using Pulse Width Modulation (PWM). PWM can be time-based or frequency based. Frequency-based modulation has disadvantages like a wide range of frequencies to achieve the desired control of the switch which in turn will give the desired output voltage. Time-based Modulation is mostly used for DC-DC converters. It is simple to construct and use. The frequency remains constant in this type of PWM modulation. The Boost converter has two modes of operation.

Mode I : Switch is ON, Diode is OFF

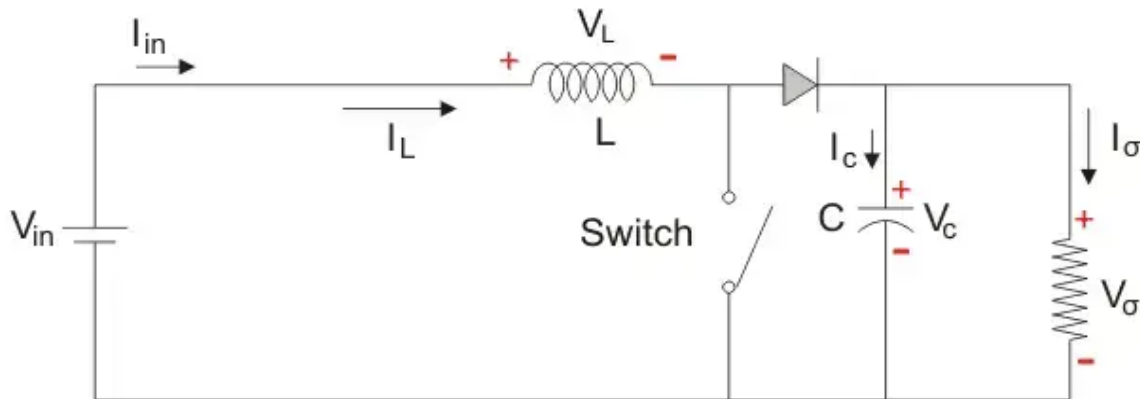
The Switch is ON and therefore represents a short circuit ideally offering zero resistance to the flow of current so when the switch is ON all the current will flow through the switch and back to the DC input source. Let us say the switch is on for a time T_{ON} and is off for a time T_{OFF} .



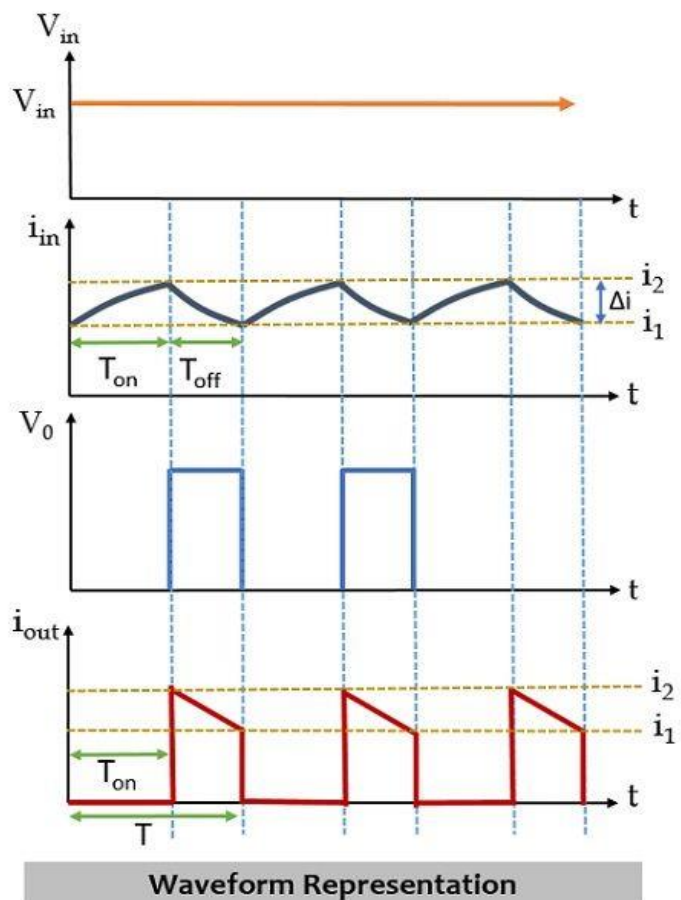
While performing the analysis of the Boost converter, we have to keep in mind that

- The inductor current is continuous and this is made possible by selecting an appropriate value of L .
- The inductor current in steady state rises from a value with a positive slope to a maximum value during the ON state and then drops back down to the initial value with a negative slope. Therefore the net change of the inductor current over anyone complete cycle is zero.

Mode II : Switch is OFF, Diode is ON

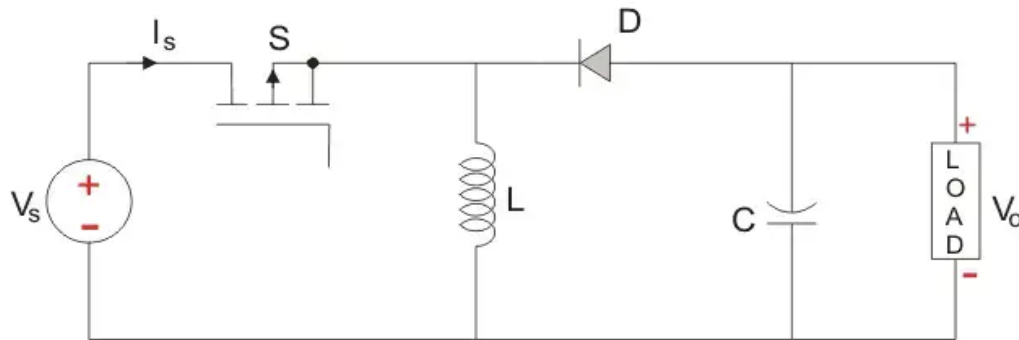


In this mode, the polarity of the inductor is reversed. The energy stored in the inductor is released and is ultimately dissipated in the load resistance, and this helps to maintain the flow of current in the same direction through the load and also step-up the output voltage as the inductor is now also acting as a source in conjunction with the input source.



Buck boost converter

DC-DC converters, commonly referred to as choppers, include the versatile Buck-Boost converter. This converter can function as either a step-down or step-up converter, depending on its duty cycle, denoted as D .

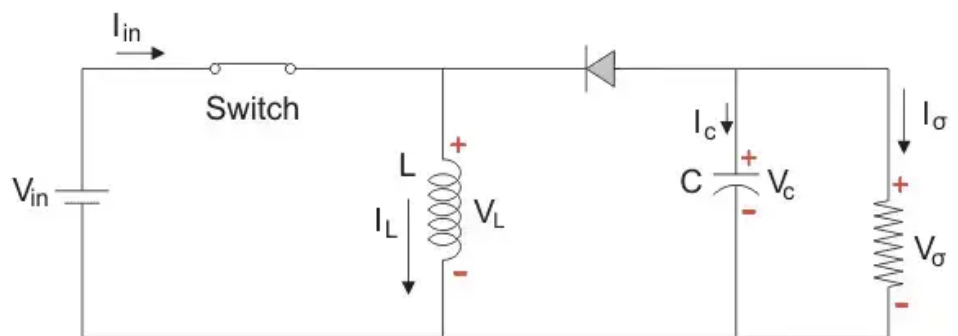


Mode I : Switch is ON, Diode is OFF

The Switch is ON and therefore represents a short circuit ideally offering zero resistance to the flow of current so when the switch is ON all the current will flow through the switch and the inductor and back to the DC input source.

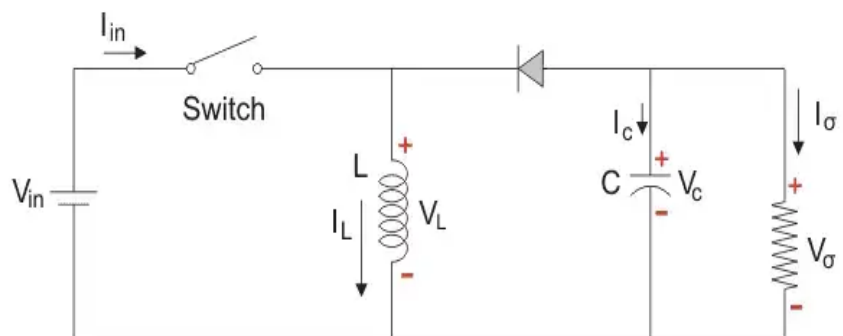
The inductor stores charge during the time the switch is ON and when the solid state switch is OFF the polarity of the Inductor reverses so that current flows through the load and through the diode and back to the inductor. So the

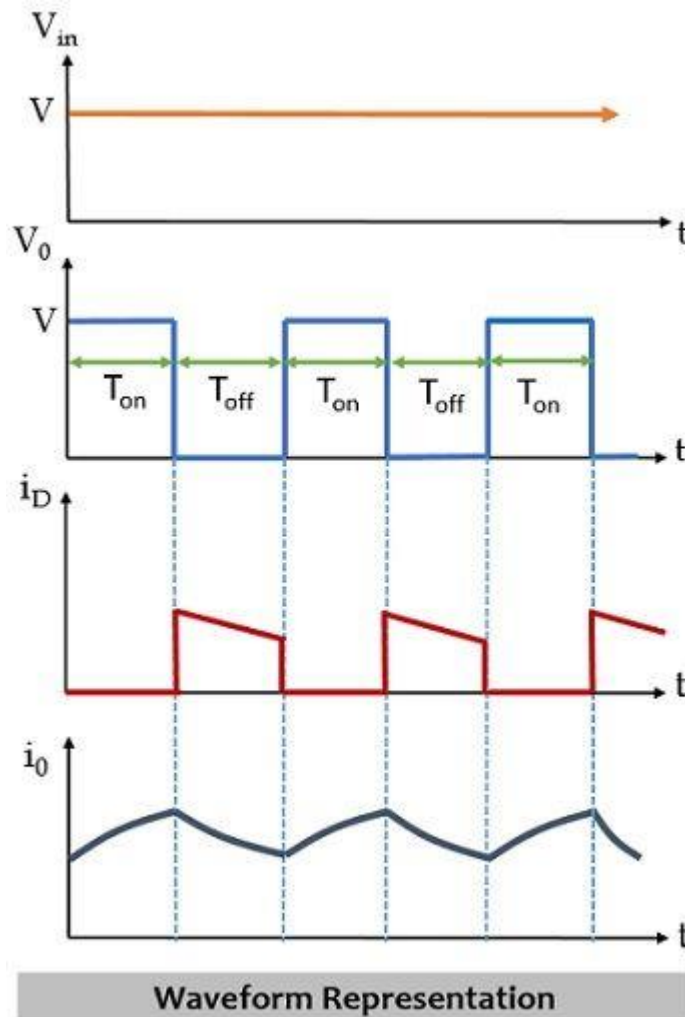
direction of current through the inductor remains the same



Mode II : Switch is OFF, Diode is ON

In this mode the polarity of the inductor is reversed and the energy stored in the inductor is released and is ultimately dissipated in the load resistance and this helps to maintain the flow of current in the same direction through the load and also step-up the output voltage as the inductor is now also acting as a source in conjunction with the input source.





Selection of inverter

Inverter Selection:

When choosing an inverter for your hybrid solar system, consider the following factors:

1. **Power Rating:** Assess your system's power requirements by considering both current and future load demands. Select an inverter that can handle the expected power needs, including any potential expansions.
2. **User-Friendliness:** Look for inverters that are easy to install and operate. Consider features such as a lightweight design and the availability of wheels for convenient movement.
3. **AC Distribution Board (ACDB) Compatibility:** Ensure that the inverter can be seamlessly integrated with your existing AC distribution board. Check if the inverter has adequate space for incoming and outgoing cable connections.
4. **Monitoring Capabilities:** Opt for inverters with advanced monitoring features. These can provide valuable insights into solar power generation, battery usage, and system performance. Remote monitoring options are particularly beneficial for real-time tracking and troubleshooting.

5. **Voltage Regulation:** Select an inverter that offers stable output voltage. This is crucial for compensating for voltage drops in the cables and ensuring consistent power supply to your connected devices.
6. **DG Synchronization :** DG Synchronization: When grid power is unavailable or turned off, we rely on DG sets to supply power. Therefore, the chosen Hybrid inverter should synchronize with the inverter, allowing us to use solar power and DG power in sync mode.
7. **Hybrid Inverter Capacity :** Load in KVA + Future requirement + Battery Charging Capacity

Battery Selection:

Choosing the right battery is essential for the reliable operation and longevity of your hybrid solar system. Consider the following factors:

1. **Discharge and Charging Currents:** Evaluate the system's load requirements and select a battery that can handle the expected discharge and charging currents effectively. Ensure that the battery can deliver sufficient power to meet peak load demands without compromising its longevity.
2. **Crank Amp Rating:** Consider the inrush currents generated by certain loads, such as motors, when selecting a battery. Choose a battery with an appropriate crank amp rating to handle these sudden power surges without causing any damage.
3. **Battery Type:** While lead-acid batteries are commonly used in hybrid solar systems, consider exploring alternative options like lithium-ion batteries. Lithium-ion batteries offer advantages such as higher energy density, faster charging times, longer lifespan, and greater depth of discharge.

Backup Time Calculation:

Determining the backup time for your hybrid solar system involves careful consideration of various factors:

1. **Solar Generation Variability:** Take into account the fluctuations in solar power generation throughout the day. Calculate the backup time based on the worst-case scenario when solar power generation is at its lowest.
2. **Inrush Current Considerations:** Account for the inrush currents that certain loads may generate during system operation. Ensure that the battery capacity can handle these high current demands without affecting the system's performance.
3. **Nighttime Load Requirements:** Accurately assess the power needs during nighttime operation. Consider all the loads that will be powered by the battery during this period to calculate the required backup time.
4. **Battery back-up time =** back up time needed to cater days load + Back up time needed to cater night time load + System Crank power back up!

Selecting the right inverter, battery, and backup time is crucial for maximizing the efficiency and reliability of your hybrid solar system. By considering factors such as power rating, user-friendliness, ACDB compatibility, monitoring capabilities, discharge and charging currents, crank amp rating, battery type, solar generation variability, inrush current considerations, and nighttime load requirements, you can ensure that your system meets your energy needs while providing uninterrupted power supply and sustainable energy solutions

Array sizing of solar PV

1. Determine the Suns Peak Hours Available Per Day

If a solar panel is rated at say 100 Wp (watts peak) it would supply 100 watts of peak power at the brightest part of the day. If the average peak sun hours for a particular location is given as 4.5 hours, this means then that our solar panel will provide 450 watt-hours (4.5 hrs x 100 Wp) a day of peak electricity during the day. Obviously the sun shines longer than 4.5 hours a day, but here we are interested in the number of hours of full sun, as it is this that will generate the maximum 100 watts of solar energy.

2. Determine Your Energy Needs In Terms Of Watts Per Hour

To determine the required overall power rating of a photovoltaic solar system required to power a home, the electrical energy needs in terms of watts per hour should first be evaluated. It depends on the load connected the panel by the user.

3. Optimize Your Power Demands and Usage

Solar panels and arrays are designed to supply a certain amount of energy consumption. If the home exceeds the planned limits this additional energy will need to come from somewhere either from the utility grid costing you money, a backup generator or storage batteries.

4. Determine the Type of Solar Panels You Wish to Use

There are many hundreds of different size solar panels available to choose from ranging from small 20 watt panels to larger and heavier 250 watt panels at 12, 24 or 48 volts and all with their own set of advantages and disadvantages

5. Size Your Array

Now for the final part to estimate the size of your solar array. First you will need to divide the previously calculated total watt-hours by the peak sunlight hours. This should give you the total wattage of solar panels that you will need and then add a little extra to make up for the cloudy dull days.

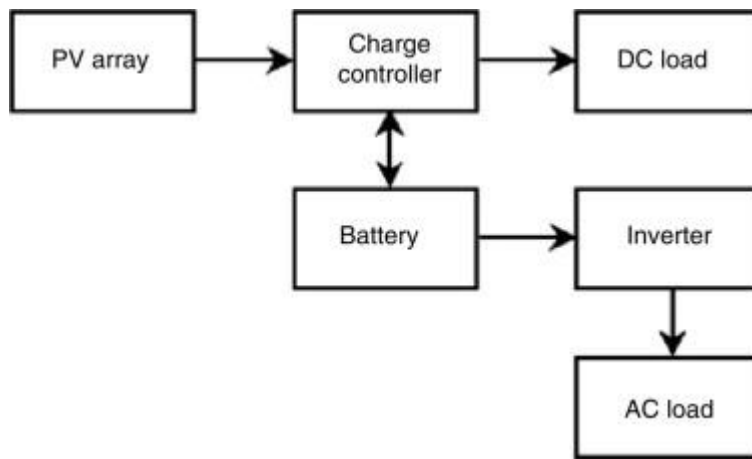
This value gives you the total number of solar panels we need to generate a given amount of Watt-hours (or kWh) for our home in your given location. For example if we need a 1000 watt system, then that's 10 x 100 watt panels or 5 x 200 watt panels.

Types of PV Systems

Three main types of PV systems: stand-alone (off-grid), grid-connected, and hybrid.

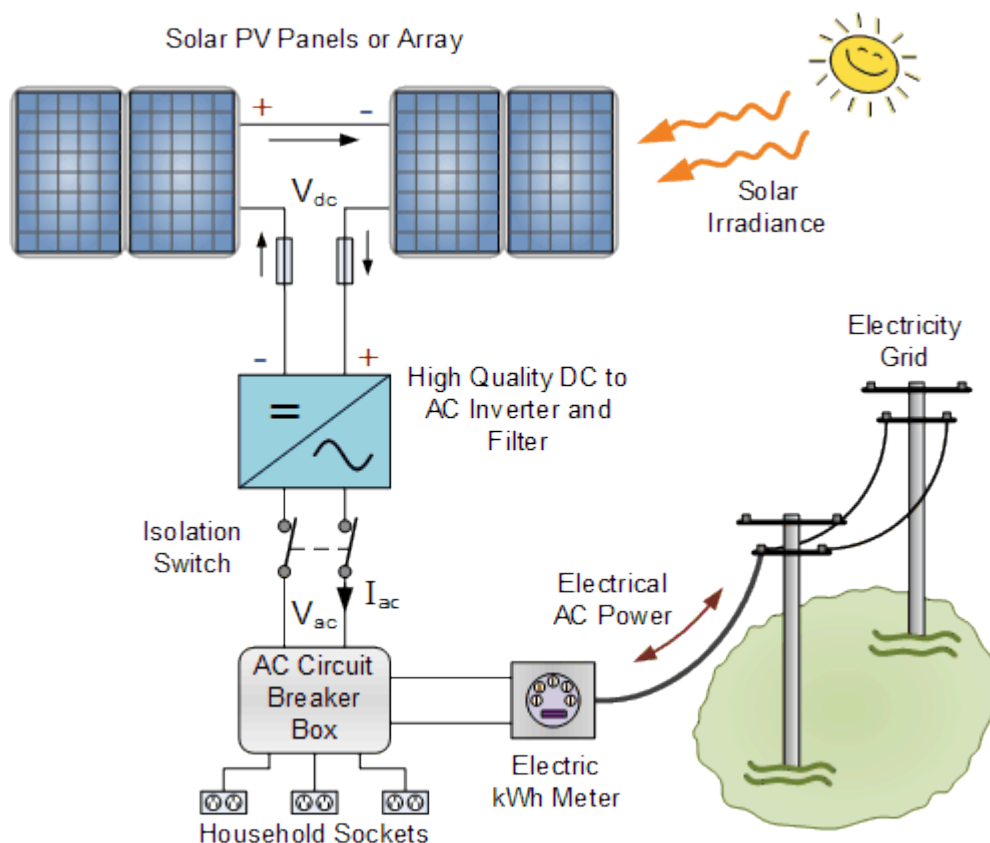
1. Stand-Alone Systems (off-Grid PV Systems)

Stand-alone systems rely on PV power only. These systems can comprise only PV modules and a load or can include batteries for energy storage. When using batteries charge regulators are included, which switch off the PV modules when batteries are fully charged, and switch off the load in case batteries become discharged below a limit. The batteries must have enough capacity to store the energy produced during the day to be used at night and during periods of poor weather. Solar street light describes a standalone PV power generating device. It comprises a compact fluorescent lamp, two 35 watt solar modules and an 80 Ah tubular cell battery.



2. Grid-Connected Systems

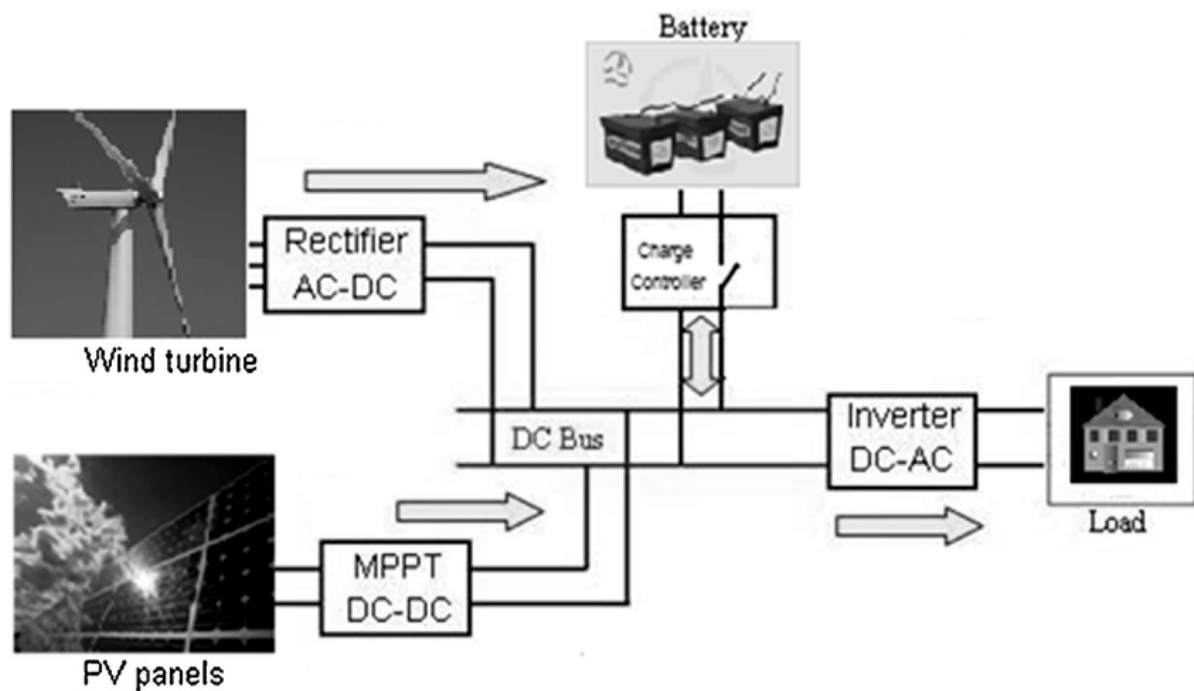
A grid-connected photovoltaic power system is connected with the state electric grid and do not require batteries. The system operates to supplement the grid power during the daytime when a substantial quantum of solar energy is extracted from the sunlight. During night the grid power alone feeds the load. This system also supplies emergency power during any short period of grid failure. This system requires additional equipment to control voltage, Frequency and waveform so as to conform to conditions for feeding the power into the grid.



3. Hybrid Systems

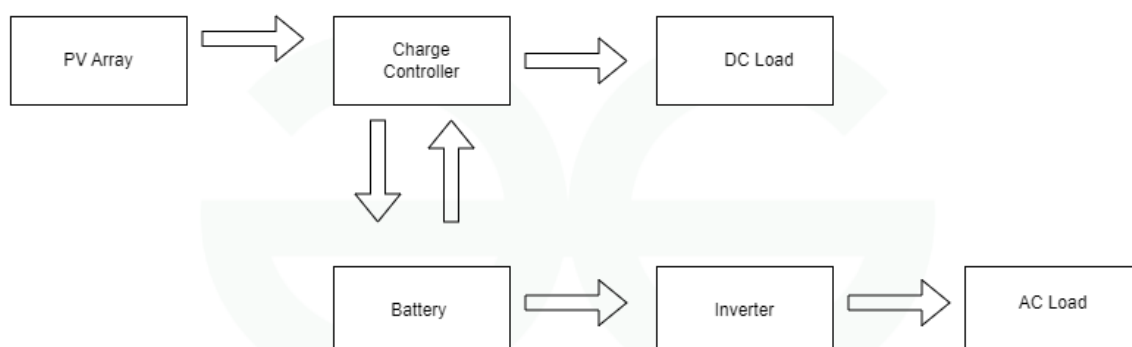
Hybrid systems consist of combination of PV modules and a complementary means of electricity generation such as a diesel and gas or wind generator. Schematically is a hybrid system. In order to optimize the operations of the two generators, hybrid systems typically

require more sophisticated controls than stand-alone PV systems. For example, in the case of PV/diesel systems, the diesel engine must be started when battery reaches a given discharge level and stopped again when battery reaches an adequate state of charge.



Block Diagram of Solar Energy

A solar energy block diagram illustrates the key components and their interconnections in solar power systems. Here's a simplified explanation of the main components typically found in such a diagram.



- **Solar panels (photovoltaic modules) :** Solar panels are the primary components that capture sunlight and convert it into electrical energy through the photovoltaic effect .These panels are made up of semiconductor materials like silicon.
- **Inverter:** The direct current electricity generated by solar panels needs to be converted into alternating current to be compatible with most electrical appliances and the grid. The inverter performs this conversion.
- **Charge controller:** In off grid solar systems with energy storage, a charge controller is used to regulate the charging and discharging of the batteries. It prevents overcharging and excessive discharging, extending the life span of the batteries.
- **Battery bank:** In off-grid or hybrid solar systems energy storage is often required to store excess electricity generated during sunny periods for use during cloudy days or at night. A battery bank stores this energy for later use.
- **Load:** The load represents the electrical appliances or devices that consume the electricity generated by the solar power system. This can include household appliances, lighting and other electrical equipment.

UNIT IV

ANALYSIS OF POWER CONVERTERS FOR HYBRID ENERGY SYSTEMS

Power converters play a significant role in converting the DC to DC or AC and AC to DC which maintains the power supply driving the hybrid power transmission system and other vehicle auxiliary loads.

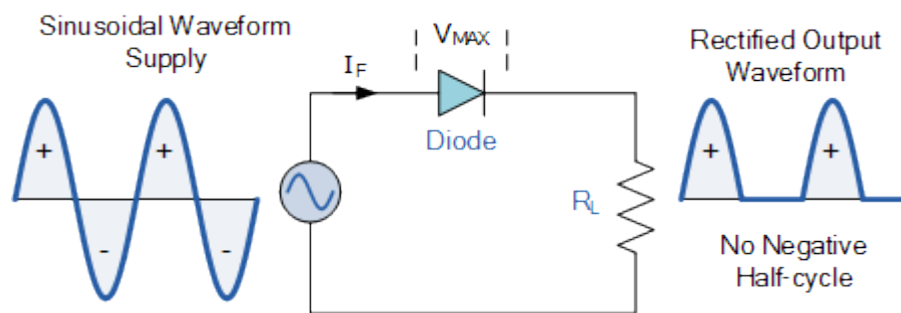
AC to DC converter:

The ac to dc converter is done in hybrid energy by the following methods

- (i) Half bridge rectifier
- (ii) Full bridge rectifier

Half bridge uncontrolled rectifier:

In a single-phase half-wave rectifier, either the negative or positive half of the AC voltage flows, while the other half of the AC voltage is blocked. Hence the output receives only one half of the AC wave. A single diode is required for a single-phase half-wave rectification and three diodes for a three-phase supply. Half wave rectifier produces more amount of ripple content than full-wave rectifiers and to eliminate the harmonics it requires much more filtering.



The output voltage can be expressed as the following expression:

The input supply voltage AC is given as $V_m \sin \omega t$.

The output voltage time interval is 0 to π .

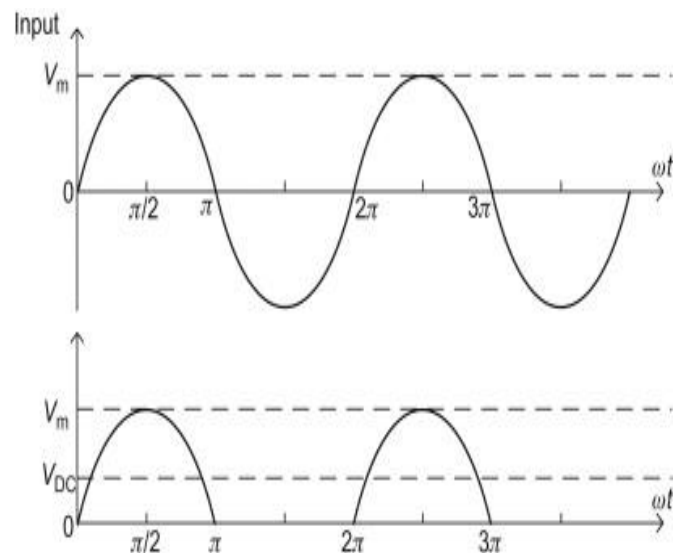
$$V_0 = \frac{1}{2\pi} \int_0^{\pi} [V_m \sin \omega t \, d(\omega t)] = \frac{V_m}{2\pi} [-\cos \omega t]_0^{\pi}$$

$$V_0 = -\frac{V_m}{2\pi} [\cos \pi - \cos 0]$$

$$V_0 = \frac{-V_m}{2\pi} (-1 - 1)$$

$$V_0 = \frac{2V_m}{2\pi}$$

$$V_0 = \frac{V_m}{\pi}$$



Bridge Rectifier:

- It consists of two thyristors T1, T2 and two diodes D1, D2.
- During positive half supply of the AC supply, T1 and D1 are forward biased. When T1 is triggered at a firing angle $\omega t = \pi + \alpha$, T1 and D1 come to on state. Now the load current path is P-T1-R-D1-N. During this period we get positive output voltage and current.
- At $\omega t = \pi + \alpha$, the load current and load voltage reach to zero, then T1, D1 come to off state due to natural commutation.
- During negative half cycle of the AC supply, T2 and D2 is forward biased. When T2 is triggered at firing angle $\omega t = \pi + \alpha$, T2 and D2 come to on state. The load current path is N-T2-R-D2-P. During this period, we get positive output voltage and current.
- At $\omega t = \pi + \alpha$, the load voltage and current reaches to zero, then T2, D2 come to off state due to natural commutation.

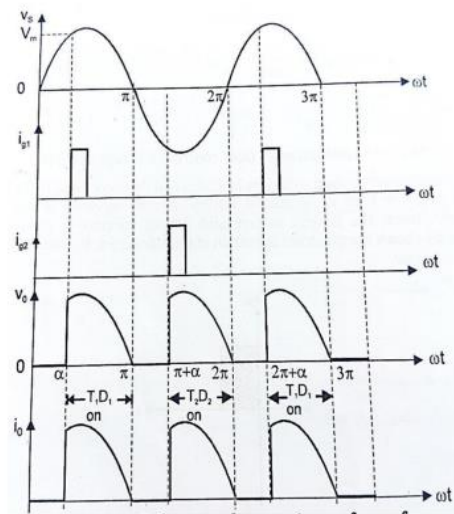
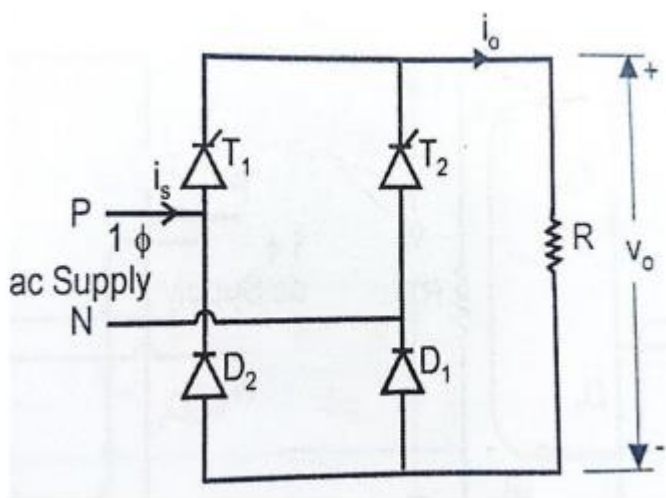


Fig. 3.8 Single phase half controlled rectifier with R load

The output voltage can be expressed as given below:

$$V_{dc} = \frac{1}{\pi} \int_{\alpha}^{\pi} V_m \sin \omega t \, d(\omega t) = \frac{V_m}{\pi} [-\cos \omega t]_{\alpha}^{\pi}$$

$$V_{dc} = -\frac{V_m}{\pi} [\cos \pi - \cos \alpha]$$

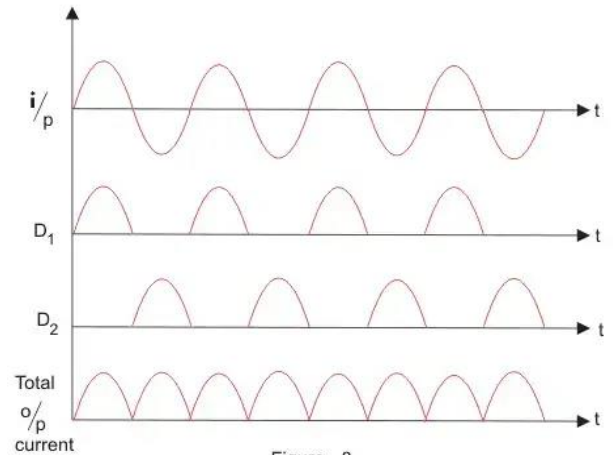
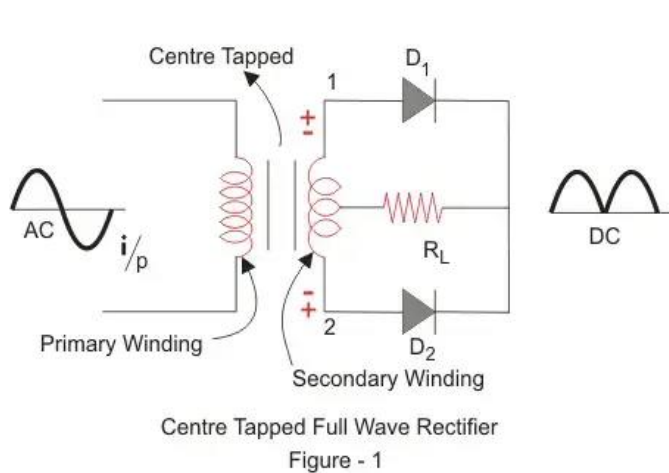
$$V_{dc} = \frac{V_m}{\pi} [1 + \cos \alpha]$$

FULL BRIDGE RECTIFIER

Full wave rectifiers are further classified into:

- (i) Centre-tapped Full Wave Rectifier
- (ii) Full Wave Bridge Rectifier

Center-tapped full wave rectifier:

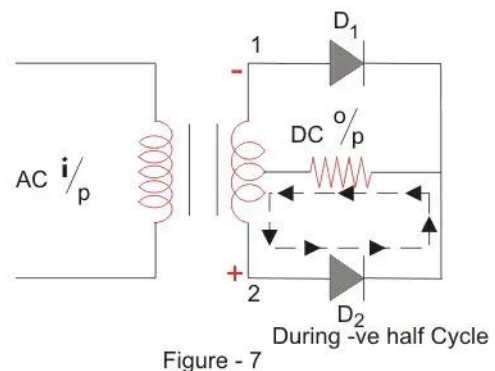
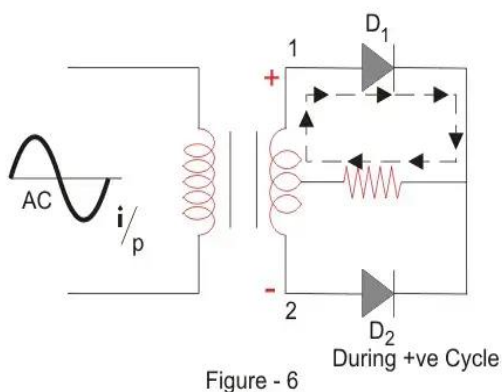


It is a normal transformer with one slight modification. It has an additional wire connected to the exact centre of the secondary winding. This type of construction divides the AC voltage into two equal and opposite voltages, namely +Ve voltage (V_a) and -Ve voltage (V_b).

The total output voltage is $V = V_a + V_b$

Working of Centre-tapped Full Wave Rectifier :

During the positive half-cycle of the AC voltage, terminal 1 will be positive, centre-tap will be at zero potential, and terminal 2 will be negative potential. This will lead to forwarding bias in diode D_1 and cause current to flow through it. During this time, diode D_2 is in reverse bias and will block current through it.



During the negative half-cycle of the input AC voltage, terminal 2 will become positive relative to terminal 1 and centre-tap. This will lead to forwarding bias in diode D_2 and cause current to flow through it. During this time, diode D_1 is in reverse bias and will block current through it. As a result, both half-cycles are allowed to pass through. The average output DC voltage here is almost twice the DC output voltage of a half-wave rectifier.

Bridge rectifier:

The bridge rectifier consist of four diode A,B,C,D. and four junctions 1,2,3,4.

The input is connected to the junction 1&2, the load is connected to the junction 3&4.

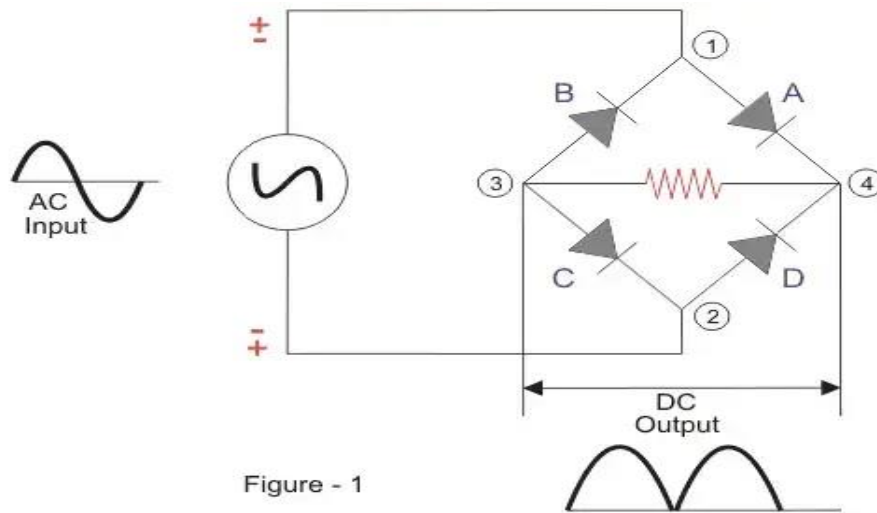


Figure - 1

Working of bridge rectifier:

We apply an AC across the bridge. During the positive half-cycle, terminal 1 becomes positive, and terminal 2 becomes negative. This will cause the diodes A and C to become forward-biased, and the current will flow through it. Meanwhile, diodes B and D will become reverse-biased and block current through them. The current will flow from 1 to 4 to 3 to 2.

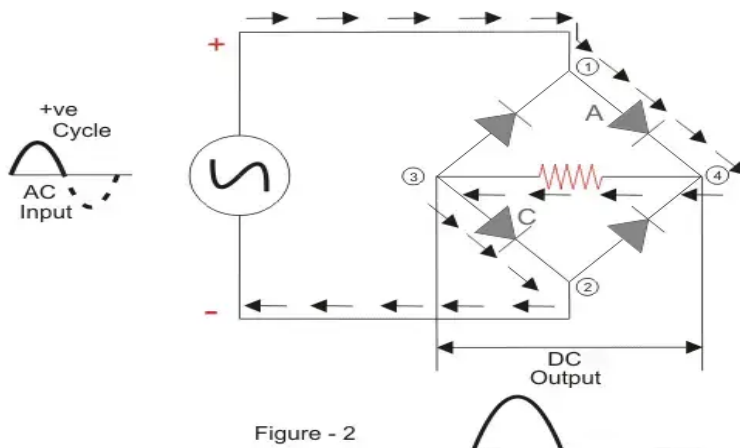


Figure - 2

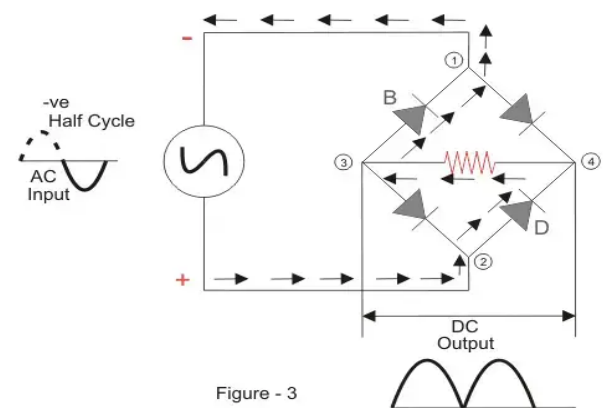


Figure - 3

During the negative half-cycle, terminal 1 will become negative, and terminal 2 will become positive. This will cause the diodes B and D to become forward-biased and will allow current through them. At the same time, diodes A and C will be reverse-biased and will block the current through them. The current will flow from 2 to 4 to 3 to 1.

SINGLE PHASE FULLY CONTROLLED BRIDGE RECTIFIER WITH R LOAD

- **During positive half cycle**

T1, T2 are forward biased and they are triggered simultaneously.

At $\omega t = \pi + \alpha$, T1, T2 are conducting, then current flows through the path P-T1-R-T2-N.

At $\omega t = \pi + \alpha$, V_s falls to zero and current also goes to zero. Hence T1, T2 are turned off.

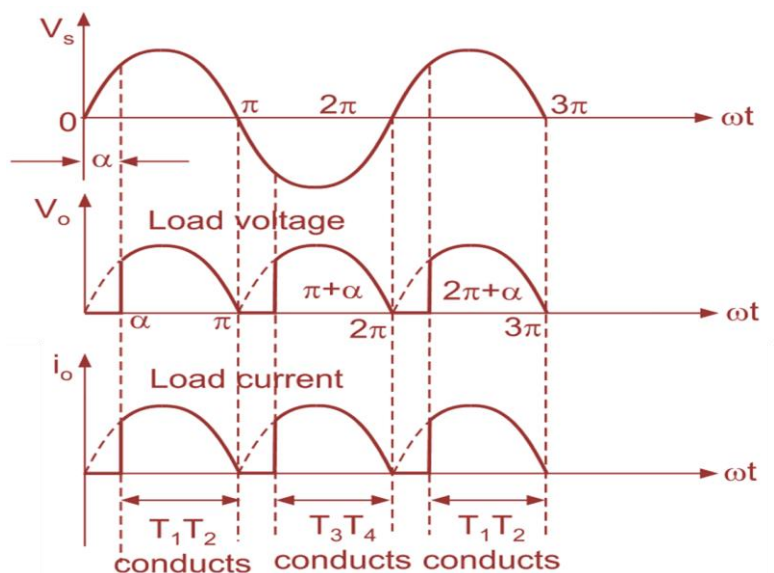
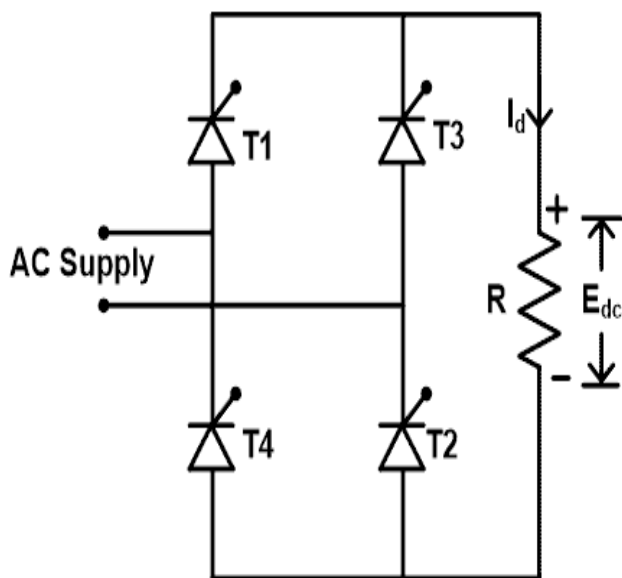
- **During negative half cycle**

T3, T4 are forward bias and they are triggered simultaneously.

At $\omega t = \pi + \alpha$, T3, T4 are conducting, then current flows through the path N-T3-R-T4-P.

At $\omega t = \pi + \alpha$, Supply voltage V_s and current goes to zero and T3, T4 are turned off.

- The output voltage can be varied by varying the firing angle α .
- So, the load current is always discontinuous with purely resistive load.
- By using full converter with R load, the output voltage and output current is always positive.
- A fully controlled rectifier with R load acts as a one quadrant converter.



The output voltage is given by the expression:

The output voltage appears from α to π .

$$V_{dc} = \frac{1}{\pi} \int_{\alpha}^{\pi} V_m \sin \omega t \, d(\omega t) = \frac{V_m}{\pi} [-\cos \omega t]_{\alpha}^{\pi}$$

$$V_{dc} = -\frac{V_m}{\pi} [\cos \pi - \cos \alpha]$$

$$V_{dc} = \frac{V_m}{\pi} (1 + \cos \alpha)$$

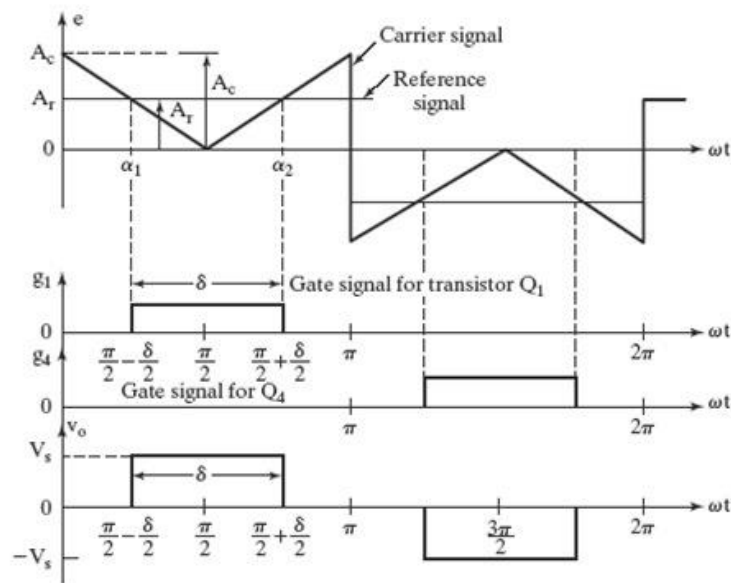
PWM INVERTERS

An inverter whose functionality depends upon the pulse width modulation technology is referred to as PWM inverters.

The technique of PWM in an inverter comprises of two signals. One signal is for the reference and the other will be the carrier. The pulse required for switching the mode of the inverter can be generated by the comparison among those two signals. There are various PWM techniques.

Single Pulse Width Modulation (SPWM)

For every half cycle, there is only one pulse available to control the technique. The square wave signal will be for reference and a triangular wave will be the carrier. The gate pulse generated will be the result of the comparison of the carrier and the reference signals. Higher harmonics is the major drawback of this technique.



Multiple Pulse Width Modulation (MPWM)

MPWM technique is used to overcome the drawback of SPWM. Instead of a single pulse, multiple pulses are used for every half cycle of the voltage at the output. The frequency at the output is controlled by controlling the frequency of the carrier.

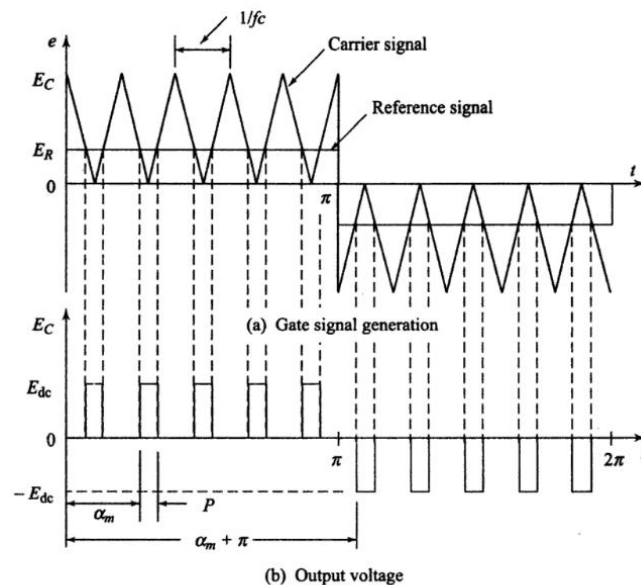
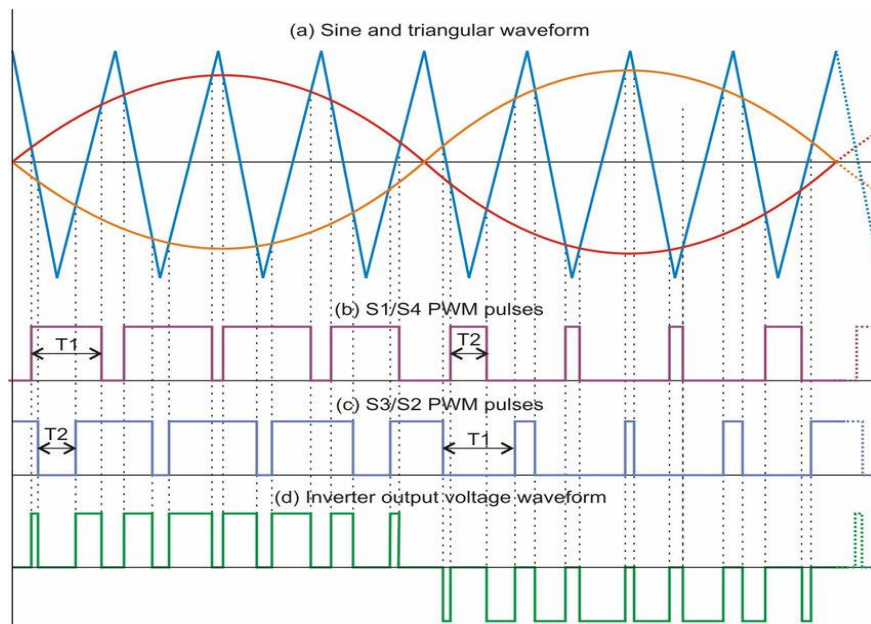


Fig.1 Multiple-pulse width modulation

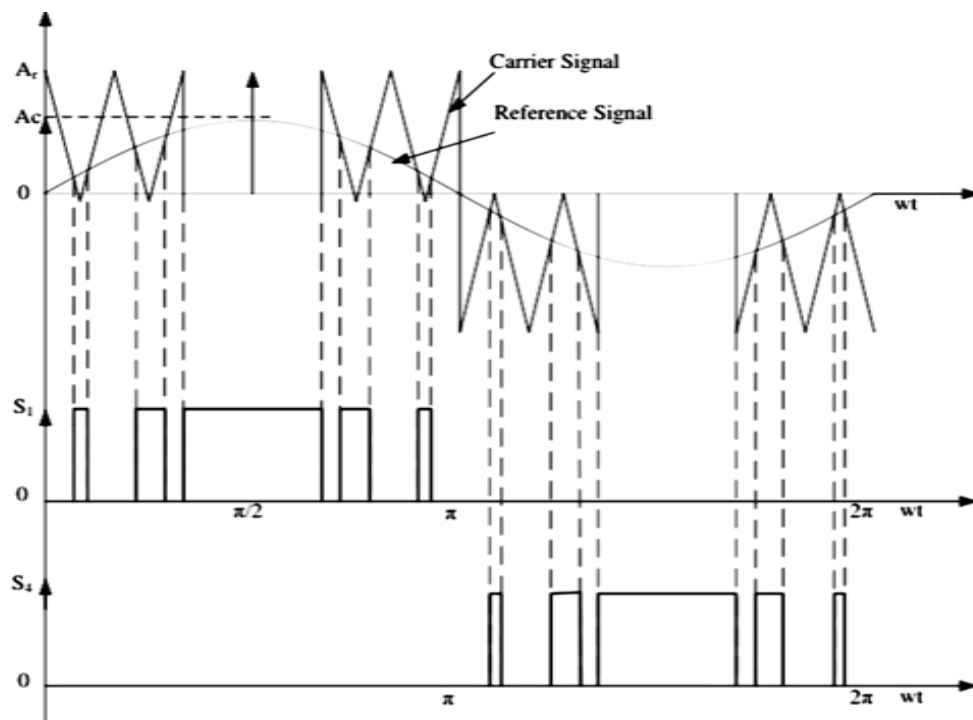
Sinusoidal Pulse Width Modulation

In this type of PWM technique, instead of a square wave, a sine wave is used as a reference and the carrier will be a triangular wave. The sine wave will be the output and its RMS value of voltage is controlled by the modulation index.



Modified Sinusoidal Pulse Width Modulation

The carrier wave is applied for the first and the last sixty-degree interval per every half cycle. This modification is introduced to improve the harmonic characteristics. It decreases the loss due to switching and increases the fundamental component.

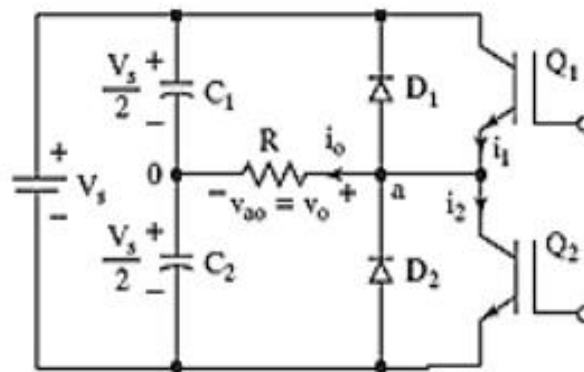


SINGLE PHASE PWM INVERTER

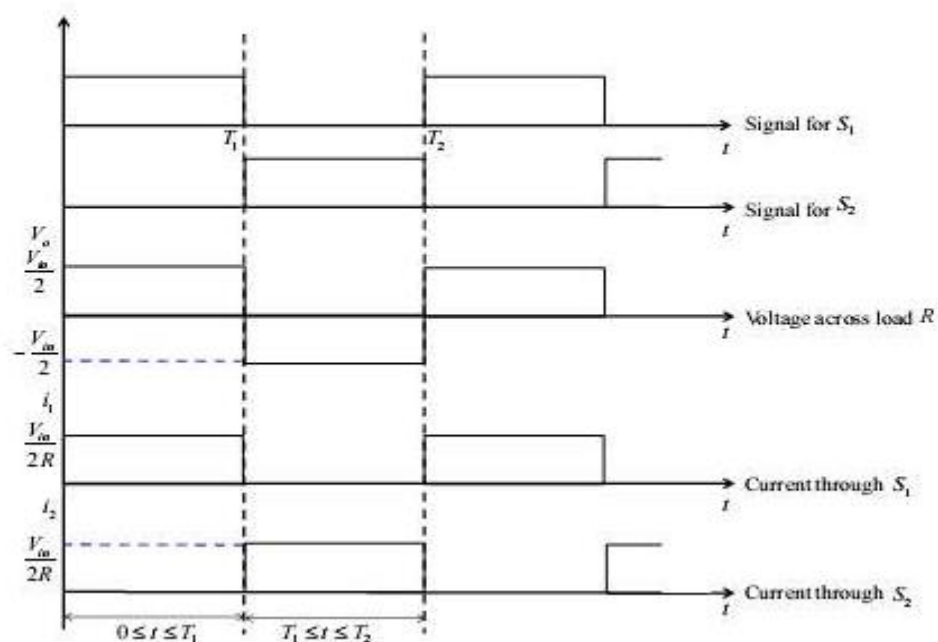
A single phase Half Bridge DC-AC inverter is shown in Figure below .

The analysis of the DC-AC inverters is done taking into accounts the following assumptions and conventions.

- 1) The current entering node a is considered to be positive.
- 2) The switches S_1 and S_2 are unidirectional, i.e. they conduct current in one direction.
- 3) The current through S_1 is denoted as i_1 and the current through S_2 is i_2 . The switching sequence is so design is shown in Figure below. Here, switch S_1 is on for the time duration $0 \leq t \leq T_1$ and the switch S_2 is on for the time duration $T_1 \leq t \leq T_2$. When switch S_1 is turned on, the instantaneous voltage across the load is $v_o = V_{in}/2$ When the switch S_2 is only turned on, the voltage across the load is $v_o = -V_{in}/2$.



OUTPT WAVE FORM OF SINGLE PHASE INVERTER



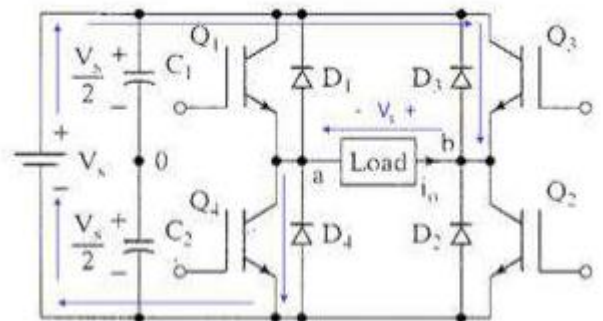
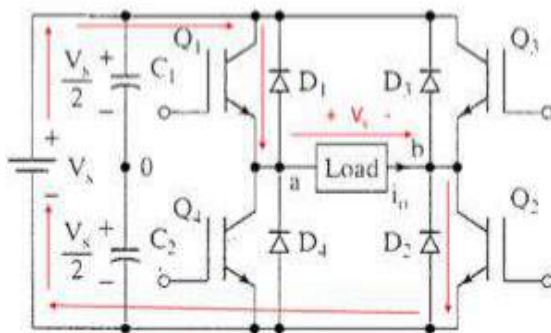
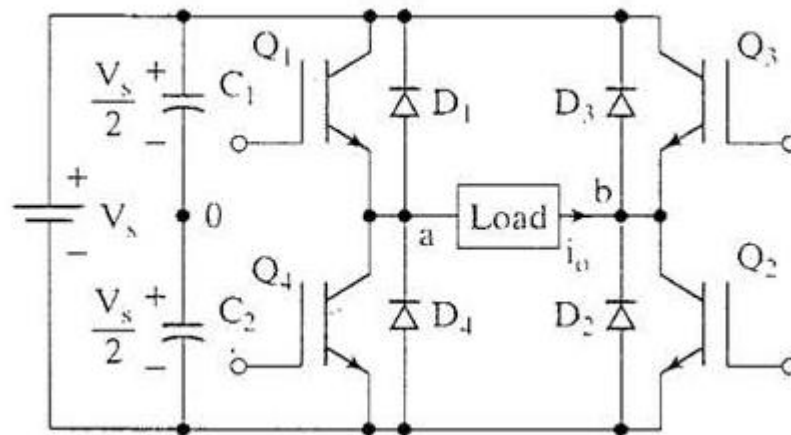
Single Phase Full Bridge converter

A single phase bridge DC-AC inverter is shown in Figure below. The analysis of the single phase DC-AC inverters is done taking into account following assumptions and conventions.

- 1) The current entering node a in Figure 8 is considered to be positive.
- 2) The switches S1, S2, S3 and S4 are unidirectional, i.e. they conduct current in one direction.

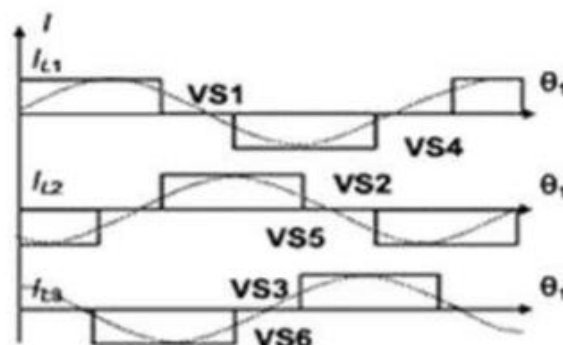
When the switches S1 and S2 are turned on simultaneously for a duration $0 = t = T_1$, the the input voltage V_{in} appears across the load and the current flows from point a to b.

$Q1 - Q2$ ON, $Q3 - Q4$ OFF $\Rightarrow v_o = V_s$



If the switches S3 and S4 turned on duration $T_1 \leq t \leq T_2$, the voltage across the load the load is reversed and the current through the load flows from point b to a.

$Q1 - Q2$ OFF, $Q3 - Q4$ ON $\Rightarrow v_o = -V_s$



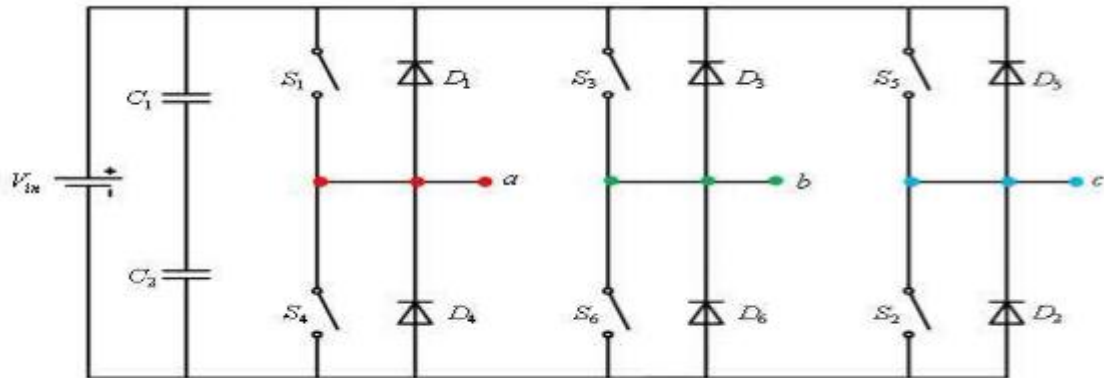
THREE PHASE PWM INVERTER

Three phase inverters are normally used for high power applications. The advantages of a three phase inverter are:

- The frequency of the output voltage waveform depends on the switching rate of the switches and hence can be varied over a wide range.
- The direction of rotation of the motor can be reversed by changing the output phase sequence of the inverter.
- The ac output voltage can be controlled by varying the dc link voltage.

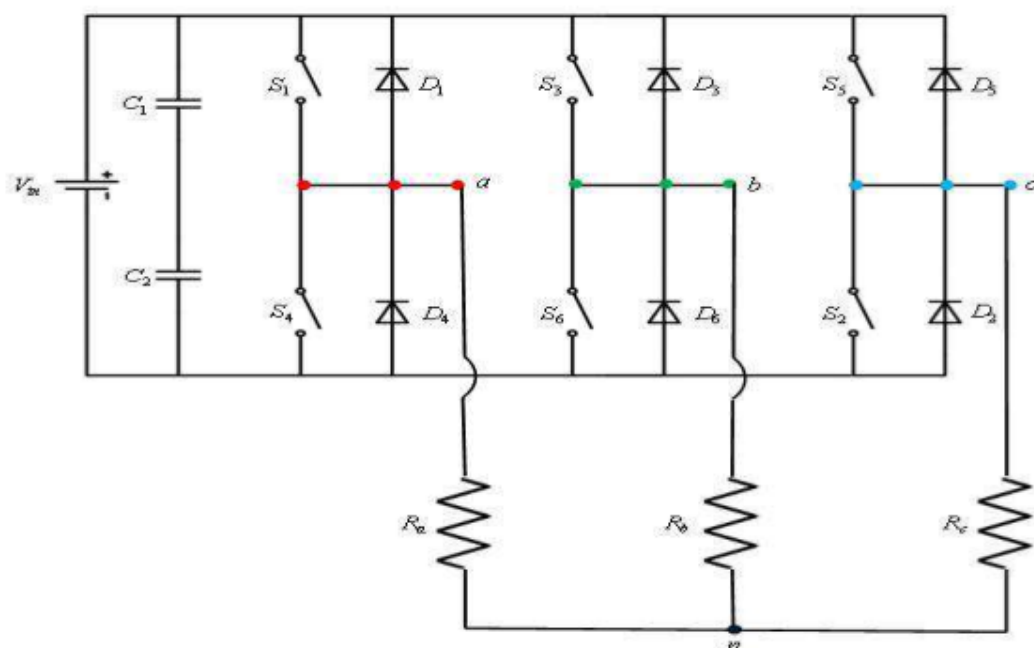
The general configuration of a three phase DC-AC inverter is shown in **Figure** Two types of control signals can be applied to the switches:

- 180° conduction
- 120° conduction



- 180° conduction

In this mode of operation each switch conducts for 180°. Hence, at any instant of time **three switches** remain **on**. When S_1 is **on**, the terminal **a** gets connected to the positive terminal of input DC source. Similarly, when S_4 is **on**, terminal **a** gets connected to the negative terminal of input DC source. There are six possible modes of operation in a cycle and each mode is of 60° duration and the explanation of each mode is as follows:



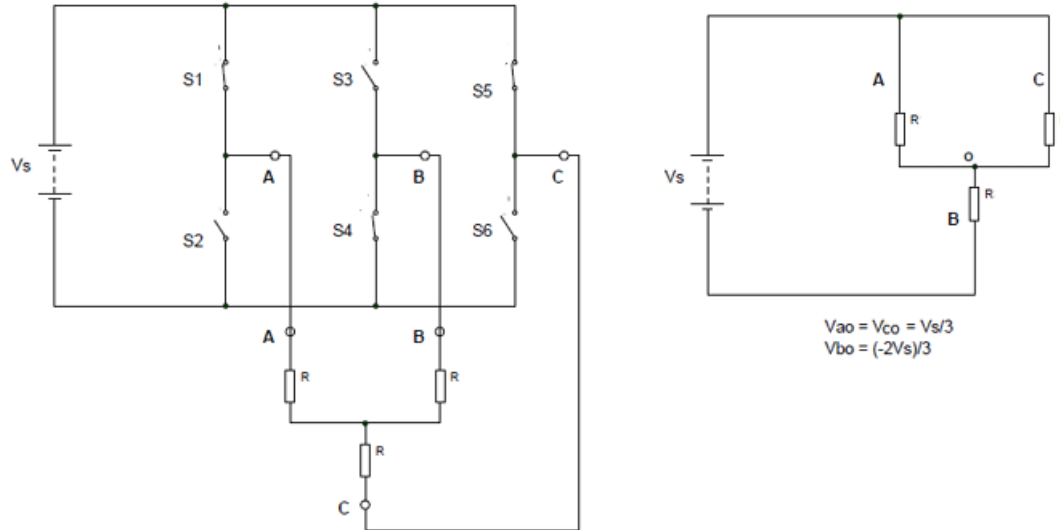
From 0-60: S1, S4 & S5 are closed and the remaining three switches are opened.

From 60-120: S1, S4 & S6 are closed and the remaining three switches are opened.

From 120-180: S1, S3&S6 are closed and the remaining three switches are opened.

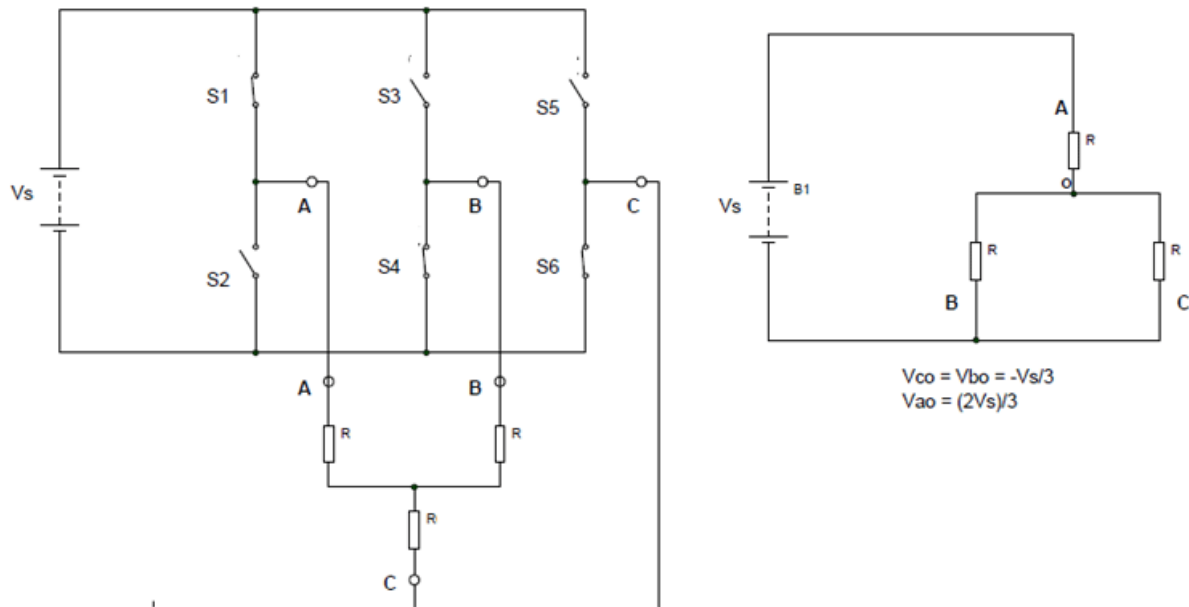
And the sequence of switching goes on like that. Now let us draw the simplified circuit for each step to better understand the current flow and voltage parameters.

Step1: (for 0-60) S1, S4&S5 are closed while the remaining three switches are open. In such a case, the simplified circuit can be as shown below.



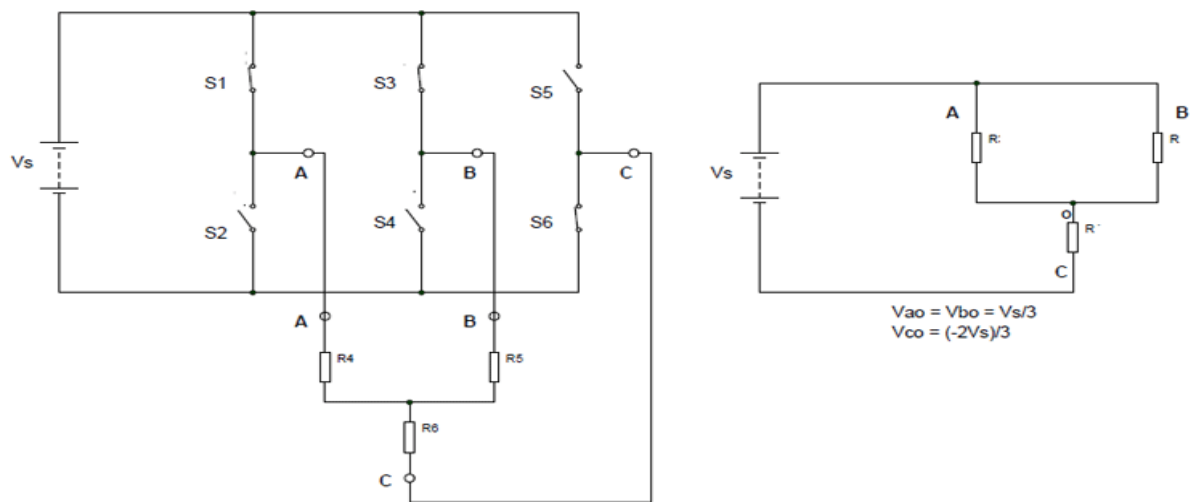
So for 0 to 60: $V_{ao} = V_{co} = V_s/3$; $V_{bo} = -2V_s/3$

Step2: (for 60 to 120) S1, S4&S6 are closed while the remaining three switches are open. In such a case, the simplified circuit can be as shown below.

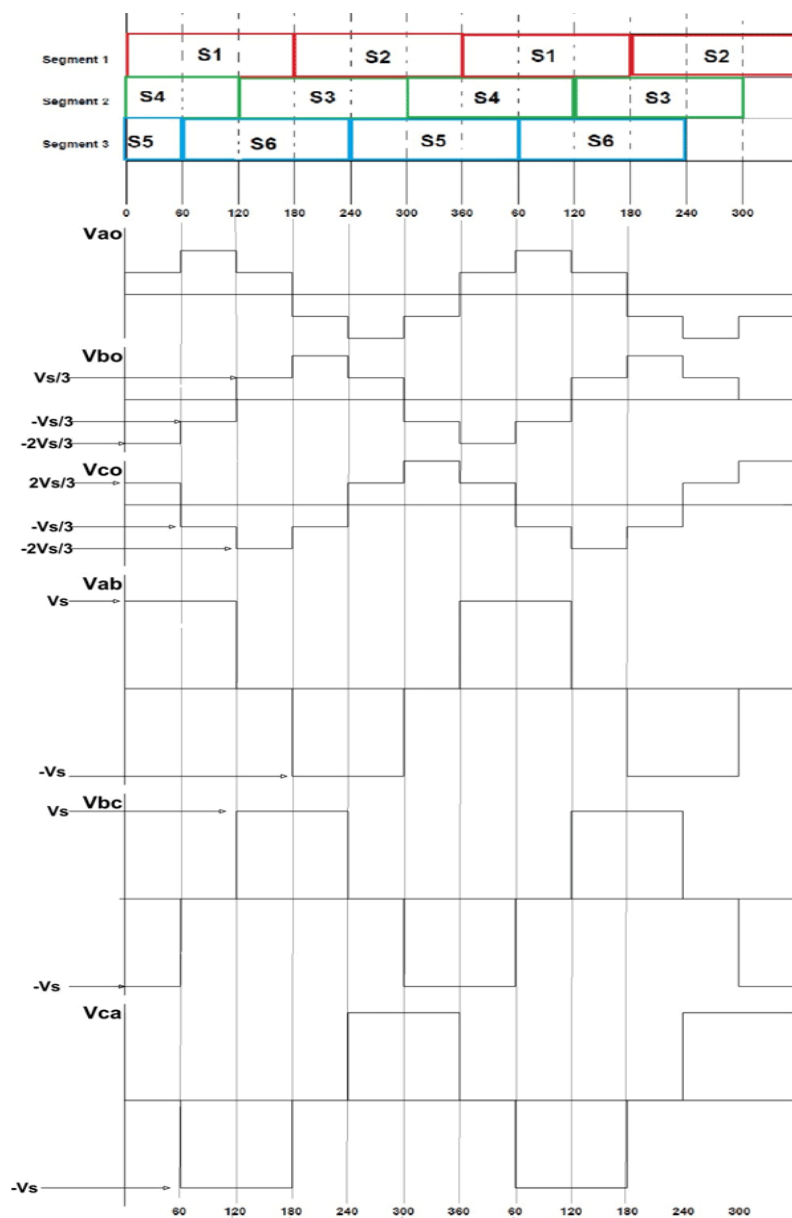


So for 60 to 120: $V_{bo} = V_{co} = -V_s/3$; $V_{ao} = 2V_s/3$

Step3: (for 120 to 180) S1, S3&S6 are closed while the remaining three switches are open. In such a case, the simplified circuit can be drawn as below. So for 120 to 180: $V_{ao} = V_{bo} = V_s/3$; $V_{co} = -2V_s/3$

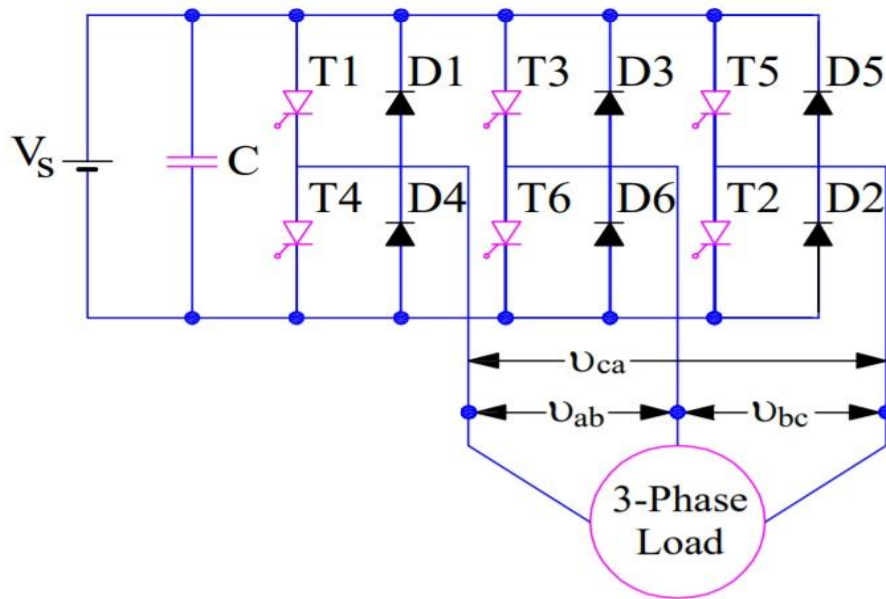


Output waveform

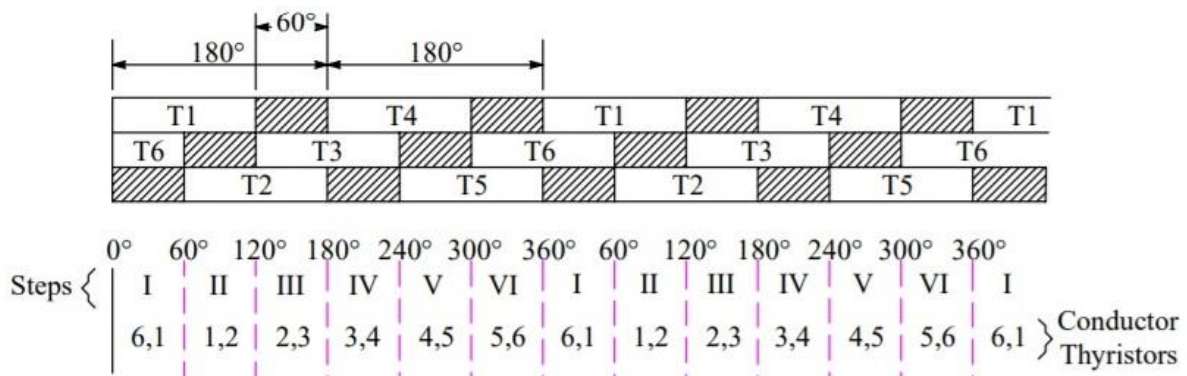


120° conduction mode

The power circuit diagram of a 120° Mode Inverter is shown in the figure below.



Operation of 120° Mode Inverter:



In the first row of table, T1 is shown to be conducting for 120° and for the next 60° neither T1 nor T4 conducts. T4 is turned ON at $\omega t = 180^\circ$ and it further conducts for next 120° i.e. up to $\omega t = 300^\circ$. This simply means that for 60° interval i.e. from $\omega t = 300^\circ$ to 360° , neither T1 nor T4 conducts. In fact, at $\omega t = 300^\circ$, T4 is turned OFF and at $\omega t = 360^\circ$, T1 is turned ON again.

In the second row of table, T3 is turned ON at $\omega t = 120^\circ$ and it conducts for next 120°. Then 60° interval elapses during which neither T3 nor T6 conducts. At $\omega t = 300^\circ$, T6 is turned ON. It also conducts for next 120° and then 60° interval elapses after which T3 is turned ON again. The third row is also completed in the same manner.

Phase to neutral voltage $V_{ao} = V_s/2$

Phase to neutral voltage $V_{bo} = -V_s/2$

Phase to neutral voltage $V_{co} = 0$

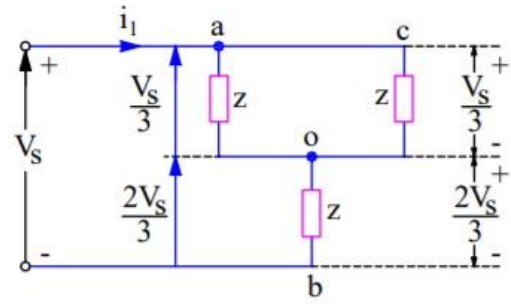
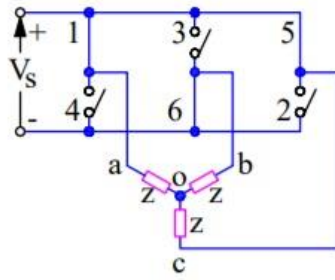
Line voltage V_{ab} , V_{bc} and V_{ca} may be

$V_{ab} = V_{ao} + V_{ob} = V_s$

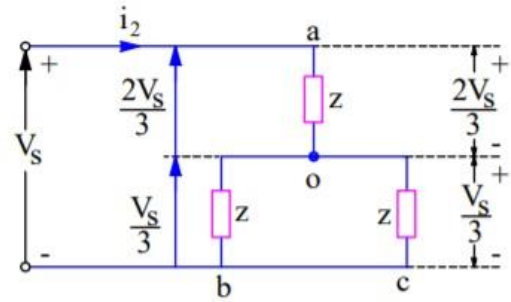
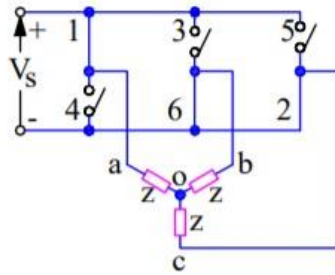
$V_{bc} = V_{bo} + V_{oc} = -V_s/2$

$V_{ca} = V_{co} + V_{oa} = -V_s/2$

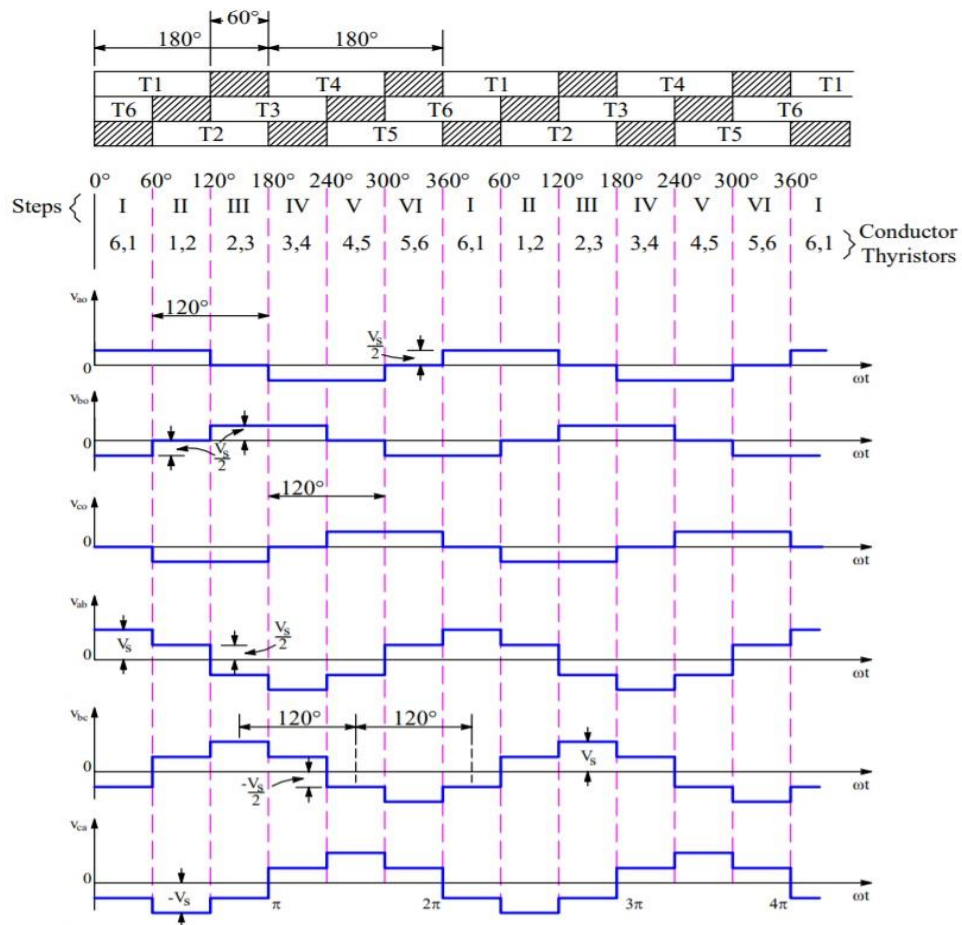
Step-I



Step-II

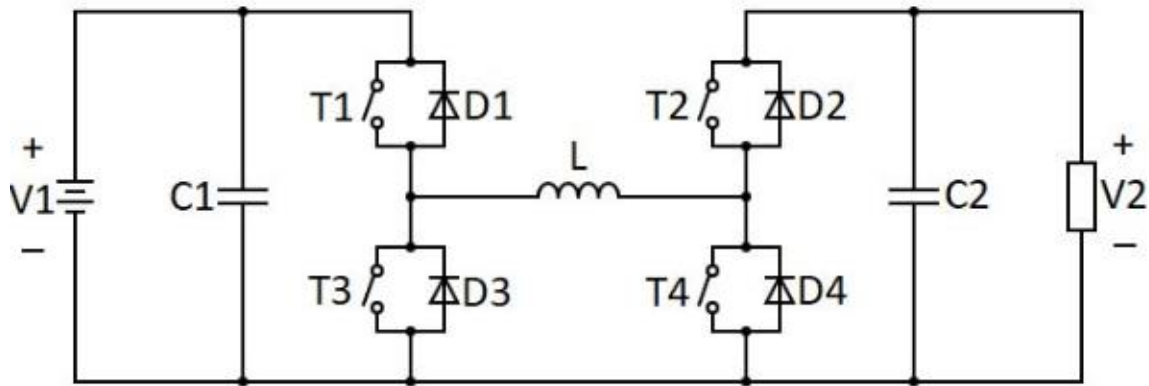


Output waveform:



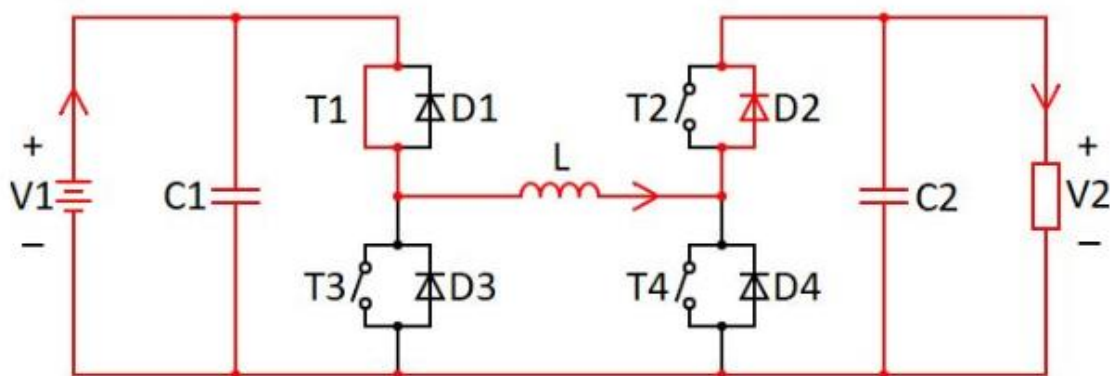
Bi-Directional converter:

A bidirectional converter is a power electronic device that enables the bidirectional flow of energy between two different sources. This means that the converter can transfer power in both directions, allowing energy to be efficiently exchanged between, for example, a battery and a power grid.

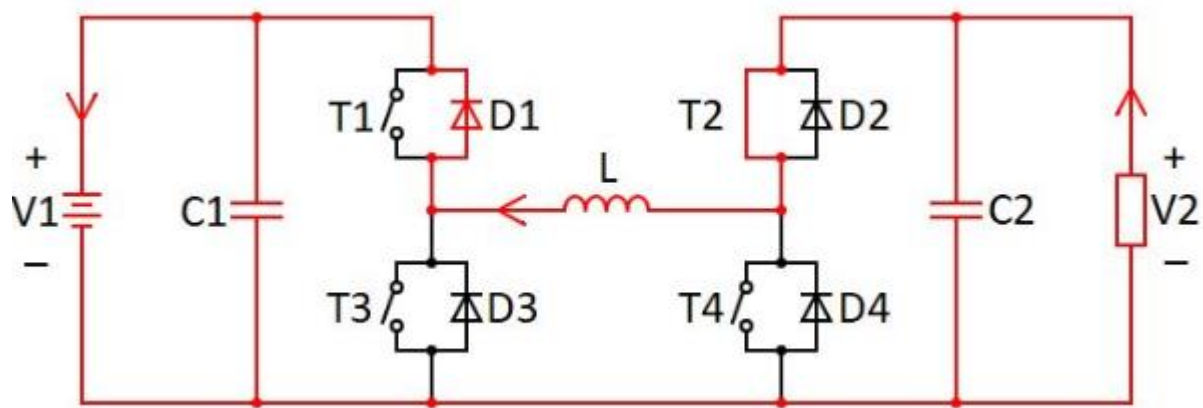


The chosen topology is shown in Fig. It is a symmetric bidirectional buck-boost converter. The name implies that the converter is capable of having a battery pack $V1$ with either higher or lower voltage than the load $V2$. Furthermore the converter will be able to both power the load with the battery and also run current backwards, charging the battery. The load of the converter will in this application be a common DC bus with a fixed voltage .

The inductor L is the main component in this type of circuit. It is the inductor, in combination with the other components, that makes it possible to change the voltage to higher or lower levels. The ability to charge energy in the inductors magnetic field gives another source of power besides the battery. With this secondary source one can either choose to power the load only from the inductor in buck mode, or combine the battery and the inductor to power the load in boost mode. The inductance also help smoothing out the current in the circuit because of its characteristics, not being able to change its current flow instantaneously. To reduce voltage ripple, capacitors $C1$ and $C2$ are included in the circuit.



The transistor $T1$ will still be "ON" but now the transistor $T4$ is turned "OFF" forcing the current to go through the diode $D2$. The battery and the inductor will now power the load together making the voltage over the load higher than the battery voltage.

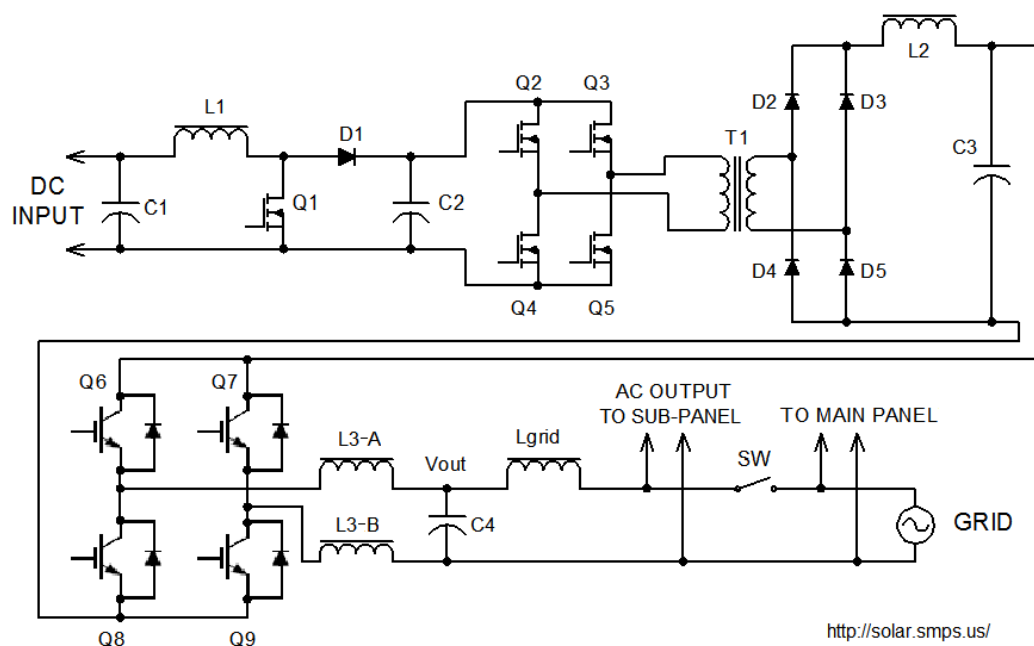


The second phase of the boost charging mode In this phase, transistor T2 is “ON”, diode D1 is conducting and the inductance is discharging, pushing current towards the battery. The voltage over the battery is boosted since the inductor voltage is added with the load voltage.

GRID INTERACTIVE INVERTER

GRID INTERACTIVE (GRID-TIE) INVERTERS

A grid-tie inverter converts direct current (DC) into an alternating current (AC) suitable for injecting into an electrical power grid, normally 120V RMS at 60Hz or 240V RMS at 50 Hz. Grid-tie inverters are used between local electrical power generators: solar panel, wind turbine, hydro-electric, and the grid. In order to inject electrical power efficiently and safely into the grid, grid-tie inverters must accurately match the voltage and phase of the grid sine wave AC waveform. Some electricity companies will pay for electrical power that is injected into the grid. Payment is arranged in several ways. With net metering the electricity company pays for the net power injected into the grid, as recorded by a meter in the customer's premises.



<http://solar.smps.us/>

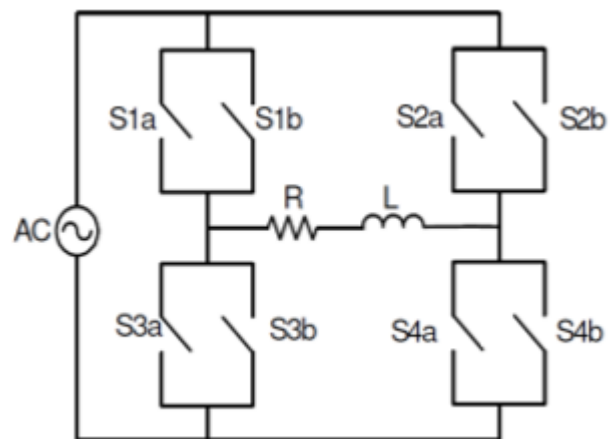
Grid-tie inverters convert DC electrical power into AC power suitable for injecting into the electric utility company grid. The grid tie inverter (GTI) must match the phase of the grid and maintain the output voltage slightly higher than the grid voltage at any instant. A high-quality modern grid-tie inverter has a fixed unity power factor, which means its output voltage and current are perfectly lined up, and its phase angle is within 1 degree of the AC power grid. The inverter has an on-board computer which senses the current AC grid waveform, and outputs a voltage to correspond with the grid. However, supplying reactive power to the grid might be necessary to keep the voltage in the local grid inside allowed limitations. Otherwise, in a grid 97 segment with considerable power from renewable sources, voltage levels might rise too much at times of high production, i.e. around noon with solar panels.

Grid-tie inverters are also designed to quickly disconnect from the grid if the utility grid goes down. It ensures that in the event of a blackout, the grid tie inverter will shut down to prevent the energy it transfers from harming any line workers who are sent to fix the power grid. Properly configured, a grid tie inverter enables a home owner to use an alternative power generation system like solar or wind power without extensive rewiring and without batteries. If the alternative power being produced is insufficient, the deficit will be sourced from the electricity grid.

MATRIX CONVERTER

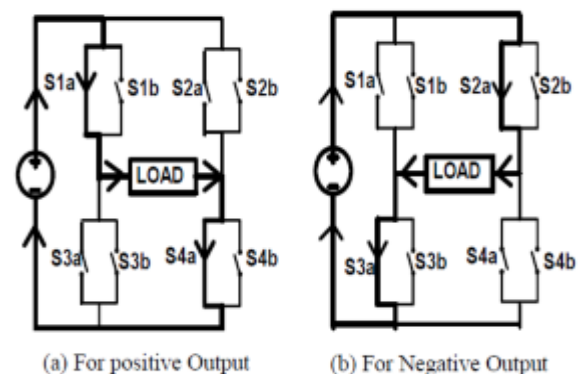
SINGLE PHASE MATRIX CONVERTER

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



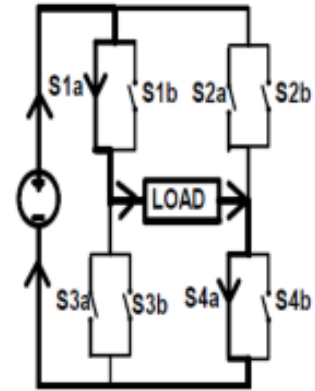
Single Phase Matrix Converter as an INVERTER

For an inverter operation, the input is DC for positive half output switches S1a and S4a will conduct while negative output switches S2a and S3a will conduct.



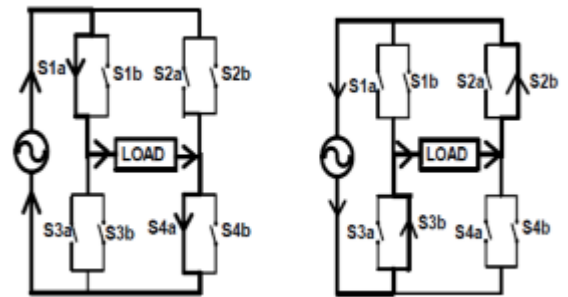
Single Phase Matrix Converter as an CHOPPER

Chopper refers to the process of converting a fixed DC voltage into variable DC voltage. For a chopper operation the input is DC, switches S1a and S4a will conduct.

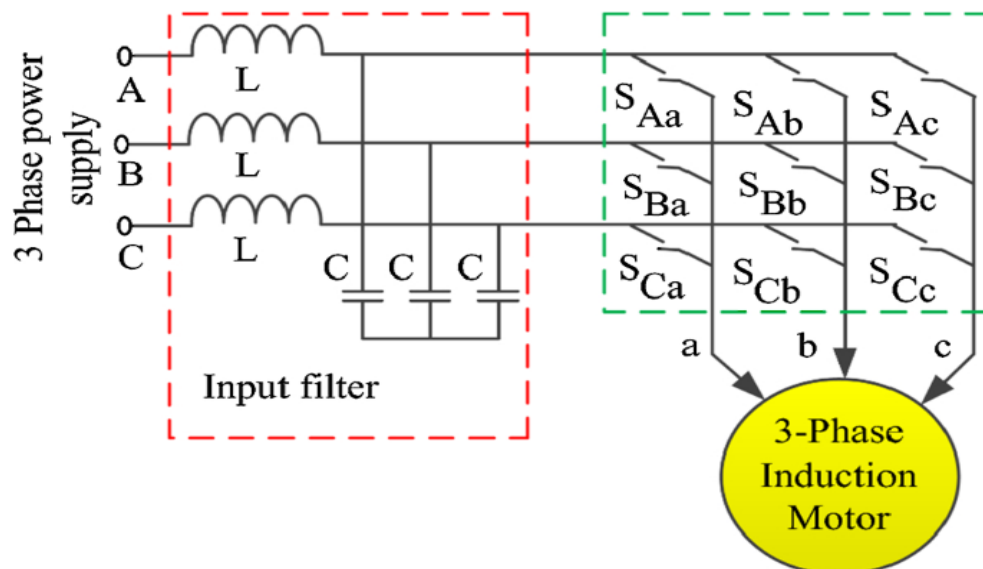


Single Phase Matrix Converter as an RECTIFIER

Rectifier refers to the process of converting an AC voltage or current to DC voltage or current. For a rectifier operation, the input is AC for positive half output switches S1a and S4a will conduct while negative output switches S3b and S2b will conduct.



THREE PHASE MATRIX CONVERTER



Three phase matrix converter consists of nine bidirectional switches. It has been arranged into three groups of three switches. Each group is connected to each phase of the output. These arrangements of switches can connect any input phase. These 3x3 arrangements can have 512 switching states. Among them only 27 switching states are permitted to operate this converter. Here A, B and C are input phase voltage connected to the

output phase. Figure shows synchronous operating state vectors of three matrix converter. It shows that the converter switches are switched on rotational basis. In this case no two switches in a leg are switched on simultaneously.

These states will not generate gate pulse when one phase of the supply is switched off. The matrix converter consists of 9 bi-directional switches that allow any output phase to be connected to any input phase. The input terminals of the converter are connected to a three phase voltage-fed system, usually the grid, while the output terminal are connected to a three phase current-fed system, like an induction motor might be. The capacitive filter on the voltage fed side and the inductive filter on the current-fed side represented in the scheme are intrinsically necessary. Their size is inversely proportional to the matrix converter switching frequency. It is worth noting that due to its inherent bi-directionality and symmetry a dual connection might be also feasible for the matrix converter: a current-fed system at the input and a voltage-fed system at the output.

Taking into account that the converter is supplied by a voltage source and usually feeds an inductive load, the input phases should never be shortcircuited and the output currents should not be interrupted. From a practical point of view these rules imply that one and only one bi-directional switch per output phase must be switched on at any instant. By this constraint, in a three phase to three phase matrix converter 27 are the permitted switching combinations.

MERTIS of Matrix converter

- i) No need of capacitors for power exchange,
- ii) Four-quadrant operation is possible,
- iii) Unity power factor operation at the input side of the MC

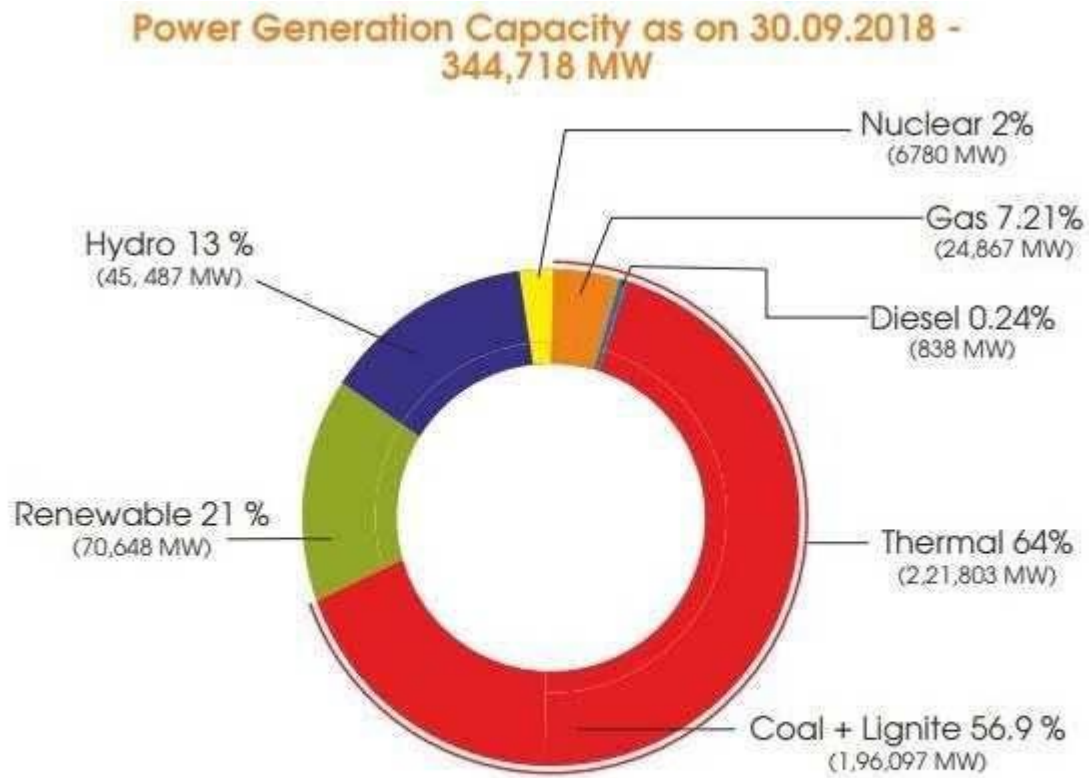
DEMERTIS of Matrix converter

- i) lack bilateral switches that are fully controlled and able to operate at high frequencies.
- ii) Its voltage ratio that is output to input voltage is limited.

UNIT-V

CASE STUDIES FOR HYBRID ENERGY SYSTEM

Range and Type of hybrid system



Sources	Thermal	Renewable	Hydro	Nuclear	Total
Share (MW)	2,21,803	70,648	45,487	6,780	344,718