POWER SYSTEM I

LECTURE NOTES

B TECH (IV SEM)

Prepared by:

Mr. AMIT KUMAR VIDYARTHI, Assistant Professor

Department of Electrical & Electronics Engineering

K. K COLLEGE OF ENGINEERING & TECHNOLOGY

POWER SYSTEM I

Module I: Basic Concepts:

Evolution of Power Systems and Present-Day Scenario. Structure of a power system: Bulk Power Grids and Micro-grids. Generation: Conventional and Renewable Energy Sources. Distributed Energy Resources. Energy Storage. Transmission and Distribution Systems: Line diagrams, transmission and distribution voltage levels and topologies (meshed and radial systems). Synchronous Grids and Asynchronous (DC) interconnections. Review of Three-phase systems. Analysis of simple three-phase circuits. Power Transfer in AC circuits and Reactive Power.

Module II: Power System Components :

Overhead Transmission Lines and Cables: Electrical and Magnetic Fields around conductors, Corona. Parameters of lines and cables. Capacitance and Inductance calculations for simple configurations. Travelling-wave Equations. Sinusoidal Steady state representation of Lines: Short, medium and long lines. Power Transfer, Voltage profile and Reactive Power. Characteristics of transmission lines. Surge Impedance Loading. Series and Shunt Compensation of transmission lines. Transformers: Three-phase connections and Phase-shifts. Three-winding transformers, autotransformers, Neutral Grounding transformers. Tap-Changing in transformers. Transformer Parameters. Single phase equivalent of three-phase transformers. Synchronous Machines: Steady-state performance characteristics. Operation when connected to infinite bus. Real and Reactive Power Capability Curve of generators. Typical waveform under balanced terminal short circuit conditions – steady state, transient and sub-transient equivalent circuits. Loads: Types, Voltage and Frequency Dependence of Loads. Per-unit System and per-unit calculations.

Module III: Over-voltages and Insulation Requirements:

Generation of Over-voltages: Lightning and Switching Surges. Protection against Over-voltages, Overhead Line Insulators: Introduction, types of insulators, Potential distribution over a string of suspension insulators, Methods of equalizing the potential, testing of insulators. Insulation Coordination. Propagation of Surges. Voltages produced by travelling surges. Bewley Diagrams.

Module IV: Fault Analysis and Protection Systems :

Method of Symmetrical Components (positive, negative and zero sequences). Balanced and Unbalanced Faults. Representation of generators, lines and transformers in sequence networks.

Computation of Fault Currents. Neutral Grounding. Switchgear: Types of Circuit Breakers. Attributes of Protection schemes, Back-up Protection. Protection schemes (Over-current, directional, distance protection, differential protection) and their application.

Module V: Introduction to DC Transmission & Renewable Energy Systems

DC Transmission Systems: Line-Commutated Converters (LCC) and Voltage Source Converters (VSC). LCC and VSC based dc link, Real Power Flow control in a dc link. Comparison of ac and dc transmission. Solar PV systems: I-V and P-V characteristics of PV panels, power electronic interface of PV to the grid. Wind Energy Systems: Power curve of wind turbine. Fixed and variable speed turbines. Permanent Magnetic Synchronous Generators and Induction Generators, Power Electronics interfaces of wind generators to the grid.

Text Books:

1. J. Grainger and W. D. Stevenson, "Power System Analysis", McGraw Hill Education,1994.

2. O. I. Elgerd, "Electric Energy Systems Theory", McGraw Hill Education,1995.

3. A. R. Bergen and V. Vittal, "Power System Analysis", Pearson Education Inc.,1999.

4."C. L. Wadhawa", "Generation and utilization of Electrical Energy", New age International (P) Limited, Publishers 1997.

5."C. L. Wadhawa", "Electrical Power Systems", New age International (P) Limited, Publishers 1997.

6."M. L. Soni, P. V. Gupta, U. S. Bhatnagar and A. Chakraborti", "A Text Book on Power System Engineering", DhanpatRai and Co. Pvt. Ltd, 1999.

Reference Books :

1. D. P. Kothari and I. J. Nagrath, "Modern Power System Analysis", McGraw HillEducation,2003.

2. B. M. Weedy, B. J. Cory, N. Jenkins, J. Ekanayake and G. Strbac, "ElectricPowerSystems", Wiley, 2012.

3."M.V. Deshpande", "Elements of Power Station design and practice", Wheeler Publishing, 3rd Edition 1999.

4."S. N. Singh", "Electrical Power Generation, Transmission and Distribution", PHI, 2003.

5."V.K Mehta and Rohit Mehta", "Principles of Power Systems", S. Chand& Company Ltd, New Delhi, 2004.

POWER SYSTEM 1

Module1

An electric power system is a network of electrical components deployed to supply, transfer, and use electric power. An example of a power system is the electrical grid that provides power to homes and industry within an extended area. The electrical grid can be broadly divided into the generators that supply the power, the transmission system that carries the power from the generating centres to the load centres, and the distribution system that feeds the power to nearby homes and industries. Smaller power systems are also found in industry, hospitals, commercial buildings and homes. The majority of these systems rely upon three-phase AC power—the standard for large-scale power transmission and distribution across the modern world. Specialized power systems that do not always rely upon three-phase AC power are found in aircraft, electric rail systems, ocean liners, submarines and automobiles.

BASICS OF ELECTRICAL POWER SYSTEM

Electric power is the product of two quantities: current and voltage. These two quantities can vary with respect to time or can be kept at constant levels.

Most refrigerators, air conditioners, pumps and industrial machinery use AC power whereas most computers and digital equipment use DC power (digital devices plugged into the mains typically have an internal or external power adapter to convert from AC to DC power). AC power has the advantage of being easy to transform between voltages and is able to be generated and utilised by brushless machinery. DC power remains the only practical choice in digital systems and can be more economical to transmit over long distances at very high voltages

The ability to easily transform the voltage of AC power is important for two reasons: Firstly, power can be transmitted over long distances with less loss at higher voltages. So in power systems where generation is distant from the load, it is desirable to step-up (increase) the voltage of power at the generation point and then step-down (decrease) the voltage near the load. Secondly, it is often more economical to install turbines that produce higher voltages than would be used by most appliances, so the ability to easily transform voltages means this mismatch between voltages can be easily managed.

Solid state devices, which are products of the semiconductor revolution, make it possible to transform DC power to different voltages, build brushless DC machines and convert between AC and DC power. Nevertheless, devices utilising solid state technology are often more expensive than their traditional counterparts, so AC power remains in widespread use.

Components of power system

Supplies

All power systems have one or more sources of power. For some power systems, the source of power is external to the system but for others, it is part of the system itself—it is these internal power sources that are discussed in the remainder of this section. Direct current power can be supplied by batteries, fuel cells or photovoltaic cells. Alternating current power is typically supplied by a rotor that spins in a magnetic field in a device known as a turbo generator. There have been a wide range of techniques used to spin a turbine's rotor, from steam heated using fossil fuel (including coal, gas and oil) or nuclear energy to falling water (hydroelectric power) and wind (wind power).

The speed at which the rotor spins in combination with the number of generator poles determines the frequency of the alternating current produced by the generator. All generators on a single synchronous system, for example, the national grid, rotate at sub-multiples of the same speed and so generate electric current at the same frequency. If the load on the system increases, the generators will require more torque to spin at that speed and, in a steam power station, more steam must be supplied to the turbines driving them. Thus the steam used and the fuel expended directly relate to the quantity of electrical energy supplied. An exception exists for generators incorporating power electronics such as gearless wind turbines or linked to a grid through an asynchronous tie such as a HVDC link — these can operate at frequencies independent of the power system frequency.

Depending on how the poles are fed, alternating current generators can produce a variable number of phases of power. A higher number of phases leads to more efficient power system operation but also increases the infrastructure requirements of the system.[24] Electricity grid systems connect multiple generators operating at the same frequency: the most common being three-phase at 50 or 60 Hz.

There are a range of design considerations for power supplies. This range from the obvious: How much power should the generator be able to supply? What is an acceptable length of time for starting the generator (some generators can take hours to start)? Is the availability of the power source acceptable (some renewable are only available when the sun is shining or the wind is blowing)? To the more technical: How should the generator start (some turbines act like a motor to bring themselves up to speed in which case they need an appropriate starting circuit)? What is the mechanical speed of operation for the turbine and consequently what is the number of poles required? What type of generator is suitable (synchronous or asynchronous) and what type of rotor (squirrel-cage rotor, wound rotor, salient pole rotor or cylindrical rotor).

Loads

Power systems deliver energy to loads that perform a function. These loads range from household appliances to industrial machinery. Most loads expect a certain voltage and, for alternating current devices, a certain frequency and number of phases. The appliances found in residential settings, for example, will typically be single-phase operating at 50 or

60 Hz with a voltage between 110 and 260 volts (depending on national standards). An exception exists for larger centralized air conditioning systems as in some countries these are now typically three-phase because this allows them to operate more efficiently. All electrical appliances also have a wattage rating, which specifies the amount of power the device consumes. At any one time, the net amount of power consumed by the loads on a power system must equal the net amount of power produced by the supplies less the power lost in transmission.

Making sure that the voltage, frequency and amount of power supplied to the loads is in line with expectations is one of the great challenges of power system engineering. However it is not the only challenge, in addition to the power used by a load to do useful work (termed real power) many alternating current devices also use an additional amount of power because they cause the alternating voltage and alternating current to become slightly out-of-sync (termed reactive power). The reactive power like the real power must balance (that is the reactive power produced on a system must equal the reactive power consumed) and can be supplied from the generators, however it is often more economical to supply such power from capacitors (see "Capacitors and reactors" below for more details).

A final consideration with loads has to do with power quality. In addition to sustained overvoltage's and under voltages (voltage regulation issues) as well as sustained deviations from the system frequency (frequency regulation issues), power system loads can be adversely affected by a range of temporal issues. These include voltage sags, dips and swells, transient overvoltages, flicker, high-frequency noise, phase imbalance and poor power factor. Power quality issues occur when the power supply to a load deviates from the ideal. Power quality issues can be especially important when it comes to specialist industrial machinery or hospital equipment.

Conductors

Conductors carry power from the generators to the load. In a grid, conductors may be classified as belonging to the transmission system, which carries large amounts of power at high voltages (typically more than 69 kV) from the generating centres to the load centres, or the distribution system, which feeds smaller amounts of power at lower voltages (typically less than 69 kV) from the load centres to nearby homes and industry.[30]

Choice of conductors is based on considerations such as cost, transmission losses and other desirable characteristics of the metal like tensile strength. Copper, with lower resistivity than aluminium, was once the conductor of choice for most power systems. However, aluminium has a lower cost for the same current carrying capacity and is now often the conductor of choice. Overhead line conductors may be reinforced with steel or aluminium alloys.

Conductors in exterior power systems may be placed overhead or underground. Overhead conductors are usually air insulated and supported on porcelain, glass or polymer insulators. Cables used for underground transmission or building wiring are insulated with cross-linked polyethylene or other flexible insulation. Conductors are often stranded for to make them more flexible and therefore easier to install.

Conductors are typically rated for the maximum current that they can carry at a given temperature rise over ambient conditions. As current flow increases through a conductor it heats up. For insulated conductors, the rating is determined by the insulation. For bare conductors, the rating is determined by the point at which the sag of the conductors would become unacceptable.

Capacitors & Reactor

The majority of the load in a typical AC power system is inductive; the current lags behind the voltage. Since the voltage and current are out-of-phase, this leads to the emergence of an "imaginary" form of power known as reactive power. Reactive power does no measurable work but is transmitted back and forth between the reactive power source and load every cycle. This reactive power can be provided by the generators themselves but it is often cheaper to provide it through capacitors, hence capacitors are often placed near inductive loads (i.e. if not on-site at the nearest substation) to reduce current demand on the power system (i.e. increase the power factor).

Reactors consume reactive power and are used to regulate voltage on long transmission lines. In light load conditions, where the loading on transmission lines is well below the surge impedance loading, the efficiency of the power system may actually be improved by switching in reactors. Reactors installed in series in a power system also limit rushes of current flow; small reactors are therefore almost always installed in series with capacitors to limit the current rush associated with switching in a capacitor. Series reactors can also be used to limit fault currents.

Capacitors and reactors are switched by circuit breakers, which results in moderately large step changes of reactive power. A solution to this comes in the form of synchronous condensers, static VAR compensators and static synchronous compensators. Briefly, synchronous condensers are synchronous motors that spin freely to generate or absorb reactive power.[35] Static VAR compensators work by switching in capacitors using thyristors as opposed to circuit breakers allowing capacitors to be switched-in and switched-out within a single cycle. This provides a far more refined response than circuit-breaker-switched capacitors. Static synchronous compensators take this a step further by achieving reactive power adjustments using only power electronics.

Power electronics

Power electronics are semiconductor based devices that are able to switch quantities of power ranging from a few hundred watts to several hundred megawatts. Despite their relatively simple function, their speed of operation (typically in the order of nanoseconds means they are capable of a wide range of tasks that would be difficult or impossible with conventional technology. The classic function of power electronics is rectification, or the conversion of AC-to-DC power, power electronics are therefore found in almost every digital device that is supplied from an AC source either as an adapter that plugs into the wall (see photo) or as component internal to the device. High-powered power electronics can also be used to convert AC power to DC power for long distance transmission in a system known as HVDC. HVDC is used because it proves to be more economical than similar high voltage AC systems for very long distances (hundreds to thousands of kilometres). HVDC is also desirable for interconnects because it allows frequency independence thus improving system stability. Power electronics are also essential for any power source that is required to produce an AC output but that by its nature produces a DC output. They are therefore used by photovoltaic installations.

Power electronics also feature in a wide range of more exotic uses. They are at the heart of all modern electric and hybrid vehicles—where they are used for both motor control and as part of the brushless DC motor. Power electronics are also found in practically all modern petrol-powered vehicles, this is because the power provided by the car's batteries alone is insufficient to provide ignition, air-conditioning, internal lighting, radio and dashboard displays for the life of the car. So the batteries must be recharged while driving—a feat that is typically accomplished using power electronics. Whereas conventional technology would be unsuitable for a modern electric car, commutators can and have been used in petrol-powered cars, the switch to alternators in combination with power electronics has occurred because of the improved durability of brushless machinery.

Some electric railway systems also use DC power and thus make use of power electronics to feed grid power to the locomotives and often for speed control of the locomotive's motor. In the middle twentieth century, rectifier locomotives were popular, these used power electronics to convert AC power from the railway network for use by a DC motor. Today most electric locomotives are supplied with AC power and run using AC motors, but still use power electronics to provide suitable motor control. The use of power electronics to assist with the motor control and with starter circuits, in addition to rectification, is responsible for power electronics appearing in a wide range of industrial machinery. Power electronics even appear in modern residential air conditioners allow are at the heart of the variable speed wind turbine

Protective device

The Power systems contain protective devices to prevent injury or damage during failures. The quintessential protective device is the fuse. When the current through a fuse exceeds a certain threshold, the fuse element melts, producing an arc across the resulting gap that is then extinguished, interrupting the circuit. Given that fuses can be built as the weak point of a system, fuses are ideal for protecting circuitry from damage. Fuses however have two problems: First, after they have functioned, fuses must be replaced as they cannot be reset. This can prove inconvenient if the fuse is at a remote site or a spare fuse is not on hand. And second, fuses are typically inadequate as the sole safety device in most power systems as they allow current flows well in excess of that that would prove lethal to a human or animal.

The first problem is resolved by the use of circuit breakers—devices that can be reset after they have broken current flow. In modern systems that use less than about 10 kW, miniature circuit breakers are typically used. These devices combine the mechanism that initiates the trip (by sensing excess current) as well as the mechanism that breaks the current flow in a single unit. Some miniature circuit breakers operate solely on the basis of electromagnetism. In these miniature circuit breakers, the current is run through a solenoid, and, in the event of excess current flow, the magnetic pull of the solenoid is sufficient to force open the circuit breakers contacts (often indirectly through a tripping mechanism). A better design, however, arises by inserting a bimetallic strip before the solenoid—this means that instead of always producing a magnetic force, the solenoid only produces a magnetic force when the current is strong enough to deform the bimetallic strip and complete the solenoid's circuit.

In higher powered applications, the protective relays that detect a fault and initiate a trip are separate from the circuit breaker. Early relays worked based upon electromagnetic principles similar to those mentioned in the previous paragraph, modern relays are application-specific computers that determine whether to trip based upon readings from the power system. Different relays will initiate trips depending upon different protection schemes. For example, an over current relay might initiate a trip if the current on any phase exceeds a certain threshold whereas a set of differential relays might initiate a trip if the sum of currents between them indicates there may be current leaking to earth. The circuit breakers in higher powered applications are different too. Air is typically no longer sufficient to quench the arc that forms when the contacts are forced open so a variety of techniques are used. One of the most popular techniques is to keep the chamber enclosing the contacts flooded with sulphur hexafluoride (SF_6)—a non-toxic gas with sound arc-quenching properties. Other techniques are discussed in the reference.

The second problem, the inadequacy of fuses to act as the sole safety device in most power systems, is probably best resolved by the use of residual current devices (RCDs). In any properly functioning electrical appliance, the current flowing into the appliance on the active line should equal the current flowing out of the appliance on the neutral line. A residual current device works by monitoring the active and neutral lines and tripping the active line if it notices a difference. Residual current devices require a separate neutral line for each phase and to be able to trip within a time frame before harm occurs. This is typically not a problem in most residential applications where standard wiring provides an active and neutral line for each appliance (that's why your power plugs always have at least two tongs) and the voltages are relatively low however these issues limit the effectiveness of RCDs in other applications such as industry. Even with the installation of an RCD, exposure to electricity can still prove fatal.

SCADA system

In large electric power systems, supervisory control and data acquisition (SCADA) is used for tasks such as switching on generators, controlling generator output and switching in or out system elements for maintenance. The first supervisory control systems implemented consisted of a panel of lamps and switches at a central console near the controlled plant. The lamps provided feedback on the state of the plant (the data acquisition function) and the switches allowed adjustments to the plant to be made (the supervisory control function). Today, SCADA systems are much more sophisticated and, due to advances in communication systems, the consoles controlling the plant no longer need to be near the plant itself. Instead, it is now common for plants to be controlled with equipment similar (if not identical) to a desktop computer. The ability to control such plants through computers has increased the need for security—there have already been reports of cyber-attacks on such systems causing significant disruptions to power system.

Power system components

The electrical power system can be divided into three major components: generation (G), transmission (T), and distribution (D) as shown in Fig. 1. The generating system provides the system with electric energy.

Transmission and Sub-Transmission Systems

The transmission and sub-transmission systems are meshed networks; that is, there is more than one path from one point to another. This multiple-path structure increases the reliability of the transmission system. The transmission network is a high-voltage network designed to carry power over long distances from generators to load points. The sub-transmission network is a low-voltage network whose purpose is to transport power over shorter distances from bulk power substations to distribution substations. The transmission system, which is usually 132 to 765 kilovolts (kV), and the sub-transmission system, which is usually 34 to 132 kV, consists of:

1. Insulated wires or cables for transmission of power
2. Transformers for converting from one voltage level to another
3. Protective devices, such as circuit breakers, relays, communication and control systems
4. Physical structures for containing the foregoing, such as transmission towers and substations

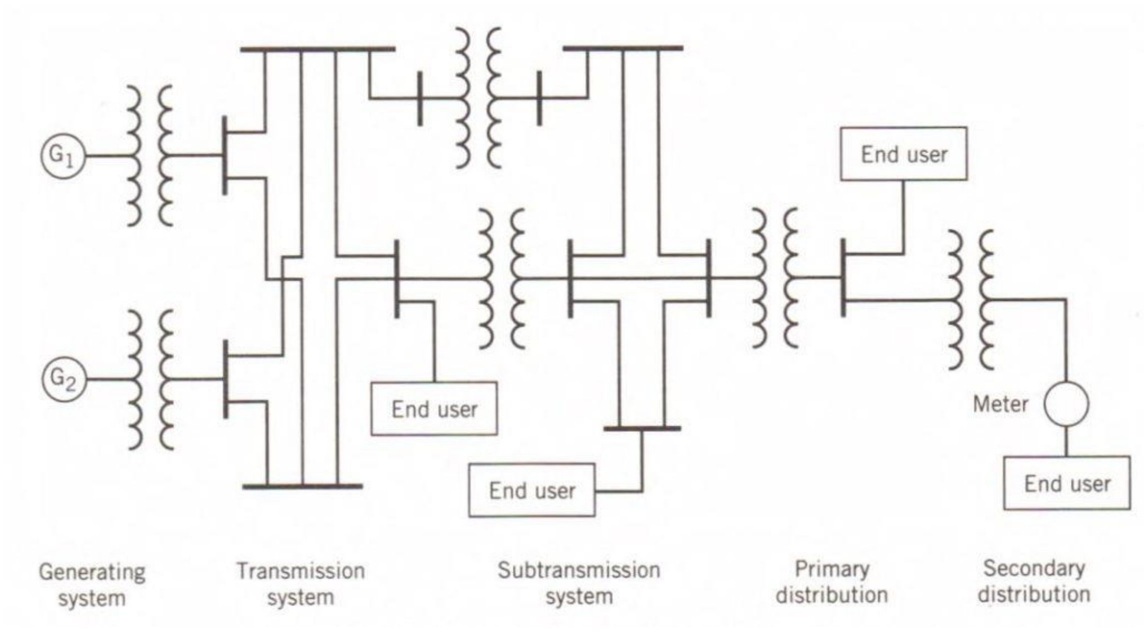


Figure 1: Simple power system structure

Conventional energy sources

Oil (Petroleum)

Oil is the life line of global economy. The identified deposits from which oil can be extracted profitably at present prices with current technology are known as oil resources. Thirteen countries of the world make up the Organisation of Petroleum Exporting Countries (OPEC), which have 67% of these reserves. About one fourth of the oil reserves are located in Saudi Arabia. It is further estimated that the undiscovered oil will also be 2 just located in Middle East Thus, the world oil supplies and prices are likely to be controlled by OPEC over a long period of time. United States of America is the world's largest consumer of oil using 30% of global total, whereas it has only 4% of the world's oil reserves. Maximum use of oil is in transportation (63%), followed by industry (24%), residential and commercial buildings (8%) and electric utilities (8%). At the present rate of consumption, the world's crude oil reserves are estimated to be depleted in 40 years and there may be enough undiscovered oil lasting for another 40 years: Some analysts argue that rising oil prices will stimulate exploration and that the earth's crust may contain more oil than is generally thought. Such oil even if it exists, lies about 10 kilometres or still more below the surface (twice the depth of wells known today). Some analysts strongly believe that at the current rate of use of crude oil, the following are expected: • Saudi Arabia, with the largest known crude oil reserves, could supply all the world's needs for another 10 years. • The estimated reserves under Alaskas North slope (the largest reserve of North America) would meet U.S. demand for just 3 years. • All undiscovered deposits could-meet world demand for 30-40 years.

Coal

About 68% of worlds proven coal reserves and 85% of the estimated undiscovered coal deposits are located in U.S.A., C.I.S. and China. About 55% of U.S. coal reserves are found west of Mississippi River. Coal is the most abundant conventional fossil fuel in the world. Identified world reserves of coal should last about 210 years at the current rate of usage and just 65 years, if the rate, of usage increases by 2% per year. The world unidentified coal reserves are however, projected to last about 900 years at current rate and 150 years, if usage rate increases by 2%.

Natural Gas

About 40% of the world's natural gas reserves are in CIS countries. Other countries with proven natural gas reserves are Iran (14%), United States (5%), Qatar (4%), Saudi Arabia (3%) and Nigeria (3%). Geologists expect to find more natural gas, especially in unexplored LDCs (less developed countries)

Renewable energy sources

1. Solar energy
2. Wind energy
3. Hydro energy
4. Tidal energy
5. Geothermal energy
6. Biomass energy

Distributed energy resources

Increased demands on the nation's electrical power systems and incidences of electricity shortages, power quality problems, rolling blackouts, and electricity price spikes have caused many utility customers to seek other sources of high-quality, reliable electricity. Distributed Energy Resources (DER), small-scale power generation sources located close to where electricity is used (e.g., a home or business), provide an alternative to or an enhancement of the traditional electric power grid.

DER is a faster, less expensive option to the construction of large, central power plants and high-voltage transmission lines. They offer consumers the potential for lower cost, higher service reliability, high power quality, increased energy efficiency, and energy independence. The use of renewable distributed energy generation technologies and "green power" such as wind, photovoltaic, geothermal, biomass, or hydroelectric power can also provide a significant environmental benefit.

Distributed energy resources (DER) are electric generation units (typically in the range of 3 kW to 50 MW) located within the electric distribution system at or near the end user. They are parallel to the electric utility or stand-alone units. DER have been available for many years, and are known by different names such as generators, back-up generators, or on-site power systems.

Energy storage

Energy storage can take many forms, and can involve the storage of electricity directly or as potential (or kinetic) energy that can be used to generate electricity when it is needed. Electricity can also be stored in the chemical systems of batteries, both in bulk scale and in modular forms as summarized below. Storage systems generally replenish their energy using electricity generated at low-demand (off-peak) times. Storage of energy is measured both in terms of the maximum rated power capacity (for storage charge/discharge) measured in megawatts (MW) or in terms of energy storage capacity over time, measured in megawatt-hours (MWh).

Hydropower pumped storage (HPS), compressed air energy storage (CAES), and cryogenic energy storage are examples of technologies that store potential (or kinetic) energy. These examples of the mostly large, monolithic systems used for energy storage today do not store electricity directly, but provide a means of producing electricity by use of a stored medium (e.g., water or air). The gradual release of the stored medium physically turns the shaft of a turbine connected to an electric generator, converting potential energy from the stored medium to electricity. Other opportunities for energy storage from the production of hydrogen gas are being explored, but are not a focus of this report.[13]

Batteries are chemical systems that produce electricity when the component parts and chemicals combine to create a flow of electrons, thus creating an electrical current. The potential to produce an electrical charge can be stored directly in large chemical systems (e.g. flow batteries) or in modular battery systems composed of smaller cells (such as lead-acid or lithium ion batteries). The smaller cells of modular battery systems do not store large amounts of electricity individually, but can be aggregated in battery systems to provide larger amounts of power.

The major potential energy and battery storage technologies for energy storage discussed in this report are summarized below:

Hydropower pumped storage: Water stored in an upper reservoir is released to a lower reservoir through a turbine to generate electricity. Water is pumped in reverse at times of low demand to store energy. HPS is the most widely-used technology for storing energy on the electric grid.

Compressed air energy storage: Compressed air is heated and expanded in a turbine to generate electricity. Compressing air causes it to cool and it is stored in a tank or cavern using off-peak electricity to store energy.

Liquid air (cryogenic) energy storage: Ambient air cooled to a liquid state is re-gasified and injected into a turbine when used to generate electricity. Ambient air is cooled and compressed to a liquid state to restore the system, and is stored in insulated tanks.

Flywheels: A cylinder rotating around a core in a vacuum at high speeds stores kinetic energy. Slowing the cylinder releases energy to turn a generator to produce electricity, and speeding up the cylinder stores energy.

Flow Batteries: Liquid electrolytes[14] with positive and negative charges are stored in large, separate tanks. Electric charge is drawn from the electrolytes by electrodes as they are pumped through a central tank where the liquids are separated by a membrane based on charge, and the spent liquids returned to separate tanks.

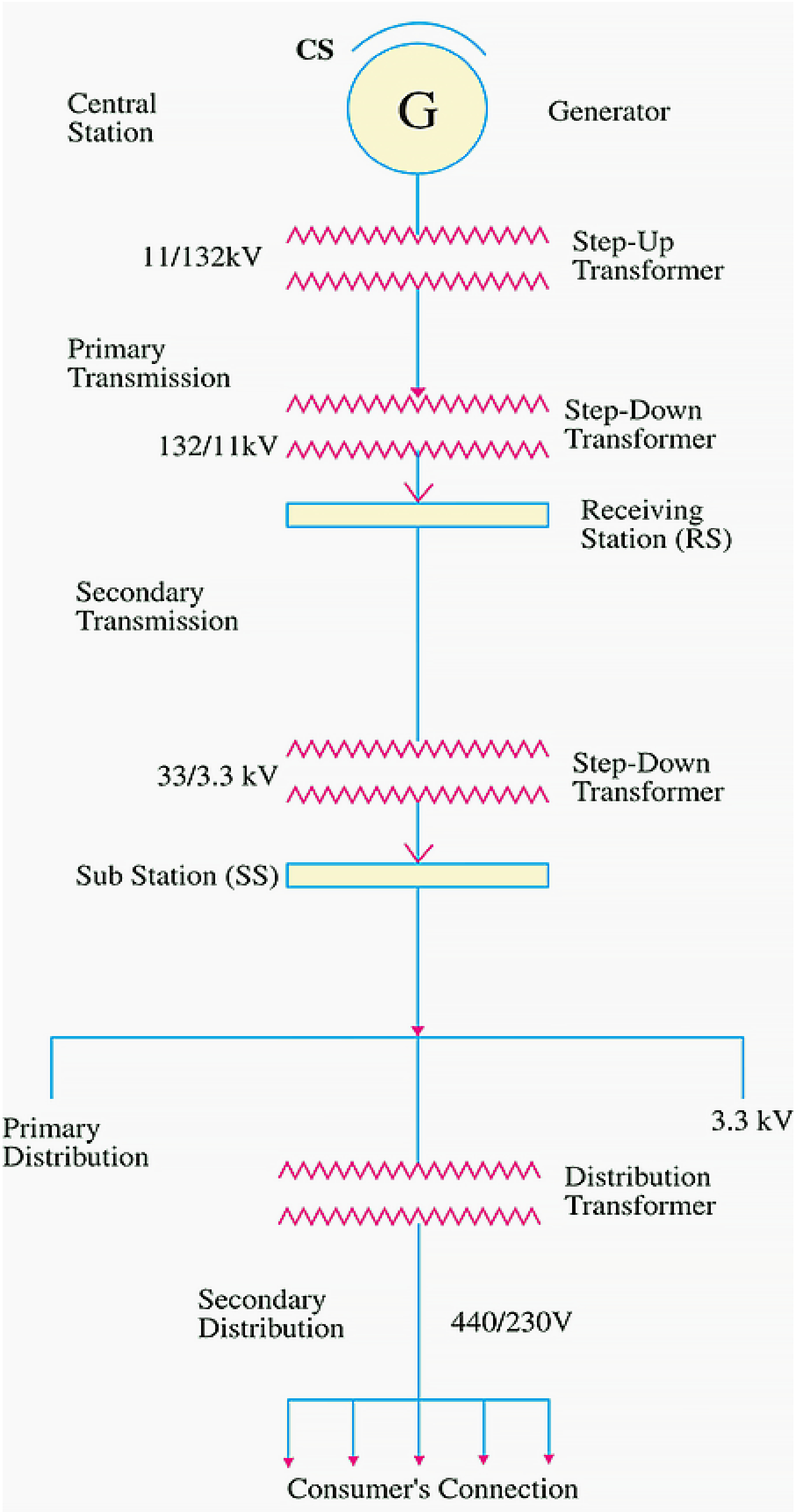
Lead-acid batteries: One of the oldest and most used methods of energy storage uses connected compartments (cells) made of a lead alloy and lead, immersed in a water-sulfuric acid electrolyte, which combine to generate an electric charge.

Lithium ion (Li Ion) batteries: Movement of lithium ions from the positive electrode (cathode) to the negative electrode (anode) through an electrolyte (commonly a lithium salt solution) creates an electric charge. Li Ion batteries have a cathode made of lithium-cobalt oxide, and an anode made of carbon. When batteries are recharged, the lithium ions move in reverse.

Nickel Cadmium (NiCad), Nickel-metal Hydride (NiMH), Sodium Sulfur (NaS), Sodium-Nickel Chloride ($NaNiCl_2$) batteries: Different chemical systems can be used for battery storage. Commonly, the movement of charged particles from cathode to anode through an electrolyte generates an electric current.

Transmission and distribution system

Line diagram


CS
Central Station
G
Generator
11/132kV
Step-Up Transformer
Primary Transmission
Step-Down Transformer
132/11kV
Receiving Station (RS)
Secondary Transmission
33/3.3 kV
Step-Down Transformer
Sub Station (SS)
Primary Distribution
3.3 kV
Distribution Transformer
Secondary Distribution
440/230V
Consumer's Connection

Synchronous grid connection

In HVAC link the two AC systems are interconnected by an AC link. For interconnecting the AC system, it is necessary that there should be sufficiently close frequency control on each of the two systems.

For the 50Hz system, the frequency should lie between 48.5 Hz and 51.5 Hz. Such an interconnection is known as synchronous interconnection or synchronous tie. The AC link provides a rigid connection between two AC systems to be interconnected. But the AC interconnection has certain limitations.

The interconnection of an AC system has suffered from the following problems.

1. The interconnection of the two AC networks is the synchronous tie. The frequency disturbances in one system are transferred to the other system.
2. The power swings in one system affect the other system. Large power swing in one system may result in frequent tripping due to which major fault occurs in the system. This fault causes complete failure of the whole interconnected system.
3. There is an increase in the fault level if an existing AC system is connected with the other AC system with an AC tie line. This is because the additional parallel line reduces the equivalent reactance of the interconnected system. If the two AC system are connected to the fault line, then the fault level of an each AC system remains unchanged.

Asynchronous grid connection

The DC interconnection or DC tie provides a loose coupling between the two AC system to be interconnected. The DC tie between two AC systems is non-synchronous (Asynchronous). The DC interconnection has the certain advantages. They are as follows.

1. The DC interconnection system is asynchronous thus the system which is to be interconnected is either of the same frequency or at the difference frequency. The DC link thus provides the advantages of interconnection of two AC network at different frequencies. It also enables the system to operate independently and to maintain their frequency standards.
2. The HVDC links provide fast and reliable control of magnitude and direction of power flow by controlling the firing angle of converters. The rapid control of power flow increases the limit of transient stability.
3. The power swings in the interconnected AC networks can be damped rapidly by modulating the power flow through the DC tie. Thus, the stability of the system is increased.

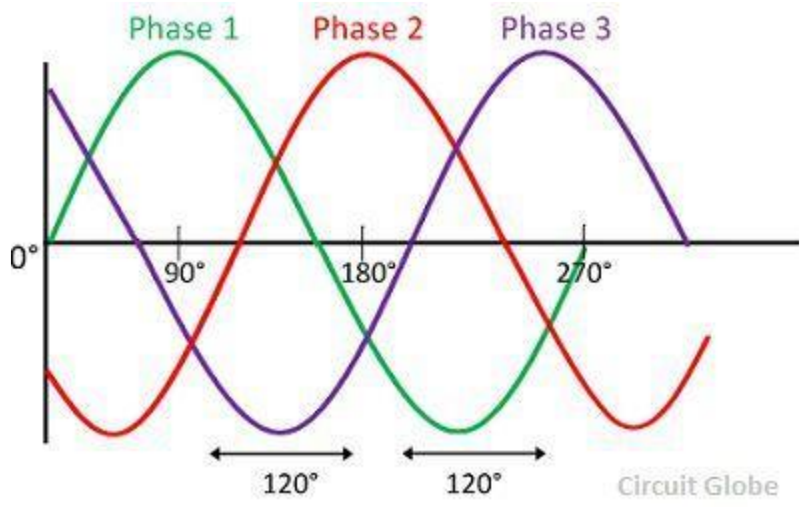
Three phase system

Definition: The system which has three phases, i.e., the current will pass through the three wires, and there will be one neutral wire for passing the fault current to the earth is known as the three phase system. In other words, the system which uses three wires for generation, transmission and distribution is known as the three phase system. The three phase system is also used as a single phase system if one of their phase and the neutral wire is taken out from it. The sum of the line currents in the 3-phase system is equal to zero, and their phases are differentiated at an angle of 120º.

The three-phase system has four wires, i.e., the three current carrying conductors and the one neutral. The cross section area of the neutral conductor is half of the live wire. The current in the neutral wire is equal to the sum of the line current of the three wires and consequently equal to √3 times the zero phase sequence components of current.

The three-phase system has several advantages like it requires fewer conductors as compared to the single phase system. It also gives the continuous supply to the load. The three-phase system has higher efficiency and minimum losses.

The three phase system induces in the generator which gives the three phase voltage of equal magnitude and frequency. It provides an uninterruptible power, i.e., if one phase of the system is disturbed, then the remaining two phases of the system continue supplies the power. The magnitude of the current in one phase is equal to the sum of the current in the other two phases of the system



The 120º phase difference of the three phases is must for the proper working of the system. Otherwise, the system becomes damaged.

Active and reactive power transfer in AC circuits

In a simple alternating current (AC) circuit consisting of a source and a linear time-invariant load, both the current and voltage are sinusoidal at the same frequency. If the load is purely resistive, the two quantities reverse their polarity at the same time. At every instant the product of voltage and current is positive or zero, the result being that the direction of energy flow does not reverse. In this case, only active power is transferred. If the load is purely reactive, then the voltage and current are 90 degrees out of phase. For two quarters of each cycle, the product of voltage and current is positive, but for the other two quarters, the product is negative, indicating that on average, exactly as much energy flows into the load as flows back out. There is no net energy flow over each half cycle. In this case, only reactive power flows: There is no net transfer of energy to the load; however, electrical power does flow along the wires and returns by flowing in reverse along the same wires. The current required for this reactive power flow dissipates energy in the line resistance, even if the ideal load device consumes no energy itself. Practical loads have resistance as well as inductance, or capacitance, so both active and reactive powers will flow to normal loads.

Module: 2 Power system components

Electrical and magnetic field around conductors

Whenever current travels through a conductor, a magnetic field is generated; a fact famously stumbled upon by Hans Christian Ørsted around 1820. Depending on the shape of the conductor, the contour of the magnetic field will vary. If the conductor is a wire, however, the magnetic field always takes the form of concentric circles arranged at right angles to the wire. The magnetic field is strongest in the area closest to the wire, and its direction depends upon the direction of the current that produces the field. There is a simple method of determining the direction of the magnetic field generated around a current-carrying wire commonly called the right hand rule. According to this rule, if the thumb of the right hand is pointed in the direction of the conventional current, the direction that the rest of the fingers need to curl in order to make a fist (or to wrap around the wire in question) is the direction of the magnetic field.

Corona effect

Corona Discharge (also known as the Corona Effect) is an electrical discharge caused by the ionization of a fluid such as air surrounding a conductor that is electrically charged. The corona effect will occur in high voltage systems unless sufficient care is taken to limit the strength of the surrounding electric field.
Corona discharge can cause an audible hissing or cracking noise as it ionizes the air around the conductors. This is common in high voltage electric power transmission lines. The corona effect can also produce a violet glow, production of ozone gas around the conductor, radio interference, and electrical power loss.
The corona effect occurs naturally due to the fact that air is not a perfect insulator – containing many free electrons and ions under normal conditions. When an electric field is established in the air between two conductors, the free ions and electrons in the air will experience a force. Due to this effect, the ions and free electrons get accelerated and moved in the opposite direction.

The charged particles during their motion collide with one another and also with slow-moving uncharged molecules. Thus the number of charged particles increases rapidly. If the electric field is strong enough, a dielectric breakdown of air will occur and an arc will form between the conductors.

Electric power transmission deals with the bulk transfer of electrical energy, from generating stations situated many kilometers away from the main consumption centers or the cities. For this reason, the long-distance transmission conductors are of utmost necessity for effective power transfer – which in-evidently results in huge losses across the system
Minimizing these energy losses has been a major challenge for power engineers. Corona discharge can significantly reduce the efficiency of EHV (Extra High Voltage) lines in power systems.

Two factors are important for corona discharge to occur:

1. Alternating electrical potential difference must be supplied across the line.
2. The spacing of the conductors, must be large enough compared to the line diameter.

When an alternating current is made to flow across two conductors of a transmission line whose spacing is large compared to their diameters, the air surrounding the conductors (composed of ions) is subjected to dielectric stress.
At low values of the supply voltage, nothing occurs as the stress is too small to ionize the air outside. But when the potential difference increases beyond some threshold value (known as the critical disruptive voltage), the field strength becomes strong enough for the air surrounding the conductors to dissociated into ions – making it conductive. This critical disruptive voltage occurs at approximately 30 kV.
The ionized air results in electric discharge around the conductors (due to the flow of these ions). This gives rise to a faint luminescent glow, along with the hissing sound accompanied by the liberation of ozone.

This phenomenon of electric discharge occurring in high voltage transmission lines is known as the corona effect. If the voltage across the lines continues to increase, the glow and hissing noise becomes more and more intense – inducing a high power loss into the system.

Factors Affecting Corona Loss

The line voltage of the conductor is the main determining factor for corona discharge in transmission lines. At low values of voltage (lesser than the critical disruptive voltage) the stress on the air is not high enough to cause dielectric breakdown – and hence no electrical discharge occurs.

With increasing voltage, the corona effect in a transmission line occurs due to the ionization of atmospheric air surrounding the conductors – it is mainly affected by the conditions of the cable as well as the physical state of the atmosphere. The main factors affecting corona discharge are:

- Atmospheric Conditions
- Condition of Conductors
- Spacing Between Conductors

Atmospheric Conditions

We have proved that the voltage gradient for dielectric breakdown of air is directly proportional to the density of air. Hence in a stormy day, due to continuous air flow, the number of ions presents surrounding the conductor is far more than normal, and hence it’s more likely to have electrical discharge in transmission lines on such a day, compared to a day with the fairly clear weather. The system has to be designed considering those extreme situations.

Condition of Conductors

This particular phenomenon depends highly on the conductors and its physical condition. It has an inverse proportionality relationship with the diameter of the conductors. i.e., with the increase in diameter, the effect of corona on power system reduces considerably. Also, the presence of dirt or roughness of the conductor reduces the critical breakdown voltage, making the conductors more prone to corona losses. Hence in most cities and industrial areas having high pollution, this factor is of reasonable importance to counter the ill effects it has on the system.

Spacing between Conductors

As already mentioned, for corona to occur in the spacing between the lines effectively should be much higher compared to its diameter, but if the length gets increased beyond a certain limit, the dielectric stress on the air reduces, and consequently, the effect of corona reduces as well. If the spacing is made too large, then corona for that region of the transmission line might not occur at all.

Reducing Corona Discharge

Corona discharge always results in power loss. Energy is lost in the form of light, sound, heat, and chemical reactions. Although these losses are individually small, over time they can add up to significant power loss in high voltage networks.

Corona discharge can be reduced by:

- **Increasing the conductor size:** A larger conductor diameter results in a decrease in the corona effect.
- **Increasing the distance between conductors:** Increasing conductor spacing decreases the corona effect.
- **Using bundled conductors:** Bundled conductors increase the effective diameter of the conductor – hence reducing the corona effect.
- **Using corona rings**: The electric field is stronger where there is a sharp conductor curvature. Because of this corona discharge occurs first at the sharp points, edges, and corners. Corona rings reduce the corona effect by ‘rounding out’ conductors (i.e. making them less sharp). They are used at the terminals of very high voltage equipment (such as at the bushings of high voltage transformers). A corona ring is electrically connected to the high voltage conductor, encircling the points where the corona effect is most likely to occur. This encircling significantly reduces the sharpness of the surface of the conductor – distributing the charge across a wider area. This in turn reduces corona discharge.

Parameter of Transmission line

The performance of transmission line depends on the parameters of the line. The transmission line has mainly four parameters, resistance, inductance, and capacitance and shunt conductance. These parameters are uniformly distributed along the line. Hence, it is also called the distributed parameter of the transmission line. The inductance and resistance form series impedance whereas the capacitance and conductance form the shunt admittance

Line inductance – The current flow in the transmission line induces the magnetic flux. When the current in the transmission line changes, the magnetic flux also varies due to which emf induces in the circuit. The magnitude of inducing emf depends on the rate of change of flux. Emf produces in the transmission line resist the flow of current in the conductor, and this parameter is known as the inductance of the line.

Line capacitance – In the transmission lines, air acts as a dielectric medium. This dielectric medium constitutes the capacitor between the conductors, which store the electrical energy, or increase the capacitance of the line. The capacitance of the conductor is defined as the present of charge per unit of potential difference.

Capacitance is negligible in short transmission lines whereas in long transmission; it is the most important parameter. It affects the efficiency, voltage regulation, power factor and stability of the system.

Shunt conductance – Air act as a dielectric medium between the conductors. When the alternating voltage applies in a conductor, some current flow in the dielectric medium because of dielectric imperfections. Such current is called leakage current. Leakage current depends on the atmospheric condition and pollution like moisture and surface deposits. Shunt conductance is defined as the flow of leakage current between the conductors. It is distributed uniformly along the whole length of the line. The symbol Y represented it, and it is measured in Siemens.

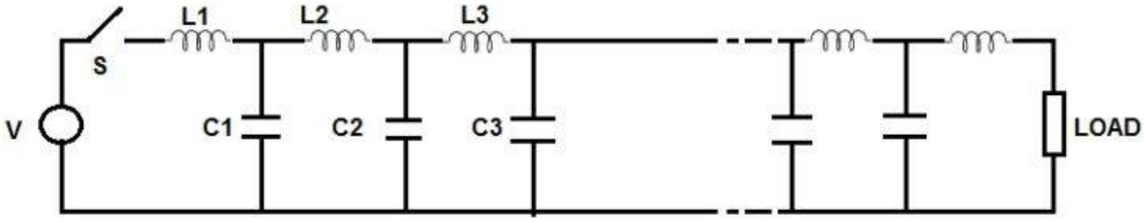
Travelling wave equation

Travelling wave on transmission line is the voltage / current waves which propagate from the source end to the load end during the transient condition. These waves travel along the line with the velocity equal to velocity of light if line losses are neglected. But practically there always exists some line loss and hence these waves propagate along the line with velocity somewhat lower than the velocity of light.

Concept of Travelling Wave

We know that short transmission line and medium transmission line are studied by their equivalent T or π model. But these models are only useful to study and analyze the steady state response of the line. In case where we are interested in the study of transient behaviour, these models are not useful as the line parameters are actually not lumped rather they are non-uniformly distributed over the entire length of the line. For transient analysis, it is very important to consider the line parameters like shunt capacitance and inductance to be distributed and hence their effect must be considered

Let us consider a lossless transmission line. Let L and C be the inductance and capacitance per unit length of the line.



When the switch S is closed, the voltage at the load end does not appear immediately at the load end. As soon as the Switch S is closed, inductance L1 acts as open circuit and capacitance C1 acts as short circuit. Therefore as far as the capacitor C1 is not charged to some value, the charging of C2 through L2 is not possible. This means that charging of C2 through L2 will take some finite time. Similar reasoning applies to the other successive sections. Thus we see that whenever switch S is closed, there is a gradual voltage build up from the source end to the load end over the transmission line. This gradual voltage build up can be thought of due to a voltage wave travelling from one end to the other and the gradual charging of capacitor through inductor is due to current wave.

Relationship between Voltage and Current Wave

Let the voltage wave and current wave travels a distance x in time t. Therefore the inductance and capacitance of line up to distance x will be Lx and Cx respectively. Let this wave travels a distance dx in time dt.
Since line is assumed to be lossless, whatever is the value of voltage wave and current wave at the beginning, the same will be at any time t. This means that, the magnitude of voltage and current wave at time t will be V and I respectively.
Hence the stored charge in shunt capacitance Q = VCx
and the flux in the series inductance Ø = ILx

But I = dQ/dt

= CVdx/dt

But dx/dt = velocity of travelling wave = v (say)

Therefore, I = CVv …….(1)

The voltage developed across the shunt capacitance,

V= dØ/dt

=ILdx/dt

= ILv

V = ILv ……….(2)

Dividing equation (1) and (2), we get

$V/I = \sqrt{(L/C)}$

The above expression is the ratio of voltage and current having the dimension of impedance. Therefore it is called Surge Impedance. Note that Surge Impedance is the square root of ratio of series inductance L per unit length of line and shunt capacitance C per unit length of line. This simply means that this value will remain constant for a given transmission line. This value will not change due to change in length of line. The value of surge impedance for a typical transmission line is around 400 Ohm and that for a cable is around 40 ohm. Notice that the value of surge impedance for cable is less than that of transmission line. This is due to the higher value of capacitance of cable compared to the transmission line

Velocity of Travelling Wave:

To get velocity of travelling wave, multiply (1) and (2) as below.

$VI = (CVv) \times (LIv)$

$v^2 = 1/LC$

$\mathbf{v = \sqrt{(1/LC)}}$

Short Transmission line

A **short transmission line** is defined as a transmission line with an effective length less than 80 km (50 miles), or with a voltage less than 69 kV. Unlike medium transmission lines and long transmission lines, the line charging current is negligible, and hence the shunt capacitance can be ignored.
For short length, the shunt capacitance of this type of line is neglected and other parameters like electrical resistance and inductor of these short lines are lumped.

Medium Transmission line

A medium transmission **line** is defined as a transmission line with an effective length more than 80 km (50 miles) but less than 250 km (150 miles). Unlike a short transmission line, the line charging current of a medium transmission line is appreciable and hence the shunt capacitance must be considered (this is also the case for long transmission lines). This shunt capacitance is captured within the admittance ("Y") of the ABCD circuit parameters.
The ABCD parameters of a medium length transmission line is calculated using lumped shunt admittance, along with the lumped impedance in series to the circuit. These lumped parameters of a medium length transmission line can be represented using three different models, namely:

1. Nominal **Π** representation (nominal pi model)
2. Nominal **T** representation (nominal T model)
3. End Condenser Method

Long Transmission line

A long transmission line is defined as a transmission line with an effective length more than 250 km (150 miles). Unlike short transmission lines and medium transmission lines, it is no longer reasonable to assume that the line parameters are lumped. To accurately model a long transmission line we must consider the exact effect of the distributed parameters over the entire length of the line.

Surge impedance loading

Surge Impedance Loading (SIL) is a very important parameter for the determining of the maximum loading capacity (MW loading) of transmission lines.

Surge impedance is nothing but the characteristic impedance (Zc) of the lossless transmission line. It is also known as the Natural impedance of the line.

As we all know that a long transmission line (length > 250 km) is represented by a distributed parameter model. In Distributed parameter model of the long transmission line, resistance (R), inductance (L), capacitance (C) and conductance (G) are uniformly distributed over the whole length of line.

Let us assume that the line has shunt admittance (y) per unit length series impedance (z) per unit length. Then the Characteristic impedance (Zc) of any lossless transmission line is defined as the square root of (z/y).

Where, z = R + jwL and **y** = G + jwC.

If we putt the value of **z** and **y** in the definition of (Zc), then we found that Characteristic Impedance is a complex quantity. However, for lossless transmission line (R=0 and G= 0)

z = jwL and y = jwC.

Hence according to definition Characteristic Impedance (Zc) is calculated as:

Characteristic Impedance (Zc) = square root of (jwL/jwC).

On simplifying it we got a result as:

Zs= Zc = square root of (L/C).

Significance of Surge impedance

The significance of surge impedance is that if a pure resistance load that is equal to the surge impedance is connected to the end of line with no resistance, a voltage surge introduced by the shunt capacitor to the sending end of the line would be completely absorbed by the series inductance at the receiving end of the transmission line. In this case, the voltage at receiving end would have the same magnitude as the sending end voltage and also have a phase angle lagging with respect to sending end by an amount equal to the time required to travel across the line from sending end to receiving end.

Surge impedance (Zs) is a technical term that is used mostly in electrical science in connection with the Surges on transmission lines which may appear due to switching or lightning operation in our Electrical power system.

Series and shunt compensation of Transmission line

In series compensation, the FACTS is connected in series with the power system. It works as a controllable voltage source. Series inductance occurs in long transmission lines, and when a large current flows this causes a large voltage drop. To compensate, series capacitors are connected, decreasing the effect of the inductance.

Shunt compensation

In shunt compensation, power system is connected in shunt (parallel) with the FACTS. It works as a controllable current source. Shunt compensation is of two types:

Shunt capacitive compensation

This method is used to improve the power factor. Whenever an inductive load is connected to the transmission line, power factor lags because of lagging load current. To compensate, a shunt capacitor is connected which draws current leading the source voltage. The net result is improvement in power factor.

Shunt inductive compensation

This method is used either when charging the transmission line, or, when there is very low load at the receiving end. Due to very low, or no load – very low current flows through the transmission line. Shunt capacitance in the transmission line causes voltage amplification (Ferranti Effect). The receiving end voltage may become double the sending end voltage (generally in case of very long transmission lines). To compensate, shunt inductors are connected across the transmission line.

Three phase transformer connection and phase shift

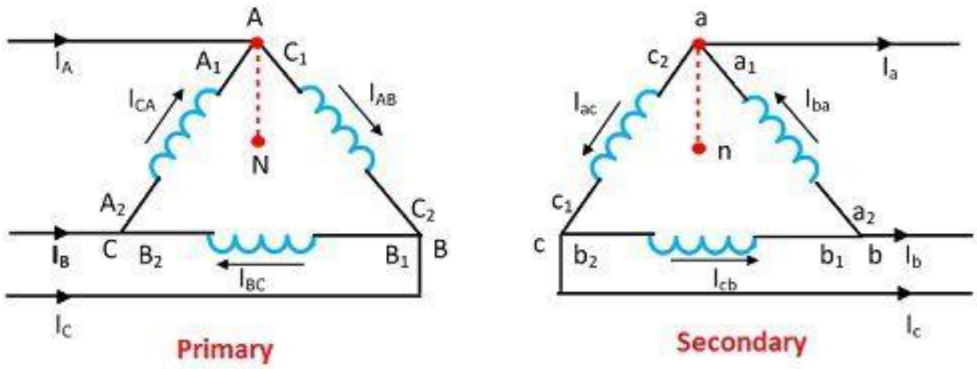
The three phase transformer consists three transformers either separate or combined with one core. The primary and secondary of the transformer can be independently connected either in star or delta. There are four possible connections for a 3-phase transformer bank.

1. Δ – Δ (Delta – Delta) Connection
2. Y – Y (Star – Star) Connection
3. Δ – Y (Delta – Star) Connection
4. Y – Δ (Star – Delta) Connection

The choice of connection of three phase transformer depends on the various factors likes the availability of a neutral connection for grounding protection or load connections, insulation to ground and voltage stress, availability of a path for the flow of third harmonics, etc. The various types of connections are explained below in details.

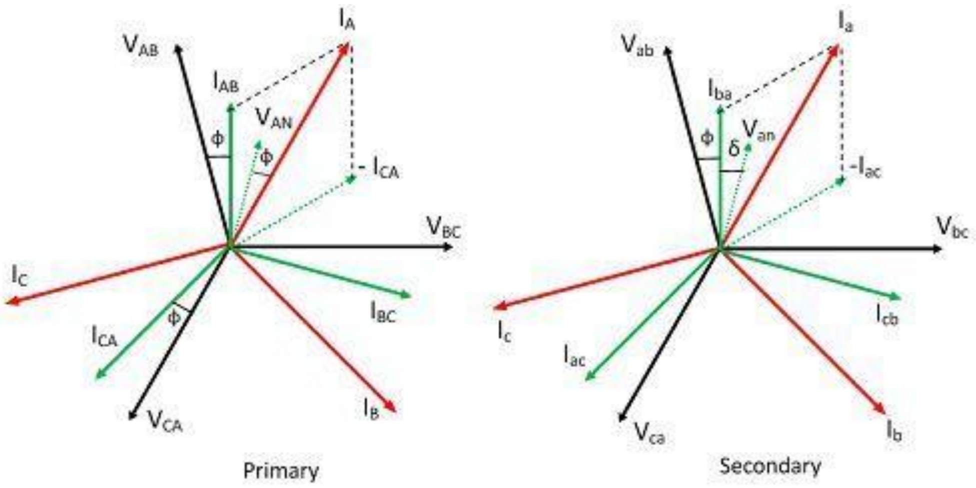
. **Delta-Delta (Δ-Δ) Connection**

The delta-delta connection of three identical single phase transformer is shown in the figure below. The secondary winding a_1a_2 is corresponding to the primary winding A_1A_2, and they have the same polarity. The polarity of the terminal a connecting a_1 and c_2 is same as that connecting A_1 and C_2. The figure below shows the phasor diagram for lagging power factor cosϕ



Delta-Delta Connection of Transformer

Circuit Globe



Phasor Diagram of Delta-Delta Connection of Transformer

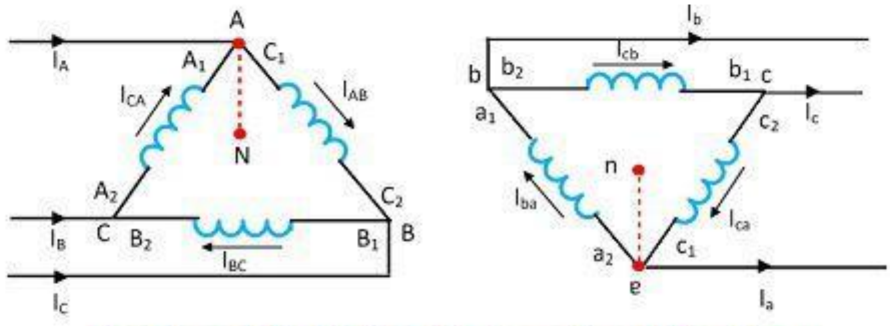
Circuit Globe

The magnetising current and voltage drops in impedances have been neglected. Under the balanced condition, the line current is √3 times the phase winding current. In this configuration, the corresponding line and phase voltage are identical in magnitude on both primary and secondary sides.

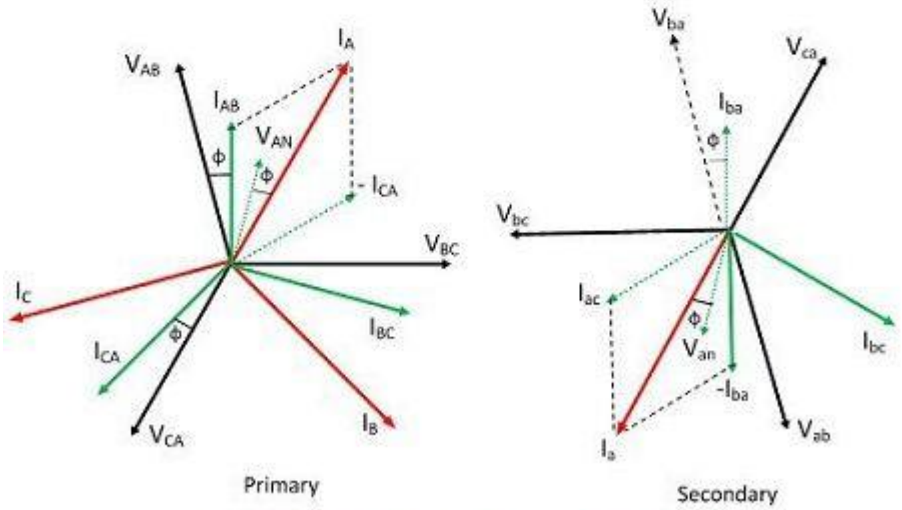
The secondary line-to-line voltage is in phase with the primary line-to-line voltage with a voltage ratio equal to the turns ratio.

If the connection of the phase windings is reversed on either side, the phase difference of 180° is obtained between the primary and the secondary system. Such a connection is known as an 180º connection.

The delta-delta connection with 180º phase shift is shown in the figure below. The phasor diagram of a three phase transformer shown that the secondary voltage is in phase opposition with the primary voltage.



180° Phase Shift of Delta-Delta Connection of Transformer



180 Phase Shift of Delt Delta Connection of Transformer

Advantages of delta–delta connection of transformer

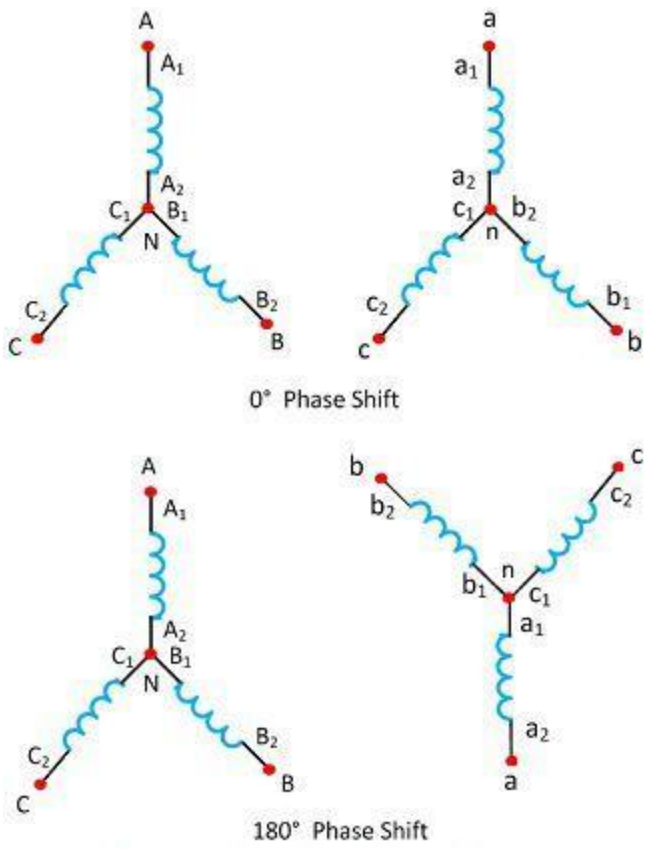
The following are the advantages of the delta-delta configuration of transformers.

1. The delta-delta transformer is satisfactory for a balanced and unbalanced load.
2. If one transformer fails, the remaining two transformers will continue to supply the three-phase power. This is called an open delta connection.
3. If third harmonics present, then it circulates in a closed path and therefore does not appear in the output voltage wave.

The only disadvantage of the delta-delta connection is that there is no neutral. This connection is useful when neither primary nor secondary requires a neutral and the voltage are low and moderate.

. Star-Star (Y-Y) Connection of Transformer

The star-star connection of three identical single phase transformer on each of the primary and secondary of the transformer is shown in the figure below. The phasor diagram is similar as in delta-delta connection



Star-Star Connection of Transformer

Problems Associated With Star-Star Connection

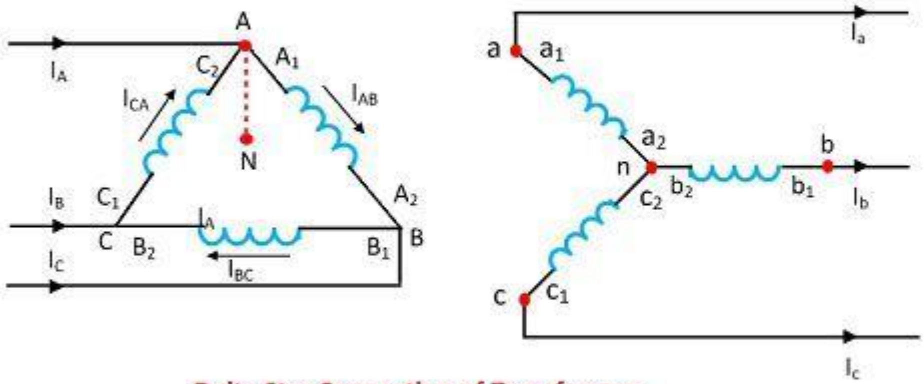
The star-star connection has two very serious problems. They are

1. The Y-Y connection is not satisfactory for the unbalance load in the absence of a neutral connection. If the neutral is not provided, then the phase voltages become severely unbalance when the load is unbalanced.
2. The Y-Y connection contains a third harmonics, and in balanced conditions, these harmonics are equal in magnitude and phase with the magnetising current. Their sum at the neutral of star connection is not zero, and hence it will distort the flux wave which will produce a voltage having a harmonics in each of the transformers

The unbalanced and third harmonics problems of Y-Y connection can be solved by using the solid ground of neutral and by providing tertiary windings.

Delta-Star (Δ-Y) Connection

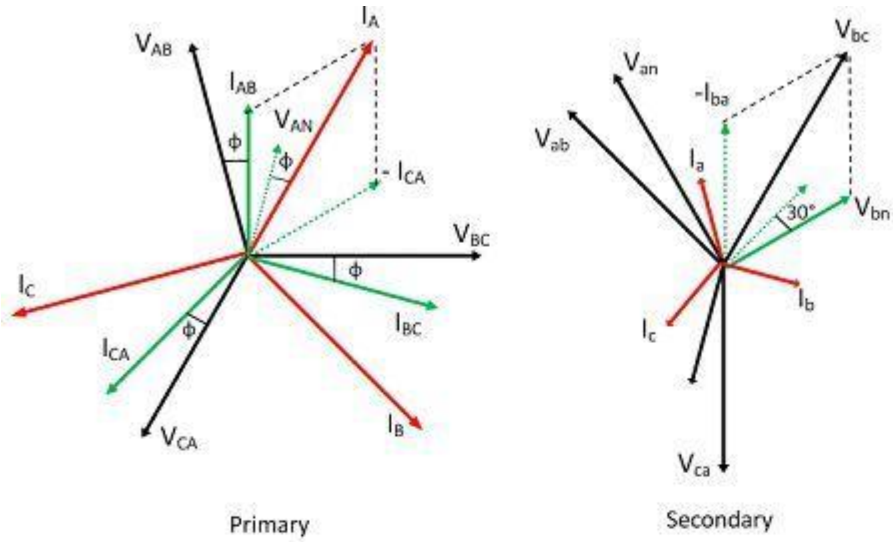
The Δ-Y connection of the three winding transformer is shown in the figure below. The primary line voltage is equal to the secondary phase voltage. The relation between the secondary voltages is $V_{LS} = \sqrt{3}\, V_{PS}$.



Delta Star Connection of Transformer

Circuit Globe

The phasor diagram of the Δ-Y connection of the three phase transformer is shown in the figure below. It is seen from the phasor diagram that the secondary phase voltage V_{an} leads the primary phase voltage V_{AN} by 30°. Similarly, V_{bn} leads V_{BN} by 30º and V_{cn} leads V_{CN} by 30º.This connection is also called +30º connection.



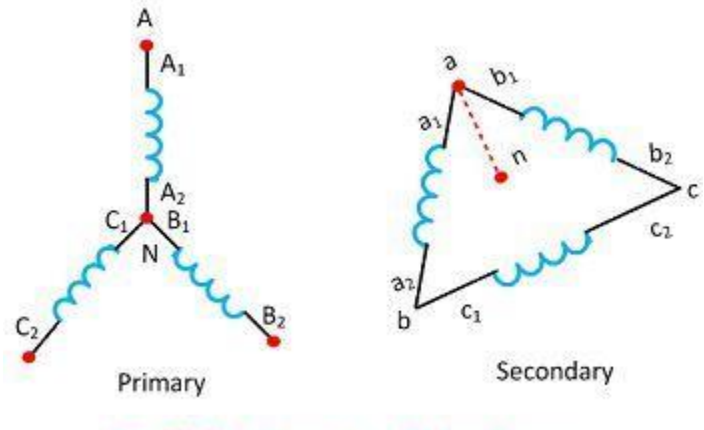
Phasor Diagram of Delta-Star Connection of Transformer

Circuit Globe

By reversing the connection on either side, the secondary system voltage can be made to lag the primary system by 30°. Thus, the connection is called -30° connection.

. **Star-Delta (Y-Δ) Connection**

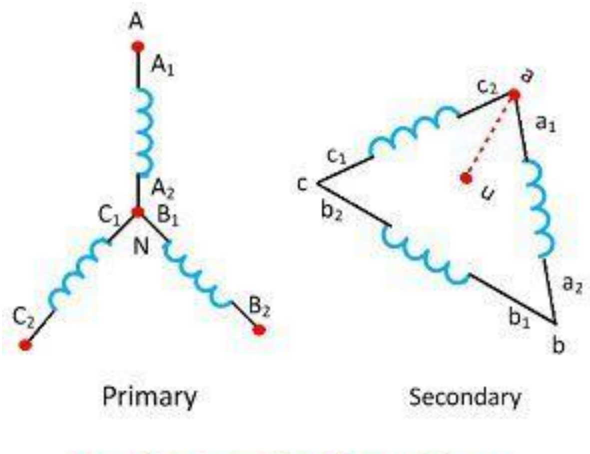
The star-delta connection of three phase transformer is shown in the figure above. The primary line voltage is √3 times the primary phase voltage. The secondary line voltage is equal to the secondary phase voltage. The voltage ratio of each phase is



Star-Delta Connection of Transformer

The phasor diagram of the configuration is shown in the figure above. There is a phase shift of 30 lead exists between respective phase voltage. Similarly, 30° leads exist between respective phase voltage. Thus the connection is called +30º connection.

The phase shows the star-delta connection of transformer for a phase shift of 30° lag. This connection is called – 30° connection. This connection has no problem with the unbalanced load and thirds harmonics. The delta connection provided balanced phase on the Y side and provided a balanced path for the circulation of third harmonics without the use of the neutral wire.



Star-Delta Connetion of a transformer

Open delta or V-V Connection

If one transformer of delta-delta connection is damaged or accidentally opened, then the defective transformer is removed, and the remaining transformer continues to work as a three phase bank. The rating of the transformer bank is reduced to 58% of that of the actual bank. This is known as the open delta or V-V delta. Thus, in open winding transformer, two transformers are used instead of three for the 3-phase operation.

If the three transformers are connected in delta-delta configuration and are supplying rated load and if the connection becomes V-V transformer, the current in each phase winding is increased by √3 times. The full line current flows in each of the two phase windings of the transformer. Thus the each transformer in the V-V system is overloaded by 73.2%.

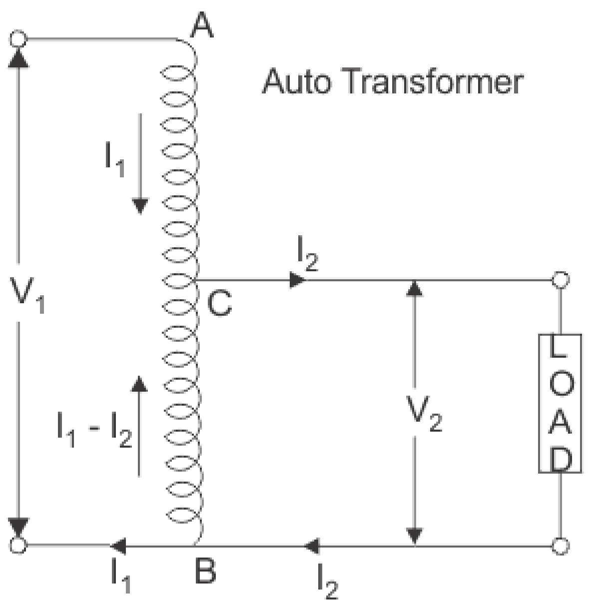
It should be noticed that the load should be reduced by √3 times in case of an open delta connected transformer. Otherwise, serious overheating and breakdown of the two transformers may take place.

Autotransformer

An autotransformer (or auto transformer) is a type of electrical transformer with only one winding. The "auto" prefix refers to the single coil acting alone (Greek for "self") – not to any automatic mechanism. An auto transformer is similar to a two winding transformer but varies in the way the primary and secondary winding of the transformer are interrelated.

Autotransformer Theory

In an auto transformer, one single winding is used as primary winding as well as secondary winding. But in two windings transformer two different windings are used for primary and secondary purpose. A circuit diagram of auto transformer is shown below.



The winding AB of total turns N_1 is considered as primary winding. This winding is tapped from point 'C' and the portion BC is considered as secondary. Let's assume the number of turns in between points 'B' and 'C' is N_2.

if V_1 voltage is applied across the winding i.e. in between 'A' and 'C'.

$$So\ voltage\ per\ turn\ in\ this\ winding\ is\ \frac{V_1}{N_1}$$

Hence, the voltage across the portion BC of the winding, will be

$$\frac{V_1}{N_1} X N_2\ and\ from\ the\ figure\ above,\ this\ voltage\ is\ V_2$$

$$Hence,\ \frac{V_1}{N_1} X N_2 = V_2$$

$$\Rightarrow \frac{V_2}{V_1} = \frac{N_2}{N_1} = Constant = K$$

As BC portion of the winding is considered as secondary, it can easily be understood that value of constant 'k' is nothing but turns ratio or voltage ratio of that **auto transformer**. When load is connected between secondary terminals i.e.between 'B' and 'C', load current I_2 starts flowing. The current in the secondary winding or common winding is the difference of I_2 and I_1.

Advantages of using Auto Transformers

The advantages of an auto transformer include:

1. For transformation ratio = 2, the size of the **auto transformer** would be approximately 50% of the corresponding size of two winding transformer. For transformation ratio say 20 however the size would be 95 %. The saving in cost of the material is of course not in the same proportion. The saving of cost is appreciable when the ratio of transformer is low, that is lower than 2. Thus auto transformer is smaller in size and cheaper.
2. An auto transformer has higher efficiency than two winding transformer. This is because of less ohmic loss and core loss due to reduction of transformer material.
3. Auto transformer has better voltage regulation as voltage drop in resistance and reactance of the single winding is less.

Disadvantages of Using Auto Transformer

The disadvantages of an auto transformer include:

1. Because of electrical conductivity of the primary and secondary windings the lower voltage circuit is liable to be impressed upon by higher voltage. To avoid breakdown in the lower voltage circuit, it becomes necessary to design the low voltage circuit to withstand higher voltage.

2. The leakage flux between the primary and secondary windings is small and hence the impedance is low. This results into severer short circuit currents under fault conditions.
3. The connections on primary and secondary sides have necessarily needs to be same, except when using interconnected starring connections. This introduces complications due to changing primary and secondary phase angle particularly in the case of delta/delta connection.
4. Because of common neutral in a star/star connected auto transformer it is not possible to earth neutral of one side only. Both their sides should have their neutrality either earth or isolated.
5. It is more difficult to maintain the electromagnetic balance of the winding when voltage adjustment tappings are provided. It should be known that the provision of tapping on an auto transformer increases considerably the frame size of the transformer. If the range of tapping is very large, the advantages gained in initial cost is lost to a great event.

Neutral grounding transformer

A grounding transformer or earthing transformer is a type of auxiliary transformer used in three-phase electric power systems to provide a ground path to either an ungrounded wye or a delta-connected system. Grounding transformers are part of an earthing system of the network. They let three-phase (delta connected) systems accommodate phase-to-neutral loads by providing a return path for current to a neutral.

Grounding transformers are typically used to:

- Provide a relatively low-impedance path to ground, thereby maintaining the system neutral at or near ground potential.
- Limit the magnitude of transient overvoltages when restriking ground faults occur.
- Provide a source of ground fault current during line-to-ground faults.
- Permit the connection of phase-to-neutral loads when desired.

Grounding transformers most commonly incorporate a single winding transformer with a zigzag winding configuration, but may also be created with a wye-delta winding transformer. Neutral grounding transformers are very common on generators in power plants and wind farms.Neutral grounding transformers are sometimes applied on high-voltage (sub-transmission) systems, such as at 33 kV, where the circuit would otherwise not have a ground; for example, if a system is fed by a delta-connected transformer. The grounding point of the transformer may be connected through a resistor or arc suppression coil to limit the fault current on the system in the event of a line-to-ground fault.

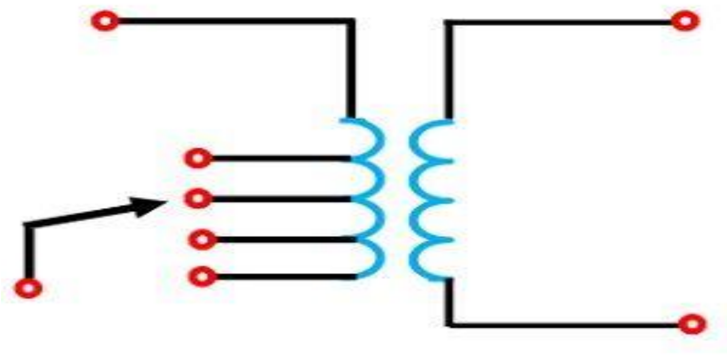
Tap changing Transformer

The change of voltage is affected by changing the numbers of turns of the transformer provided with taps. For sufficiently close control of voltage, taps are usually provided on the high voltage windings of the transformer. There are two types of tap-changing transformers

1. Off-load tap changing transformer
2. On-load tap changing transformer

Off-load tap changing transformer

In this method, the transformer is disconnected from the main supply when the tap setting is to be changed. The tap setting is usually done manually.



Off-load tap-changing transformer

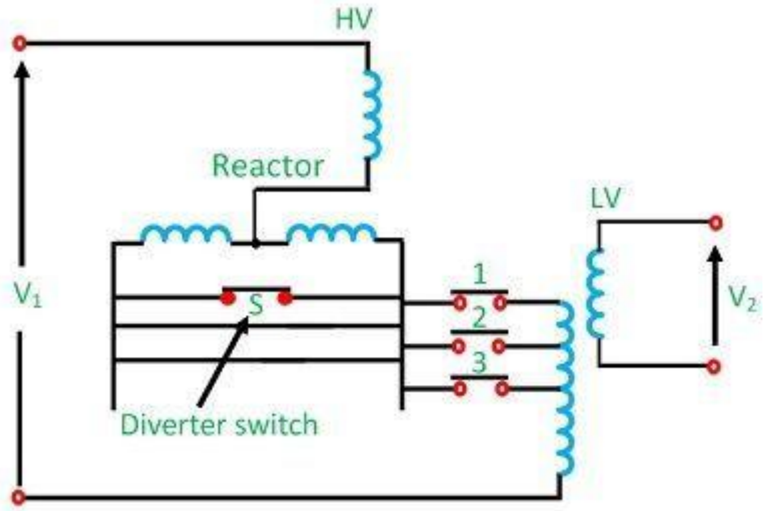
On-load tap-changing transformer

In order that the supply may not be interrupted, on-load tap changing transformer are sued. Such a transformer is known as a tap-changing under load transformer. While tapping, two essential conditions are to be fulfilled.

- The load circuit should not be broken to avoid arcing and prevent the damage of contacts.

No parts of the windings should be short–circuited while adjusting the tap. The tap changing employing a center tapped reactor R show in the figure above. Here S is the diverter switch, and 1, 2, 3 are selector switch. The transformer is in operation with switches 1 and S closed. To change to tap 2, switch S is opened, and 2 is closed. Switch 1 is then opened, and S closed to complete the tap change. It is to be noted that the diverter switch operates on load, and no current flows in the selector switches during tap changing. During the tap change only half of the reactance which limits the

It is to be noted that the diverter switch operates on load, and no current flows in the selector switches during tap changing. During the tap change, only half of the reactance which limits the current is connected in the circuit.



On-load tap changing using a reactor

Module: 3 Over voltage and insulation requirements

Generation of overvoltage

Causes of Over voltage in Power System

Increase in voltage for the very short time in power system is called as the over voltage. it is also known as the voltage surge or voltage transients. The voltage stress caused by over voltage can damage the lines and equipment's connected to the system, There are two types of causes of over voltage in power system. 1. Over voltage due to external causes 2. Over voltage due to internal causes Transient over voltages can be generated at high frequency (load switching and lightning), medium frequency (capacitor energizing), or low frequency.Over voltage due to external causes: This cause of over voltage in power system is the lightning strokes in the cloud. Now, how lightning strokes are produced. So when electric charges get accumulated in clouds due to thunder Strom caused due to some bad atmosphere process. This type of over voltages originates from atmospheric disturbances, mainly due to lightning. This takes the form of a surge and has no direct relationship with the operating voltage of the line. It may be due to any of the following causes: A) Direct lightning stroke B) Electromagnetically induced over voltages due to lightning discharge taking place near the line, called 'side stroke'. C) Voltages induced due to atmospheric changes along the length of the line. D) Electrostatically induced voltages due to presence of charged clouds nearby. E) Electrostatically induced over voltages due to the frictional effects of small particles like dust or dry snow in the atmosphere or due to change in the altitude of the line. The potential between the clouds and earth breaks down and lightning flash takes place between the cloud and ground when this voltage becomes 5 to 20 million volts or when the potential gradient becomes 5000V to 10000V per cm. There are two types of lightning strokes. 1. Direct lightning strokes 2. Indirect lightning strokeS

over-voltage-spike

Over voltages are caused on power systems due to external and internal influencing factors. The voltage stress caused by over voltage can damage the lines and equipment's connected to the system. Over voltages arising on a system can be generally classified into two main categories as below:

External Over voltages This type of over voltages originates from atmospheric disturbances, mainly due to lightning. This takes the form of a surge and has no direct relationship with the operating voltage of the line. It may be due to any of the following causes:

a) Direct lightning stroke b) Electromagnetically induced over voltages due to lightning discharge taking place near the line, called 'side stroke'. c) Voltages induced due to atmospheric changes along the length of the line. d) Electrostatically induced voltages due to presence of charged clouds nearby. e) Electrostatically induced over voltages due to the frictional effects of small particles like dust or dry snow in the atmosphere or due to change in the altitude of the line.

Internal Over voltages

These over voltages are caused by changes in the operating conditions of the power system. These can be divided into two groups as below:

1. Switching over voltages or Transient over operation voltages of high frequency:

   This is caused when switching operation is carried out under normal conditions or when fault occurs in the network. When an unloaded long line is charged, due to Ferranti Effect the receiving end voltage is increased considerably resulting in over voltage in the system. Similarly when the primary side of the transformers or reactors is switched on, over voltage of transient nature occurs.

2. Temporary over voltages:

   These are caused when some major load gets disconnected from the long line under normal or steady state condition.

   EFFECTS OF OVER VOLTAGES ON POWER SYSTEMS

   Over voltage tends to stress the insulation of the electrical equipment's and likely to cause damage to them when it frequently occurs. Over voltage caused by surges can result in spark over and flash over between phase and ground at the weakest point in the network, breakdown of gaseous/solid/ liquid insulation, failure of transformers and rotating machines.

   Overvoltage Protection

   There are always a chance of suffering an electrical power system from abnormal over voltages. These abnormal over voltages may be caused due to various reason such as, sudden interruption of heavy load, lightening impulses, switching impulses etc. These over voltage stresses may damage insulation of various equipments and insulators of the power system. Although, all the over voltage stresses are not strong enough to damage insulation of system, but still these over voltages also to be avoided to ensure the smooth operation of electrical power system. These all types of destructive and non destructive abnormal over voltages are eliminated from the system by means of overvoltage protection.

   Voltage Surge

   The over voltage stresses applied upon the power system, are generally transient in nature. Transient voltage or voltage surge is defined as sudden sizing of voltage to a high peak in very short duration.The voltage surges are transient in nature, that means they exist for very short duration. The main cause of these voltage surges in power system are due to lightning impulses and switching impulses of the system. But over voltage in the power system may also be caused by, insulation failure, arcing ground and resonance etc. The voltage surges appear in the electrical power system due to switching surge, insulation failure, arcing ground and resonance are not very large in magnitude. These over voltages hardly cross the twice of the normal voltage level. Generally, proper insulation to the different equipment of power system is sufficient to prevent any damage due to these over voltages. But over voltages occur in the power system due to lightning is very high. If over voltage protection is not provided to the power system, there may be high chance of severe damage. Hence all over voltage protection devices used in power system mainly due to lightning surges.

Switching Impulse or Switching Surge

When a no load transmission line is suddenly switched on, the voltage on the line becomes twice of normal system voltage. This voltage is transient in nature. When a loaded line is suddenly switched off or interrupted, voltage across the line also becomes high enough current chopping in the system mainly during opening operation of air blast circuit breaker, causes over voltage in the system. During insulation failure, a live conductor is suddenly earthed. This may also caused sudden over voltage in the system. If emf wave produced by alternator is distorted, the trouble of resonance may occur due to 5th or higher harmonics. Actually for frequencies of 5th or higher harmonics, a critical situation in the system so appears, that inductive reactance of the system becomes just equal to capacitive reactance of the system. As these both reactance cancel each other the system becomes purely resistive. This phenomenon is called resonance and at resonance the system voltage may be increased enough. But all these above mentioned reasons create over voltages in the system which are not very high in magnitude. But over voltage surges appear in the system due to lightning impulses are very high in amplitude and highly destructive. The affect of lightning impulse hence must be avoided for over voltage protection of power system

Methods of Protection Against Lightning

These are mainly three main methods generally used for protection against lightning. They are

1. Earthing screen

.2. Overhead earth wire.

3. Lighning arrester or surge dividers.

Earthing Screen

Earthing screen is generally used over electrical substation. In this arrangement a net of GI wire is mounted over the sub-station. The GI wires, used for earthing screen are properly grounded through different sub-station structures. This network of grounded GI wire over electrical sub-station, provides very low resistance path to the ground for lightning strokes. This method of high voltage protection is very simple and economic but the main drawback is, it can not protect the system from travelling wave which may reach to the sub-station via different feeders.

Overhead Earth Wire

This method of over voltage protection is similar as earthing screen. The only difference is, an earthing screen is placed over an electrical sub-station, whereas, overhead earth wire is placed over electrical transmission network. One or two stranded GI wires of suitable cross-section are placed over the transmission conductors. These GI wires are properly grounded at each transmission tower. These overhead ground wires or earth wire divert all the lightning strokes to the ground instead of allowing them to strike directly on the transmission conductors.

Lightning Arrester

The previously discussed two methods, i.e. earthing screen and over-head earth wire are very suitable for protecting an electrical power system from directed lightning strokes but system from directed lightning strokes but these methods can not provide any protection against high voltage travelling wave which may propagate through the line to the equipment of the sub-station.The lightning arrester is a devices which provides very low impedance path to the ground for high voltage travelling waves. The concept of a lightning arrester is very simple. This device behaves like a nonlinear electrical resistance. The resistance decreases as voltage increases and vice-versa, after a certain level of voltage.The functions of a lightning arrester or surge dividers can be listed as below. Under normal voltage level, these devices withstand easily the system voltage as electrical insulator and provide no conducting path to the system current. On occurrence of voltage surge in the system, these devices provide very low impedance path for the excess charge of the surge to the ground. After conducting the charges of surge, to the ground, the voltage becomes to its normal level. Then lightning arrester regains its insulation properly and prevents regains its insulation property and prevents further conduction of current, to the ground. There are different types of lightning arresters used in power system, such as rod gap arrester, horn gap arrester, multi-gap arrester, expulsion type LA, value type LA. In addition to these the most commonly used lightning arrester for over voltage protection now-a-days gapless ZnO lightning arrester is also used.

INSULATION COORDINATION

Insulation Coordination in Power System was introduced to arrange the electrical insulation levels of different components in the electrical power system including transmission network, in such a manner, that the failure of insulator, if occurs, confindes to the place where it would result in the least danmage of the system, easy to repair and replace, and results least disturbance to the power supply. When any over voltage appears in the electrical power system, then there may be a chance of failure of its insulation system. Probability of failure of insulation, is high at the weakest insulation point nearest to the source of over voltage. In power system and transmission networks, insulation is provided to the all equipment and components. Insulators in some points are easily replaceable and repairable compared to other. Insulation in some points are not so easily replaceable and repairable and the replacement and repairing may be highly expensive and require long interruption of power. Moreover failure of insulator at these points may causes bigger part of electrical network to be out of service. So, it is desirable that in situation of insulator failure, only the easily replaceable and repairable insulator fails. The overall aim of insulation coordination is to reduce to an economically and operationally acceptable level the cost and disturbance caused by insulation failure. In insulation coordination method, the insulation of the various parts of the system must be so graded that flash over if occurs it must be at intended points. For proper understanding the insulation coordination we have to understand first, some basic terminologies of the electrical power system. Let us have a discussion. Nominal System Voltage Nominal System Voltage is the phase to phase voltage of the system for which the system is normally designed. Such as 11 KV, 33 KV, 132 KV, 220 KV, 400 KV systems.

Maximum System Voltage

Maximum System Voltage is the maximum allowable power frequency voltage which can occurs may be for long time during no load or low load condition of the power system. It is also measured in phase to phase manner. List of different nominal system voltage and their corresponding maximum system voltage is given below for reference,

Nominal System Voltage in KV 11 33 66 132 220 400

Maximum System Voltage in KV 12 36 72.5 145 245 420 NB –

It is observed from above table that generally maximum system voltage is 110 % of corresponding nominal system voltage up to voltage level of 220 KV, and for 400 KV and above it is 105 %. Factor of Earthing This is the ratio of the highest rms phase to earth power frequency voltage on a sound phase during an earth fault to the rms phase to phase power frequency voltage which would be obtained at the selected location without the fault. This ratio characterizes, in general terms, the earthing conditions of a system as viewed from the selected fault location.

Effectively Earthed System

A system is said to be effectively earthed if the factor of earthing does not exceed 80 % and non-effectively earthed if it does.Factor of earthing is 100 % for an isolated neutral system, while it is 57.7 % (1/√3 = 0.577) for solidly earthed system.

Insulation Level

Every electrical equipment has to undergo different abnormal transient over voltage situation in different times during its total service life period. The equipment may have to withstand lightning impulses, switching impulses and/or short duration power frequency over voltages. Depending upon the maximum level of impulse voltages and short duration power frequency over voltages that one power system component can withstand, the insulation level of high voltage power system is determined. During determining the insulation level of the system rated less than 300 KV, the lightning impulse withstand voltage and short duration power frequency withstand voltage are considered. For equipment rated more or equal 300 KV, switching impulse withstand voltage and short duration power frequency withstand voltage are considered.

Lightning Impulse Voltage

The system disturbances occur due to natural lightning, can be represented by three different basic wave shapes. If a lightning impulse voltage travels some distance along the transmission line before it reaches to a insulator its wave shaped approaches to full wave, and this wave is referred as 1.2/50 wave. If during travelling, the lightning disturbance wave causes flash over across an insulator the shape of the wave becomes chopped wave. If a lightning stroke hits directly on the insulator then the lightning impulse voltage may rise steep until it is relieved by flash over, causing sudden, very steep collapse in voltage. These three waves are quite different in duration and in shapes.

Switching Impulse

During switching operation there may be uni-polar voltage appears in the system. The wave form of which may be periodically damped or oscillating one. Switching impulse wave form has steep front and long damped oscillating tale.

Short Duration Power Frequency Withstand Voltage

Short duration power frequency withstand voltage is the prescribed rms value of sinusoidal power frequency voltage that the electrical equipment shall withstand for a specific period of time normally 60 seconds.

Protection Level Voltage of Protective Device

Over voltage protective device like surge arrestors or lightning arrestors are designed to withstand a certain level of transient over voltage beyond which the devices drain the surge energy to the ground and therefore maintain the level of transient over voltage up to a specific level. Thus transient over voltage can not exceed that level. The protection level of over voltage protective device is the highest peak voltage value which should not be exceeded at the terminals of over voltage protective device when switching impulses and lightening impulses are applied.

Module 4: Fault analysis and Protective system

Symmetrical component Analysis

Unbalanced three phase systems can be split into three balanced components, namely Positive Sequence (balanced and having the same phase sequence as the unbalanced supply), Negative Sequence (balanced and having the opposite phase sequence to the unbalanced supply) and Zero Sequence (balanced but having the same phase and hence no phase sequence). These are known as the Symmetrical Components or the Sequence Components . The phase components are the addition of the symmetrical components and can be written as follow

a = a1 + a2 + a0

b = b1 + b2 + b0

c = c1 + c2 + c0

The unknown unbalanced system has three unknown magnitudes and three unknown angles with respect to the reference direction. Similarly, the combination of the 3 sequence components will also have three unknown magnitudes and three unknown angles with respect to the reference direction. Thus the original unbalanced system effectively has 3 complex unknown quantities a, b and c (magnitude and phase angle of each is independent), and that each of the balanced components have only one independent complex unknown each, as the others can be written by symmetry. Thus the three sets of symmetrical components also have effectively 3 complex unknown quantities. These are usually selected as the components of the first phase a (i.e. a0, a1 and a2) . One of the other phases could have been selected as well, but all 3 components should be selected for the same phase. Thus it should be possible to convert from either sequence components to phase components or vice versa.

Definition of the operator α

When the balanced components are considered, we see that the most frequently occurring angle is 1200 . In complex number theory, we defined j as the complex operator which is equal to √-1 and a magnitude of unity, and more importantly, when operated on any complex number rotates it anti-clockwise by an angle of 900 .

i.e. j = √-1 = 1 ∠900

In like manner, we define a new complex operator α which has a magnitude of unity and when operated on any complex number rotates it anti-clockwise by an angle of 1200 .

i.e. α = 1 ∠1200 = - 0.500 + j 0.866

Some Properties of α

$\alpha = 1\angle 2\pi/3$ or $1\angle 1200$

$\alpha2 = 1\angle 4\pi/3$ or $1\angle 2400$ or $1\angle -1200$

$\alpha3 = 1\angle 2\pi$ or $1\angle 3600$ or 1

i.e. $\alpha3 - 1 = (\alpha - 1)(\alpha2 + \alpha + 1) = 0$

Analysis of decomposition of phasors

Let us again examine the sequence components of the unbalanced quantity, with each of the components written in terms of phase a components, and the operator α,

We can express all the sequence components in terms of the quantities for A phase using the properties of rotation of 00 , 1200 or 2400 .

$a = a0 + a1 + a2$

$b = a0 + \alpha2\ a1 + \alpha\ a2$

$c = a0 + \alpha\ a1 + \alpha2\ a2$

Protective system

DESIGN CONSIDERATION

Protection system adopted for securing protection and the protection scheme i.e. the coordinated arrangement of relays and accessories is discussed for the following elements of power system. i) Hydro Generators ii) Generator Transformers iii) H. V. Bus bars iv) Line Protection and Islanding Primary function of the protective system is to detect and isolate all failed or faulted components as quickly as possible, thereby minimizing the disruption to the remainder of the electric system. Accordingly the protection system should be dependable (operate when required), secure (not operate unnecessarily), selective (only the minimum number of devices should operate) and as fast as required. Without this primary requirement protection system would be largely ineffective and may even become liability.

3.1.1 Reliability of Protection Factors affecting reliability are as follows; i) Quality of relays ii) Component and circuits involved in fault clearance e.g. circuit breaker trip and control circuits, instrument transformers iii) Maintenance of protection equipment iv) Quality of maintenance operating staff Failure records indicate the following order of likelihood of relays failure, breaker, wiring, current transformers, voltage transformers and D C. battery. Accordingly local and remote back up arrangement are required to be provided.

3.1.2 Selectivity Selectivity is required to prevent unnecessary loss of plant and circuits. Protection should be provided in overlapping zones so that no part of the power system remains unprotected and faulty zone is disconnected and isolated.

3.1.3 Speed Factors affecting fault clearance time and speed of relay is as follows: i) Economic consideration ii) Selectivity iii) System stability iv) Equipment damage

3.1.4 Sensitivity Protection must be sufficiently sensitive to operate reliably under minimum fault conditions for a fault within its own zone while remaining stable under maximum load or through fault condition.

3.1.5 Protection Zones Overlapping zones of protection are provided so that no part of power system remains unprotected. The point of connection of the protection with the power system normally defines the zone boundary and generally corresponds to the position of the current transformers. Current transformers if provided on both 106 sides of circuit breaker overlap . If they are provided on one side blind spots occur , Fault between CT and the circuit breaker will not trip the feeder CB and fault current will continue to flow until cleared by back up protection.

3.1.6 Primary and back up Protection The design of a protective system should include backup protection to allow for failures and for periodic maintenance of the interrupting devices, sensing devices, and protective relays. Backup protection may be either remote or local or it may be a combination of both schemes. Remote backup protection consists of relays that are set to respond to faults in the next zone of protection. This type of protection is relatively slow as it should allow time for the primary relaying in that zone to operate. It also may cause interruption to large portions of the electric supply system. In some cases, local backup protection is justified. Local backup consists of two sets of independent primary protection and breaker-failure relaying. Ideally, this should include two independent sets of current transformers, voltage transformers, protective relays, and breaker trip coils, but only one breaker-failure relaying system is required. Each protective relay system should be isolated so that a failure in one will not affect the other. Among other things, this requires that the control power for each system be supplied from separate low-voltage circuit breakers or fuses. Two forms of back up protection are provided. These are protection failure or circuit breaker failure. Best form of back up protection for any system is one in which both ac and dc supplies are completely separate from main protection. Economic consideration determines the extent to which back up protection is provided.

3.1.7 Fault Data Protective relay systems measure the current, voltage, or a combination of current and voltage during fault conditions. Fault current magnitude, and the associated change in voltage, varies with the type of fault and with the location of the fault with respect to the sensing devices

3.1.8 Fault Current Versus Load Current In most cases, fault exceeds normal load current by a factor of 2 or more. However, special consideration should be given to situations where load current is greater than fault current. For example, on systems that are grounded through a neutral impedance, the ground fault current is lower than the normal load current magnitude. For this situation, the use of separate ground fault relaying is required. High-voltage phase over-current devices should not respond to maximum load current because these devices are applied to provide protection for short-circuits but not for maximum loads. Conductors, transformers, and other current-carrying devices should be rated to carry the maximum expected load, taking into account load profiles, diversity, and short time equipment ratings. Occasionally, special overload protection is provided for high-voltage equipment, but this should generally be avoided because of the difficulty of coordinating these schemes while maintaining reliable operation of the power system. However, overload protection is required for low-voltage equipment.

3.1.9 Circuit-Interrupting Devices Fuses are single phase protective devices that combine sensing and interrupting functions into a single unit. Fuse operation is based on the magnitude and duration of current flowing in each phase of the circuit. The primary application considerations include maximum load, minimum and maximum fault current available, interrupting rating, operating time of the fuse relative to the operating time of protective devices on both the consumer and utility systems, and the effects of single-phase supply due to the operation of one fuse. Miniature circuit breakers are replacing fuses. A circuit breaker is an interrupting device designed for normal switching functions as well as for fault interruption. Circuit breakers offer considerable flexibility and are available in variety of voltage, current, and fault current interrupting ratings. High-voltage circuit breakers are equipped with separate electrically operated close and trip coils that can be controlled by any required protection and control package. Lowvoltage circuit breakers can be equipped with shunt trip devices but are usually self-contained with integral thermal magnetic or solid-state trip units. A considerations in the application of interrupting devices is the source of control power for the close and trip coils. A station battery is considered the most reliable source of dc control power, because battery output voltage is not affected by the ac voltage drop that can occur during short-circuit conditions. A capacitive trip device will store energy for a short period of time that is sufficient to trip a breaker. This device may be used under circumstances when it is not practical to use a battery. When capacitive trip is used, the power to both the trip and close circuits is AC. The location of the ac source must be on the utility side of the main beaker to ensure power is available to close the main breaker.

3.1.10 Sensing Devices Protective relay must be isolated from the high-voltage system but require current and voltage quantities proportional to those on the electric supply system. The standard ratings for protective relays are normally 5 A and 110 V, 50 Hz. Current and voltage transformers produce these relay input quantities

3.1.11 Type of Protective Relays There are many types of protective relays and protection schemes available. The types of protective relays that are usually used for various elements of hydro station

Over current relays

Over current relay schemes are relatively low cost and simple to use. These are used primarily on distribution and sub-transmission feeders where fault load and currents are in one direction. An over current relay operates when the magnitudes of the current in its circuit exceeds a preset value. Selectivity with over current relays may be achieved by one of the following methods. i. Grading the magnitude of the fault current ii. Grading time of operation iii. Combination of magnitude and time iv. Direction of fault current Following types of over current relays may be used for the protection of outgoing feeders:- i) The inverse definite minimum time (IDMT) relay having a characteristics which conforms to the requirements of IS 1885 – Part IX. ii) A combined IDMT relay and high set instantaneous relay, with low transient over reach. iii) A very inverse definite minimum time relay iv) Extremely inverse definite minimum time relay v) Definite time over-current relay Relay selection and settings is governed by the following Time - Current Characteristics of over current relays. i) Time delay ii) Instantaneous and iii) Combination of (i) and (ii) Time delay is provided by time multiplier setting which varies the time in which the relay will close its contacts for given value of fault current. Plug setting - Varies range of current setting at which relay will operate. Characteristics of the relay are given in IS: 38642 Part-1. Definite time current relays operate at a constant time predetermined by adjustment and are independent of current magnitude as long as it is sufficient to operate the relay. IEEE std. 37.113 recommends three phase and one ground time over current relay and instantaneous over current relays for sub transmission line feeder. Phase currents are used as operating quantity. Typical 164 connection is shown in Figure 3.33. Phase over current relays operate for all possible faults types, but require pick up settings to be higher than the maximum expected normal or emergency load flow condition. Over current relays in the neutral 50/51 N do not operate for balanced loads or for 3 phase faults but operate for ground faults or unbalanced load and pick up settings are kept well below expected load.

Direction Over current Relay

Directional over current relays respond to faults in one direction only. This is accomplished by providing the relay with a measured quantity for reference. This input can be voltage, a current or both. Application of different types of over current time relays as per IS: 3842 is given in table 3.8. The basic directional over current relay scheme consists of four time over current relay units or element – one for each phase and one for ground fault (residual) current. Instantaneous trip unit which may or may not be directional can be added to provide high speed relay operation for close – in faults. Three CTs located at the line terminal – one for each phase unit and sum of the three for residual unit are provided. The arrangement is same as for non directional over current relay and co-ordination with other devices is also similar. Directional over current element is generally used to supervise the output of the over current element. In this method, the over current element is free to operate for any current in excess of its pick up setting. However, tripping occurs only when directional element also operates

Distance Relays

Distance relays operate by measuring both voltage and current (VR and IR in figure 3.37) at the terminal (power house end) of the transmission line feeder to determine if the fault is in the relays zone of protection. The operating characteristics can be described using R – X diagram as shown in figure 3.37 on two terminal lines without tap lines, the impedance of the transmission line is fixed and reach of the relay is largely due to network changes. The term impedance relay is sometimes used interchangeably with the term distance relay. There are several distance relay characteristics of which impedance relay is only one. The basic distance relay characteristics are as follows: a) Impedance. The impedance relay does not take into account the phase angle between the voltage and the current applied to it. For this reason, the impedance characteristic in the R – X plane is a circle 167 with its center at the origin. The relay operates when the measured impedance is less than the setting (i.e., it is within the circle). The relay has a current coil producing torque equal to K 1 I and a voltage restraining coil producing a torque equal to K 2 U.

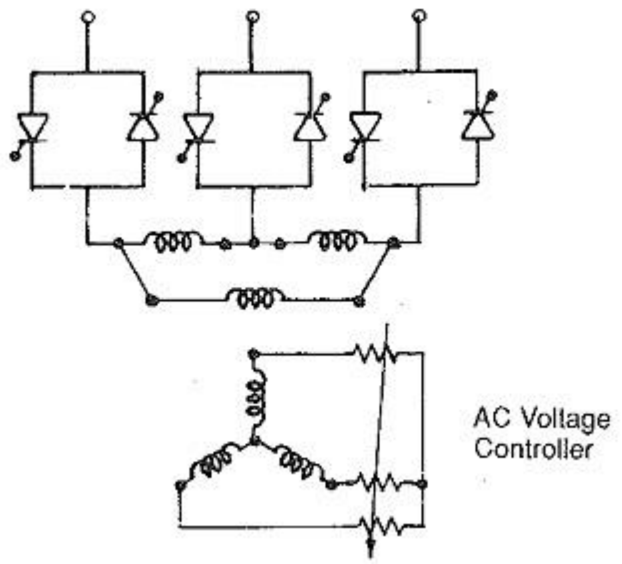
Distance Schemes

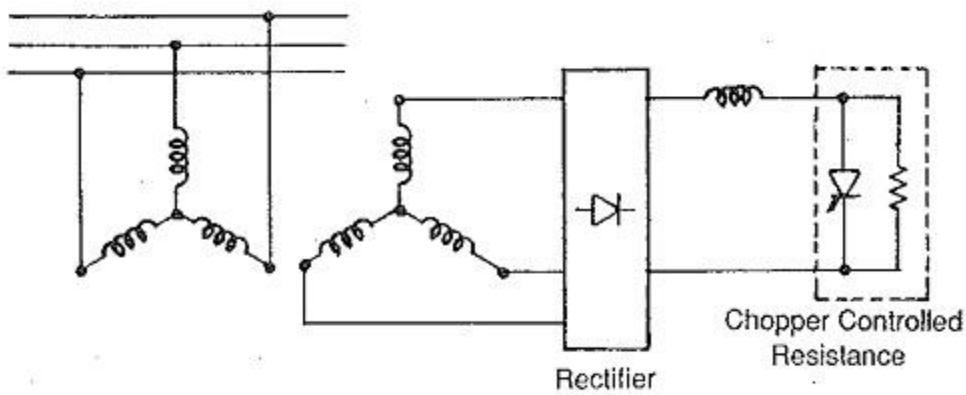
In distance relays the fault distance impedance actually measured depends on the actual magnitude of current and voltage, the relay connections, type of fault and impedances in the fault in addition to the line impedance. It is impossible to successfully eliminate these additional features in distance measurement for all possible operating conditions. Therefore composite schemes employing several relays and different relay characteristics are employed. Starter Relays for Distance Protection: Primary function of starting relays, sometimes referred to as fault detectors is to control the timing relay for extending the reach of measuring relay into second and third zone. They must have directional features when used with impedance and reactance measuring system. A distance scheme comprises starting relays, impedance measuring unit, zone timers and tripping relays. To cater for the economic and technical requirements of any particular network, a range of schemes is necessary from which a choice may be made. The schemes generally employed to meet the protection requirements of low, medium and high voltage networks may be classified into three main groups: a) Schemes designed for protection against phase faults only; b) Schemes designed for protection against all types of faults – phase and earth – using separate units for each type of fault (also referred to as non-switched schemes); and c) Schemes designed for protection against various type of faults using one set of units only but incorporating switching features (also referred to as switched schemes)

Module 5 : Introduction to dc transmission and renewable energy

Line Commutated Converters

In these Phase Controlled Line Commutated Converters, the commutation voltage, i.e. the voltage required to transfer current from one thyristor to the other, is provided by the supply lines to which the converter is connected. The classification of these Line Commutated Converters is done in several ways. Depending on the direction of power flow, i.e. the type of energy conversion performed, they may be one quadrant or two quadrant converters. As has already been explained, a two quadrant converter allows power in both directions, and can perform both phase controlled rectification and inversion, i.e. ac to dc as well as dc to ac.





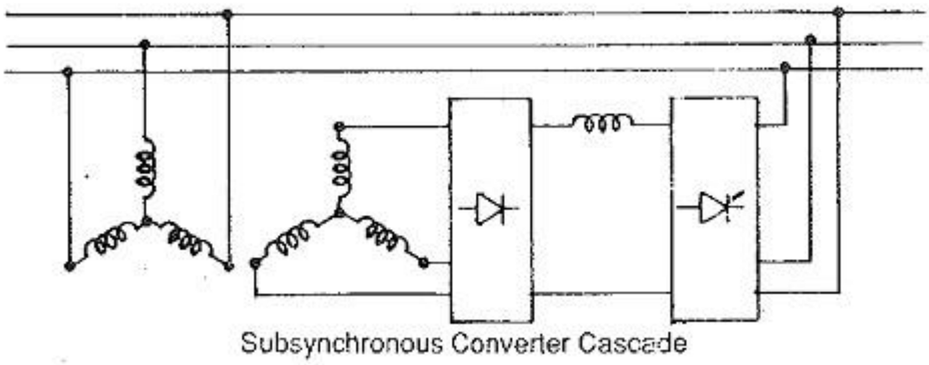


Fig. 3.9(a) *Summary of slip ring induction motor speed control*

The converter necessarily has thyristors in all positions and, is called a fully controlled converter. On the other hand, a one quadrant converter has a power flow from ac to dc and diodes can be used in a few positions of the converter. It can perform only phase controlled rectification, and is called a half controlled converter.

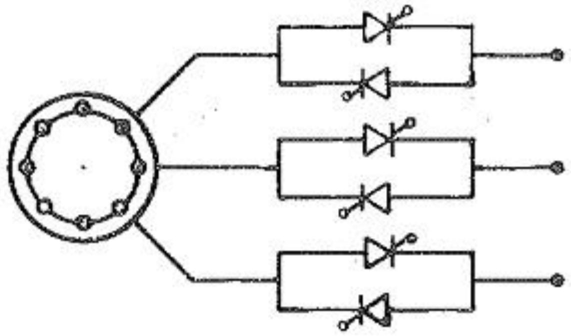
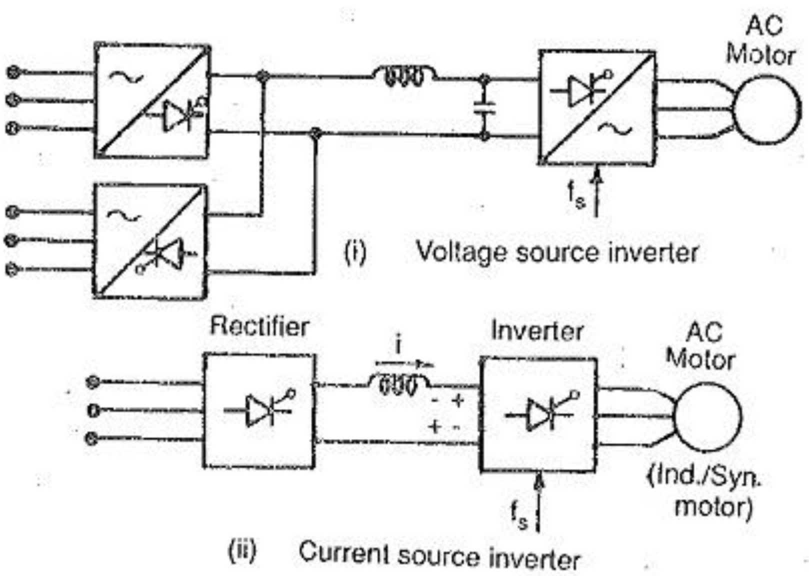


Fig. 3.9(b) *Voltage control of sq cage motor*



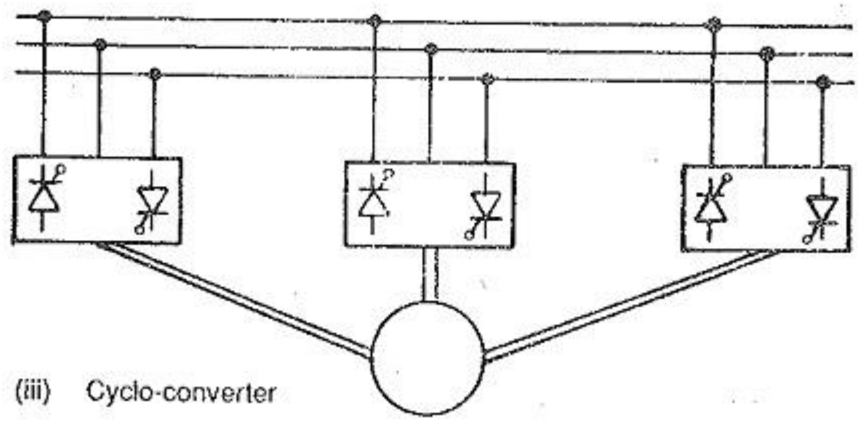


Fig. 3.9(c) *Speed control by variable frequency*

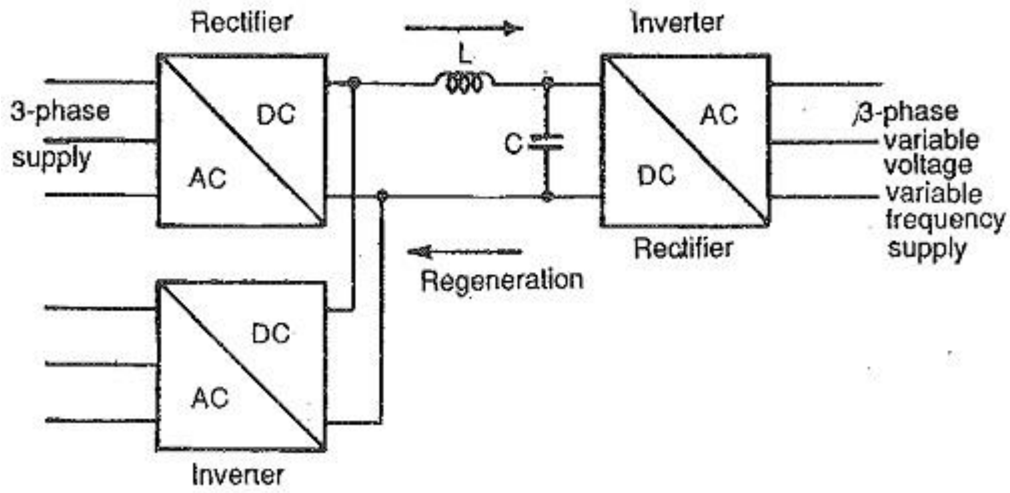


Fig. 3.10 *DC link converter*

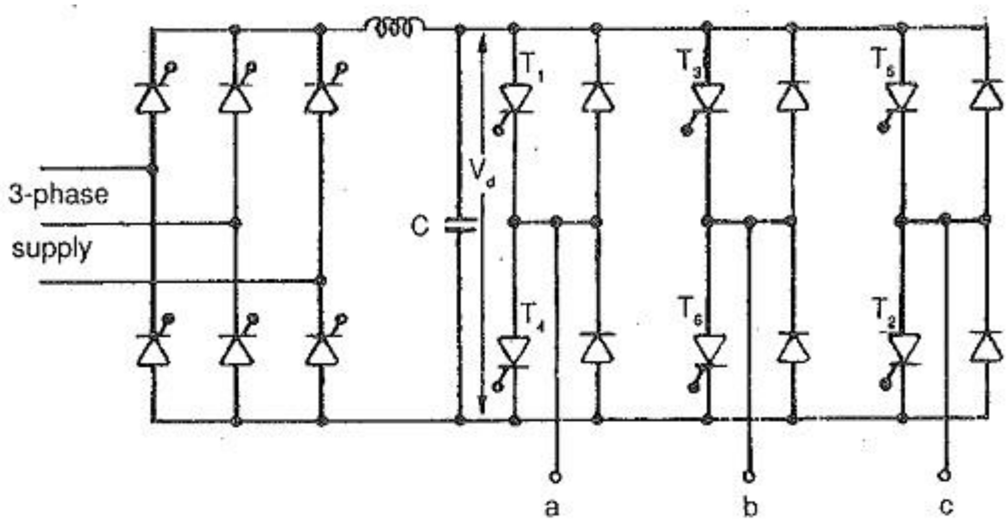


Fig. 3.11 *Voltage source inverter*

Line Commutated Converters are also classified according to the pulse number of the ac voltage superimposing the average dc voltage of the converter. Thus, we have

- **Two pulse converters**
- **Three pulse converters**
- **Six pulse converters**
- **Twelve pulse converters**

Converters can be Midpoint or bridge type converters depending upon their layout.

Voltage Source Converters (VSC)

Voltage Source Converters (VSC) are a self-commutated converters to connect HVAC and HVDC systems using devices suitable for high power electronic applications, such as Insulated Gate Bipolar Transistors (IGBTs). VSCs are capable of self-commutation being able to generate AC voltages without the need to rely on an AC system. This allows for independent rapid control of both active and reactive power and black start capability. VSCs maintain a constant polarity of the DC voltage for their building blocks, such as the 2-level or 3-level converter as well as the so-called “Modules” in a Modular Multi-Level Converter (MMC). The change of power flow direction is achieved by reversing the direction of the current. Therewith, VSCs are easier integrated in multi-terminal DC systems. VSC based HVDC systems offer a faster active power flow control with respect to the more mature CSC-HVDC, while also ensuring flexible and extended reactive power controllability at the two converter terminals.

Technology Type

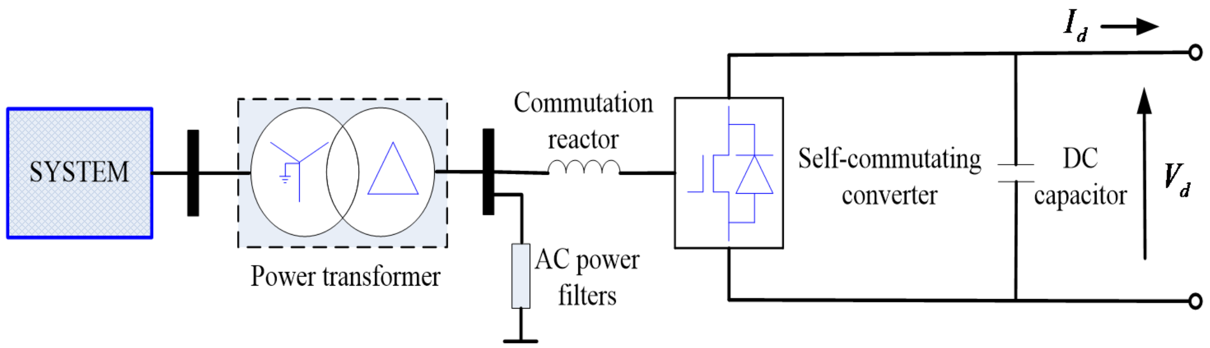
VSC can be classified with respect to the converter technology types used, which have evolved over time:

- Two-Level VSC – earliest technology used
- Three Level Diode Neutral Point Clamped (NPC) or Three Level Active NPC
- Two Level with Optimum Pulse-Width Modulation (OPWM)
- Cascaded-two Level Converter (CTL)
- Modular Multi-Level Converter (MMC), which is the latest and most advanced technology used for HVDC transmission. MMC differentiates further into the so-called Half Bridge type and Full Bridge type MMC.

  In offshore HVDC grids, MMC is becoming the preferred power electronic converter for converting between AC and DC since presenting several benefits: (i) ability to reverse the power flow without reversing the polarity of the DC voltages by DC current reversal; (ii) modularity and scalability features make it advantageous compared to other VSC topologies; (iii) its inherent capability of storing energy internally in the converter. This can benefit the system in which it is connected and enables drastic reduction of operating losses of the converter stations, by avoiding the need for high frequency switching of the semi-conductor devices.

Components & enablers

- DC/DC converter
- Transformer (Optional Tapping in series/parallel)
- DC-link capacitors
- Passive high-pass filters
- Phase reactors
- DC cables
- DC breaker (Optional)



Advantages & field of application

The VSC technology provides several technical advantages, such as resilience to commutation failure, ancillary services and reactive power control (and consequently voltage control).

In comparison to the LCC technology, VSC has a shorter history , less operating experience, so far lower maximum voltages and power transfer capability. Although power and voltage ratings have risen dramatically in recent years, the overload capability of VSC technology remains low, limited by the capability of the IGBT devices.

VSC-HVDC is best suited to interconnect remote generation facilities (e.g. offshore wind far away from shore, typically >80 km) to the main power grid; perform a black start to start-up connected offshore wind farms or to re-energize network sections, to contribute to power system and voltages stability thanks to its fast reactive power flow and voltage control at its terminals.

It is expected to support Multi-Terminal HVDC (MTDC) applications forming the backbone of potential offshore grids (like the one in the North Sea) implementation.

To date most VSC applications use submarine or underground cables. The first multi-terminal systems are in operation (in China) and others are under construction (in Europe) and the number of commercial applications is rapidly growing.

Comparison of AC and DC transmission

	Content	AC Transmission	DC Transmission
01	[Definition] What is the ac and dc transmission?	The transmission system which transmits alternating current is called an AC transmission.	The transmission system which transmits direct current is called a DC transmission.
02	Construction of AC & DC Transmission	The construction of AC transmission lines is more complicated.	The construction of DC transmission lines is less complicated.
03	Electric power	In this transmission, electric power can easily generate at high voltage.	In this transmission, electric power cannot easily generate at high voltage because of commutation problems.
04	Conductor	For the high voltage AC (HVAC) transmission, three conductors (i.e. Red, Yellow, and Blue phases) are used.	For the high voltage DC (HVDC) transmission, only two conductors (positive and negative) are used.
05	Insulation	It requires more insulation due to more conductors.	It requires less insulation due to less conductors.
06	Voltage Regulation	The AC transmission can easily increase	The DC transmission can increase and decrease the

		and decrease the voltage level by using a step-up and step-down transformer.	voltage level by using the chopper and booster.
07	Required Factors	For the AC transmission lines, capacitance, inductance, and phase displacement need.	For the DC transmission lines, capacitance, inductance, and phase displacement do not need.
08	Transformer	The transformer is used to regulate the voltage level.	The transformer does not use.
09	Capacitance effect	Due to the presence of capacitance in AC transmission lines, a continuous power loss occurs.	Due to the absence of capacitance in DC transmission lines, less power loss occurs.
10	Inductance effect	The voltage drop is more due to the presence of inductance. So, it does not provide good voltage regulation.	The voltage drop is less due to the absence of inductance. So, it provides good voltage regulation.
11	Skin effect of AC & DC transmission	Skin effect occurs in the AC transmission system.	Skin effect does not occur in the DC transmission system.
12	Corona effect of AC & DC transmission	Corona losses mostly exist in the AC system.	Corona losses rarely exist in the HVDC system.
13	Effects of transmission	Stability and surge effects find in AC	The DC transmission is free from

		transmission.	the stability and surge effects.
14	Required parts	It does not require the rectifier and inverter.	It requires the rectifier and inverter.
15	Installation Cost	Under the construction and maintenance, the AC transmission system is cheap.	Under the construction and maintenance, the DC transmission system is expensive.
16	Distance over power transmission	For short-distance power transmission, the AC transmission system is mostly preferred.	For large-distance power transmission, the DC transmission system is mostly preferred.
17	Maintenance	Maintenance of this system is easy through connected substations.	Maintenance of this system is difficult as compared to the AC system.
18	Reparing	Repairing of AC transmission is very simple over DC transmission.	Repairing of DC transmission is not simple over AC transmission

Solar PV system

Types of solar cells

There are four types of solar cells, which is given below

- Crystalline silicon cells
- Monocrystalline cells
- Polycrystalline cells

- Thin film solar cells

Monocrystalline cells

Monocrystalline solar cells are made from single crystalline silicon. They are very distinctive in their appearance as they are often coloured, and the cells hold a cylindrical shape. In order to keep the costs low and performance at optimal levels, manufacturers cut out the four sides of the monocrystalline cells. This gives them their recognisable appearance.

Advantages

- Here are some of the advantages of monocrystalline solar cells:
- They have the highest level of efficiency at 15-20%
- They require less space compared to other types due to their high efficiency
- Manufacturers state that this form of solar cell lasts the longest, with most giving them a 25-year warranty
- They perform better in low levels of sunlight, making them ideal for cloudy areas

Disadvantages

- Here are some of the disadvantages to monocrystalline solar cells:
- They are the most expensive solar cells on the market, and so not in everyone's price range
- The performance levels tend to suffer from an increase in temperature. However, it is a small loss when compared to other forms of solar cell
- There is a lot of waste material when the silicon is cut during manufacture

Polycrystalline Solar Cells

The polycrystalline solar panels were first introduced to the public in 1981. Unlike the monocrystalline cells, polycrystalline ones do not require each of the four sides to be cut. Instead, the silicon is melted and poured into square moulds. These then form perfectly shaped square cells.

Advantages

Here are some of the advantages of polycrystalline solar cells:

- The manufacturing process is cheaper and easier than the monocrystalline cells
- It avoids silicon waste
- High temperatures have less negative effects on efficiency compared with monocrystalline cells. This makes the polycrystalline cells more attractive to people in warmer areas as the price is lower

Disadvantages

Here are some of the disadvantages to polycrystalline solar cells:

- Efficiency is only around 13-16% due to low levels of silicon purity. So they are not the most efficient on the market
- They have lower output rates which make them less space efficient. So more roof space is needed for installation

Thin Film Solar Cells

Thin film solar cells are manufactured by placing several thin layers of photovoltaic on top of each other to create the module. There are actually a few different types of thin film solar cell, and the way in which they differ from each other comes down to the material used for the PV layers. The types are as follows:

- Amorphous silicon
- Cadmium telluride
- Copper indium gallium selenide
- Organic PV cells

Depending on the technology that has been used, the efficiency rates for thin film solar cells tends to vary from 7% to 13%. Since 2002, the knowledge levels and popularity for thin film solar cells has risen dramatically, which also means that research and development have been increased. Due to this, we can expect future models to hold efficiency rates of 10-16%.

Advantages

Here are some of the advantages of thin film solar cells:

- They can be manufactured to be flexible, making them widely applicable to a range of situations and building types
- Mass production is easy to achieve, making them potentially cheaper to produce than crystalline solar cells
- Shading has a similar effect on their efficiency

Disadvantages

Here are some of the disadvantages of thin film solar cells:

- They are not ideal for domestic use as thy take up a lot of space
- Low space efficiency means that they will cause further expenses in the form of enhancers, like cables of support structures
- They have a shorter lifespan and so shorter warranty periods

Solar cell materials

The basic component of a solar cell is pure silicon, which is not pure in its natural state. Pure silicon is derived from such silicon dioxides as quartzite gravel (the purest silica) or crushed quartz. The resulting pure silicon is then doped (treated with) with phosphorous and boron to produce an excess of electrons and a deficiency of electrons respectively to make a semiconductor capable of conducting electricity. The silicon disks are shiny and require an anti-reflective coating, usually titanium dioxide.

- Amorphous silicon

- Cadmium telluride
- Copper indium gallium selenide
- Organic PV cells

I V characteristics of solar cell

Solar Cell I-V Characteristic Curves show the current and voltage (I-V) characteristics of a particular photovoltaic (PV) cell, module or array giving a detailed description of its solar energy conversion ability and efficiency. Knowing the electrical I-V characteristics (more importantly P_{max}) of a solar cell, or panel is critical in determining the device's output performance and solar efficiency.

Photovoltaic solar cells convert the suns radiant light directly into electricity. With increasing demand for a clean energy source and the sun's potential as a free energy source, has made solar energy conversion as part of a mixture of renewable energy sources increasingly important. As a result, the demand for efficient solar cells, which convert sunlight directly into electricity, is growing faster than ever before.

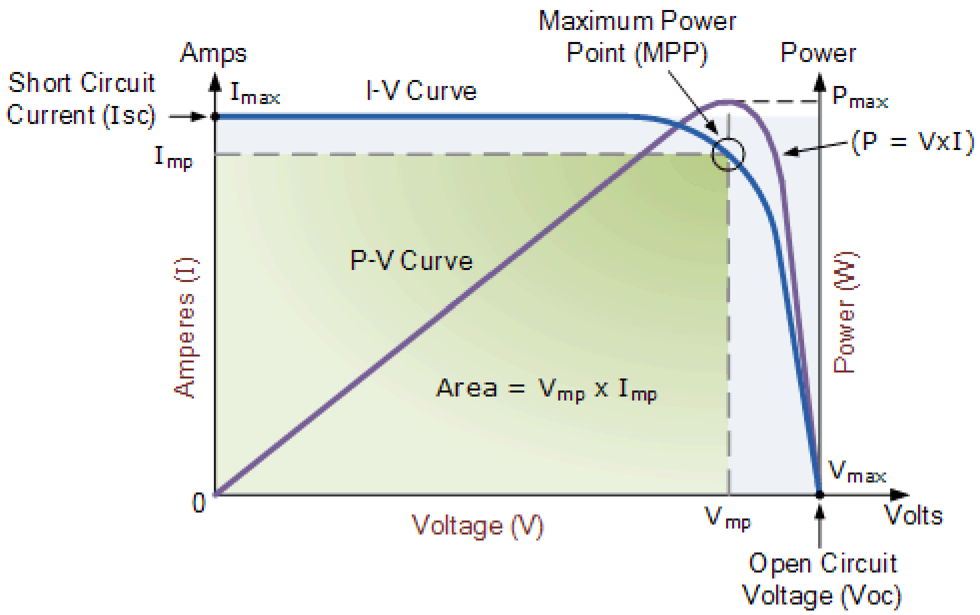
Photovoltaic (PV) cells are made made almost entirely from silicon that has been processed into an extremely pure crystalline form that absorbs the photons from sunlight and then releases them as electrons, causing an electric current to flow when the photoconductive cell is connected to an external load. There are a variety of different measurements we can make to determine the solar cell's performance, such as its power output and its conversion efficiency.

The main electrical characteristics of a PV cell or module are summarized in the relationship between the current and voltage produced on a typical solar cell I-V characteristics curve. The intensity of the solar radiation (insolation) that hits the cell controls the current (I), while the increases in the temperature of the solar cell reduces its voltage (V).

Solar cells produce direct current (DC) electricity and current times voltage equals power, so we can create solar cell I-V curves representing the current versus the voltage for a photovoltaic device.

Solar Cell I-V Characteristics Curves are basically a graphical representation of the operation of a solar cell or module summarising the relationship between the current and voltage at the existing conditions of irradiance and temperature. I-V curves provide the information required to configure a solar system so that it can operate as close to its optimal peak power point (MPP) as possible.

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. The power delivered by a single solar cell or panel is the product of its output current and voltage (I x V). If the multiplication is done, point for point, for all voltages from short-circuit to open-circuit conditions, the power curve above is obtained for a given radiation level.

With the solar cell open-circuited that is not connected to any load the current will be at its minimum (zero) and the voltage across the cell is at its maximum, known as the solar cells **open circuit voltage**, or Voc. At the other extreme, when the solar cell is short circuited, that is the positive and negative leads connected together, the voltage across the cell is at its minimum (zero) but the current flowing out of the cell reaches its maximum, known as the solar cells **short circuit current**, or Isc.

Then the span of the solar cell I-V characteristics curve ranges from the short circuit current (Isc) at zero output volts, to zero current at the full open circuit voltage (Voc). In other words, the maximum voltage available from a cell is at open circuit, and the maximum current at closed circuit. Of course, neither of these two conditions generates any electrical power, but there must be a point somewhere in between was the solar cell generates maximum power.

However, there is one particular combination of current and voltage for which the power reaches its maximum value, at Imp and Vmp. In other words, the point at which the cell generates maximum electrical power and this is shown at the top right area of the green rectangle. This is the “maximum power point” or MPP. Therefore the ideal operation of a photovoltaic cell (or panel) is defined to be at the maximum power point.

The maximum power point (MPP) of a solar cell is positioned near the bend in the I-V characteristics curve. The corresponding values of Vmp and Imp can be estimated from the open circuit voltage and the short circuit current: Vmp ≅ (0.8–0.90)Voc and Imp ≅ (0.85–0.95)Isc. Since solar cell output voltage and current both depend on temperature, the actual output power will vary with changes in ambient temperature.

PV module

PV Module or Solar PV Module is an assembly of photovoltaic (PV) cells, also known as solar cells. To achieve a required voltage and current, a group of PV module**s** (also called PV panels) are wired into large array that called PV array. A PV module is the essential component of any PV system that converts sunlight directly into direct current (DC) electricity. PV modules can be wired together in series and/or parallel to deliver voltage and current in a particular s

Types of PV Module

Crystalline Silicon PV Module

Two types of crystalline silicon (c-Si) are used to produce PV module: single crystalline silicon or known as monocrystalline silicon and multi-crystalline silicon, also called polycrystalline silicon. The polycrystalline silicon PV module has lower conversion efficiency than single crystalline silicon PV module but both of them have high conversion efficiencies that average about 10-12%

Amorphous Silicon PV Module

Amorphous silicon (a-Si) PV module or thin-film silicon PV module absorbs light more effectively than crystalline silicon PV module, so it can be made thinner. It suits for any applications that high efficiency is not required and low cost is important. The typical efficiency of amorphous silicon PV module is around 6%.

PV array

An interconnected system of PV modules that function as a single electricity-producing unit is called PV array.

PV system

A stand alone system the solar panels are not connected to a grid but instead are used to charge a bank of batteries. These batteries store the power produced by the solar panels and then your electrical loads draw their electricity from these batteries. Stand alone solar power systems have been used for a long time in areas where no public grid is available. However, the real growth in solar power systems in the last 5 years has been in grid connects systems. Why is this? Because most people live in areas that are connected to a public grid and stand-alone systems are much, much more expensive than grid connect systems because batteries are very expensive. It is my hope that in the future we will see a fall in battery prices and that stand alone systems will be used more. However, batteries will need to become a lot cheaper for this to happen.

A grid connect system is one that works in with the local utility grid so that when your solar panels produce more solar electricity than your house is using the surplus power is fed into the grid. With a grid connect solar power system when your house requires more power than what your solar panels are producing then the balance of your electricity is supplied by the utility grid. So for example if your electrical loads in your house were consuming 20 amps of power and your solar power was only generating 12 amps then you would be drawing 8 amps from the grid. Obviously at night all of your electrical needs are supplied by the grid because with a grid connect system you do not store the power you generate during the day.

With a standalone solar system the solar panels are not connected to a grid but instead are used to charge a bank of batteries. These batteries store the power produced by the solar panels and then your electrical loads draw their electricity from these batteries. Stand alone solar power systems have been used for a long time in areas where no public grid is available. However, the real growth in solar power systems in the last 5 years has been in grid connects systems. Why is this? Because most people live in areas that are connected to a public grid and stand-alone systems are much, much more expensive than grid connect systems because batteries are very expensive. It is my hope that in the future we will see a fall in battery prices and that stand alone systems will be used more. However, batteries will need to become a lot cheaper for this to happen.

Wind energy

Wind power and its sources

Wind is the movement of air from an area of high pressure to an area of low pressure. In fact, wind exists because the sun unevenly heats the surface of the Earth. As hot air rises, cooler air moves in to fill the void. As long as the sun shines, the wind will blow. And wind has long served as a power source to humans.

SITE SELECTION CONSIDERATION FOR WECS

The power available in the wind increases rapidly with the speed; hence wind energy conversion machines should be located preferable in areas where the winds are strong and persistent. Although daily winds at a given site may be highly variable, the monthly and especially annual average are remarkably constant from year to year.

The major contribution to the wind power available at a given site is actually made by winds with speeds above the average. Nevertheless, the most suitable sites for wind turbines would be found in areas where the annual average wind speeds are known to be moderately high or high.

The site choice for a single or a spatial array of WECS is an important matter when wind electrics is looked at from the systems point of view of aero turbine generators feeding power into a conventional electric grid.

If the WECS sites are wrongly or poorly chosen the net wind electrics generated energy per year may be sub optimal with resulting high capital cost for the WECS apparatus, high costs for wind generated electric energy, and low Returns on Investment. Even if the WECS is to be a small generator not tied to the electric grid, the sitting must be carefully chosen if inordinately long break even times are to be avoided. Technical, Economic, Environmental, Social and Other actors are examined before a decision is made to erect a generating plant on a specific site.

Some of the main site selection consideration is given below:

1. High annual average wind speed:
2. Availability of anemometry data:
3. Availability of wind V(t) Curve at the proposed site:
4. Wind structure at the proposed site:
5. Altitude of the proposed site:
6. Terrain and its aerodynamic:
7. Local Ecology
8. Distance to road or railways:
9. Nearness of site to local centre/users:
10. Nature of ground:
11. Favourable land cost:

Power in the wind

Wind energy is the kinetic energy of air in motion, also called wind. Total wind energy flowing through an imaginary surface with area *A* during the time *t* is:

$E= mv^2 / 2 = (Avt\rho)\ v^2 / 2 = At\rho\ v^3 / 2$

Where ρ is the density of air; v is the wind speed; Avt is the volume of air passing through A (which is considered perpendicular to the direction of the wind); Avtρ is therefore the mass m passing through "A". $\frac{1}{2}\rho v^2$ is the kinetic energy of the moving air per unit volume.

Power is energy per unit time, so the wind power incident on *A* (e.g. equal to the rotor area of a wind turbine) is:

$P = E / t = A\rho\, v^3 / 2$

Wind power in an open air stream is thus proportional to the third power of the wind speed;

Classification of wind turbine and rotor

There are two basic types of wind turbines: those with a horizontal axis, and those with a a vertical axis.

The majority of wind turbines have a horizontal axis: a propeller-style design with blades that rotate around a horizontal axis. Horizontal axis turbines are either upwind (the wind hits the blades before the tower) or downwind (the wind hits the tower before the blades). Upwind turbines also include a yaw drive and motor -- components that turns the nacelle to keep the rotor facing the wind when its direction changes.

While there are several manufacturers of vertical axis wind turbines, they have not penetrated the utility scale market (100 kW capacity and larger) to the same degree as horizontal access turbines. Vertical axis turbines fall into two main designs:

- Drag-based, or Savonius, turbines generally have rotors with solid vanes that rotate about a vertical axis.
- Lift-based, or Darrieus, turbines have a tall, vertical airfoil style (some appear to have an eggbeater shape)

Types of wind rotors

Starting from classical horizontal axis rotors (old windmills), a lot of types of wind rotors were developed as time went on, some of them were excellent. Indeed the first windmills developed in Mesopotamia were built with vertical axis, mounting, radially, some vertical flags. After some centuries and thanks to the deep experience gained, man optimized the rotor reaching excellent results such as the Dutch and Greek windmills.

Wind rotors can be divided into three main groups:

- With horizontal axis
- With vertical axis
- Hybrid

Moreover, wind rotors can be classified into:

RESISTANCE SYSTEMS**:** where the blade offers resistance to the wind which presses on it making it move and generating mechanical energy.

LIFT SYSTEMS**:** where the blade, of aerodynamic form, exploits the lift principle, i.e. the air flow (wind) which allows it to move generating mechanical energy

SYSTEM WITH HORIZONTAL AXIS

In this case the axis is perpendicular to the wind direction and the blades move to the direction of the air flux. The SAVONIUS rotor (from the name of the Finlander J. Savonius who invented it in 1929) is the simplest type. It can be built opposing two half cylinders hinged on the axis of the rotor itself. In this type of rotor a system of orientation of the blades is not necessary; however not all the surface is exposed to the wind. In fact, while a blade collects the air flux and it is pushed, the other one turns to the opposite side, reducing the performance.

The main characteristics of this wind rotor are the following ones:

- front area totally used
- high speed of rotation
- high coefficient of lift
- high power obtainable

Thanks to the high speed of rotation granted by this rotor, the complete system is very simple to be built and to be joined to the electrical generators. However, the propeller demands a refined technology as it has to grant lightness and strength. Moreover, the propeller generator could create some problems: small mistakes in its construction can destroy the whole system, tower included. This is why it is better to keep the turns number low and constant through brakes or aerodynamic solutions of different types.

SYSTEM WITH VERTICAL AXIS

In this case the axis is perpendicular to the wind direction and the blades move to the direction of the air flux. The SAVONIUS rotor (from the name of the Finlander J. Savonius who invented it in 1929) is the simplest type. It can be built opposing two half cylinders hinged on the axis of the rotor itself. In this type of rotor a system of orientation of the blades is not necessary; however not all the surface is exposed to the wind. In fact, while a blade collects the air flux and it is pushed, the other one turns to the opposite side, reducing the performance.

The main characteristics of this wind rotor are the following ones:

- low speed of rotation
- high mechanical torque
- modest performance

There is also an aerodynamic limit which prevents to improve, beyond a certain level, the efficiency of the Savonius rotors. They are proper to mechanical uses as the water pumps. Indeed they are mostly used in rural area.

HYBRID SYSTEMS
They are the youngest and they combine the advantageous characteristics of both the systems with horizontal and vertical axis. In general they are with vertical axis with propellers or blades derived from the previous ones. Here are some examples: the Darrieous rotor, the Cycloturbine, the Ropatec rotor, the rotor with delta flange (see the photo), ext.

The main characteristics of this wind rotor are the following ones:

- **easiness** of construction
- high speed of rotation
- no orientation system
- power coefficients close to the theoretical value