Aircraft Electric Systems

- In Section 1 of this course you will cover these topics:
- Direct Current Power Supplies
- Alternating Current Power Supplies
- Power Conversion Equipment

Topic Objective:

At the end of this topic student will able to learn:

- Direct current
- Low-Voltage Applications
- Power Supply
- Types of direct current
- Commercial electric power transmission
- Various definitions
- Power supply
- Electrical power supplies
- Power supply types
- Linear power supply
- AC/ DC supply
- Switched-mode power supply
- Uninterruptible power supply
- Computer power supply
- Welding power supply
- Switched mode mobile phone charger
- Polarity
- Power conversion

Definition/Overview:

Direct current: Direct current (DC or "continuous current") is the unidirectional flow of electric charge. Direct current is produced by such sources as batteries, thermocouples, solar cells, and commutator-type electric machines of the dynamo type. Direct current may flow in a conductor such as a wire, but can also be through semiconductors, insulators, or even through a vacuum as in electron or ion beams. In direct current, the electric charges flow in the same direction, distinguishing it from alternating current (AC). A term formerly used for direct current was Galvanic current.

Power supply: Power supply is a reference to a source of electrical power. A device or system that supplies electrical or other types of energy to an output load or group of loads is called a power supply unit or PSU. The term is most commonly applied to electrical energy supplies, less often to mechanical ones, and rarely to others.

Key Points:

1. **Direct current**

Direct-current installations usually have different types of sockets, switches, and fixtures, mostly due to the low voltages used, from those suitable for alternating current. It is usually important with a direct-current appliance not to reverse polarity unless the device has a diode bridge to correct for this (most battery-powered devices do not).

2. **Low-Voltage Applications**

DC is commonly found in many low-voltage applications, especially where these are powered by batteries, which can produce only DC, or solar power systems, since solar cells can produce only DC. Most automotive applications use DC, although the alternator is an AC device which uses a rectifier to produce DC. Most electronic circuits require a DC power supply. Applications using fuel cells (mixing hydrogen and oxygen together with a catalyst to produce electricity and water as byproducts) also produce only DC.

Most telephones connect to a twisted pair of wires, and internally separate the AC component of the voltage between the two wires (the audio signal) from the DC component of the voltage between the two wires (used to power the phone).

Telephone exchange communication equipment, such as DSLAM, uses standard -48V DC power supply. The negative polarity is achieved by grounding the positive terminal of power supply system and the battery bank. This is done to prevent electrolysis depositions. An electrified third rail can be used to power both underground (subway) and over ground trains.

3. Power Supply

A power supply (sometimes called a power supply unit or PSU) is a device or system that supplies electrical or other types of energy to an output load or group of loads. The term is most commonly applied to electrical energy supplies, less often to mechanical ones, and rarely to others.

4. Types of Direct Current

Direct current may be obtained from an alternating current supply by use of a current-switching arrangement called a rectifier, which contains electronic elements (usually) or electromechanical elements (historically) that allow current to flow only in one direction. Direct current may be made into alternating current with an inverter or a motor-generator set.

5. Commercial Electric Power Transmission

The first commercial electric power transmission (developed by Thomas Edison in the late nineteenth century) used direct current. Because of the advantage of alternating current over direct current in transforming and transmission, electric power distribution today is nearly all alternating current. For applications requiring direct current, such as third rail power systems, alternating current is distributed to a substation, which utilizes a rectifier to convert the power to direct current.

Direct current is used to charge batteries, and in nearly all electronic systems as the power supply. Very large quantities of direct-current power are used in production of aluminum and other electrochemical processes. Direct current is used for some railway propulsion, especially in urban areas. High voltage direct current is used to transmit large amounts of power from remote generation sites or to interconnect alternating current power grids.

6. Various definitions

Within electrical engineering, the term DC is a synonym for "constant". For example, the voltage across a DC voltage source is constant as is the current through a DC current source. The DC solution of an electric circuit is the solution where all voltages and currents are constant. It can be shown that any voltage or current waveform can be decomposed into a sum of a DC component and a time-varying component. The DC component is defined to be the average value of the voltage or current over all time. The average value of the time-varying component is zero.

Although DC stands for "Direct Current", DC sometimes refers to "constant polarity." With this definition, DC voltages can vary in time, such as the raw output of a rectifier or the fluctuating voice signal on a telephone line. Some forms of DC (such as that produced by a voltage regulator) have almost no variations in voltage, but may still have variations in output power and current.

7. Electrical power supplies

This term covers the power distribution system together with any other primary or secondary sources of energy such as:

- Conversion of one form of electrical power to another desired form and voltage. This typically involves converting 120 or 240 volt AC supplied by a utility company (see electricity generation) to a well-regulated lower voltage DC for electronic devices. Low voltage, low power DC power supply units are commonly integrated with the devices they supply, such as computers and household electronics. For other examples, see switched-mode power supply, linear regulator, rectifier and inverter (electrical).
- Batteries
- Chemical fuel cells and other forms of energy storage systems
- Solar power
- Generators or alternators (particularly useful in vehicles of all shapes and sizes, where the engine has torque to spare, or in semi-portable units containing an internal combustion engine and a generator) (For large-scale power supplies, see electricity generation.)

Constraints that commonly affect power supplies are the amount of power they can supply, how long they can supply it without needing some kind of refueling or recharging, how stable their output voltage or current is under varying load conditions, and whether they provide continuous power or pulses.

The regulation of power supplies is done by incorporating circuitry to tightly control the output voltage and/or current of the power supply to a specific value. The specific value is closely maintained despite variations in the load presented to the power supply's output, or any reasonable voltage variation at the power supply's input. This kind of regulation is commonly categorized as a Stabilized power supply.

8. Power supply types

Power supplies for electronic devices can be broadly divided into linear and switching power supplies. The linear supply is a relatively simple design that becomes increasingly bulky and heavy for high current devices; voltage regulation in a linear supply can result in low efficiency. A switched-mode supply of the same rating as a linear supply will be smaller, is usually more efficient, but will be more complex.

9. Linear power supply

A home-made linear power supply (used here to power amateur radio equipment)

An AC powered linear power supply usually uses a transformer to convert the voltage from the wall outlet (mains) to a different, usually a lower voltage. If it is used to produce DC, a rectifier is used. A capacitor is used to smooth the pulsating current from the rectifier. Some small periodic deviations from smooth direct current will remain, which is known as ripple. These pulsations occur at a frequency related to the AC power frequency (for example, a multiple of 50 or 60 Hz).

The voltage produced by an unregulated power supply will vary depending on the load and on variations in the AC supply voltage. For critical electronics applications a linear regulator will be used to stabilize and adjust the voltage. This regulator will also greatly reduce the ripple and noise in the output DC current. Linear regulators often provide current limiting, protecting the power supply and attached circuit from overcurrent.

Adjustable linear power supplies are common laboratory and service shop test equipment, allowing the output voltage to be set over a wide range. For example, a bench power supply used by circuit designers may be adjustable up to 30 volts and up to 5 amperes output. Some can be driven by an external signal, for example, for applications requiring a pulsed output.

The simplest DC power supply circuit consists of a single diode and resistor in series with the AC supply. This circuit is common in rechargeable flashlights.

10.AC/ DC supply

In the past, mains electricity was supplied as DC in some regions, AC in others. A simple, cheap linear power supply would run directly from either AC or DC mains, often without using a transformer. The power supply consisted of a rectifier and a capacitor filter. The rectifier was essentially a conductor, having no sudden effect when operating from DC.

11.Switched-mode power supply

A switched-mode power supply (SMPS) works on a different principle. AC mains input is directly rectified without the use of a transformer, to obtain a DC voltage. This voltage is then sliced into small pieces by a high-speed electronic switch. The size of these slices grows larger as power output requirements increase.

The input power slicing occurs at a very high speed (typically 10 kHz 1 MHz). High frequency and high voltages in this first stage permit much smaller step down transformers than are in a linear power supply. After the transformer secondary, the AC is again rectified to DC. To keep output voltage constant, the power supply needs a sophisticated feedback controller to monitor current draw by the load.

Modern switched-mode power supplies often include additional safety features such as the crowbar circuit to help protect the device and the user from harm. In the event that an abnormal high current power draw is detected, the switched-mode supply can assume this is a direct short and will shut itself down before damage is done. For decades PC computer power supplies have also provided a power good signal to the motherboard which prevents operation when abnormal supply voltages are present.

Switched mode power supplies have an absolute limit on their minimum current output. They are only able to output above a certain wattage and cannot function below that point. In a no-load condition the frequency of the power slicing circuit increases to great speed, causing the isolation transformer to act as a tesla coil, causing damage due to the resulting very high voltage power spikes. Switched-mode supplies with protection circuits may briefly turn on but then shut down when no load has been detected. A very small low-wattage dummy load such as a ceramic power resistor or 10 watt light bulb can be attached to the supply to allow it to run with no primary load attached.

Power factor has become a recent issue of concern for computer manufacturers. Switched mode power supplies have traditionally been a source of power line harmonics and have a very poor power factor. Many computer power supplies built in the last few years now include power factor correction built right into the switched-mode supply, and may advertise the fact that they offer 1.0 power factor.

By slicing up the sinousoidal AC wave into very small discrete pieces, the portion of the AC current not used stays in the power line as very small spikes of power that cannot be utilized by AC motors and results in waste heating of power line transformers. Hundreds of switched mode power supplies in a building can result in poor power quality for other customers surrounding that building, and high electric bills for the company if they are billed according to their power factor in addition to the kilowatts used. Filtering capacitor banks may be needed on the building power mains to suppress and absorb these negative power factor effects.

12.Uninterruptible power supply

An Uninterruptible Power Supply (UPS) takes its power from two or more sources simultaneously. It is usually powered directly from the AC mains, while simultaneously charging a storage battery. Should there be a dropout or failure of the mains, the battery instantly takes over so that the load never experiences an interruption. Such a scheme can supply power as long as the battery charge suffices, e.g., in a computer installation, giving the operator sufficient time to effect an orderly system shutdown without loss of data. Other UPS schemes may use an internal combustion engine or turbine to continuously supply power to a system in parallel with power coming from the AC mains. The engine-driven generators would normally be idling, but could come to full power in a matter of a few seconds in order to keep vital equipment running without interruption. Such a scheme might be found in hospitals or telephone central offices.

13.Computer power supply

A modern computer power supply is a switched-mode supply designed to convert 110-240 V AC power from the mains supply, to several output both positive (and historically negative) DC voltages in the range 12V to 3.3V. The first computer power supplies were linear devices, but as cost became a driving factor, and weight became important, switched mode supplies are almost universal.

The diverse collection of output voltages also have widely varying current draw requirements, which are difficult to all be supplied from the same switched-mode source. Consequently most modern computer power supplies actually consist of several different switched mode supplies, each producing just one voltage component and each able to vary its output based on component power requirements, and all are linked together to shut down as a group in the event of a fault condition.

The most common modern computer power supplies are built to conform to the ATX form factor. The power rating of a PC power supply is not officially certified and is self-claimed by each manufacturer. A common way to reach the power figure for PC PSUs is by adding the power available on each rail, which will not give a true power figure. The more reputable makers advertise "True Wattage Rated" to give consumers the idea that they can trust the power advertised.

14.Welding power supply

Arc welding uses electricity to melt the surfaces of the metals in order to join them together through coalescence. The electricity is provided by a welding power supply, and can either be AC or DC. Arc welding typically requires high currents of over 80 amps, while spot welding requires currents as high as 12 000 amps. Older welding power supplies consisted of transformers or engines driving generators, while modern ones implement semiconductors and even microprocessors, greatly reducing their size and weight.

15.Switched mode mobile phone charger

A linear or switched-mode power supply (or in some cases just a transformer) that is built into the top of a plug is known as a "wall wart", "power brick", "plug pack", "plug-in adapter", "adapter block", "domestic mains adapter" or just "power adapter". They are even more diverse than their names; often with either the same kind of DC plug offering different voltage or polarity, or a different plug offering the same voltage. "Universal" adapters attempt to replace missing or damaged ones, using multiple plugs and selectors for different voltages and polarities. Replacement power supplies must match the voltage of, and supply at least as much current as, the original power supply.

The least expensive AC units consist solely of a small transformer, while DC adapters include a few additional diodes. Whether or not a load is connected to the power adapter, the transformer has a magnetic field continuously present and normally cannot be completely turned off unless unplugged.

Because they consume standby power, they are sometimes known as "electricity vampires" and may be plugged into a power strip to allow turning them off. Expensive switched-mode power supplies can cut off leaky electrolyte-capacitors, use powerless MOSFETs, and reduce their working frequency to get a gulp of energy once in a while to power, for example, a clock, which would otherwise need a battery.

16.Power conversion

The term "power supply" is sometimes restricted to those devices that convert some other form of energy into electricity (such as solar power and fuel cells and generators). A more accurate term for devices that convert one form of electric power into another form (such as transformers and linear regulators) is power converter. The most common conversion is AC-DC. This is a conversion from the household current AC, to the DC current that is used in your car, and most electronics.

Topic Objective:

At the end of this topic student will able to learn:

- Transmission, distribution, and domestic power supply
- Electricity distribution
- AC power supply frequencies

- Effects at high frequencies
- Techniques for reducing AC resistance
- Techniques for reducing radiation loss

Definition/Overview:

Alternating Current: In alternating current (AC, also ac) the movement (or flow) of electric charge periodically reverses direction. An electric charge would for instance move forward, then backward, then forward, then backward, over and over again. In direct current (DC), the movement (or flow) of electric charge is only in one direction.

Key Points:

1. Alternating Current

Used generically, AC refers to the form in which electricity is delivered to businesses and residences. The usual waveform of an AC power circuit is a sine wave, however in certain applications different waveforms are used, such as triangular or square waves. Audio and radio signals carried on electrical wires are also examples of alternating current. In these applications, an important goal is often the recovery of information encoded (or modulated) onto the AC signal.

2. History

A power transformer developed by Lucien Gaulard of France and John Dixon Gibbs of England was demonstrated in London in 1881, and attracted the interest of Westinghouse. They also exhibited the invention in Turin in 1884, where it was adopted for an electric lighting system. Many of their designs were adapted to the particular laws governing electrical distribution in the

UK. In 1882, 1884, and 1885 Gaulard and Gibbs applied for patents on their transformer; however, these were overturned due to actions initiated by Sebastian Ziani de Ferranti and others.

Ferranti went into this business in 1882 when he set up shop in London designing various electrical devices. Ferranti bet on the success of alternating current power distribution early on, and was one of the few experts in this system in the UK. In 1887 the London Electric Supply Corporation (LESCo) hired Ferranti for the design of their power station at Deptford. He designed the building, the generating plant and the distribution system. On its completion in 1891 it was the first truly modern power station, supplying high-voltage AC power that was then "stepped down" for consumer use on each street. This basic system remains in use today around the world. Many homes all over the world still have electric meters with the Ferranti AC patent stamped on them.

William Stanley, Jr. designed one of the first practical devices to transfer AC power efficiently between isolated circuits. Using pairs of coils wound on a common iron core, his design, called an induction coil, was an early transformer. The AC power system used today developed rapidly after 1886, and includes key concepts by Nikola Tesla, who subsequently sold his patent to George Westinghouse. Lucien Gaulard, John Dixon Gibbs, Carl Wilhelm Siemens and others contributed subsequently to this field. AC systems overcame the limitations of the direct current system used by Thomas Edison to distribute electricity efficiently over long distances even though Edison attempted to discredit alternating current as too dangerous during the War of Currents.

The first commercial power plant in the United States using three-phase alternating current (invented earlier by Nikola Tesla) was at the Mill Creek hydroelectric plant near Redlands, California in 1893 designed by Almirian Decker. Decker's design incorporated 10,000 volt three-phase transmission and established the standards for the complete system of generation, transmission and motors used today.

The first AC power system in Croatia, by Jaruga power plant was set in operation on 28 August 1895 in 20'00 hours, three days after the power plant on the Niagara Falls. The two generators (42 Hz, 550 kW each) and the transformers were produced and installed by the Hungarian company Ganz. The transmission line from the power plant to the City of ibenik was 11.5 km long on wooden towers, and the municipal distribution grid 3000V/110 V included six transforming stations. Jaruga was a first commercial hydro power plant built in Europe, and second in the world.

Alternating current circuit theory evolved rapidly in the latter part of the 19th and early 20th century. Notable contributors to the theoretical basis of alternating current calculations include Charles Steinmetz, James Clerk Maxwell, Oliver Heaviside, and many others. Calculations in unbalanced three-phase systems were simplified by the symmetrical components methods discussed by Charles Legeyt Fortescue in 1918.

3. Transmission, distribution, and domestic power supply

AC voltage may be increased or decreased with a transformer. Use of a higher voltage leads to significantly more efficient transmission of power. The power losses in a conductor are a product of the square of the current and the resistance of the conductor, described by the formula P = I2R. This means that when transmitting a fixed power on a given wire, if the current is doubled, the power loss will be four times greater.

Since the power transmitted is equal to the product of the current and the voltage (assuming no phase difference), the same amount of power can be transmitted with a lower current by increasing the voltage. Therefore it is advantageous when transmitting large amounts of power to distribute the power with high voltages (often hundreds of kilovolts).

High voltage transmission lines deliver power from electric generation plants over long distances using alternating current. These lines are located in eastern Utah.

However, high voltages also have disadvantages, the main one being the increased insulation required, and generally increased difficulty in their safe handling. In a power plant, power is generated at a convenient voltage for the design of a generator, and then stepped up to a high voltage for transmission. Near the loads, the transmission voltage is stepped down to the voltages used by equipment. Consumer voltages vary depending on the country and size of load, but generally motors and lighting are built to use up to a few hundred volts between phases.

The utilization voltage delivered to equipment such as lighting and motor loads is standardized, with an allowable range of voltage over which equipment is expected to operate. Standard power utilization voltages and percentage tolerance vary in the different mains power systems found in the world.

Modern high-voltage, direct-current electric power transmission systems contrast with the more common alternating-current systems as a means for the efficient bulk transmission of electrical power over long distances. HVDC systems, however, tend to be more expensive and less efficient over shorter distances than transformers. Transmission with high voltage direct current was not feasible when Edison, Westinghouse and Tesla were designing their power systems, since there was then no way to economically convert AC power to DC and back again at the necessary voltages.

Three-phase electrical generation is very common. Three separate coils in the generator stator are physically offset by an angle of 120 to each other. Three current waveforms are produced that are equal in magnitude and 120 out of phase to each other.

If the load on a three-phase system is balanced equally among the phases, no current flows through the neutral point. Even in the worst-case unbalanced (linear) load, the neutral current will not exceed the highest of the phase currents. Non-linear loads (e.g. computers) may require an oversized neutral bus and neutral conductor in the upstream distribution panel to handle harmonics. Harmonics can cause neutral conductor current levels to exceed that of one or all phase conductors.

For three-phase at utilization voltages a four-wire system is often used. When stepping down three-phase, a transformer with a Delta (3-wire) primary and a Star (4-wire, centre-earthed) secondary is often used so there is no need for a neutral on the supply side.

For smaller customers (just how small varies by country and age of the installation) only a single phase and the neutral or two phases and the neutral are taken to the property. For larger installations all three phases and the neutral are taken to the main distribution panel. From the three-phase main panel, both single and three-phase circuits may lead off.

Three-wire single phase systems, with a single centre-tapped transformer giving two live conductors, is a common distribution scheme for residential and small commercial buildings in North America. This arrangement is sometimes incorrectly referred to as "two phase". A similar method is used for a different reason on construction sites in the UK. Small power tools and lighting are supposed to be supplied by a local center-tapped transformer with a voltage of 55V between each power conductor and the earth. This significantly reduces the risk of electric shock in the event that one of the live conductors becomes exposed through an equipment fault whilst still allowing a reasonable voltage for running the tools.

A third wire, called the bond wire, is often connected between non-current-carrying metal enclosures and earth ground. This conductor provides protection from electric shock due to accidental contact of circuit conductors with the metal chassis of portable appliances and tools. Bonding all non-current-carrying metal parts into one complete system ensures there is always a low impedance path to ground sufficient to carry any fault current for as long as it takes for the system to clear the fault. This low impedance path allows the maximum amount of fault current, causing the overcurrent protection device (Breakers, fuses) to trip or burn out as quickly as possible, bringing the electrical system to a safe state. All bond wires are bonded to ground at the main service panel, as is the Neutral/Identified conductor if present.

4. AC power supply frequencies

The frequency of the electrical system varies by country; most electric power is generated at either 50 or 60 Hz. See List of countries with mains power plugs, voltages and frequencies. Some countries have a mixture of 50 Hz and 60 Hz supplies, notably Japan. A low frequency eases the design of low speed electric motors, particularly for hoisting, crushing and rolling applications, and commutator-type traction motors for applications such as railways, but also causes a noticeable flicker in incandescent lighting and an objectionable flicker in fluorescent lamps. 16⅔ Hz power is still used in some European rail systems, such as in Austria, Germany, Norway, Sweden and Switzerland. The use of lower frequencies also provided the advantage of lower impedance losses, which are proportional to frequency. The original Niagara Falls generators were built to produce 25 Hz power, as a compromise between low frequency for traction and heavy induction motors, while still allowing incandescent lighting to operate (although with noticeable flicker); most of the 25 Hz residential and commercial customers for Niagara Falls power were converted to 60 Hz by the late 1950s, although some 25 Hz industrial customers still existed as of the start of the 21st century.

Off-shore, military, textile industry, marine, computer mainframe, aircraft, and spacecraft applications sometimes use 400 Hz, for benefits of reduced weight of apparatus or higher motor speeds.

5. Effects at high frequencies

A direct, constant current flows uniformly throughout the cross-section of the (uniform) wire that carries it. With alternating current of any frequency, the current is forced towards the outer surface of the wire, and away from the center. This is because an electric charge which accelerates (as is the case of an alternating current) radiates electromagnetic waves, and materials of high conductivity (the metal which makes up the wire) do not allow propagation of electromagnetic waves. This phenomenon is called skin effect.

At very high frequencies the current no longer flows in the wire, but effectively flows on the surface of the wire, within a thickness of a few skin depths. The skin depth is the thickness at which the current density is reduced by 63%. Even at relatively low frequencies used for high power transmission (5060 Hz), non-uniform distribution of current still occurs in sufficiently thick conductors. For example, the skin depth of a copper conductor is approximately 8.57 mm at 60 Hz, so high current conductors are usually hollow to reduce their mass and cost.

Since the current tends to flow in the periphery of conductors, the effective cross-section of the conductor is reduced. This increases the effective AC resistance of the conductor, since resistance is inversely proportional to the cross-sectional area in which the current actually flows. The AC resistance often is many times higher than the DC resistance, causing a much higher energy loss due to ohmic heating (also called I2R loss).

5.1.Techniques for reducing AC resistance

For low to medium frequencies, conductors can be divided into stranded wires, each insulated from one other, and the individual strands specially arranged to change their relative position within the conductor bundle. Wire constructed using this technique is called Litz wire. This measure helps to partially mitigate skin effect by forcing more equal current flow throughout the total cross section of the stranded conductors. Litz wire is used for making high Q inductors, reducing losses in flexible conductors carrying very high currents at power frequencies, and in the windings of devices carrying higher radio frequency current (up to hundreds of kilohertz), such as switch-mode power supplies and radio frequency transformers.

5.2.Techniques for reducing radiation loss

As written above, an alternating current is made of electric charge under periodic acceleration, which causes radiation of electromagnetic waves. Energy that is radiated represents a loss. Depending on the frequency, different techniques are used to minimize the loss due to radiation.

5.3.Twisted pairs

At frequencies up to about 1 GHz, wires are paired together in cabling to form a twisted pair in order to reduce losses due to electromagnetic radiation and inductive coupling. A twisted pair must be used with a balanced signalling system, where the two wires carry equal but opposite currents. The result is that each wire in the twisted pair radiates a signal that is effectively cancelled by the other wire, resulting in almost no electromagnetic radiation.

5.4.Coaxial cables

At frequencies above 1 GHz, unshielded wires of practical dimensions lose too much energy to radiation, so coaxial cables are used instead. A coaxial cable has a conductive wire inside a conductive tube. The current flowing on the inner conductor is equal and opposite to the current flowing on the inner surface of the outer tube. This causes the electromagnetic field to be completely contained within the tube, and (ideally) no energy is radiated or coupled outside the tube. Coaxial cables have acceptably small losses for frequencies up to about 20 GHz. For microwave frequencies greater than 20 GHz, the dielectric losses (due mainly to the dissipation factor of the dielectric layer which separates the inner wire from the outer tube) become too large, making waveguides a more efficient medium for transmitting energy.

5.5.Waveguides

Waveguides are similar to coax cables, as both consist of tubes, with the biggest difference being that the waveguide has no inner conductor. Waveguides can have any arbitrary cross section, but rectangular cross sections are the most common. Because waveguides do not have an inner conductor to carry a return current, waveguides cannot deliver energy by means of an electric current, but rather by means of a guided electromagnetic field. Although surface currents do flow on the inner walls of the waveguides, those surface currents do not carry power. Power is carried by the guided electromagnetic fields. The surface currents are set up by the guided electromagnetic fields and have the effect of keeping the fields inside the waveguide and preventing leakage of the fields to the space outside the waveguide.

Waveguides have dimensions comparable to the wavelength of the alternating current to be transmitted, so they are only feasible at microwave frequencies. In addition to this mechanical feasibility, electrical resistance of the non-ideal metals forming the walls of the waveguide cause dissipation of power (surface currents flowing on lossy conductors dissipate power). At higher frequencies, the power lost to this dissipation becomes unacceptably large.

5.6.Fiber optics

At frequencies greater than 200 GHz, waveguide dimensions become impractically small, and the ohmic losses in the waveguide walls become large. Instead, fiber optics, which are a form of dielectric waveguides, can be used. For such frequencies, the concepts of voltages and currents are no longer used.

Topic : Power Conversion Equipment

Topic Objective:

At the end of this topic student will able to learn:

- Power Conversion
- Linear power supply
- Switched-Mode power supply
- Uninterruptible power supply
- AC/ DC supply
- Linear power supply
- Power supply types

Definition/Overview:

Power Conversion: In electrical engineering, power conversion has a more specific meaning, namely converting electric power from one form to another. This could be as simple as a transformer to change the voltage of AC power, but also includes far more complex systems. The term can also refer to a class of electrical machinery that is used to convert one frequency of electrical power into another frequency.

Key Points:

1. **Power Conversion**

Energy may be transformed so that it may be used by other natural processes or machines, or else to provide some service to society (such as heat, light, or motion). For example, an internal combustion engine converts the potential chemical energy in gasoline and oxygen into the propulsive energy that moves a vehicle. A solar cell converts solar radiation into electrical energy that can then be used to light a bulb or power a computer. The generic name for a device which converts energy from one form to another is transducer.

2. Power supply types

Power supplies for electronic devices can be broadly divided into linear and switching power supplies. The linear supply is a relatively simple design that becomes increasingly bulky and heavy for high current devices; voltage regulation in a linear supply can result in low efficiency. A switched-mode supply of the same rating as a linear supply will be smaller, is usually more efficient, but will be more complex.

3. Linear power supply

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The voltage produced by an unregulated power supply will vary depending on the load and on variations in the AC supply voltage. For critical electronics applications a linear regulator will be used to stabilize and adjust the voltage. This regulator will also greatly reduce the ripple and noise in the output DC current. Linear regulators often provide current limiting, protecting the power supply and attached circuit from overcurrent.

Adjustable linear power supplies are common laboratory and service shop test equipment, allowing the output voltage to be set over a wide range. For example, a bench power supply used by circuit designers may be adjustable up to 30 volts and up to 5 amperes output. Some can be driven by an external signal, for example, for applications requiring a pulsed output. The simplest DC power supply circuit consists of a single diode and resistor in series with the AC supply. This circuit is common in rechargeable flashlights.

4. AC/ DC supply

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The input power slicing occurs at a very high speed (typically 10 kHz 1 MHz). High frequency and high voltages in this first stage permit much smaller step down transformers than are in a linear power supply. After the transformer secondary, the AC is again rectified to DC. To keep output voltage constant, the power supply needs a sophisticated feedback controller to monitor current draw by the load.

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Switched mode power supplies have an absolute limit on their minimum current output. They are only able to output above certain wattage and cannot function below that point. In a no-load condition the frequency of the power slicing circuit increases to great speed, causing the isolation transformer to act as a tesla coil, causing damage due to the resulting very high voltage power spikes. Switched-mode supplies with protection circuits may briefly turn on but then shut down when no load has been detected. A very small low-wattage dummy load such as a ceramic power resistor or 10 watt light bulb can be attached to the supply to allow it to run with no primary load attached.

Power factor has become a recent issue of concern for computer manufacturers. Switched mode power supplies have traditionally been a source of power line harmonics and have a very poor power factor. Many computer power supplies built in the last few years now include power factor correction built right into the switched-mode supply, and may advertise the fact that they offer 1.0 power factor.

By slicing up the sinousoidal AC wave into very small discrete pieces, the portion of the AC current not used stays in the power line as very small spikes of power that cannot be utilized by AC motors and results in waste heating of power line transformers. Hundreds of switched mode power supplies in a building can result in poor power quality for other customers surrounding that building, and high electric bills for the company if they are billed according to their power factor in addition to the kilowatts used. Filtering capacitor banks may be needed on the building power mains to suppress and absorb these negative power factor effects.

6. Uninterruptible power supply

An Uninterruptible Power Supply (UPS) takes its power from two or more sources simultaneously. It is usually powered directly from the AC mains, while simultaneously charging a storage battery. Should there be a dropout or failure of the mains, the battery instantly takes over so that the load never experiences an interruption. Such a scheme can supply power as long as the battery charge suffices, e.g., in a computer installation, giving the operator sufficient time to effect an orderly system shutdown without loss of data. Other UPS schemes may use an internal combustion engine or turbine to continuously supply power to a system in parallel with power coming from the AC mains. The engine-driven generators would normally be idling, but could come to full power in a matter of a few seconds in order to keep vital equipment running without interruption. Such a scheme might be found in hospitals or telephone central offices.

- In Section 2 of this course you will cover these topics:
- External And Auxiliary Power Supplies
- Power Distribution

Topic Objective:

At the end of this topic student will able to learn:

- Uninterruptible power supply
- Alarm Power Supply Unit
- Power conversion

- Mechanical power supplies
- Rotary
- DC power
- Ferro-resonant
- Hybrid Topology / Double Conversion on Demand
- Double-conversion / online
- Line-interactive
- Offline / standby
- Technologies

Definition/Overview:

Uninterruptible power supply: An uninterruptible power supply (UPS), also known as a battery back-up, provides emergency power and, depending on the topology, line regulation as well to connected equipment by supplying power from a separate source when utility power is not available. It differs from an auxiliary or emergency power system or standby generator, which does not provide instant protection from a momentary power interruption. A UPS, however, can be used to provide uninterrupted power to equipment, typically for 515 minutes until an auxiliary power supply can be turned on or utility power is restored.

Key Points:

1. Uninterruptible power supply

An Uninterruptible Power Supply (UPS) takes its power from two or more sources simultaneously. It is usually powered directly from the AC mains, while simultaneously charging a storage battery. Should there be a dropout or failure of the mains, the battery instantly takes over so that the load never experiences an interruption. Such a scheme can supply power as long as the battery charge suffices, e.g., in a computer installation, giving the operator sufficient time to effect an orderly system shutdown without loss of data. Other UPS schemes may use an internal combustion engine or turbine to continuously supply power to a system in parallel with power coming from the AC mains. The engine-driven generators would normally be idling, but could come to full power in a matter of a few seconds in order to keep vital equipment running without interruption. Such a scheme might be found in hospitals or telephone central offices.

2. Alarm Power Supply Unit

A Alarm Power Supply Unit (APSU) takes its power from the AC mains and converts this to a DC supply while simultaneously charging a 12-24 volt storage battery. During a mains power dropout or failure, the battery instantly takes over so that the load never experiences an interruption. The APSU's main function is to power Network Access Devices (Modems, Switches, and Routers) and includes an IP stack that supports SNMP, UDP, and TCP/IP Alarm monitoring protocols. The APSU can report a mains failure, battery low etc and most importantly reboot the Network Access Devices to ensure the communication gateway is always available. Designed to increase reliability of broadband circuits where failure must be prevented, attended to and reported continuously to any conventional Alarm monitoring service provider.

3. Power conversion

The term "power supply" is sometimes restricted to those devices that convert some other form of energy into electricity (such as solar power and fuel cells and generators). A more accurate term for devices that convert one form of electric power into another form (such as transformers and linear regulators) is power converter. The most common conversion is AC-DC. This is a conversion from the household current AC, to the DC current that is used in your car, and most electronics.

4. Technologies

The general categories of modern UPS systems are on-line, line-interactive, and standby. An on-line UPS uses a "double conversion" method of accepting AC input, rectifying to DC for passing through the battery (or battery strings), then inverting back to AC for powering the protected equipment. A line-interactive UPS maintains the inverter in line and redirects the battery's DC current path from the normal charging mode to supplying current when power is lost. In a standby ("off-line") system the load is powered directly by the input power and the backup power circuitry is only invoked when the utility power fails. Most UPS below 1 kVA are of the line-interactive or standby variety which are usually less expensive.

For large power units, Dynamic Uninterruptible Power Supply are sometimes used. A synchronous motor/alternator is connected on the mains via a choke. Energy is stored in a flywheel. When the mains power fails, an Eddy-current regulation maintains the power on the load. DUPS are sometimes combined or integrated with a diesel-genset, forming a diesel rotary uninterruptible power supply, or DRUPS.

Fuel cell UPS have been developed in recent years using hydrogen and a fuel cell as a power source, potentially providing long run times in a small space. A fuel cell replaces the batteries used in other UPS designs.

5. Offline / standby

The Offline / Standby UPS (SPS) offers only the most basic features, providing surge protection and battery backup. Usually the Standby UPS offers no battery capacity monitoring or self-test capability, making it the least reliable type of UPS since it could fail at any moment without warning. These are also the least expensive, selling for as little as US$40. The SPS may be worse than using nothing at all, because it gives the user a false sense of security of being assured protection that may not work when needed the most.

With this type of UPS, a user's equipment is normally connected directly to incoming utility power with the same voltage transient clamping devices used in a common surge protected plug strip connected across the power line. When the incoming utility voltage falls below a predetermined level the SPS turns on its internal DC-AC inverter circuitry, which is powered from an internal storage battery. The SPS then mechanically switches the connected equipment on to its DC-AC inverter output. The switch over time is stated by most manufacturers as being less than 4 milliseconds, but typically can be as long as 25 milliseconds depending on the amount of time it takes the Standby UPS to detect the lost utility voltage.

6. Line-interactive

The Line-Interactive UPS is similar in operation to a Standby UPS, but with the addition of a multi-tap variable-voltage autotransformer. This is a special type of electrical transformer that can add or subtract powered coils of wire, thereby increasing or decreasing the magnetic field and the output voltage of the transformer.

This type of UPS is able to tolerate continuous undervoltage brownouts and overvoltage surges without consuming the limited reserve battery power. It instead compensates by auto-selecting different power taps on the autotransformer. Changing the autotransformer tap can cause a very brief output power disruption, so the UPS may chirp for a moment, as it briefly switches to battery before changing the selected power tap.

Autotransformers can be engineered to cover a wide range of varying input voltages, but this also increases the number of taps and the size, weight, complexity, and expense of the UPS. It is common for the autotransformer to only cover a range from about 90v to 140v for 120v power, and then switch to battery if the voltage goes much higher or lower than that range.

In low-voltage conditions the UPS will use more current than normal so it may need a higher current circuit than a normal device. For example to power a 1000 watt device at 120 volts, the UPS will draw 8.32 amps. If a brownout occurs and the voltage drops to 100 volts, the UPS will draw 10 amps to compensate. This also works in reverse, so that in an overvoltage condition, the UPS will need fewer amps of current.

7. Double-conversion / online

The Online UPS is ideal for environments where electrical isolation is necessary or for equipment that is very sensitive to power fluctuations. Although once previously reserved for very large installations of 10kW or more, advances in technology have permitted it to now be available as a common consumer device, supplying 500 watts or less. The Online UPS is generally more expensive but may be necessary when the power environment is "noisy" such as in industrial settings, for larger equipment loads like data centers, or when operation from an extended-run backup generator is necessary.

The basic technology of the online UPS is the same as in a Standby or Line-Interactive UPS. However it typically costs much more, due to it having a much greater current AC-to-DC battery-charger/rectifier, and with the rectifier and inverter designed to run continuously with improved cooling systems. It is called a Double-Conversion UPS due to the rectifier directly driving the inverter, even when powered from normal AC current.

In an Online UPS, the batteries are always connected to the inverter, so that no power transfer switches are necessary. When power loss occurs, the rectifier simply drops out of the circuit and the batteries keep the power steady and unchanged. When power is restored, the rectifier resumes carrying most of the load and begins charging the batteries, though the charging current may be limited to prevent the high-power rectifier from overheating the batteries and boiling off the electrolyte.

The main advantage to the on-line UPS is its ability to provide an electrical firewall between the incoming utility power and sensitive electronic equipment. While the Standby and Line-Interactive UPS merely filters the input utility power, the Double-Conversion UPS provides a layer of insulation from power quality problems. It allows control of output voltage and frequency regardless of input voltage and frequency.

8. Hybrid Topology / Double Conversion on Demand

Recently there has been hybrid topology UPSs hitting the marketplace. These hybrid designs do not have an official designation, although one named used by HP and Eaton is Double Conversion on Demand. This style of UPS is targeted towards high efficiency applications while still maintaining the features and protection level offered by double conversion.

A hybrid (double conversion on demand) UPS operates as an offline/standby UPS when power conditions are within a certain preset window. This allows the UPS to achieve very high efficiency ratings. When the power conditions fluctuate outside of the predefined windows, the UPS switches to online/double conversion operation. In double conversion mode the UPS can adjust for voltage variations without having to use battery power, can filter out line noise and control frequency. Examples of this hybrid/double conversion on demand UPS design are the HP R8000, HP R12000, HP RP12000/3 and the Eaton BladeUPS.

9. Ferro-resonant

Ferro-resonant units operate in the same way as a standby UPS unit with the exception that a ferro-resonant transformer is used to filter the output. This transformer is designed to hold energy long enough to cover the time between switching from line power to battery power and effectively eliminates the transfer time. Many ferro-resonant UPSs are 90-93% efficient and offer excellent isolation.

This used to be the dominant type of UPS and is limited to around the 15KVA range. These units are still mainly used in some industrial settings due to the robust nature of the UPS. Many ferro-resonant UPSs utilizing controlled ferro technology may not interact with power-factor-correcting equipment.

10. DC power

A UPS designed for powering DC equipment is very similar to an online UPS, except that it does not need an output inverter, and often the powered device does not need a power supply. Rather than converting AC to DC to charge batteries, then DC to AC to power the external device, and then back to DC inside the powered device, some equipment accepts DC power directly and allows one or more conversion steps to be eliminated. This equipment is more commonly known as a rectifier.

Many systems used in telecommunications use 48 volt DC power, because it is not considered a high-voltage by most electrical codes and is exempt from many safety regulations, such as being installed in conduit and junction boxes. DC has typically been the dominant power source for telecommunications, and AC has typically been the dominant source for computers and servers.

There has been much experimentation with 48v DC power for computer servers, in the hope of reducing the likelihood of failure and the cost of equipment. However, to supply the same amount of power, the current must be greater than an equivalent 120v or 240v circuit, and greater current requires larger conductors and/or more energy to be lost as heat.

High voltage DC (380 volts) is finding use in some data center applications, and allows for small power conductors, but is subject to the more complex electrical code rules for safe containment of high voltages.

11. Rotary

A Rotary UPS uses the inertia of a high-mass spinning flywheel to provide short-term ride-through in the event of power loss. The flywheel also acts as a buffer against power spikes and sags, since such short-term power events are not able to appreciably affect the rotational speed of the high-mass flywheel. It is also one of the oldest designs, predating vacuum tubes and integrated circuits.

It can be considered to be online since it spins continuously under normal conditions. However, unlike an electronic double-conversion UPS, it is only capable of providing reserve power for a few seconds before the flywheel has slowed and the protection fails. It is traditionally used in conjunction with standby diesel generators, providing backup power only for the brief period of time the engine needs to start running and stabilize its output.

The Rotary UPS is generally reserved for applications needing more than 10,000 watts of protection, to justify the expense of an extremely large and heavy power system that can only be transported by forklift or crane. A larger flywheel or multiple flywheels operating in parallel will increase the reserve running time, but at greatly increasing cost due to the size and weight of the precision-balanced flywheels.

Because the flywheels are a mechanical power source, it is not necessary to use an electric motor or generator as an intermediary between it and a diesel engine designed to provide emergency power. By using a transmission gearbox, the rotational inertia of the flywheel can be used to directly start up a diesel engine, and once running, the diesel engine can be used to directly spin the flywheel. Multiple flywheels can likewise be connected in parallel through mechanical countershafts, without the need for separate motors and generators for each flywheel.

They are normally designed to provide very high current output compared to a purely electronic UPS, and are better able to provide inrush current for inductive loads such as motor startup or compressor loads, as well as medical MRI and cath lab equipment. It is also able to tolerate short-circuit conditions up 17 times larger than an electronic UPS, permitting one device to blow a fuse and fail while other devices still continue to be powered from the Rotary UPS.

Its life cycle is usually far greater than a purely electronic UPS, up to 30 years or more. But they do require periodic downtime for mechanical maintenance (ball bearing replacement), while solid-state designs, using batteries, do not require downtime if the batteries can be hot-swapped, which is usually the case for larger units.

Topic Objective:

At the end of this topic student will able to learn:

- Electricity distribution
- Transmission, distribution, and domestic power supply
- Electricity distribution
- AC power supply frequencies
- Effects at high frequencies
- Techniques for reducing AC resistance
- Techniques for reducing radiation loss
- Modern distribution systems
- High Voltage DC

- Economic and political

Definition/Overview:

Electricity distribution: Electricity distribution is the final stage in the delivery (before retail) of electricity to end users. A distribution system's network carries electricity from the transmission system and delivers it to consumers. Typically, the network would include medium-voltage (less than 50 kV) power lines, electrical substations and pole-mounted transformers, low-voltage (less than 1000 V) distribution wiring and sometimes electricity meters.

Key Points:

1. Electricity distribution

In the early days of electricity distribution, direct current (DC) generators were connected to loads at the same voltage. The generation, transmission and loads had to be of the same voltage because there was no way of changing DC voltage levels, other than inefficient motor-generator sets. Low DC voltages were used (on the order of 100 volts) since that was a practical voltage for incandescent lamps, which were the primary electrical load. Low voltage also required less insulation for safe distribution within buildings.

The losses in a cable are proportional to the square of the current, the length of the cable, and the resistivity of the material, and are inversely proportional to cross-sectional area. Early transmission networks used copper, which is one of the best economically feasible conductors for this application. To reduce the current and copper required for a given quantity of power transmitted would require a higher transmission voltage, but no efficient method existed to change the voltage of DC power circuits. To keep losses to an economically practical level the Edison DC system needed thick cables and local generators. Early DC generating plants needed to be within about 1.5 miles (2.4 km) of the farthest customer to avoid excessively large and expensive conductors.

2. History

A power transformer developed by Lucien Gaulard of France and John Dixon Gibbs of England was demonstrated in London in 1881, and attracted the interest of Westinghouse. They also exhibited the invention in Turin in 1884, where it was adopted for an electric lighting system. Many of their designs were adapted to the particular laws governing electrical distribution in the UK. In 1882, 1884, and 1885 Gaulard and Gibbs applied for patents on their transformer; however, these were overturned due to actions initiated by Sebastian Ziani de Ferranti and others.

Ferranti went into this business in 1882 when he set up shop in London designing various electrical devices. Ferranti bet on the success of alternating current power distribution early on, and was one of the few experts in this system in the UK. In 1887 the London Electric Supply Corporation (LESCo) hired Ferranti for the design of their power station at Deptford. He designed the building, the generating plant and the distribution system. On its completion in 1891 it was the first truly modern power station, supplying high-voltage AC power that was then "stepped down" for consumer use on each street. This basic system remains in use today around the world. Many homes all over the world still have electric meters with the Ferranti AC patent stamped on them.

William Stanley, Jr. designed one of the first practical devices to transfer AC power efficiently between isolated circuits. Using pairs of coils wound on a common iron core, his design, called an induction coil, was an early transformer. The AC power system used today developed rapidly after 1886, and includes key concepts by Nikola Tesla, who subsequently sold his patent to George Westinghouse. Lucien Gaulard, John Dixon Gibbs, Carl Wilhelm Siemens and others contributed subsequently to this field. AC systems overcame the limitations of the direct current system used by Thomas Edison to distribute electricity efficiently over long distances even though Edison attempted to discredit alternating current as too dangerous during the War of Currents.

The first commercial power plant in the United States using three-phase alternating current (invented earlier by Nikola Tesla) was at the Mill Creek hydroelectric plant near Redlands, California in 1893 designed by Almirian Decker. Decker's design incorporated 10,000 volt three-phase transmission and established the standards for the complete system of generation, transmission and motors used today.

The first AC power system in Croatia, by Jaruga power plant was set in operation on 28 August 1895 in 20'00 hours, three days after the power plant on the Niagara Falls. The two generators (42 Hz, 550 kW each) and the transformers were produced and installed by the Hungarian company Ganz. The transmission line from the power plant to the City of ibenik was 11.5 km long on wooden towers, and the municipal distribution grid 3000V/110 V included six transforming stations. Jaruga was a first commercial hydro power plant built in Europe, and second in the world.

Alternating current circuit theory evolved rapidly in the latter part of the 19th and early 20th century. Notable contributors to the theoretical basis of alternating current calculations include Charles Steinmetz, James Clerk Maxwell, Oliver Heaviside, and many others. Calculations in unbalanced three-phase systems were simplified by the symmetrical components methods discussed by Charles Legeyt Fortescue in 1918.

3. Transmission, distribution, and domestic power supply

AC voltage may be increased or decreased with a transformer. Use of a higher voltage leads to significantly more efficient transmission of power. The power losses in a conductor are a product of the square of the current and the resistance of the conductor, described by the formula P = I2R. This means that when transmitting a fixed power on a given wire, if the current is doubled, the power loss will be four times greater.

Since the power transmitted is equal to the product of the current and the voltage (assuming no phase difference), the same amount of power can be transmitted with a lower current by increasing the voltage. Therefore it is advantageous when transmitting large amounts of power to distribute the power with high voltages (often hundreds of kilovolts). High voltage transmission lines deliver power from electric generation plants over long distances using alternating current. These lines are located in eastern Utah.

However, high voltages also have disadvantages, the main one being the increased insulation required, and generally increased difficulty in their safe handling. In a power plant, power is generated at a convenient voltage for the design of a generator, and then stepped up to a high voltage for transmission. Near the loads, the transmission voltage is stepped down to the voltages used by equipment. Consumer voltages vary depending on the country and size of load, but generally motors and lighting are built to use up to a few hundred volts between phases.

The utilization voltage delivered to equipment such as lighting and motor loads is standardized, with an allowable range of voltage over which equipment is expected to operate. Standard power utilization voltages and percentage tolerance vary in the different mains power systems found in the world.

Modern high-voltage, direct-current electric power transmission systems contrast with the more common alternating-current systems as a means for the efficient bulk transmission of electrical power over long distances. HVDC systems, however, tend to be more expensive and less efficient over shorter distances than transformers. Transmission with high voltage direct current was not feasible when Edison, Westinghouse and Tesla were designing their power systems, since there was then no way to economically convert AC power to DC and back again at the necessary voltages.

Three-phase electrical generation is very common. Three separate coils in the generator stator are physically offset by an angle of 120 to each other. Three current waveforms are produced that are equal in magnitude and 120 out of phase to each other.

If the load on a three-phase system is balanced equally among the phases, no current flows through the neutral point. Even in the worst-case unbalanced (linear) load, the neutral current will not exceed the highest of the phase currents. Non-linear loads (e.g. computers) may require an oversized neutral bus and neutral conductor in the upstream distribution panel to handle harmonics. Harmonics can cause neutral conductor current levels to exceed that of one or all phase conductors.

For three-phase at utilization voltages a four-wire system is often used. When stepping down three-phase, a transformer with a Delta (3-wire) primary and a Star (4-wire, centre-earthed) secondary is often used so there is no need for a neutral on the supply side.

For smaller customers (just how small varies by country and age of the installation) only a single phase and the neutral or two phases and the neutral are taken to the property. For larger installations all three phases and the neutral are taken to the main distribution panel. From the three-phase main panel, both single and three-phase circuits may lead off.

Three-wire single phase systems, with a single centre-tapped transformer giving two live conductors, is a common distribution scheme for residential and small commercial buildings in North America. This arrangement is sometimes incorrectly referred to as "two phase". A similar method is used for a different reason on construction sites in the UK. Small power tools and lighting are supposed to be supplied by a local center-tapped transformer with a voltage of 55V between each power conductor and the earth. This significantly reduces the risk of electric shock in the event that one of the live conductors becomes exposed through an equipment fault whilst still allowing a reasonable voltage for running the tools.

A third wire, called the bond wire, is often connected between non-current-carrying metal enclosures and earth ground. This conductor provides protection from electric shock due to accidental contact of circuit conductors with the metal chassis of portable appliances and tools. Bonding all non-current-carrying metal parts into one complete system ensures there is always a low impedance path to ground sufficient to carry any fault current for as long as it takes for the system to clear the fault. This low impedance path allows the maximum amount of fault current, causing the overcurrent protection device (Breakers, fuses) to trip or burn out as quickly as possible, bringing the electrical system to a safe state. All bond wires are bonded to ground at the main service panel, as is the Neutral/Identified conductor if present.

4. AC power supply frequencies

The frequency of the electrical system varies by country; most electric power is generated at either 50 or 60 Hz. See List of countries with mains power plugs, voltages and frequencies. Some countries have a mixture of 50 Hz and 60 Hz supplies, notably Japan. A low frequency eases the design of low speed electric motors, particularly for hoisting, crushing and rolling applications, and commutator-type traction motors for applications such as railways, but also causes a noticeable flicker in incandescent lighting and an objectionable flicker in fluorescent lamps. 16⅔ Hz power is still used in some European rail systems, such as in Austria, Germany, Norway, Sweden and Switzerland. The use of lower frequencies also provided the advantage of lower impedance losses, which are proportional to frequency. The original Niagara Falls generators were built to produce 25 Hz power, as a compromise between low frequency for traction and heavy induction motors, while still allowing incandescent lighting to operate (although with noticeable flicker); most of the 25 Hz residential and commercial customers for Niagara Falls power were converted to 60 Hz by the late 1950s, although some 25 Hz industrial customers still existed as of the start of the 21st century.

Off-shore, military, textile industry, marine, computer mainframe, aircraft, and spacecraft applications sometimes use 400 Hz, for benefits of reduced weight of apparatus or higher motor speeds.

5. Effects at high frequencies

A direct, constant current flows uniformly throughout the cross-section of the (uniform) wire that carries it. With alternating current of any frequency, the current is forced towards the outer surface of the wire, and away from the center. This is because an electric charge which accelerates (as is the case of an alternating current) radiates electromagnetic waves, and materials of high conductivity (the metal which makes up the wire) do not allow propagation of electromagnetic waves. This phenomenon is called skin effect.

At very high frequencies the current no longer flows in the wire, but effectively flows on the surface of the wire, within a thickness of a few skin depths. The skin depth is the thickness at which the current density is reduced by 63%. Even at relatively low frequencies used for high power transmission (5060 Hz), non-uniform distribution of current still occurs in sufficiently thick conductors. For example, the skin depth of a copper conductor is approximately 8.57 mm at 60 Hz, so high current conductors are usually hollow to reduce their mass and cost.

Since the current tends to flow in the periphery of conductors, the effective cross-section of the conductor is reduced. This increases the effective AC resistance of the conductor, since resistance is inversely proportional to the cross-sectional area in which the current actually flows. The AC resistance often is many times higher than the DC resistance, causing a much higher energy loss due to ohmic heating (also called I2R loss).

5.1.Techniques for reducing AC resistance

For low to medium frequencies, conductors can be divided into stranded wires, each insulated from one other, and the individual strands specially arranged to change their relative position within the conductor bundle. Wire constructed using this technique is called Litz wire. This measure helps to partially mitigate skin effect by forcing more equal current flow throughout the total cross section of the stranded conductors. Litz wire is used for making high Q inductors, reducing losses in flexible conductors carrying very high currents at power frequencies, and in the windings of devices carrying higher radio frequency current (up to hundreds of kilohertz), such as switch-mode power supplies and radio frequency transformers.

5.2.Techniques for reducing radiation loss

As written above, an alternating current is made of electric charge under periodic acceleration, which causes radiation of electromagnetic waves. Energy that is radiated represents a loss. Depending on the frequency, different techniques are used to minimize the loss due to radiation.

5.3.Twisted pairs

At frequencies up to about 1 GHz, wires are paired together in cabling to form a twisted pair in order to reduce losses due to electromagnetic radiation and inductive coupling. A twisted pair must be used with a balanced signalling system, where the two wires carry equal but opposite currents. The result is that each wire in the twisted pair radiates a signal that is effectively cancelled by the other wire, resulting in almost no electromagnetic radiation.

5.4.Coaxial cables

At frequencies above 1 GHz, unshielded wires of practical dimensions lose too much energy to radiation, so coaxial cables are used instead. A coaxial cable has a conductive wire inside a conductive tube. The current flowing on the inner conductor is equal and opposite to the current flowing on the inner surface of the outer tube. This causes the electromagnetic field to be completely contained within the tube, and (ideally) no energy is radiated or coupled outside the tube. Coaxial cables have acceptably small losses for frequencies up to about 20 GHz. For microwave frequencies greater than 20 GHz, the dielectric losses (due mainly to the dissipation factor of the dielectric layer which separates the inner wire from the outer tube) become too large, making waveguides a more efficient medium for transmitting energy.

5.5.Waveguides

Waveguides are similar to coax cables, as both consist of tubes, with the biggest difference being that the waveguide has no inner conductor. Waveguides can have any arbitrary cross section, but rectangular cross sections are the most common. Because waveguides do not have an inner conductor to carry a return current, waveguides cannot deliver energy by means of an electric current, but rather by means of a guided electromagnetic field. Although surface currents do flow on the inner walls of the waveguides, those surface currents do not carry power. Power is carried by the guided electromagnetic fields. The surface currents are set up by the guided electromagnetic fields and have the effect of keeping the fields inside the waveguide and preventing leakage of the fields to the space outside the waveguide.

Waveguides have dimensions comparable to the wavelength of the alternating current to be transmitted, so they are only feasible at microwave frequencies. In addition to this mechanical feasibility, electrical resistance of the non-ideal metals forming the walls of the waveguide cause dissipation of power (surface currents flowing on lossy conductors dissipate power). At higher frequencies, the power lost to this dissipation becomes unacceptably large.

5.6.Fiber optics

At frequencies greater than 200 GHz, waveguide dimensions become impractically small, and the ohmic losses in the waveguide walls become large. Instead, fiber optics, which are a form of dielectric waveguides, can be used. For such frequencies, the concepts of voltages and currents are no longer used.

6. Modern distribution systems

Electric distribution substations transform power from transmission voltage to the lower voltage used for local distribution to homes and businesses The modern distribution system begins as the primary circuit leaves the sub-station and ends as the secondary service enters the customer's meter socket. A variety of methods, materials, and equipment are used among the various utility companies, but the end result is similar. First, the energy leaves the sub-station in a primary circuit, usually with all three phases.

The most common type of primary is known as a wye configuration (so named because of the shape of a "Y".) The wye configuration includes 3 phases (represented by the three outer parts of the "Y") and a neutral (represented by the center of the "Y".) The neutral is grounded both at the substation and at every power pole. In a typical 12470Y/7200 volt system, the pole mount transformer's primary winding is rated for 7200 volts and is connected across one phase of power and the neutral. The primary and secondary (low voltage) neutrals are bonded (connected) together to provide a path to blow the primary fuse if any fault occurs that allows primary voltage to enter the secondary lines. An example of this type of fault would be a primary phase falling across the secondary lines. Another example would be some type of fault in the transformer itself.

The other type of primary configuration is known as delta. This method is older and less common. Delta is so named because of the shape of the Greek letter delta, a triangle. Delta has only 3 phases and no neutral. In delta there is only a single voltage, between two phases (phase to phase), while in wye there are two voltages, between two phases and between a phase and neutral (phase to neutral). Wye primary is safer because if one phase becomes grounded, that is, makes connection to the ground through a person, tree, or other object, it should trip out the fused cutout similar to a household circuit breaker tripping. In delta, if a phase makes connection to ground it will continue to function normally. It takes two or three phases to make connection to ground before the fused cutouts will open the circuit. The voltage for this configuration is usually 4800 volts. Transformers are sometimes used to step down from 7200 or 7600 volts to 4800 volts or to step up from 4800 volts to 7200 or 7600 volts. When the voltage is stepped up, a neutral is created by bonding one leg of the 7200/7600 side to ground. This is commonly used to power single phase underground services or whole housing developments that are built in 4800 volt delta distribution areas. Step downs are used in areas that have been upgraded to a 7200/12500Y or 7600/13200Y and the power company chooses to leave a section as a 4800 volt setup. Sometimes power companies choose to leave sections of a distribution grid as 4800 volts because this setup is less likely to trip fuses or reclosers in heavily wooded areas where trees come into contact with lines.

7. High Voltage DC

New technology using static inverters allows high voltage DC to be converted to high voltage AC. High Voltage DC transmission has several advantages over AC lines. It requires only two conductors instead of six, does not suffer from skin effect and has lower capacitive and inductive losses when used underground. HVDC is more expensive than AC but is cost competitive if used over long distances or underground.

8. Economic and political

Traditionally the electricity industry has been a publicly owned institution but starting in the 1970s nations began the process of deregulation and privatisation, leading to electricity markets. A major focus of these was the elimination of the former so called natural monopoly of generation, transmission, and distribution. As a consequence, electricity has become more of a commodity. The separation has also led to the development of new terminology to describe the business units, e.g. line company, wires business and network company.

- In Section 3 of this course you will cover these topics:
- Circuit Controlling Devices
- Circuit Protection Devices And Systems

Topic Objective:

At the end of this topic student will able to learn:

- Electrical Circuit
- Principles and operation
- The basic circuit
- Circuits under electrification
- Jointless track circuits
- CSEE UM71
- DPU
- Wheels and brakes
- Circuit failures
- Railhead contamination
- Track circuit clips
- Transmission of status

Definition/Overview:

Electrical Circuit: An electrical circuit is a network that has a closed loop, giving a return path for the current. A network is a connection of two or more components, and may not necessarily be a circuit.

Key Points:

1. Electrical Circuit

In electronics, components of an electronic circuit can be connected in series or in parallel. Components connected in series are connected along a single path, so the same current flows through all of the components. Components connected in parallel are connected so the same voltage is applied to each component. A circuit composed solely of components connected in series is known as a series circuit; likewise, one connected completely in parallel is known as a parallel circuit.

In a series circuit, the current through each of the components is the same, and the voltage across the components is the sum of the voltages across all the components. In a parallel circuit, the voltage across each of the components is the same, and the total current is the sum of the currents through all the components.

As an example, consider a very simple circuit consisting of four light bulbs and one 6 V battery. If a wire joins the battery to one bulb, to the next bulb, to the next bulb, to the next bulb, then back to the battery, in one continuous loop, the bulbs are said to be in series. If each bulb is wired to the battery in a separate loop, the bulbs are said to be in parallel. If the four light bulbs are connected in series, the same current flows through all of them, and the voltage drop is 1.5 V across each bulb. If the light bulbs are connected in parallel, the current flowing through the light bulbs combine to form the current flowing in the battery, while the voltage drop is 6 V across each bulb.

In a series circuit, every device must function for the circuit to be complete. One bulb burning out in a series circuit kills the circuit. In parallel circuits, each light has its own circuit, so all but one light could be burned out, and the last one will still function.

2. Principles and operation

The basic principle behind the track circuit lies in the connection of the two rails by the wheels and axle of locomotives and rolling stock to short out an electrical circuit. This circuit is monitored by electrical equipment to detect the presence or absence of the trains. Since this is a safety appliance, fail-safe operation is crucial; therefore the circuit is designed to indicate the presence of a train when failures occur. On the other hand, false occupancy readings are disruptive to railroad operations and are to be minimized.

Track circuits allow railway signalling systems to operate semi-automatically, by displaying signals for trains to slow down or stop in the presence of occupied track ahead of them. They help prevent dispatchers and operators from causing accidents, both by informing them of track occupancy and by preventing signals from displaying unsafe indications.

3. The basic circuit

A track circuit typically has power applied to each rail and a relay coil wired across them. Each circuit detects a defined section of track, such as a block. These sections are separated by insulated joints, usually in both rails. To prevent one circuit from falsely powering another in the event of insulation failure, the electrical polarity is usually reversed from section to section. Circuits are commonly battery-powered at low voltages (1.5 to 12 V DC) to protect against line power failures. The relays and the power supply are attached to opposite ends of the section in order to prevent broken rails from electrically isolating part of the track from the circuit.

When no train is present, the relay is energised by the current flowing from the power source through the rails. When a train is present, its axles short (shunt) the rails together; the current to the track relay coil drops, and it is de-energised. Circuits through the relay contacts therefore report whether or not the track is occupied.

4. Circuits under electrification

In almost all railway electrification schemes one or both of the rails are used to carry the return current. This prevents use of the basic DC track circuit because the substantial traction currents overwhelm the very small track signal currents.

To accommodate this, AC track circuits use alternating current signals instead of DC currents. Typically, the AC frequency is in the range of audio frequencies, from 91 Hz up to a 250 Hz. The relays are arranged to detect the selected frequency and to ignore DC and AC traction frequency signals. Again, fail safe principles dictate that the relay interprets the presence of the signal as unoccupied track, whereas a lack of a signal indicates the presence of a train. The AC signal can be coded and locomotives equipped with inductive pickups to create a cab signalling system.

In this system, impedance bonds are used to connect items which must be electrically connected for electrification purposes but which must remain isolated to track circuit frequencies for the track circuit to function. AC circuits are sometimes used in areas where conditions introduce stray currents which interfere with DC track circuits.

In some countries, AC-immune DC track circuits are used on AC electrified lines. One method provides 5V DC to the rails, one of the rails being the traction return and the other being the signal rail. When a relay is energised and attached to the track, normal voltage is 5V DC. When there is a break in the circuit and there is no train, the voltage rises to 9V DC which provides a very good means for fault finding. This system filters out the voltage induced in the rails from the overhead lines.

5. Jointless track circuits

Jointless track circuits use audio frequency tuned circuits to create what amounts to a block joint to signalling frequency currents and a very low impedance to electrification power frequency currents.

Frequencies of the Aster SF 15 type track circuit are 1700 Hz and 2300 Hz on one track and 2000 Hz and 2600 Hz on the other. SF stands for Single Frequency and was the name given to the units made under licence by ML Engineering in Plymouth, UK. The original Aster track circuits were made by the Aster company in France. These frequencies are by definition unmodulated.

TI21 type track circuits use eight nominal frequencies, from 1549 Hz to 2593 Hz. Actual transmission is +/- 17Hz around the nominal frequency. The signal is FSK modulated at 4.8Hz unless overridden by the MOD terminal on the front panel. TI stands for 'traction immune' and was the name used by ML Engineering in Plymouth. ML Engineering was taken over by various companies and is currently owned by Bombardier Transportation.

To simplify traction pack design in locomotives many track circuit manufacturers now transmit a unique code from the transmitter to the receiver. Such systems include the Siemens FTG S, Westinghouse (Invensys) FS3000 and Bombardier EBI Track 400. Coding prevents interference from affecting both the safety and availability of the track circuit.

6. CSEE UM71

CSEE are another kind of jointless track circuit. It uses 1700Hz and 2300Hz on one track and 2000Hz and 2600Hz on the other. To reduce the chance of stray currents causing a wrong side failure the basic frequencies are modulated +/15 Hz or so. Different rates of modulation can be detected by eqiuipment on the trains and used for ATC.

7. DPU

A jointless track circuit such as the CSEE can be divided with a Data Pickup Unit (DPU), which is cheaper than splitting it into two track circuits. The DPU consists of a tuned coil which detects the presence or absence of current in the adjacent rail and picks up or drops a relay accordingly. One use of DPUs is for timing circuits.

8. Wheels and brakes

Railway wheels are made from steel and provide a good short circuit from rail to rail. An exception would be wooden hubs on some wheels of early English railways which would not operate track circuits at all.

The longer the train and the more wheels the better. Short trains or single engines can be a problem. Single Budd railmotors which are lightweight had some problems when they stopped, and had to make a double stop to ensure good contact with the rails. Cast iron brake blocks tend to clean the wheels of non-conductive debris (for example leaf mulch and sand-based compounds applied to the rails to improve adhesion in icy conditions), while disc brakes do not.

9. Circuit failures

Failure modes that result in an incorrect "track clear" signal may allow a train to enter an occupied block, creating the risk of a collision. Wheel scale and short trains may also be a problem. They may also cause the warning systems at a grade crossing to fail to activate. This is why in UK practice, a treadle is also used in the circuitry.

Different means are used to respond to these types of failures. For example, the relays are designed to a very high level of reliability. In areas with electrical problems different types of track circuits may be used which are less susceptible to interference. Speeds may be restricted when and where fallen leaves are an issue. Traffic may be embargoed in order to let equipment pass which does not reliably shunt the rails.

Sabotage is possible; in the 1995 Palo Verde derailment, saboteurs electrically connected sections of rail which they had displaced to conceal the breaks in the track they had made. The track circuit therefore did not detect the breaks, and the engineer was not given a stop indication.

10. Railhead contamination

For a track circuit to operate reliably, the railheads must be kept clean of rust by the regular passage of trains' wheels. Track circuited lines that are not used regularly can become so rusty as to prevent vehicles being detected. Seldom-used points and crossovers and the extremities of terminal platform lines are prone to rusting.

11. Transmission of status

Track circuit occupancy status, along with status of other signal and switch related devices, may be integrated with a local control panel as well as a remote rail control centre. If the track circuit contains a relay, it can be connected to device for sending status information via a communications link. The status can then be displayed and stored for archival for purposes of incident investigation and operations-related analysis. Many signalling systems also have local event recorders for recording track circuit status.

12. Track circuit clips

A simple piece of safety equipment that can be carried by trains is a track-circuit clip. This is simply a length of wire connecting two metal sprung clips that will clip onto a rail. In case of accident or obstruction a clip applied to a track will indicate that that track is occupied, therefore putting signals to danger. As an example of use, if a train is derailed on a double track, and is foul of the second track, application of a clip to the second track will immediately return signals protecting the second track to danger. This procedure is a much more effective safety measure than attempting to contact a signalling centre by telephone because its effect is immediate and automatic.

Topic Objective:

At the end of this topic student will able to learn:

- Electrical Circuit
- Airfield Traffic Pattern
- Wind direction
- Applications
- Basic principles
- Induction law

Definition/Overview:

Electrical Circuit: An electrical circuit is a network that has a closed loop, giving a return path for the current. A network is a connection of two or more components, and may not necessarily be a circuit. Electrical networks that consist only of sources (voltage or current), linear lumped elements (resistors, capacitors, inductors), and linear distributed elements (transmission lines) can be analyzed by algebraic and transform methods to determine DC response, AC response, and transient response. A network that also contains active electronic components is known as an electronic circuit. Such networks are generally nonlinear and require more complex design and analysis tools.

Key Points:

1. Airfield Traffic Pattern

An airfield traffic pattern is a standard path followed by aircraft when taking off or landing. At an airport, the pattern (or circuit in the Commonwealth) is a standard path for coordinating air traffic. It differs from "straight in approaches" and "direct climb outs" in that aircraft using a traffic pattern remain close to the airport. Patterns are usually employed at small general aviation (GA) airfields and military airbases. Most large airports avoid the system, unless there is GA activity as well as commercial flights. However, a pattern of sorts is used at airports in some cases, such as when an aircraft is required to go around.

2. Wind direction

Pilots prefer to take off and land facing into the wind. This has the effect of reducing aircraft speed over ground and hence reducing the distance required to perform either maneuver. The exception to this rule is at alpine airports, 'Altiports' where the runway is on a severe slope. In these instances, takeoffs are made downhill and landings uphill, with the slope aiding in acceleration and deceleration.

Many airfields have runways facing a variety of directions. The purpose of this is to provide arriving aircraft with the best runway to land on, according to the wind direction. Runway orientation is determined from historical data of the prevailing winds in the area. This is especially important for single-runway airports that don't have the option of a second runway pointed in an alternate direction. A common scenario is to have two runways arranged at or close to 90 degrees to one another, so that aircraft can always find a suitable runway. Almost all runways are reversible, and aircraft use whichever runway in whichever direction is best suited to the wind. In light and variable wind conditions, the direction of the runway in use might change several times during the day.

The Pilots Operating Handbook (POH) displays the maximum demonstrated crosswind component for the aircraft, this figure is based on a pilot with average experience and, in most cases, could easily be exceeded by an experienced pilot. Many pilots set their own crosswind limitations based on their skill. High-wing aircraft are more difficult to control in crosswinds compared to low-wing aircraft.

3. Applications

A key application of transformers is to reduce the current before transmitting electrical energy over long distances through wires. Most wires have resistance and so dissipate electrical energy at a rate proportional to the square of the current through the wire. By transforming electrical power to a high-voltage, and therefore low-current form for transmission and back again afterwards, transformers enable the economic transmission of power over long distances. Consequently, transformers have shaped the electricity supply industry, permitting generation to be located remotely from points of demand. All but a fraction of the world's electrical power has passed through a series of transformers by the time it reaches the consumer.

4. Basic principles

The transformer is based on two principles: first, that an electric current can produce a magnetic field (electromagnetism) and, second, that a changing magnetic field within a coil of wire induces a voltage across the ends of the coil (electromagnetic induction). By changing the current in the primary coil, one changes the strength of its magnetic field; since the changing magnetic field extends into the secondary coil, a voltage is induced across the secondary.

- An ideal step-down transformer showing magnetic flux in the core
- An ideal step-down transformer showing magnetic flux in the core

A simplified transformer design is shown to the left. A current passing through the primary coil creates a magnetic field. The primary and secondary coils are wrapped around a core of very high magnetic permeability, such as iron; this ensures that most of the magnetic field lines produced by the primary current are within the iron and pass through the secondary coil as well as the primary coil.

5. Induction law

The voltage induced across the secondary coil may be calculated from Faraday's law of induction, which states that:

V_{S} = N_{S} \frac{d\Phi}{dt}

where VS is the instantaneous voltage, NS is the number of turns in the secondary coil and Φ equals the total magnetic flux through one turn of the coil. If the turns of the coil are oriented perpendicular to the magnetic field lines, the flux is the product of the magnetic field strength B and the area A through which it cuts. The area is constant, being equal to the cross-sectional area of the transformer core, whereas the magnetic field varies with time according to the excitation of the primary. Since the same magnetic flux passes through both the primary and secondary coils in an ideal transformer, the instantaneous voltage across the primary winding equals

- In Section 4 of this course you will cover these topics:
- Measuring Instruments And Warning Indication Systems
- Power Utilization Motors

Topic Objective:

At the end of this topic student will able to learn:

- Electronic circuit
- Analog circuits
- Digital circuits
- Mixed-signal circuits
- Three Basic Parts

Definition/Overview:

Electronic Circuit: An electronic circuit is an electrical circuit that connects active and passive electronic components such as resistors, capacitors, microprocessors, transistors or vacuum tubes. The electronic circuits are typically built using a printed circuit board (PCB) that is used to mechanically support and electrically connect electronic components.

Key Points:

1. Electronic Circuit

Electronic circuits can usually be categorized as analog, digital, or mixed-signal (a combination of analog and digital) electronic circuits. The continued miniaturization and savings in power allows electronic circuits to be packaged more densely, making possible compact computers, advanced radar and navigation systems, and other devices that use very large numbers of components. Electronic circuits can display highly complex behaviors, even though they are governed by the same laws as simple electrical circuits.

2. Analog circuits

Analog electronic circuits are those in which electric signals vary continuously to correspond to the information being represented. Electronic equipment like voltage amplifiers, power amplifiers, tuning circuits, radios, and televisions are largely analog (with the exception of their control sections, which may be digital, especially in modern units).

3. Units of Analog Circuits

The basic units of analog circuits are passive (resistors, capacitors, inductors, and recently memristors) and active (independent power sources and dependent power sources). Components such as transistors may be represented by a model containing passive components and dependent sources. Another classification is to take impedance and independent sources and opamp as basic electronic components; this allows us to model frequency dependent negative resistors, gyrators, negative impedance converters, and dependent sources as secondary electronic components. There are two main types of circuits: series and parallel. A string of Christmas lights is a good example of a series circuit: if one goes out, they all do. In a parallel circuit, each bulb is connected to the power source separately, so if one goes out the rest still remain shining.

4. Digital circuits

In digital electronic circuits, electric signals take on discrete values to represent logical and numeric values that represent the information to be processed. Transistors are used primarily as switches to make logic gates. Examples of electronic equipment which use digital circuits include digital wristwatches, calculators and PDAs, and microprocessors.

5. Mixed-signal circuits

Mixed-signal or hybrid circuits contain elements of both analog and digital circuits. Examples include comparators, timers, PLLs, ADCs (analog-to-digital converters), and DACs (digital-to-analog converters).

Topic Objective:

At the end of this topic student will able to learn:

- Electric motor
- History and development
- Categorization of electric motors

- DC motors
- Brushed DC motors
- Coreless DC motors
- Universal motors
- AC motors
- Slip ring
- Stepper motors
- Linear motors
- Doubly-fed electric motor
- Singly-fed electric motor
- Nanotube nanomotor

Definition/Overview:

Alternating Current: In alternating current (AC, also ac) the movement (or flow) of electric charge periodically reverses direction. An electric charge would for instance move forward, then backward, then forward, then backward, over and over again. In direct current (DC), the movement (or flow) of electric charge is only in one direction.

Key Points:

1. Electric motor

An electric motor uses electrical energy to produce mechanical energy. The reverse process, that of using mechanical energy to produce electrical energy, is accomplished by a generator or dynamo. Traction motors used on locomotives often perform both tasks if the locomotive is equipped with dynamic brakes. Electric motors are found in household appliances such as fans, refrigerators, washing machines, pool pumps, floor vacuums, and fan-forced ovens.

2. History and development

The principle of conversion of electrical energy into mechanical energy by electromagnetic means was demonstrated by the British scientist Michael Faraday in 1821 and consisted of a free-hanging wire dipping into a pool of mercury. A permanent magnet was placed in the middle of the pool of mercury. When a current was passed through the wire, the wire rotated around the magnet, showing that the current gave rise to a circular magnetic field around the wire. This motor is often demonstrated in school physics classes, but brine (salt water) is sometimes used in place of the toxic mercury. This is the simplest form of a class of electric motors called homopolar motors. A later refinement is the Barlow's Wheel. These were demonstration devices, unsuited to practical applications due to limited power.

The first electric motor using electromagnets for both stationary and rotating parts was demonstrated by nyos Jedlik in 1828 Hungary, who later developed a motor powerful enough to propel a vehicle. The first commutator-type direct-current electric motor capable of a practical application was invented by the British scientist William Sturgeon in 1832. Following Sturgeon's work, a commutator-type direct-current electric motor made with the intention of commercial use was built by the American Thomas Davenport and patented in 1837. Although several of these motors were built and used to operate equipment such as a printing press, due to the high cost of primary battery power, the motors were commercially unsuccessful and Davenport went bankrupt. Several inventors followed Sturgeon in the development of DC motors but all encountered the same cost issues with primary battery power. No electricity distribution had been developed at the time. Like Sturgeon's motor, there was no practical commercial market for these motors.

The modern DC motor was invented by accident in 1873, when Znobe Gramme connected the dynamo he had invented to a second similar unit, driving it as a motor. The Gramme machine was the first electric motor that was successful in the industry.

In 1888 Nikola Tesla invented the first practicable AC motor and with it the polyphase power transmission system. Tesla continued his work on the AC motor in the years to follow at the Westinghouse company.

3. Categorization of electric motors

The classic division of electric motors has been that of DC types vs AC types. This is more a de facto convention, rather than a rigid distinction. For example, many classic DC motors run happily on AC power.

The ongoing trend toward electronic control further muddles the distinction, as modern drivers have moved the commutator out of the motor shell. For this new breed of motor, driver circuits are relied upon to generate sinusoidal AC drive currents, or some approximation of. The two best examples are: the brushless DC motor, and the stepping motor, both being polyphase AC motors requiring external electronic control.

There is a clearer distinction between a synchronous motor and asynchronous types. In the synchronous types, the rotor rotates in synchrony with the oscillating field or current (eg. permanent magnet motors). In contrast, an asynchronous motor is designed to slip; the most ubiquitous example being the common AC induction motor which must slip in order to generate torque.

4. Torque capability of motor types

When optimally designed for a given active current (i.e., torque current), voltage, pole-pair number, excitation frequency (i.e., synchronous speed), and core flux density, all categories of electric motors or generators will exhibit virtually the same maximum continuous shaft torque (i.e., operating torque) within a given physical size of electromagnetic core. Some applications require bursts of torque beyond the maximum operating torque, such as short bursts of torque to accelerate an electric vehicle from standstill. Always limited by magnetic core saturation or safe operating temperature rise and voltage, the capacity for torque bursts beyond the maximum operating torque differs significantly between categories of electric motors or generators.

Note: Capacity for bursts of torque should not be confused with Field Weakening capability inherent in fully electromagnetic electric machines (Permanent Magnet (PM) electric machine are excluded). Field Weakening, which is not readily available with PM electric machines, allows an electric machine to operate beyond the designed frequency of excitation without electrical damage.

Electric machines without a transformer circuit topology, such as Field-Wound (i.e., electromagnet) or Permanent Magnet (PM) Synchronous electric machines cannot realize bursts of torque higher than the maximum designed torque without saturating the magnetic core and rendering any increase in current as useless. Furthermore, the permanent magnet assembly of PM synchronous electric machines can be irreparably damaged, if bursts of torque exceeding the maximum operating torque rating are attempted.

Electric machines with a transformer circuit topology, such as Induction (i.e., asynchronous) electric machines, Induction Doubly-Fed electric machines, and Induction or Synchronous Wound-Rotor Doubly-Fed (WRDF) electric machines, exhibit very high bursts of torque because the active current (i.e., Magneto-Motive-Force or the product of current and winding-turns) induced on either side of the transformer oppose each other and as a result, the active current contributes nothing to the transformer coupled magnetic core flux density, which would otherwise lead to core saturation.

Electric machines that rely on Induction or Asynchronous principles short-circuit one port of the transformer circuit and as a result, the reactive impedance of the transformer circuit becomes dominant as slip increases, which limits the magnitude of active (i.e., real) current. Still, bursts of torque that are two to three times higher than the maximum design torque are realizable.

The Synchronous WRDF electric machine is the only electric machine with a truly dual ported transformer circuit topology (i.e., both ports independently excited with no short-circuited port). The dual ported transformer circuit topology is known to be unstable and requires a multiphase slip-ring-brush assembly to propagate limited power to the rotor winding set. If a precision means were available to instantaneously control torque angle and slip for synchronous operation during motoring or generating while simultaneously providing brushless power to the rotor winding set (see Brushless wound-rotor doubly-fed electric machine), the active current of the Synchronous WRDF electric machine would be independent of the reactive impedance of the transformer circuit and bursts of torque significantly higher than the maximum operating torque and far beyond the practical capability of any other type of electric machine would be realizable. Torque bursts greater than eight times operating torque have been calculated.

5. DC motors

A DC motor is designed to run on DC electric power. Two examples of pure DC designs are Michael Faraday's homopolar motor (which is uncommon), and the ball bearing motor, which is (so far) a novelty. By far the most common DC motor types are the brushed and brushless types, which use internal and external commutation respectively to create an oscillating AC current from the DC source -- so they are not purely DC machines in a strict sense.

6. Brushed DC motors

The classic DC motor design generates an oscillating current in a wound rotor with a split ring commutator, and either a wound or permanent magnet stator. A rotor consists of a coil wound around a rotor which is then powered by any type of battery.

Many of the limitations of the classic commutator DC motor are due to the need for brushes to press against the commutator. This creates friction. At higher speeds, brushes have increasing difficulty in maintaining contact. Brushes may bounce off the irregularities in the commutator surface, creating sparks. This limits the maximum speed of the machine. The current density per unit area of the brushes limits the output of the motor. The imperfect electric contact also causes electrical noise. Brushes eventually wear out and require replacement, and the commutator itself is subject to wear and maintenance. The commutator assembly on a large machine is a costly element, requiring precision assembly of many parts.

7. Brushless DC motors

Some of the problems of the brushed DC motor are eliminated in the brushless design. In this motor, the mechanical "rotating switch" or commutator/brushgear assembly is replaced by an external electronic switch synchronised to the rotor's position. Brushless motors are typically 85-90% efficient, whereas DC motors with brushgear are typically 75-80% efficient.

Midway between ordinary DC motors and stepper motors lies the realm of the brushless DC motor. Built in a fashion very similar to stepper motors, these often use a permanent magnet external rotor, three phases of driving coils, one or more Hall effect sensors to sense the position of the rotor, and the associated drive electronics. The coils are activated, one phase after the other, by the drive electronics as cued by the signals from the Hall effect sensors. In effect, they act as three-phase synchronous motors containing their own variable-frequency drive electronics. A specialized class of brushless DC motor controllers utilize EMF feedback through the main phase connections instead of Hall effect sensors to determine position and velocity. These motors are used extensively in electric radio-controlled vehicles. When configured with the magnets on the outside, these are referred to by modelists as outrunner motors.

Brushless DC motors are commonly used where precise speed control is necessary, as in computer disk drives or in video cassette recorders, the spindles within CD, CD-ROM (etc.) drives, and mechanisms within office products such as fans, laser printers and photocopiers. They have several advantages over conventional motors:

- Compared to AC fans using shaded-pole motors, they are very efficient, running much cooler than the equivalent AC motors. This cool operation leads to much-improved life of the fan's bearings.
- Without a commutator to wear out, the life of a DC brushless motor can be significantly longer compared to a DC motor using brushes and a commutator. Commutation also tends to cause a great deal of electrical and RF noise; without a commutator or brushes, a brushless motor may be used in electrically sensitive devices like audio equipment or computers.
- The same Hall effect sensors that provide the commutation can also provide a convenient tachometer signal for closed-loop control (servo-controlled) applications. In fans, the tachometer signal can be used to derive a "fan OK" signal.
- The motor can be easily synchronized to an internal or external clock, leading to precise speed control.
- Brushless motors have no chance of sparking, unlike brushed motors, making them better suited to environments with volatile chemicals and fuels.
- Brushless motors are usually used in small equipment such as computers and are generally used to get rid of unwanted heat.
- They are also very quiet motors which is an advantage if being used in equipment that is affected by vibrations.

- Modern DC brushless motors range in power from a fraction of a watt to many kilowatts. Larger brushless motors up to about 100 kW rating are used in electric vehicles. They also find significant use in high-performance electric model aircraft.

8. Coreless DC motors

Nothing in the design of any of the motors described above requires that the iron (steel) portions of the rotor actually rotate; torque is exerted only on the windings of the electromagnets. Taking advantage of this fact is the coreless DC motor, a specialized form of a brush or brushless DC motor. Optimized for rapid acceleration, these motors have a rotor that is constructed without any iron core. The rotor can take the form of a winding-filled cylinder inside the stator magnets, a basket surrounding the stator magnets, or a flat pancake (possibly formed on a printed wiring board) running between upper and lower stator magnets. The windings are typically stabilized by being impregnated with Electrical epoxy potting systems. Filled epoxies that have moderate mixed viscosity and a long gel time. These systems are highlighted by low shrinkage and low exotherm. Typically UL 1446 recognized as a potting compound for use up to 180C (Class H) UL File No. E 210549.

Because the rotor is much lighter in weight (mass) than a conventional rotor formed from copper windings on steel laminations, the rotor can accelerate much more rapidly, often achieving a mechanical time constant under 1 ms. This is especially true if the windings use aluminum rather than the heavier copper. But because there is no metal mass in the rotor to act as a heat sink, even small coreless motors must often be cooled by forced air.

These motors were commonly used to drive the capstan(s) of magnetic tape drives and are still widely used in high-performance servo-controlled systems, like radio-controlled vehicles/aircraft, humanoid robotic systems, industrial automation, medical devices, etc.

9. Slip ring

The slip ring or wound rotor motor is an induction machine where the rotor comprises a set of coils that are terminated in slip rings to which external impedances can be connected. The stator is the same as is used with a standard squirrel cage motor. By changing the impedance connected to the rotor circuit, the speed/current and speed/torque curves can be altered.

The slip ring motor is used primarily to start a high inertia load or a load that requires a very high starting torque across the full speed range. By correctly selecting the resistors used in the secondary resistance or slip ring starter, the motor is able to produce maximum torque at a relatively low current from zero speed to full speed. A secondary use of the slip ring motor is to provide a means of speed control. Because the torque curve of the motor is effectively modified by the resistance connected to the rotor circuit, the speed of the motor can be altered. Increasing the value of resistance on the rotor circuit will move the speed of maximum torque down. If the resistance connected to the rotor is increased beyond the point where the maximum torque occurs at zero speed, the torque will be further reduced.

When used with a load that has a torque curve that increases with speed, the motor will operate at the speed where the torque developed by the motor is equal to the load torque. Reducing the load will cause the motor to speed up, and increasing the load will cause the motor to slow down until the load and motor torque are equal. Operated in this manner, the slip losses are dissipated in the secondary resistors and can be very significant. The speed regulation is also very poor.

10. Stepper motors

Closely related in design to three-phase AC synchronous motors are stepper motors, where an internal rotor containing permanent magnets or a large iron core with salient poles is controlled by a set of external magnets that are switched electronically. A stepper motor may also be thought of as a cross between a DC electric motor and a solenoid. As each coil is energized in turn, the rotor aligns itself with the magnetic field produced by the energized field winding. Unlike a synchronous motor, in its application, the stepper motor may not rotate continuously;

instead, it "steps" from one position to the next as field windings are energized and de-energized in sequence. Depending on the sequence, the rotor may turn forwards or backwards, and it may change direction, stop, speed up or slow down arbitrarily at any time.

Simple stepper motor drivers entirely energize or entirely de-energize the field windings, leading the rotor to "cog" to a limited number of positions; more sophisticated drivers can proportionally control the power to the field windings, allowing the rotors to position between the cog points and thereby rotate extremely smoothly. Computer controlled stepper motors are one of the most versatile forms of positioning systems, particularly when part of a digital servo-controlled system.

Stepper motors can be rotated to a specific angle in discrete steps with ease, and hence stepper motors are used for read/write head positioning in computer floppy diskette drives. They were used for the same purpose in pre-gigabyte era computer disk drives, where the precision and speed they offered was adequate for the correct positioning of the read/write head of a hard disk drive. As drive density increased, the precision and speed limitations of stepper motors made them obsolete for hard drives--the precision limitation made them unusable, and the speed limitation made them uncompetitive--thus newer hard disk drives use voice coil-based head actuator systems.

Stepper motors were and still are often used in computer printers, optical scanners, and digital photocopiers to move the optical scanning element, the print head carriage (of dot matrix and inkjet printers), and the platen. Likewise, many computer plotters (which since the early 1990s have been replaced with large-format inkjet and laser printers) used rotary stepper motors for pen and platen movement; the typical alternatives here were either linear stepper motors or servomotors with complex closed-loop control systems.

Stepper motors were upscaled to be used in electric vehicles under the term SRM (switched reluctance machine).

11. Linear motors

A linear motor is essentially an electric motor that has been "unrolled" so that, instead of producing a torque (rotation), it produces a linear force along its length by setting up a traveling electromagnetic field.

Linear motors are most commonly induction motors or stepper motors. You can find a linear motor in a maglev (Transrapid) train, where the train "flies" over the ground, and in many roller-coasters where the rapid motion of the motorless railcar is controlled by the rail. On a smaller scale, at least one letter-size (8.5" x 11") computer graphics X-Y pen plotter made by Hewlett-Packard (in the late 1970s to mid 1980's) used two linear stepper motors to move the pen along the two orthogonal axes.

- In Section 5 of this course you will cover these topics:
- Power Utilization Systems
- Electrical Diagrams And Identification Schemes

Topic Objective:

At the end of this topic student will able to learn:

- Universal motors
- AC motors

- Components
- Torque motors
- Slip ring
- Stepper motors
- Linear motors
- Doubly-fed electric motor
- Singly-fed electric motor
- Nanotube nanomotor

Definition/Overview:

Alternating Current: In alternating current (AC, also ac) the movement (or flow) of electric charge periodically reverses direction. An electric charge would for instance move forward, then backward, then forward, then backward, over and over again. In direct current (DC), the movement (or flow) of electric charge is only in one direction.

Key Points:

1. Electric motor

An electric motor uses electrical energy to produce mechanical energy. The reverse process that of using mechanical energy to produce electrical energy, is accomplished by a generator or dynamo. Traction motors used on locomotives often perform both tasks if the locomotive is equipped with dynamic brakes. Electric motors are found in household appliances such as fans, refrigerators, washing machines, pool pumps, floor vacuums, and fan-forced ovens.

2. **Torque capability of motor**

When optimally designed for a given active current (i.e., torque current), voltage, pole-pair number, excitation frequency (i.e., synchronous speed), and core flux density, all categories of electric motors or generators will exhibit virtually the same maximum continuous shaft torque (i.e., operating torque) within a given physical size of electromagnetic core. Some applications require bursts of torque beyond the maximum operating torque, such as short bursts of torque to accelerate an electric vehicle from standstill. Always limited by magnetic core saturation or safe operating temperature rise and voltage, the capacity for torque bursts beyond the maximum operating torque differs significantly between categories of electric motors or generators.

Note: Capacity for bursts of torque should not be confused with Field Weakening capability inherent in fully electromagnetic electric machines (Permanent Magnet (PM) electric machine are excluded). Field Weakening, which is not readily available with PM electric machines, allows an electric machine to operate beyond the designed frequency of excitation without electrical damage.

Electric machines without a transformer circuit topology, such as Field-Wound (i.e., electromagnet) or Permanent Magnet (PM) Synchronous electric machines cannot realize bursts of torque higher than the maximum designed torque without saturating the magnetic core and rendering any increase in current as useless. Furthermore, the permanent magnet assembly of PM synchronous electric machines can be irreparably damaged, if bursts of torque exceeding the maximum operating torque rating are attempted.

Electric machines with a transformer circuit topology, such as Induction (i.e., asynchronous) electric machines, Induction Doubly-Fed electric machines, and Induction or Synchronous Wound-Rotor Doubly-Fed (WRDF) electric machines, exhibit very high bursts of torque because the active current (i.e., Magneto-Motive-Force or the product of current and winding-turns) induced on either side of the transformer oppose each other and as a result, the active current contributes nothing to the transformer coupled magnetic core flux density, which would otherwise lead to core saturation.

Electric machines that rely on Induction or Asynchronous principles short-circuit one port of the transformer circuit and as a result, the reactive impedance of the transformer circuit becomes dominant as slip increases, which limits the magnitude of active (i.e., real) current. Still, bursts of torque that are two to three times higher than the maximum design torque are realizable.

The Synchronous WRDF electric machine is the only electric machine with a truly dual ported transformer circuit topology (i.e., both ports independently excited with no short-circuited port). The dual ported transformer circuit topology is known to be unstable and requires a multiphase slip-ring-brush assembly to propagate limited power to the rotor winding set. If a precision means were available to instantaneously control torque angle and slip for synchronous operation during motoring or generating while simultaneously providing brushless power to the rotor winding set (see Brushless wound-rotor doubly-fed electric machine), the active current of the Synchronous WRDF electric machine would be independent of the reactive impedance of the transformer circuit and bursts of torque significantly higher than the maximum operating torque and far beyond the practical capability of any other type of electric machine would be realizable. Torque bursts greater than eight times operating torque have been calculated.

3. DC motors

A DC motor is designed to run on DC electric power. Two examples of pure DC designs are Michael Faraday's homopolar motor (which is uncommon), and the ball bearing motor, which is (so far) a novelty. By far the most common DC motor types are the brushed and brushless types, which use internal and external commutation respectively to create an oscillating AC current from the DC source -- so they are not purely DC machines in a strict sense.

4. Brushed DC motors

The classic DC motor design generates an oscillating current in a wound rotor with a split ring commutator, and either a wound or permanent magnet stator. A rotor consists of a coil wound around a rotor which is then powered by any type of battery.

Many of the limitations of the classic commutator DC motor are due to the need for brushes to press against the commutator. This creates friction. At higher speeds, brushes have increasing difficulty in maintaining contact. Brushes may bounce off the irregularities in the commutator surface, creating sparks. This limits the maximum speed of the machine. The current density per unit area of the brushes limits the output of the motor. The imperfect electric contact also causes electrical noise. Brushes eventually wear out and require replacement, and the commutator itself is subject to wear and maintenance. The commutator assembly on a large machine is a costly element, requiring precision assembly of many parts.

5. Brushless DC motors

Some of the problems of the brushed DC motor are eliminated in the brushless design. In this motor, the mechanical "rotating switch" or commutator/brushgear assembly is replaced by an external electronic switch synchronized to the rotor's position. Brushless motors are typically 85-90% efficient, whereas DC motors with brushgear are typically 75-80% efficient.

Midway between ordinary DC motors and stepper motors lies the realm of the brushless DC motor. Built in a fashion very similar to stepper motors, these often use a permanent magnet external rotor, three phases of driving coils, one or more Hall effect sensors to sense the position of the rotor, and the associated drive electronics. The coils are activated, one phase after the other, by the drive electronics as cued by the signals from the Hall effect sensors. In effect, they act as three-phase synchronous motors containing their own variable-frequency drive electronics. A specialized class of brushless DC motor controllers utilizes EMF feedback through the main phase connections instead of Hall effect sensors to determine position and velocity. These motors are used extensively in electric radio-controlled vehicles. When configured with the magnets on the outside, these are referred to by modelists as outrunner motors.

6. Coreless DC motors

Nothing in the design of any of the motors described above requires that the iron (steel) portions of the rotor actually rotate; torque is exerted only on the windings of the electromagnets. Taking advantage of this fact is the coreless DC motor, a specialized form of a brush or brushless DC motor. Optimized for rapid acceleration, these motors have a rotor that is constructed without any iron core. The rotor can take the form of a winding-filled cylinder inside the stator magnets, a basket surrounding the stator magnets, or a flat pancake (possibly formed on a printed wiring board) running between upper and lower stator magnets. The windings are typically stabilized by being impregnated with Electrical epoxy potting systems. Filled epoxies that have moderate mixed viscosity and a long gel time. These systems are highlighted by low shrinkage and low exotherm. Typically UL 1446 recognized as a potting compound for use up to 180C (Class H) UL File No. E 210549.

Because the rotor is much lighter in weight (mass) than a conventional rotor formed from copper windings on steel laminations, the rotor can accelerate much more rapidly, often achieving a mechanical time constant under 1 ms. This is especially true if the windings use aluminum rather than the heavier copper. But because there is no metal mass in the rotor to act as a heat sink, even small coreless motors must often be cooled by forced air.

These motors were commonly used to drive the capstan(s) of magnetic tape drives and are still widely used in high-performance servo-controlled systems, like radio-controlled vehicles/aircraft, humanoid robotic systems, industrial automation, medical devices, etc.

7. Slip ring

The slip ring or wound rotor motor is an induction machine where the rotor comprises a set of coils that are terminated in slip rings to which external impedances can be connected. The stator is the same as is used with a standard squirrel cage motor. By changing the impedance connected to the rotor circuit, the speed/current and speed/torque curves can be altered.

The slip ring motor is used primarily to start a high inertia load or a load that requires a very high starting torque across the full speed range. By correctly selecting the resistors used in the secondary resistance or slip ring starter, the motor is able to produce maximum torque at a relatively low current from zero speed to full speed. A secondary use of the slip ring motor is to provide a means of speed control. Because the torque curve of the motor is effectively modified by the resistance connected to the rotor circuit, the speed of the motor can be altered. Increasing the value of resistance on the rotor circuit will move the speed of maximum torque down. If the resistance connected to the rotor is increased beyond the point where the maximum torque occurs at zero speed, the torque will be further reduced.

When used with a load that has a torque curve that increases with speed, the motor will operate at the speed where the torque developed by the motor is equal to the load torque. Reducing the load will cause the motor to speed up, and increasing the load will cause the motor to slow down until the load and motor torque are equal. Operated in this manner, the slip losses are dissipated in the secondary resistors and can be very significant. The speed regulation is also very poor.

8. Stepper motors

Closely related in design to three-phase AC synchronous motors are stepper motors, where an internal rotor containing permanent magnets or a large iron core with salient poles is controlled by a set of external magnets that are switched electronically. A stepper motor may also be thought of as a cross between a DC electric motor and a solenoid. As each coil is energized in turn, the rotor aligns itself with the magnetic field produced by the energized field winding. Unlike a synchronous motor, in its application, the stepper motor may not rotate continuously;

instead, it "steps" from one position to the next as field windings are energized and de-energized in sequence. Depending on the sequence, the rotor may turn forwards or backwards, and it may change direction, stop, speed up or slow down arbitrarily at any time.

Simple stepper motor drivers entirely energize or entirely de-energize the field windings, leading the rotor to "cog" to a limited number of positions; more sophisticated drivers can proportionally control the power to the field windings, allowing the rotors to position between the cog points and thereby rotate extremely smoothly. Computer controlled stepper motors are one of the most versatile forms of positioning systems, particularly when part of a digital servo-controlled system.

Stepper motors can be rotated to a specific angle in discrete steps with ease, and hence stepper motors are used for read/write head positioning in computer floppy diskette drives. They were used for the same purpose in pre-gigabyte era computer disk drives, where the precision and speed they offered was adequate for the correct positioning of the read/write head of a hard disk drive. As drive density increased, the precision and speed limitations of stepper motors made them obsolete for hard drives--the precision limitation made them unusable, and the speed limitation made them uncompetitive--thus newer hard disk drives use voice coil-based head actuator systems.

Stepper motors were and still are often used in computer printers, optical scanners, and digital photocopiers to move the optical scanning element, the print head carriage (of dot matrix and inkjet printers), and the platen. Likewise, many computer plotters (which since the early 1990s have been replaced with large-format inkjet and laser printers) used rotary stepper motors for pen and platen movement; the typical alternatives here were either linear stepper motors or servomotors with complex closed-loop control systems. Stepper motors were upscaled to be used in electric vehicles under the term SRM (switched reluctance machine).

9. Linear motors

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10. Doubly-fed electric motor

Doubly-fed electric motors have two independent multiphase windings that actively participate in the energy conversion process with at least one of the winding sets electronically controlled for variable speed operation. Two is the most active multiphase winding sets possible without duplicating singly-fed or doubly-fed categories in the same package. As a result, doubly-fed electric motors are machines with an effective constant torque speed range that is twice synchronous speed for a given frequency of excitation. This is twice the constant torque speed range as singly-fed electric machines, which have only one active winding set.

A doubly-fed motor allows for a smaller electronic converter but the cost of the rotor winding and slip rings may offset the saving in the power electronics components. Difficulties with controlling speed near synchronous speed limit applications.

11. Singly-fed electric motor

Singly-fed electric machines incorporate a single multiphase winding set that is connected to a power supply. Singly-fed electric machines may be either induction or synchronous. The active winding set can be electronically controlled. Induction machines develop starting torque at zero speed and can operate as standalone machines. Synchronous machines must have auxiliary means for startup, such as a starting induction squirrel-cage winding or an electronic controller. Singly-fed electric machines have an effective constant torque speed range up to synchronous speed for a given excitation frequency.

The induction (asynchronous) motors (i.e., squirrel cage rotor or wound rotor), synchronous motors (i.e., field-excited, permanent magnet or brushless DC motors, reluctance motors, etc.), which are discussed on the this page, are examples of singly-fed motors. By far, singly-fed motors are the predominantly installed type of motors.

12. Nanotube nanomotor

Researchers at University of California, Berkeley, recently developed rotational bearings based upon multiwall carbon nanotubes. By attaching a gold plate (with dimensions of the order of 100nm) to the outer shell of a suspended multiwall carbon nanotube (like nested carbon cylinders), they are able to electrostatically rotate the outer shell relative to the inner core. These bearings are very robust; devices have been oscillated thousands of times with no indication of wear. These nanoelectromechanical systems (NEMS) are the next step in miniaturization that may find their way into commercial aspects in the future.

13. Materials

There is an impending shortage of many rare raw materials used in the manufacture of hybrid and electric cars. For example, the rare earth element dysprosium is required to fabricate many of the advanced electric motors used in hybrid cars. However, over 95% of the world's rare earth elements are mined in China, and domestic Chinese consumption is expected to consume China's entire supply by 2012.

While permanent magnet motors, favored in hybrids such as those made by Toyota, often use rare earth materials in their magnets, AC traction motors used in production electric vehicles such as the GM EV1, Toyota RAV4 EV and Tesla Roadster do not use permanent magnets or the associated rare earth materials. AC motors typically use conventional copper wire for their stator coils and copper or aluminum rods or bars for their rotor. AC motors do not significantly use rare earth materials.

Topic Objective:

At the end of this topic student will able to learn:

- Single-component phase diagrams
- Two-dimensional (2D) phase diagrams
- Pressure-temperature diagrams
- Other thermodynamic properties
- Three-dimensional (3D) phase diagrams
- Schematic

Definition/Overview:

Electrical Diagrams and Identification Schemes: In physical chemistry, mineralogy, and materials science, a phase diagram is a type of graph used to show the equilibrium conditions between the thermodynamically-distinct phases. In mathematics and physics, a phase diagram also has an alternative meaning, as a synonym for a phase space.

Key Points:

1. Single-component phase diagrams

The simplest phase diagrams are pressure-temperature diagrams of a single simple substance, such as water. The axes correspond to the pressure and temperature. The phase diagram shows, in pressure-temperature space, the lines of equilibrium or phase boundaries between the three phases of solid, liquid, and gas.

The markings on the phase diagram show the points where the free energy is non-analytic. The open spaces, where the free energy is analytic, correspond to the phases. The phases are separated by lines of non-analyticity, where phase transitions occur, which are called phase boundaries.

This reflects the fact that, at extremely high temperatures and pressures, the liquid and gaseous phases become indistinguishable, in what is known as a supercritical fluid. In water, the critical point occurs at around 647 K (374 C or 705 F) and 22.064 MPa.

The existence of the liquid-gas critical point reveals a slight ambiguity in the above definitions. When going from the liquid to the gaseous phase, one usually crosses the phase boundary, but it is possible to choose a path that never crosses the boundary by going to the right of the critical point. Thus, the liquid and gaseous phases can blend continuously into each other. However, the solid-liquid phase boundary can only end in a critical point this way if the solid and liquid phases have the same symmetry group.

Noteworthy is that the solid-liquid phase boundary in the phase diagram of most substances has a positive slope. This is due to the solid phase having a higher density than the liquid, so that increasing the pressure increases the melting point; the temperature at which a substance melts. In some parts of the phase diagram for water the solid-liquid phase boundary has a negative slope (especially the portion corresponding to standard pressure). This reflects the fact that ice has a lower density than water, which is an unusual property for a material.

2. Other thermodynamic properties

In addition to just temperature or pressure, other thermodynamic properties may be graphed in phase diagrams. Examples of such thermodynamic properties include specific volume, specific enthalpy, or specific entropy. For example, single-component graphs of Temperature vs. specific entropy (T vs. s) for water/steam or for a refrigerant are commonly used to illustrate thermodynamic cycles such as a Carnot cycle, Rankine cycle, or vapor-compression refrigeration cycle.

In a two-dimensional graph, two of the thermodynamic quantities may be shown on the horizontal and vertical axes. Additional thermodynamic quantities may each be illustrated in increments as a series of lines - curved, straight, or a combination of curved and straight. Each of these iso-lines represents the thermodynamic quantity at a certain constant value.

3. Three-dimensional (3D) phase diagrams

It is possible to envision three-dimensional (3D) graphs showing three thermodynamic quantities. For example for a single component, a 3D Cartesian coordinate type graph can show temperature (T) on one axis, pressure (P) on a second axis, and specific volume (v) on a third. Such a 3D graph is sometimes called a P-v-T diagram. The equilibrium conditions would be shown as a 3D curved surface with areas for solid, liquid, and vapor phases and areas where solid and liquid, solid and vapor, or liquid and vapor coexist in equilibrium. A line on the surface called a triple line is where solid, liquid and vapor can all coexist in equilibrium. The critical point remains a point on the surface even on a 3D phase diagram. An orthographic projection of the 3D P-v-T graph showing pressure and temperature as the vertical and horizontal axes effectively collapses the 3D plot into a 2D pressure-temperature diagram. When this happens, the solid-vapor, solid-liquid, and liquid-vapor surfaces collapse into three corresponding curved lines meeting at the triple point, which is the collapsed orthographic projection of the triple line.

4. Schematic

A schematic is a diagram that represents the elements of a system using abstract, graphic symbols rather than realistic pictures. A schematic usually omits all details that are not relevant to the information the schematic is intended to convey, and may add unrealistic elements that aid comprehension. For example, a subway map intended for riders may represent a subway station with a dot; the dot doesn't resemble the actual station at all but gives the viewer the information he needs without unnecessary visual clutter. A schematic diagram of a chemical process uses symbols to represent the vessels, piping, valves, pumps, and other equipment of the system, emphasizing their interconnection paths and suppressing physical details. In an electronic circuit diagram, the layout of the symbols may not resemble the layout in the physical circuit. In the schematic diagram, the symbolic elements are arranged to be more easily interpreted by the viewer.