INDUSTRIAL AUTOMATION

COURSE CODE: 5042 (REV 2021)

POWER DEVICES IN INDUSTRIAL FIELD

MODULE III NOTES

Prepared by,

Najla Pary

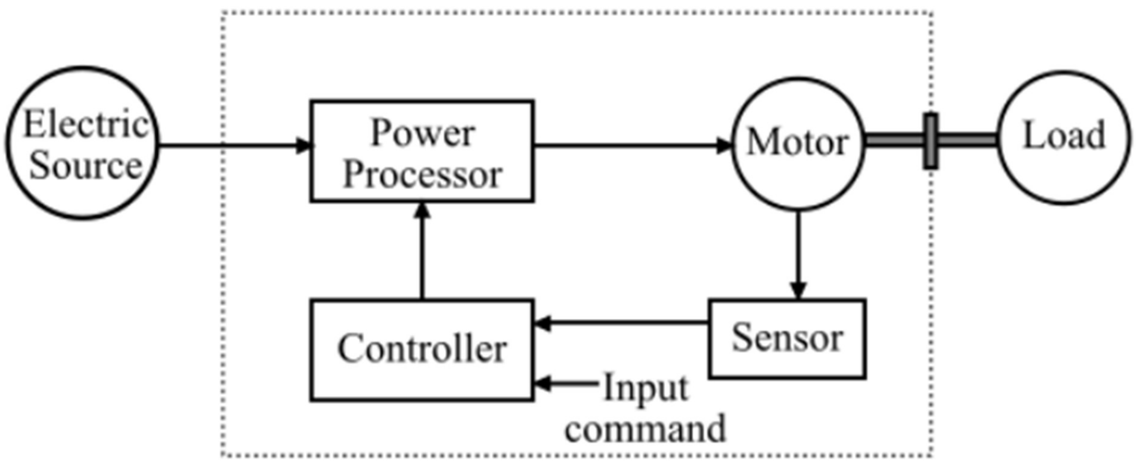
Lecturer in Electronics

GPC Perinthalmanna

Electric drive •

An Electric Drive can be defined as, a system which is used to control the movement of an electrical machine. It can be defined as an electromechanical device for converting electrical energy to mechanical energy to give motion to different machines and mechanisms for various kinds of process control.

An electric motor is the source of mechanical power. An energy transmitting device delivers power from electric motor to the driven machine (load)- it usually consists of shaft, belt, chain, rope etc. A working machine is the driven machine that performs the required process-like lathes, pumps, drilling machines, lifts, conveyor belts etc. An electric motor together with its control equipment and energy transmitting device forms an electric drive. Block diagram of electric drive is shown in the figure:



Applications of electric drives

1. Rolling mills
2. Fans, pumps, robots and washing, etc.
3. Paper machines
4. Textile mills
5. Machine tools

AC and DC Drives

Based on power supply the electrical drives are classified as AC Electrical Drive and DC Electrical Drive

AC Drive

AC drive converts the AC supply to the DC using converter circuits based on rectifier and inverts it back to the AC from DC using inverter to control the speed of electric motors. AC drive is also known as variable frequency drive (VFD) because it changes the frequency of the AC supply to control the speed of the AC motor.

DC Drive

A DC drive is a DC motor speed control system which converts the input AC supply to the DC using converter circuit based on rectifier (diodes and thyristors) to control the speed of DC motors.

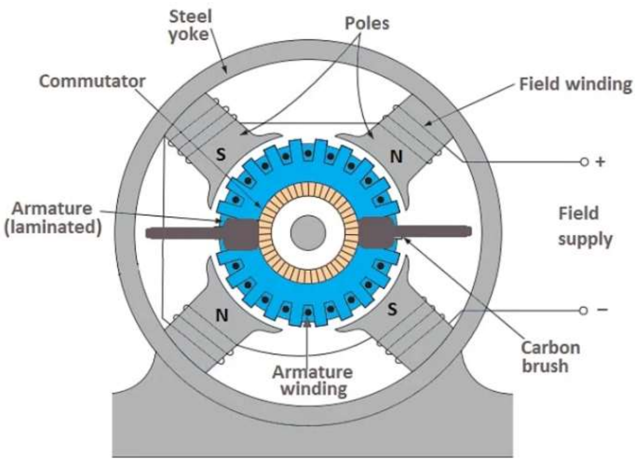
Both ac and dc motors are used for electric drives. However, ac system is preferred because the generation of AC power is more natural and efficient than the generation of DC power. Also, the ac power can be efficiently transmitted at low line losses, the voltage at the consumer premises can be maintained within prescribed limits and there is a possibility of economically stepping up and stepping down of voltages through the use of transformers.

In spite of all the above the advantages of ac system, the use of dc is essential for some applications. The basic criterion in selecting an electric motor for an electric drive system is that it should meet the power level and performance required by the load. For example, in the applications for which a high starting torque is needed, a DC series motor might be a better choice than an Induction motor (AC motor). In constant speed applications, synchronous motor (works on DC) might be a better choice than Induction motor or DC series motor.

Comparison of AC and DC drives

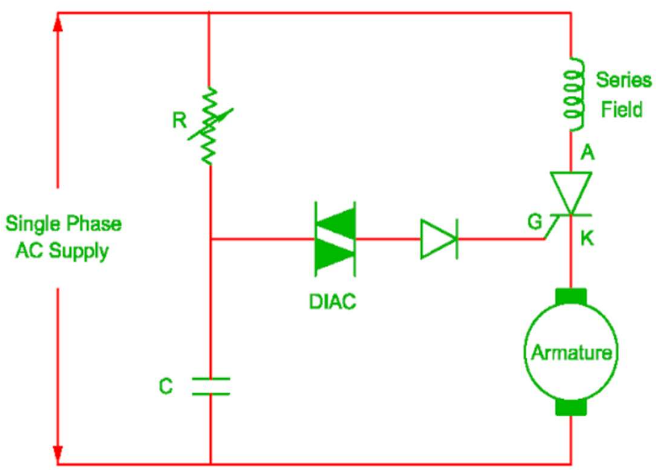
Point of Comparison	AC Drives	DC Drives
Definition	Electric drive used to control the speed of an AC motor	Electric drive used to control the speed of an DC motor
Operation	Converts AC supply into DC using rectifier circuit, then converts it back to AC (frequency changed) to control the speed of AC motor	Converts AC supply into DC of different voltage levels to control the speed of DC motor
Drive Power supply	By single phase or three phase power supply	By DC power supply such as batteries
Circuit complexity	More complex due to presence of both rectifier and inverter	Less complex due to presence of only rectifier
Speed limitation	Maximum speed can be obtained	Speed is limited
Power consumption	Consumes more power	Consumes less power
Maintenance	Less maintenance	More and frequenct maintenance
Cost	More expensive	Cheaper than AC drives

DC motor **(not important in exam point of view)**



The DC motor is the motor which converts the direct current into the mechanical work. It works on the principle that "the current carrying conductor placed in a magnetic field experiences a force". An electromagnet with field winding around it produces the magnetic field. Rotor is wound with armature winding. When current is passed through armature, it rotates, because it experiences a force in the presence of magnetic field produced by the electromagnet.

Series DC drive (Speed control of DC series motor)

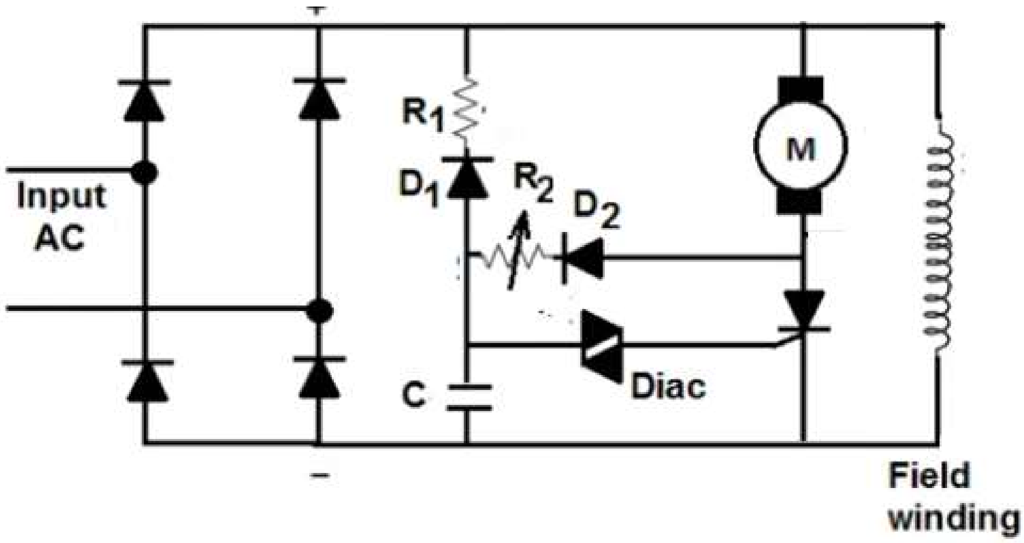


In a DC motor, the field winding forms the electromagnet and produces magnetic field around it. The armature winding is attached to the rotating part of the motor (rotor) and experiences force in presence of the magnetic field produced by the electromagnet.

In DC series motor the field windings are connected to the armature in series so that the same current flows through both the windings. The DC motor armature gets supply when SCR is turned on by gate pulse during positive half cycle of alternating supply. The charging of capacitor is done through variable resistor R. When the voltage across capacitor is equal to back emf of armature and break over voltage of diac, the SCR receives gate pulse through gate – cathode circuit.

As soon as the SCR turns on, the current passes through field winding and armature winding. The variable resistor R determines the charging rate of the capacitor C and it determines the turning ON of the diac and the gate pulses to the thyristor. The firing angle of the SCR is adjusted by changing variable resistor R. This will result in change in speed of the motor. Thus, the speed of DC motor can be efficiently controlled by adjusting the firing angle of SCR.

Shunt DC drive (Speed control of DC shunt motor)

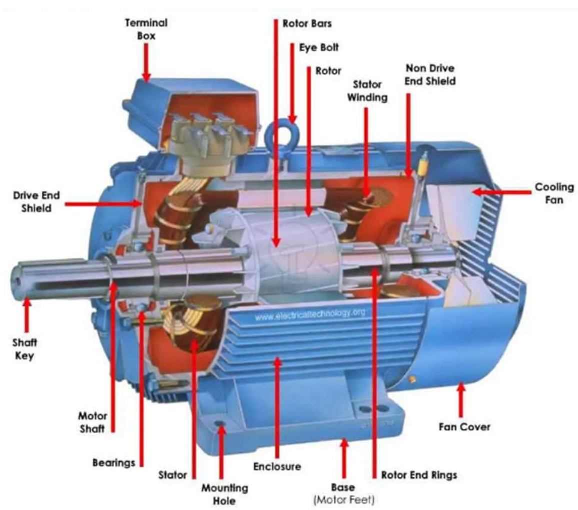


The figure shows an SCR circuit that can be used for the speed control of dc shunt motor. In this circuit, the supply voltage to the armature can be varied by varying the conduction angle of the SCR, so the smooth variation in speed is possible. Here the diac is used to trigger the SCR. The bridge rectifier is used for full-wave rectification. The field winding is connected in parallel (shunt) with the armature winding. The voltage to the armature is controlled by varying R_2.

The capacitor begins to charge in each cycle through resistance R_2, diode D_2, and the armature winding. When the capacitor is charged up to the breakdown voltage of diac, a trigger pulse is delivered to the SCR gate turning it ON. Capacitor charging time is adjusted by varying the resistor R2. If R2 is lower, firing angle will be small and the motor speed will be high. The SCR is turned OFF at the end of each half-cycle, when the anode current will be less than the holding current. At the end of each half-cycle capacitor discharges through D_1, R_1 and field winding.

Methods of speed control of Induction motors

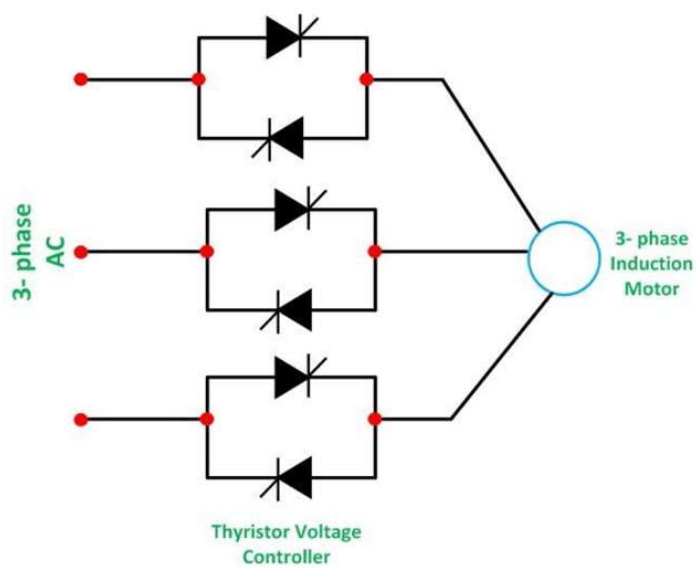
Brief about Induction motor (Not important in exam point of view)



Induction motor is a motor which works on AC (Alternating current). It has a moving part known as the rotor and a non-moving part known as the stator. When 3 phase AC supply is given to the stator, an Alternating magnetic field is produced around it. Rotor is situated in this varying magnetic field. Hence, an emf is induced in the rotor. As the ends of rotor windings are short-circuited, current starts flowing through it. Now since rotor is a current carrying coil placed in a magnetic field, it experiences a force and starts rotating. This is the basic principle of operation of Induction motor. There are two types of induction motors- squirrel cage induction motor and slip ring induction motor. The speed of Induction motors can be controlled mainly by 3 methods:

1. Stator voltage control
2. Rotor ON-OFF control
3. Variable voltage variable frequency control

Stator voltage control

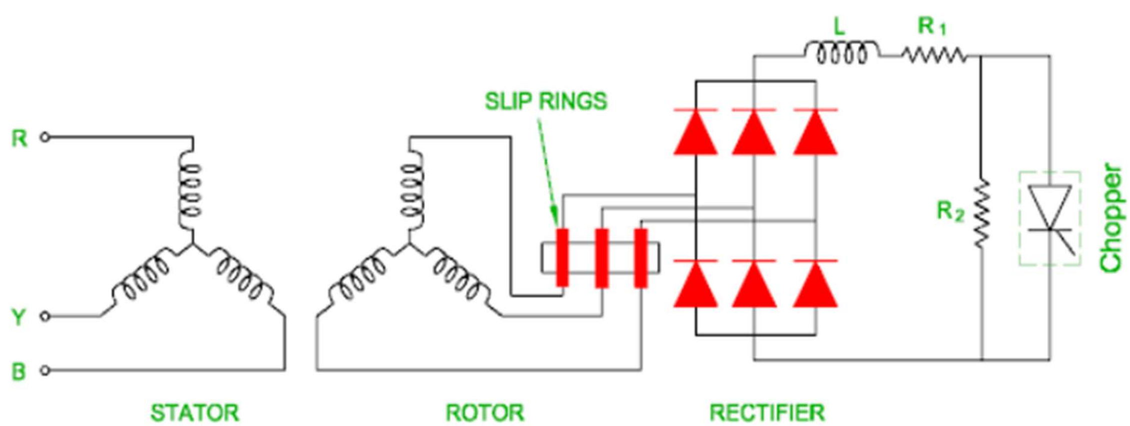


Stator voltage control method is used to control the speed of 3-phase induction motors, within a small range. The torque of 3-phase induction motor is directly proportional to the square of supply voltage. Hence, as supply voltage is increased, torque increases. In this method, 2 thyristors are connected in anti-parallel in each phase of the 3-phase AC supply. The firing of these thyristors can be accurately controlled using some suitable triggering mechanisms. Based on the instant of firing, the RMS value of voltage delivered by the thyristors changes. This alters the supply to the stator winding of the Induction motor and hence the speed is varied.

This method gives a speed control only below the normal rated speed as the operation of the voltages higher than the rated voltage is not admissible.

Rotor resistance control or rotor ON/OFF control

The speed of 3-phase induction motor can be controlled by adding external resistances in the rotor circuit. The torque of induction motor is inversely proportional to the rotor resistance. So, when resistance changes, torque changes and hence speed also changes. This type of speed control can be used only in slip ring induction motors. Adding external resistance results in power loss and generation of heat.



In the circuit, 3 phase supply is given to the stator windings. External resistances added to the rotor are R1 and R2. The SCR acts as a chopper and it can be turned ON or OFF. Chopper operates at a fixed frequency with adjustable duty cycle.

When chopper is ON, R2 is short-circuited. External resistance will be equal to R1 only. When chopper is OFF, external resistance is equal to R1+R2. Thus the resistance connected to the rotor is changed by changing the ON and OFF durations of the chopper and thus the desired speed can be obtained. High speed operation of motor is obtained by low rotor resistance. The three phase rectifier converts AC into DC. The function of the inductor is to reduce ripple at the output of the rectifier.

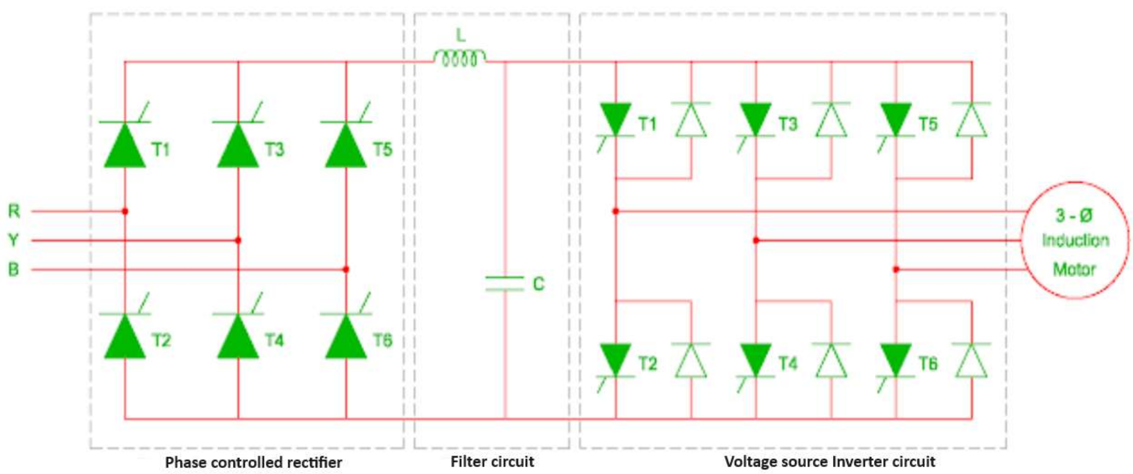
Variable voltage variable frequency control

Speed can be controlled only in a limited range in stator voltage control and rotor resistance control methods. In variable voltage variable frequency control method, both the voltage and frequency of the 3 phase supply to the stator is varied. This is done using a combination of rectifier and inverter.

3 phase supply is given to a controlled rectifier circuit, which converts AC into DC. The filter is used to smoothen out the ripples in the DC. It is converted into AC of desired output voltage and frequency using an inverter and is fed to the stator windings. The synchronous speed of an induction motor is given by,

$$Ns = \frac{120f}{p}$$

That means, synchronous peed Ns is directly proportional to the frequency of supply. As the rotor speed is dependent on Ns, rotor speed also changes with the frequency.



The basic circuit for variable voltage variable frequency control method is shown in the figure. The phase controlled rectifier converts alternating voltage into direct voltage. The combination of L and C is called the DC link. L and C together forms the filter circuit and smoothens the DC voltage from rectifier. The voltage source inverter provides variable voltage, variable frequency supply to the 3 phase induction motor. Variable voltage, variable frequency supply is obtained by adjusting the firing angle of phase controlled rectifier and voltage source inverter.

Electrical heating

If heating of objects is done using electricity, heat can be accurately controlled. In IR heating, electromagnetic radiation at IR frequency from the filament of an incandescent lamp is focussed on object to be heated. This can help in quick and uniform drying of fresh layers. Electric heating can be classified into two as follows:

1. High frequency heating: High frequency signal is used for heating purposes. Heat transfer takes place inside the material. E.g. : Induction heating heating, Dielectric heating.

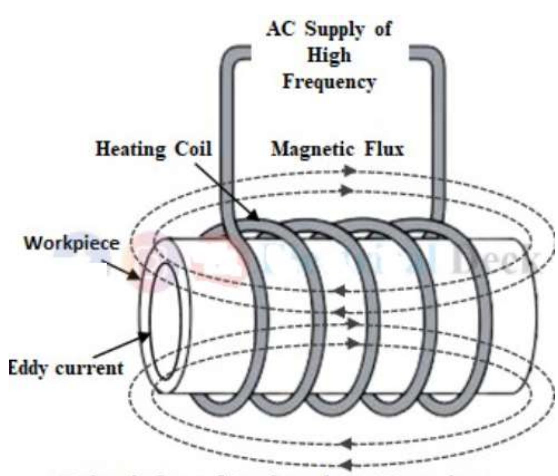
2. Power heating: High power signal is used for heating purposes.

Advantages of electrical heating

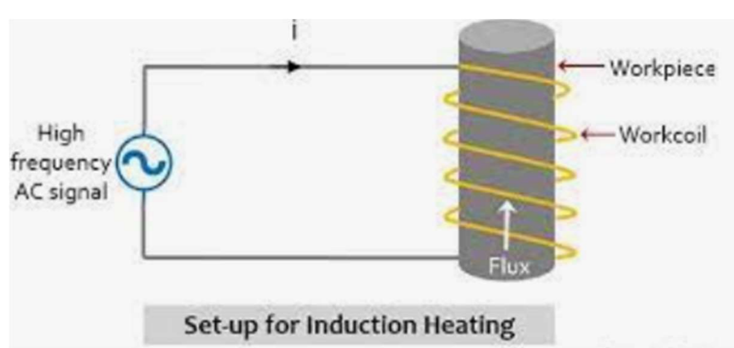
1. Cleanliness - no dust or ash is produced, it is pollution free
2. Ease of control by using automatic devices.
3. Uniform heating from outer to inner surfaces is possible.
4. Low maintenance required.

Induction heating

Induction heating can be done to materials having ferromagnetic property. Induction heating occurs due to two main factors - one is eddy current loss and the other is hysteresis loss. When a ferro magnetic material is subjected to an alternating magnetic field (produced by AC), it gets heated up by the eddy currents flowing through the material and hysteresis loss occurring in it.



Principle of Induction Heating



Set-up for Induction Heating

If a high frequency current flows through a coil surrounding a workpiece (magnetic material), circulating loops of current known as eddy current will be formed on its surface. As the frequency increases, the induced current tends to concentrate close to the outer surface of the metal. This is known as the skin effect. Due to skin effect, current density is more at the surface.

Induction heating is based on the principle of transformer. There is a primary winding though which alternating current is passed. This winding is magnetically coupled with the metal to be heated. An eddy current is induced in the metal piece when an alternating current is passed through the primary heating coil. . the value of induced eddy current depends on,

- The magnitude of primary current
- Ration of number of turns in the primary and secondary circuit
- Coefficient of magnetic coupling

In addition to eddy currents, hysteresis loss also contributes towards heating. In a fluctuating magnetic field, the orientation of magnetic molecules changes repeatedly, in every cycle. This causes friction between molecules and produces heat.

Advantages of Induction heating

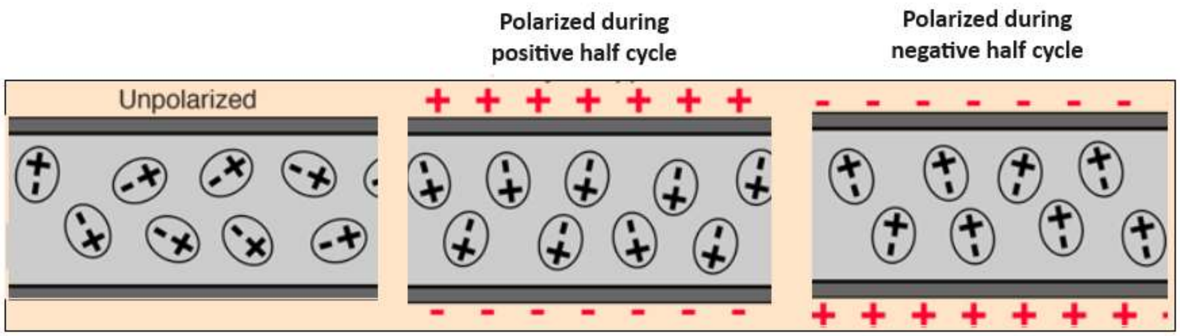
1. Heat is concentrated near the surface - can be used for surface hardening of steel.
2. Rate of heating the work piece is very large.
3. Extent of heating can be accurately controlled.
4. Electronic timers can be used for controlling the duration of heat transfer.
5. Heating can be done in vacuum or in the presence of inert gas or any other gas.

Applications of Induction heating

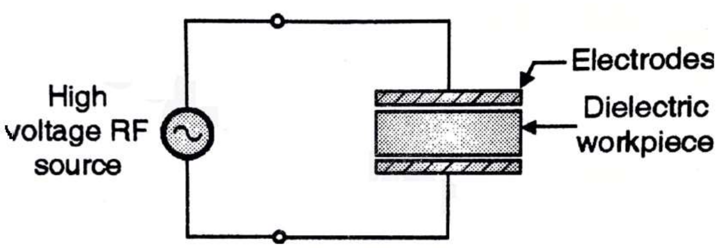
1. Surface hardening of steel
2. Annealing (change in physical and chemical properties) of brass and bronze.
3. Soldering of brass and copper
4. Melting of metals.

Dielectric Heating

Dielectric Heating is a process of electric heating by which the temperature of a dielectric (non-conducting) material is raised by the application of an alternating electric field (high voltage ac signal).



Dielectrics are insulators that has very poor conducting ability. When insulators are subjected to alternating electric field, atoms get stressed. Heat is produced because of inter atomic friction. Dielectric heating occurs due to repeated polarization of the atomic structure. When an atom is not subjected to an electric filed, positive and negative charges will be randomly oriented. Under the effect of an electric field, positive charges tend to align in the direction of electric field and negative charges align in the direction opposite to that of electric field. An atom is said to be polarized in this state. If the electric field is alternating, the forces within the atom are reversed in each cycle. Atoms are subjected to constant unrest in each positive and negative half cycles of the AC. This causes atomic friction and results in heat. Dielectric heat increases with the increase in frequency and strength of electric field.



If insulators like wood, plastic, glass or ceramics are subjected to high alternating current, their temperature will increase after some time.

The increase in temperature is due to the conversion of dielectric loss into heat. For obtaining sufficient heating effect, high voltage of about 20 KV and frequency in the range of 1 MHz to 50 MHz is used. For heating purposes, the insulator is kept between two electrodes and high frequency AC is applied across it. Higher the frequency, more will be the heat generated.

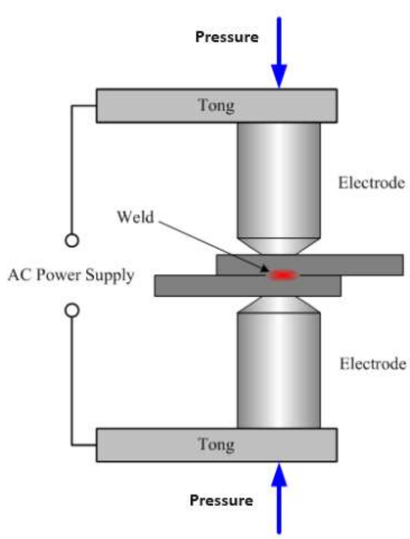
Applications of dielectric heating

1. Gluing of wood
2. Preheating of plastic preform
3. Sewing of plastic films
4. Food processing
5. Diathermy

Resistance welding

Welding is the process of union of metals by the application of heat and pressure such that the welded joint has properties of the parent metal. In electrical resistance welding, two or more pieces of metal are fused together by AC or DC of high value for a short duration through the area of contact. Duration is varied from few milli seconds to several seconds depending upon the job. In this, heat is produced by the resistance offered to the flow of current at the junction of two metals.

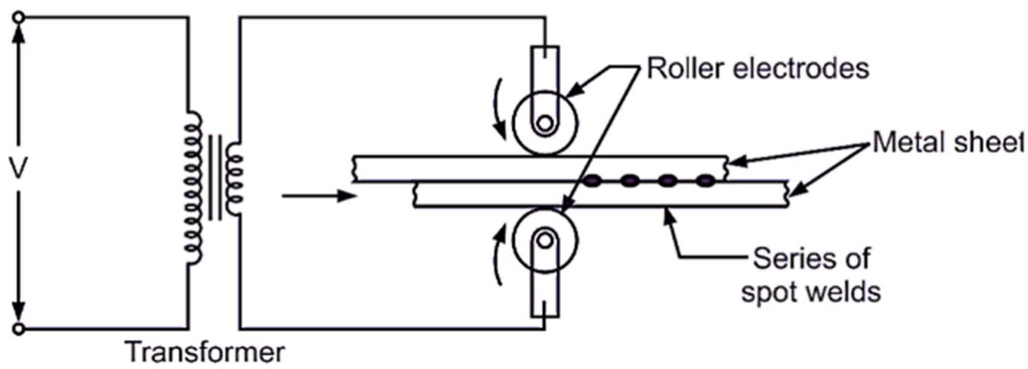
Spot welding



Spot welding is a resistance welding process that joins metal surfaces together using an electrical current. It is used to join sheet metals together. It uses heat and pressure to create a bond between the metal surfaces. Spot welding is conducted by firmly pressing copper electrodes onto both sides of the metals to be joined together. The pressure is maintained while the current is passed through, allowing the heat generated to bond the metals together. The pressure holds the metals in place, to achieve a satisfactory weld.

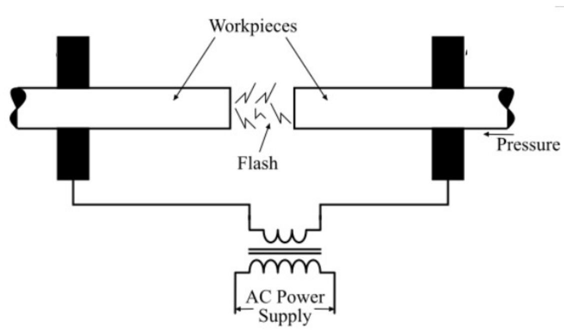
As there are chances for the electrodes to heat up during the process, water cooling is used inside the electrode. This prevents the electrodes from getting welded to the workpiece.

Seam welding



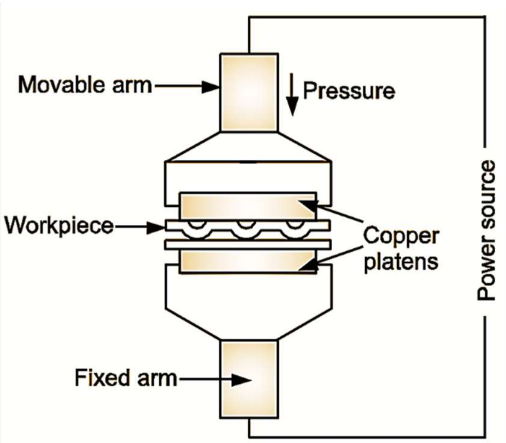
The seam welding is a type of resistance welding, in which weld is produced by roller electrodes instead of tipped electrodes. Seam welding processes produce a continuous or intermittent seam weld near the edge of two overlapped metals. It uses two machine driven roller electrodes which move over the metal workpieces. The workpieces are under pressure and the current passing through them heats the two workpieces of the metal. The amount of heat generated at the seams depends upon the magnitude of welding current flowing through it. Usually, pulses of current are given for a short interval of time. The surfaces to be welded should be clean and dust free. It is used for welding tanks, barrels, exhausts etc.

Flash welding



Flash welding is a resistance welding process, in which the ends of the workpieces are pressed together and a heavy electric current is passed through the joint. In flash welding process, the two workpieces to be welded are clamped strongly in a flash welding machine. When the two workpieces are brought together, the flash created heats the contacting surfaces. When the workpieces reach their melting temperature, the supply of current is cut off. The workpieces are brought together under high mechanical pressure, which forces the fused metal to form a good weld. This method is most suitable for welding rail ends and shaft axles.

Projection welding

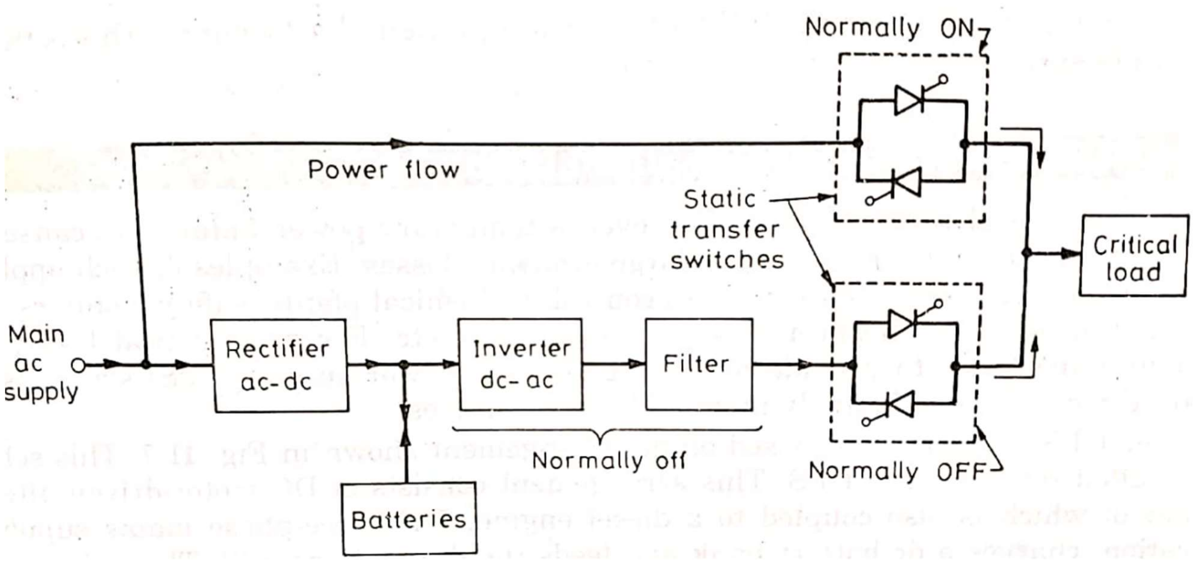


In Projection welding, different projections are formed on the workpieces for effective welding. The process uses two copper electrodes. The metal pieces to be welded are kept between these two electrodes. Projections are accurately formed on the metal workpieces by using special tools. Once the projections are formed, the raised portions on one workpiece are pressed into contact with another workpiece. At the same time, a high electric current is passed through the workpieces. When the raised portions touch the second workpiece, the electric current flows through the contact points, which heats and fuses the two metal workpieces together.

UPS

Temporary power failure can cause public inconvenience and will result in economic loss. Uninterrupted power supply is essential in various areas like offices with computer installations, process control in chemical plants, safety monitors, communication systems and hospital ICUs. UPS (Uninterrupted Power Supply) can be used during power outages. UPS are of two types: Offline UPS and Online UPS.

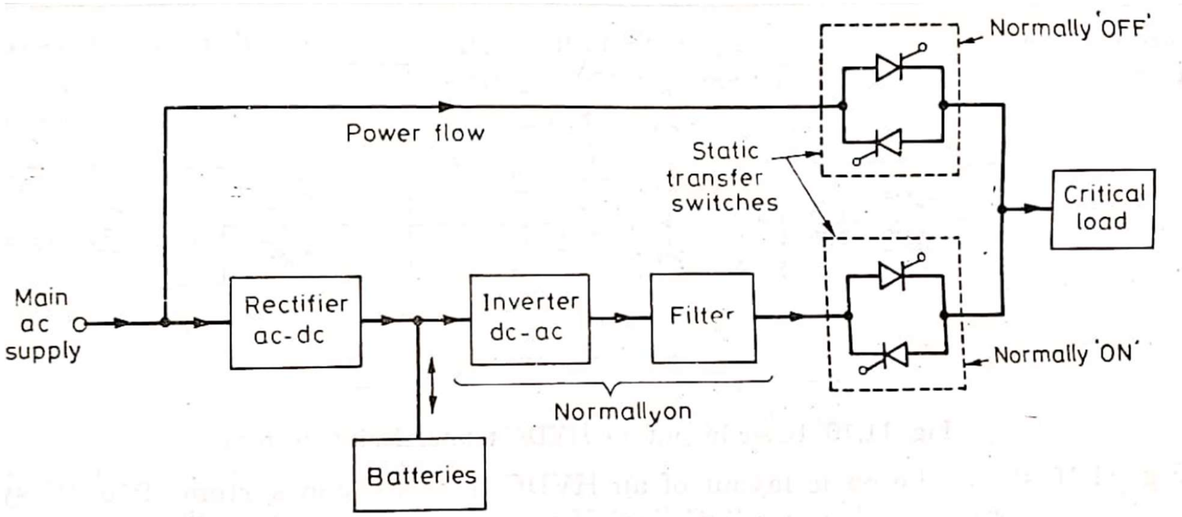
Offline UPS



Offline UPS is used in applications in which short interruption in power supply (4-5 ms) can be tolerated. In this type of UPS, under normal conditions, normally ON switch is closed. Power flows directly from mains to the load. Also, the rectifier converts AC into DC and is used to charge the batteries.

When there is power outrage, normally OFF switch becomes ON. DC voltage from battery is converted to AC using the inverter. It is filtered and given to the load through the static switch. A small flicker can be observed in lamps at the instant of power outage and when power comes back.

Online UPS



Online UPS is used in applications where momentary interruptions in power supply cannot be tolerated. In this type, under normal conditions, rectifier does AC to DC conversion and charges the battery. Inverter converts the DC from battery to AC. It is filtered and given to the load, through normally ON static switch. During power failure, stored battery voltage is utilized by the inverter to produce AC, for supplying to the load.

When there is some failure in the inverter, normally OFF switch is closed and AC mains is directly connected to the load. When the inverter failure is cleared, UPS is restored.

Nickel-cadmium battery or lead acid battery are the standby batteries used in UPS.

Advantages of online UPS over offline UPS

- It can protect the load from power supply transients
- Inverter output frequency can be obtained as desired.
- Inverter conditions the supply