Basic Electrical Principles

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- Basic Electrical Principles
- Electrical Safety
- Handy Reference Guide

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Contents

Introduction

These notes are intended for anyone who has little electrical knowledge or experience and would like to understand more about electrical systems and equipment. They are ideal for someone whose job could easily involve some form of electrical testing and component replacement. The notes are aimed at industrial electrical engineering and is not for those people who wish to install electrical supplies.

The notes are written in a language that is easy to follow and keeps the maths to a minimum and are therefore aimed at someone who wishes to understand enough to be able to carry out electrical checks and repairs without getting too involved in electrical theory.

At the end of each chapter there are Assessment Exercises that allow you to check out your understanding of the topics covered.

Chapter 1

Basic Electrical Principles

At the end of this section you will have an understanding of

- basic electrical quantities
- electrical power
- conductors and insulators
- simple circuit theory
- Ohms Law

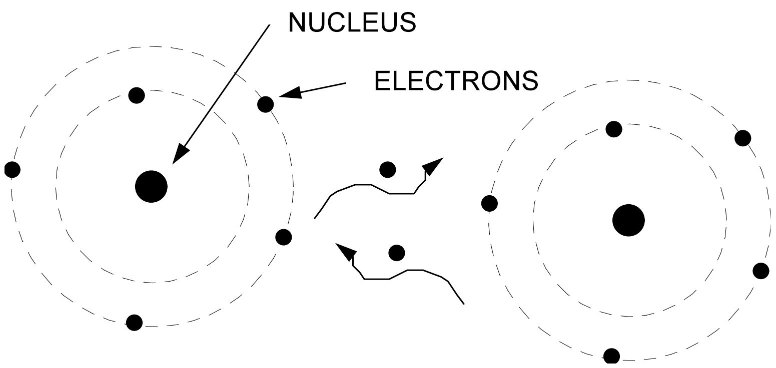
Basic Electrical Principles

Electrical Physics

As a starting point it is important to understand what is happening within an electrical system to take away the unknown and feel confident about working with electricity. First we will consider the physics behind electricity.

All matter is composed of atoms. Each atom comprises of a central nucleus with a number of electrons associated with it. One particular model suggests that this can be considered rather like the sun (the nucleus) surrounded by planets (the electrons). The number of electrons orbiting the nucleus determines the property of the atom. The simplest atom is hydrogen which has only one electron, whilst copper has twenty nine electrons surrounding it's nucleus.

Each electron carries a negative charge of electricity and this negative charge is balanced by an equal and opposite positive charge on the nucleus. The atom, as a whole is electrically neutral.



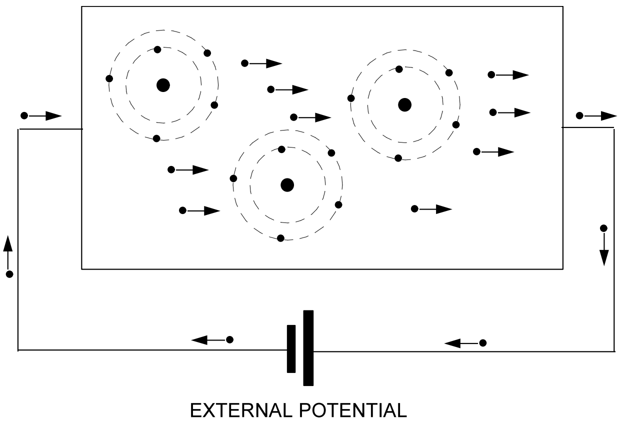
Atoms and Electrons

The electrons are able to move from atom to atom due to energy that they absorb in the form of heat. This movement can be considered as being random.

The Flow of Current

Electrons which carry charge are subjected to forces where - like polarities repel and unlike polarities attract. If an external positive charge is applied to a material then electrons may well be attracted to that positive charge. This can be considered very similar to magnetic effects where like poles repel and unlike poles attract. If there is an overall movement of electrons in one direction towards a positive charge then this constitutes an electric current.

Electric current is the steady flow of electrons moving from atom to atom. These electrons are moving under the influence of an external potential and they will be attracted towards the positive. Current is defined as the movement of positive charge and this will be in the opposite direction to the direction in which the electrons are flowing. Disregarding this anomaly electric current can simply be thought of as the flow of electricity from POSITIVE TO NEGATIVE. Current is the rate of flow of electrons.



Electron Flow

Charge can occur when an imbalance occurs between electrons and nucleus. If a material loses electrons it becomes positively charged. If a material gains electrons it becomes negatively charged.

In general, in circuits, the overall structure of electrons is not changed and therefore electrons entering a circuit will be the same as electrons leaving. This means that the materials in the circuit do not become charged. This leads to a very important concept that electrical current does not disappear. Whatever current flows into a circuit flows out of it. **Current cannot disappear.** In the case of a fault, current might be leaving a circuit through a fault condition (a short circuit to earth for example). The rule apply that the total current entering the circuit equals the total current leaving the circuit. A Residual Current Device makes use of this principle to detect the leakage of current from a circuit..

Electrical current is created by applying an external force (referred to as Electromagnetic force) to a circuit. As a result of current flow there are several possible effects created.

Chemical Effect

Generally there is no change in a metal during the passage of an electric current but some materials are chemically changed by the passage of electric current. Solutions of acid in water are decomposed. The chemical affects of an electric current are utilised in electroplating and accumulators.

Heating Effect

When electric current flows through a substance that has resistance to the flow of electric current, discussed later, that substance becomes heated. Conductors will posses resistance and some conductors are arranged to posses resistance to utilise the heating effect.

An immersion heater comprises of a length of mineral insulated cable in which the conductors are resistance wires. An electric fire element is a coil of resistance wire on a heatproof insulating rod. A lighting bulb has a very fine resistance wire known as the filament. The filament heats under the effect of the current until it becomes incandescent and emits light.

Magnetic Effect

An electric current passing through a conductor produces a magnetic field around that conductor. The polarity and intensity of the magnetic field is dependent on the direction and size of current respectively. Motors make use of the magnetic effects to create forces between magnetic fields that in turn create motion.

Electrical Units

Voltage

Voltage can be described as the driving force or pressure behind electricity. The physical term electromotive force (emf) is used to describe this quantity although the term is not used generally. Voltage is measured in volts and is often the fixed quantity in an electrical system. The voltage is the supply of energy to a circuit and consequently is supplied from a number of sources. A DC system will have a fixed DC voltage supplied from say a battery or DC Power Supply Unit. An AC system will have its AC supply typically from the mains or on occasions a local generator.

Current

Current is the flow of electrons that arises from applying a voltage to a circuit. Current is measured in amps (amperes). A flow of 1 amp is approximately six million, million, million electrons flowing per second. Current will flow when a voltage is applied and there is a complete circuit (or path). The total current flowing in a circuit will be determined by the resistance.

Resistance

Resistance is determined, amongst other things, by the material where all materials have a property called **resistivity**. This property depends upon the ability of electrons in that material to be able to leave their orbits around the nucleus and contribute to current flow. Materials where this can happen easily will be referred to as conductors whereas materials where this cannot happen easily will be referred to as non conductors or insulators. Resistivity is measured in Ohms / metre.

Some typical values of resistivity are shown in the table below

Material	Resistivity (Ω/m)	Type
Silver	1.59×10^{-8}	Conductor
Copper	1.72×10^{-8}	Conductor
Gold	$2.44 \times 10^{-}$	Conductor
Aluminium	2.82×10^{-8}	Conductor
Tungsten	5.6×10^{-8}	Conductor
Platinum	1.06×10^{-7}	Conductor
Carbon	3.5×10^{-5}	Conductor
Germanium	4.6×10^{-1}	Semi Conductor
Silicon	6.4×10^{2}	Semi Conductor
Glass	10^{10} - 10^{14}	Insulator
Hard Rubber	10^{13}	Insulator
Teflon	10^{22} - 10^{24}	Insulator

Resistance is the opposition to the flow of current. Resistance is measured in Ohms, symbol Ω and is determined by the type and size of material in which the current is attempting to flow.

The size of the material will be given by it’s length and it’s cross sectional area.

Resistance is calculated from

$$\text{Resistance} = \frac{\text{resistivity of the material X length}}{\text{cross sectional area (csa)}}$$

It can be seen from this formula that length and cross sectional area have an effect on resistance.

As length increases, resistance increases and vice versa. As cross sectional area increases resistance decreases and vice versa.

This is important in as much as cables have to be of a given size to be adequate for a particular function. Cables that are longer than they need to be could possess too much resistance and cables that are too thin could also possess too much resistance.

Conductors

In a conductor the electrons are not firmly attached to the nucleus and are normally interchanging between atoms in a random manner. They can easily leave their orbit when an external potential is applied and so will cause current to flow. A conductor is classified as a material in which there will easily be current flow i.e. one that possesses a low resistivity. Examples: silver, copper, aluminium,

Insulators

In an insulator the electrons are firmly attached to the nucleus and will not be moved from their orbit when an external potential is applied. The interchange of electrons will not take place and consequently there will be no current flow. An insulator is defined as material that will not pass current and will have a high value of resistivity. (rubber, PVC, porcelain,…)

Energy

Energy is the capacity of an object or a system to do work and is measured in Joules.

energy can neither be created nor destroyed.

Energy is converted from one source to another

Example:
A lamp converts electrical energy into light energy.
A motor converts electrical energy into mechanical energy
A battery converts chemical energy into electrical energy

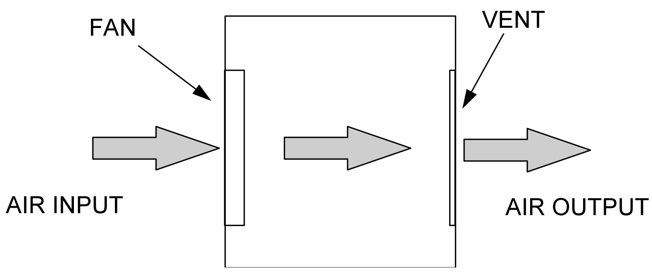
The potential energy of water in a highland reservoir is converted into kinetic energy as the water flows down the inlet tube where it is converted into electrical energy by a generator driven from a turbine.

Power

Power is the rate at which energy is delivered or consumed and is measured in Watts. In most cases the conversion of energy is not 100% efficient and a proportion of the input power appears as wanted output. The total wanted power at the output compared to the input is indicated by the efficiency of the system.

$$\text{Efficiency} = \frac{\text{Power Output}}{\text{Power Input}} \times 100\%$$

Another form of energy is always produced as a *by product*. Most commonly this *by product* is heat and it is often necessary to find ways of disposing of this heat by providing extra methods of cooling by having fins or fans. Failure to dispose of this heat can cause the equipment to overheat with serious consequences. It is important to understand how a piece of equipment is cooled and any factor that hinders this process can result in damage.



Air Cooling

Restricting the throughput of air can affect the cooling and result in overheating.

Power is lost through resistance as this causes heat. Conductors possess resistance and this generates heat and results in a power loss. For example a loud speaker coil possesses resistance. This resistance is not needed in the process of converting electrical power to sound power but will produce heat. This heat will need to be dissipated to protect the speaker from overheating.

Electrical Power

Electrical power is supplied to a circuit whenever a voltage is applied and current flows. The power supplied to that circuit will the product of voltage times the current and will be measured in watts, symbol W

$$\text{POWER (Watts)} = \text{VOLTAGE (Volts)} \times \text{CURRENT (Amps)}$$

A car starter motor taking 200A from a 12V battery will be taking 2400W of power.

Also

$$\text{CURRENT(Amps)} = \frac{\text{POWER (Watts)}}{\text{VOLTAGE (Volts)}}$$

A 2400W heater element connected to a 240V supply will take 10A.

For a given power requirement the lower the operating voltage; the higher the current consumption and vice versa. For example the car starter motor takes 200A due the low voltage whereas the same power requirement using a 240V motor would only consume 10A.

By looking at the power rating of some items of equipment it is possible to establish from this calculation the level of current that will be consumed. It is important to appreciate that some items of equipment such as motors specify the mechanical output that is available as a maximum. If the motor is not on it’s maximum load (which it ought not to be) the current drawn would be less. By looking at the motor power rating it is possible to determine the maximum current that should be drawn by the motor.

Unit Multiples and Submultiples

It is often necessary to deal with very large or very small electrical quantities and multiplying factors can be used. It would be awkward to deal with say 0.00001 amps.

ABBREVIATION	UNIT	VALUE	EXAMPLE
T	TERRA	1,000,000,000,000	Thz (Terra Hertz)
G	GIGA	1,000,000,000	Ghz (Giga Hertz)
M	MEGA	1,000,000	Mhz (Mega Hertz)
K	KILO	1,000	kV (kilovolts)
m	MILLI	0.001	mV (millivolts)
µ	MICRO	0.000001	µA (microamps)
n	NANO	0.000000001	nF (nanofarads)
p	PICO	0.000000000001	pF (picofarads)

Index Notation

Index Notation is where a number is raised to the power of 10

For example 10^3 is 10 raised to the power of 3 which is 10 X 10 X10 = 1000 = kilo

Similarly

10^6 is 10 raised to the power of 6 which 10 X 10 X 10 X 10 X 10 X 10 = 1000000=mega

10^9 = 1000000000 = giga

5 X 10^3 = 5000

7 X 10^6 = 7000000

Negative Power

10^{-1} is

$$\frac{1}{10} = 0.01$$

10^{-3} is

$$\frac{1}{10^3} = 0.003 = \text{mili}$$

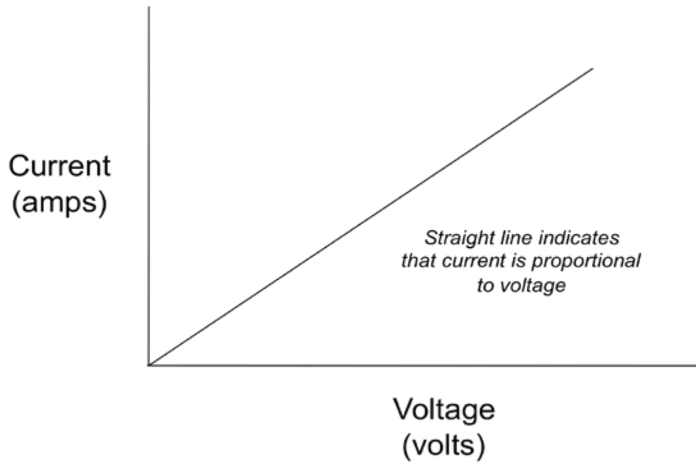
5 X 10^{-3} A = 5mA

8 X 10^{-6}A = 8µA (micro Amp)

Ohm’s Law

The most commonly used principle in electrical systems is Ohm’s Law, that gives the relationship between voltage, current and resistance.

VOLTAGE = CURRENT × RESISTANCE



Current v Voltage Graph

The relationship between voltage and current is linear i.e. as the voltage increases then the current increases and vice versa. Simple calculations can be carried out to determine the current that will flow in a circuit of a given resistance.
Alternative forms of Ohms Law:

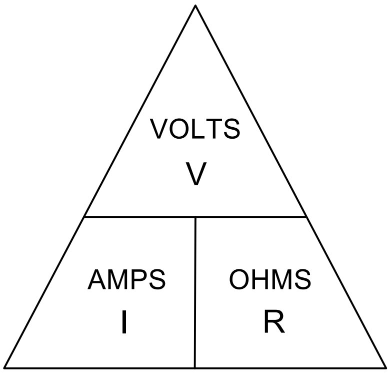
$$\textbf{CURRENT} = \frac{\textbf{VOLTAGE}}{\textbf{RESISTANCE}}$$

and

$$\textbf{RESISTANCE} = \frac{\textbf{VOLTAGE}}{\textbf{CURRENT}}$$

For simplicity Ohm’s Law can be viewed as a triangle that reminds us of the relationship between voltage, current and resistance.

Ohm's Law Triangle



Note:

V = Voltage

I = Current

R = Resistance

Example:

A 20 volt supply is applied to a circuit that has a resistance of 10 ohms. What current will flow.

From

$$\text{Current} = \frac{\text{Voltage}}{\text{Resistance}}$$

$$I = \frac{20V}{10\Omega} = 2A$$

Using Ohm's Law to understand electrical fault conditions

Using the expression

$$\textbf{CURRENT} = \frac{\textbf{VOLTAGE}}{\textbf{RESISTANCE}}$$

it is possible to consider the causes of problems in electrical systems.

Current is what creates the end result; current through a heater element creates heat; current through a motor creates the torque and therefore the movement. If the current through any device or circuit is not what it is supposed to be the output will not be what it is supposed to be.

Too little current

If the current flow through a item of equipment is too low the output from the equipment, in whatever energy form this is, will be low (ie insufficient heat) this would be created by either a

(a) too low voltage applied to the equipment

or

(b) a too higher resistance within the equipment

If the voltage supplied to equipment is low then this could mean that the supply voltage coming into the equipment is low which needs to be investigated. Alternatively the supply voltage could be at it's correct level but there is a fault which is causing a volt drop within the control circuit. See Volt Drops.

If the resistance of the equipment (or the circuit supplying the equipment) is too high then this could be caused by a loose connection, a worn contact.

The extreme situation would be ZERO current. This situation would be caused by

(a) no supply voltage

or

(b) a very, very high (infinite) resistance which would mean that the circuit has no path through it and there is a complete disconnection of the circuit. This condition is known as an **OPEN CIRCUIT**. The symptom of an open circuit is the equipment or system does not operate.

Too much current

If a circuit tried to take too much current this would be caused by

(a) too much voltage (a higher than normal voltage)

or

(b) too little resistance.

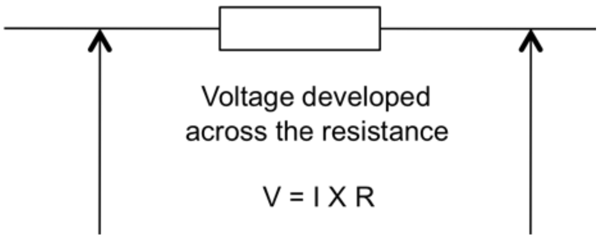
An over-voltage condition would suggest that there is a problem with the supply. This condition is fairly rare for extended periods but can happen as a surge for a short duration of time. Such effects might occur for example during electric storms.

Too little resistance is caused when the circuit path is in someway reduced. This can be caused by conducting parts coming into contact such as cables with damaged insulation coming into contact with each other or the casing or enclosure. This condition is referred to as a **SHORT CIRCUIT**.

NOTE: Excessive current would be prevented by the operation of a circuit protection device such as a fuse or circuit breaker.

Volt Drops

Whenever current flows through a resistance there will be a voltage developed across that resistance.



Voltage across resistance

Example:

A current of 10A flows through a resistance of 5Ω. What will be the voltage developed across the resistance.

VOLTAGE = CURRENT × RESISTANCE

Voltage = 10 × 5 = 50V

Volt drops can be created by faults in systems. Discussed further in Chapter 2 Electrical Circuits.

Heating Effects Within Circuits

When current flows through a resistance heat is produced. This heat is produced by the energy needed to move electrons through a material. All electrical systems need to manage the heat that is produced and ensure that it is displaced. Therefore all conductors (and other parts that will absorb the heat from conductors) will have a method by which heat is removed. In many cases that heat removal is by convection and radiation into the surrounding air.

It is important to appreciate that any change in the system that will reduce the ability of the conductor to cool will cause heat to be retained and therefore the conductor could overheat.

Such things might include the covering of cables, leaving cables wound on a reel, covering ventilation holes or failures of fans.

The heat within a conductor can rise considerably which could eventually lead to the melting of insulation and subsequent exposure of live conductors which exposes a real danger of electric shock. Heat can also increase to the extent that there is a danger of fire. Any given conductor in a circuit will have a maximum current that can flow through it whilst allowing for the heat that is generated to be removed by the cooling method. Currents in excess of this value will cause potential overheating and dangers. Conductors therefore can never be allowed to have more than this maximum value of current flowing in them and a means has to be provided to prevent this over-current. Such protection is provided by the use of fuses and circuit breakers.

The heat produced within a conductor would be given by I^2R *(the square of the current multiplied by the resistance). This means that the heat that is produced is proportional to the square of the current.
If the current in a conductor doubled the heat would increase by a factor or four (two squared). If the current in a conductor increased by factor of three the heat would increase by a factor of nine (three squared). This can explain why conductors will soon get very hot within a circuit if excessive current is allowed to flow.

This principle applies to any conductor in any position within a circuit including cables, switches, connectors, plugs, sockets, fittings etc.

* This formula is determined by combining Ohms Law with the formula for power.

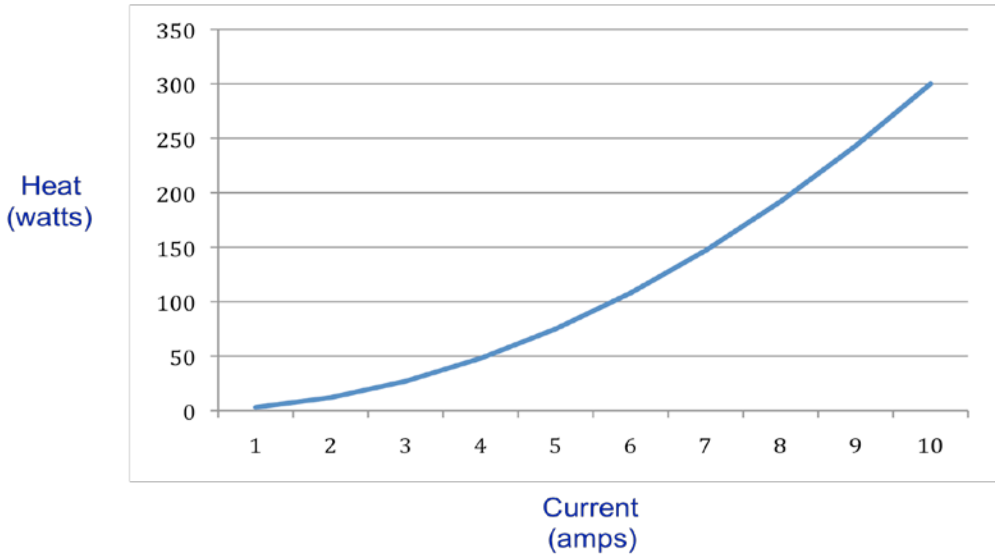
POWER = VOLTAGE X CURRENT

From Ohms Law

VOLTAGE = CURRENT X RESISTANCE

By replacing VOLTAGE in the Power equation with CURRENT X RESISTANCE we have

POWER = CURRENT X RESISTANCE X CURRENT
= CURRENT X CURRENT X RESISTANCE
= CURRENT ^{2} X RESISTANCE
= I^2 R



Heat v Current

EXERCISE

1 Current is the

- a flow of electrons
- b amount of energy
- c power in a circuit
- d electrical force

2 Resistance is measured in

- a amps
- b volts
- c watts
- d ohms

3 Power is

- a the flow current
- b measured in joules
- c the rate of energy dissipation
- d the amount of current

4 According to Ohms Law if voltage doubles

- a resistance doubles
- b current halves
- c resistance halves
- d current doubles

5 The Power delivered to a circuit with a 230V supply providing 12A is

- a 230W
- b 12W
- c 19.2W
- d 2.76KW

6 When current flows through a conductor what is produced around that conductor

a light

b inductance

c a magnetic field

d capacitance

7 If the length of cable doubles, resistance

a doubles

b halves

c stays the same

d reduces

8 A current of 5A flows through a resistance of 2Ω. What is the voltage across the resistance ?

a 10V

b 5V

c 2V

d 2.5V

9 A current of 10A flows through a resistance of 12Ω. How much heat is produced ?

a 1200OW

b 120W

c 1200W

d 12W

10 Mega is

a 10^{3}

b 10^{6}

c 10^{12}

d 10^{2}

Chapter 2

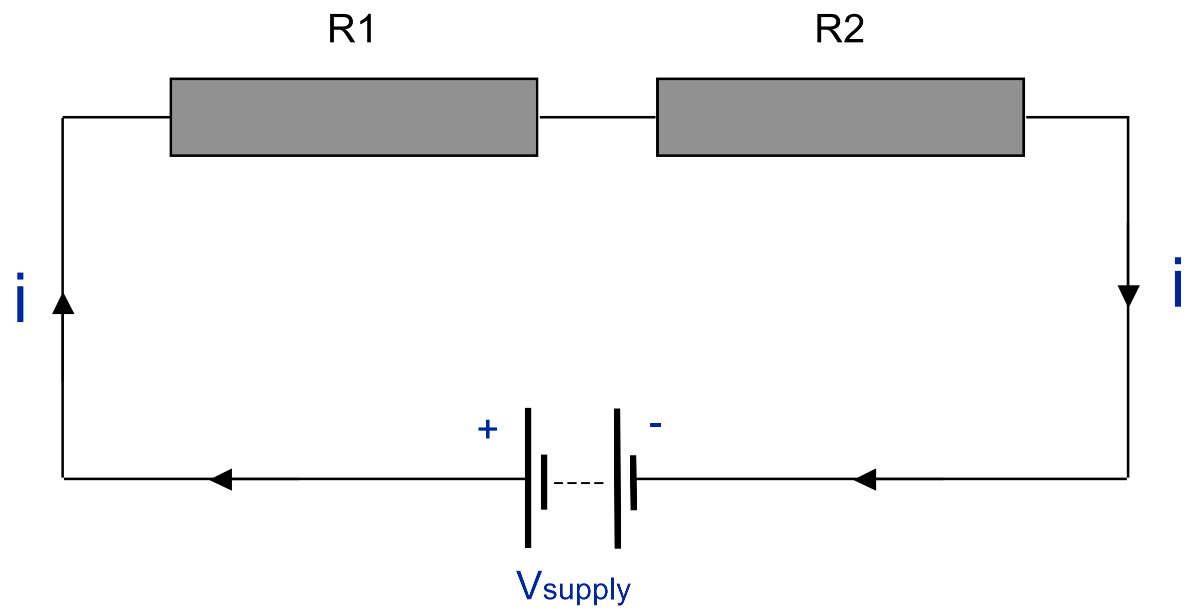
Electrical Circuits

At the end of this section you will have an understanding of

- series circuits
- parallel circuits
- series parallel circuits

Electrical Circuits

Series Circuits



Series Circuit

Consider a circuit where two items are connected together in such a way that the current path is through both components. There are two basic features

- the same current will flow through both component
- there will be volt drops across both components

Voltage Law in closed circuit:

The sum of the voltage drops around the circuit will add up to the supply voltage, i.e. there is no voltage lost.

Suppose the two components have resistances of R1 and R2, then the volt drops across the resistances will be calculated from Ohms Law as the product of current and resistance.

Volt drop across R1 = $I \times R1$
Volt drop across R2 = $I \times R2$

The total volt drop around the circuit will then be

$$(I \times R1) + (I \times R2)$$

The supply voltage can be expressed as current times total circuit resistance

$$I \times R_{(total)}$$

Therefore

Supply voltage = Volt drop across R1 + Volt drop across R2

$$I \times R_{(total)} = (I \times R1) + (I \times R2)$$

Note that I is common to all parts in the equation and therefore can be removed. This gives,

$$R_{(total)} = R1 + R2$$

This circuit is a SERIES CIRCUIT where the total resistance is given by

$$R_{(total)} = R1 + R2$$

Generally expression:

THE TOTAL RESISTANCE IN A SERIES CIRCUIT IS THE SUM OF ALL THE INDIVIDUAL RESISTANCES

$$\mathbf{R_{(total)} = R1 + R2 + R3 + \ldots.}$$

Examples

Three resistances of 10Ω, 25Ω and 35Ω are connected in series.
The total resistance will be

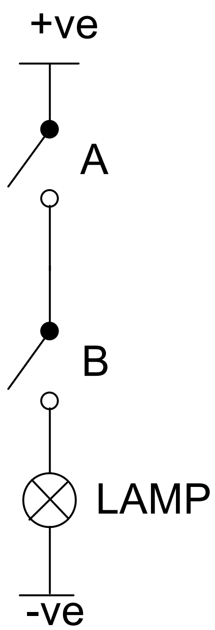
$$10 + 25 + 35 = 70\Omega$$

A cable of total resistance 0.3Ω is joined to a cable with resistance 0.15Ω.

The total cable resistance will be

$$0.3 + 0.15 = 0.45\Omega$$

Switches connected in series.



In this simple circuit shown, what condition do the switches need to be in for the lamp to light ?

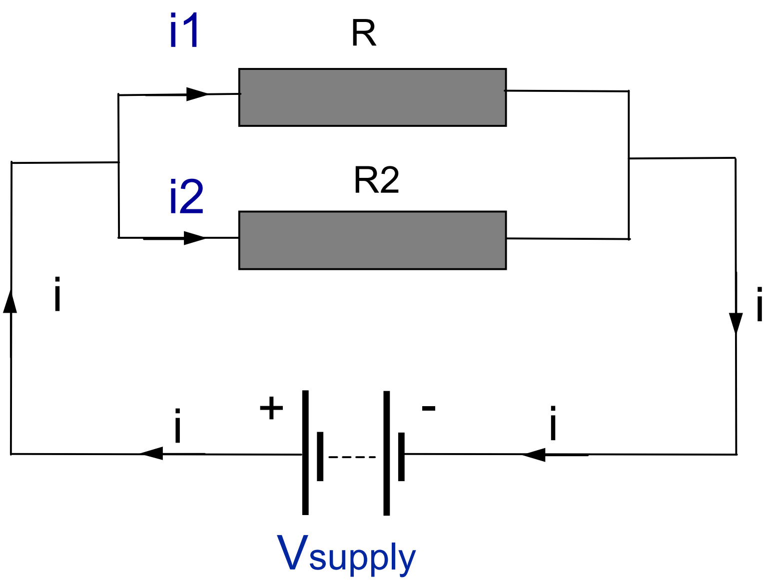
The two switches both need to be operated or turned on.

This can be phrased as switch A AND switch B will need to be on for the lamp to operate.

This is an example of a control function where the lamp is controlled by the two switches A and B. By connected the switches in series it gives this specific control function of requiring both switches to be on.

In logic control circuits this function is known as the AND function

Parallel Circuits



Parallel Circuits

Now consider a circuit where two resistances are connected such that they are both connected to the same supply. There are two basic features

- each component will have the same voltage across it

- the current drawn from the supply will split with a proportion of the current flowing through R1 and the remainder flowing through R2.

The current through either resistance can be expressed as

$$I = \frac{\text{Voltage}}{\text{Resistance}}$$

The total current drawn from the supply will be the sum of the currents through the two resistances.

From this it can be appreciated that the current drawn by two resistances connected in parallel would be more that the current drawn by one resistance. If the two resistances were the same value then the current drawn from the supply would be TWICE the value compared to one resistance.

Suppose a 10Ω resistance is connected to a 10 V supply then the current drawn would be 1A. If a second resistance is connected in parallel it would also draw 1A. The current drawn from the supply would then be 2A.

Greater current drawn suggests that the resistance of the parallel circuit (ie both resistances) is less than the single circuit of one resistance because it draws more current. More precisely the current drawn is TWICE and therefore the combined resistance must be HALF. The effect of adding parallel resistance to a circuit DECREASES the overall resistance. A formula can be used to calculate the overall resistance of a parallel circuit

$$\frac{1}{R_{(total))}} = \frac{1}{R1} + \frac{1}{R2}$$

General expression:

THE RECIPROCAL OF THE TOTAL RESISTANCE IS EQUAL TO THE SUM OF THE RECIPROCALS OF EACH PARALLEL RESISTANCE

$$\frac{1}{R_{(total)}} = \frac{1}{R1} + \frac{1}{R2} + \frac{1}{R3} \ldots$$

When there are only two resistances, there is an alternative although easier to use formula

$$\textbf{TOTAL RESISTANCE} = \frac{\textbf{PRODUCT}}{\textbf{SUM}}$$

$$R_{(total)} = \frac{R1 \times R2}{R1 + R2}$$

Example

1. Two equal resistances of 10Ω are connected in parallel.

The total resistance will be calculated by

$$\frac{\text{PRODUCT}}{\text{SUM}} = \frac{10 \times 10}{10 + 10} = \frac{100}{20} = 5\Omega$$

Note that when the two resistances are equal the resistance is halved.

2. Two resistances of 20Ω and 30Ω are connected in parallel.

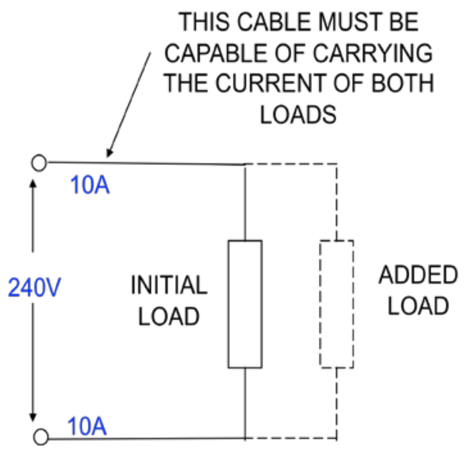
The total resistance is given by

$$\frac{\text{PRODUCT}}{\text{SUM}} = \frac{20 \times 30}{20 + 30} = \frac{600}{50} = 12\Omega$$

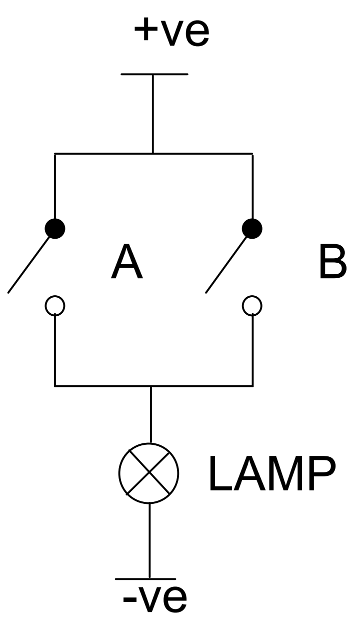
When a resistance has another resistance connected in parallel, then that resistance is reduced. The most that a resistance is decreased by is to a half of its value when the parallel resistance is equal to the initial resistance.

When resistance is reduced then the current drawn by that circuit will increase. This is understandable since a parallel circuit is another load that will draw current.

It is important to appreciate that when a parallel circuit is connected the initial supply cable must be capable of carrying this extra current.



Switches connected in Parallel



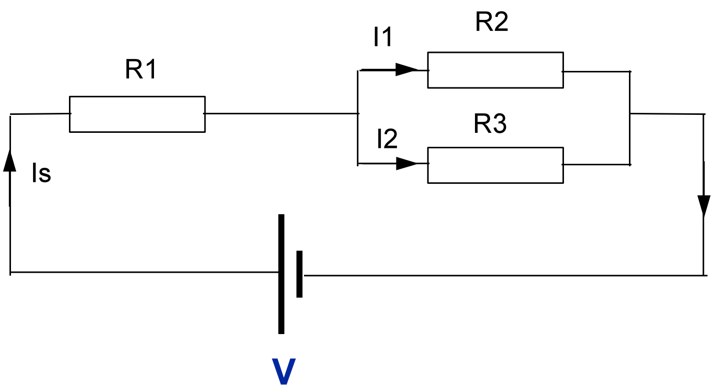
In this simple circuit shown, what condition do the switches need to be in for the lamp to light ?

Switch A can be turned on OR switch B can be turned on to operate the lamp.

This gives another specific control function where either of the switches (or both) can be turned on to operate the lamp.

In logic control circuits this is called the OR function.

Series - Parallel Circuits

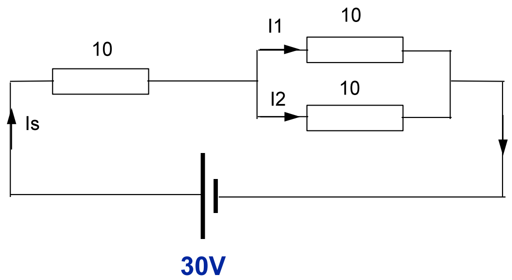


Series – Parallel Circuit

A series parallel arrangement consists of a mixture of series and parallel circuits.

It can be seen that the circuit consists of a series resistance in series with a parallel network. This circuit could be analysed by calculating the parallel resistance first (R2 in parallel with R3) and then considering this in series with the series resistor(R1).

Example



Total resistance is given by

10 Ω in parallel with 10 Ω

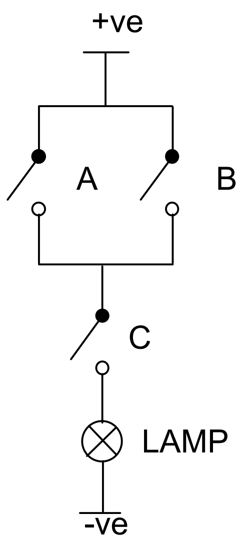
$$\frac{\text{PRODUCT}}{\text{SUM}} = \frac{10 \times 10}{10 + 10} = \frac{100}{20} = 5\Omega$$

This value is in series with 10Ω

Total circuit resistance is therefore 10Ω + 5Ω = **15**Ω

$$\text{Circuit Current} = \frac{30\text{V}}{15\Omega} = 2\text{A}$$

Switches connected in a series and parallel arrangement.



In the circuit there is a parallel and series combination. This consists of switches A and B connected in parallel with switch C connected in series with it.

This will give a specific control function and in this case it is

Switch A or/and Switch B AND switch C.

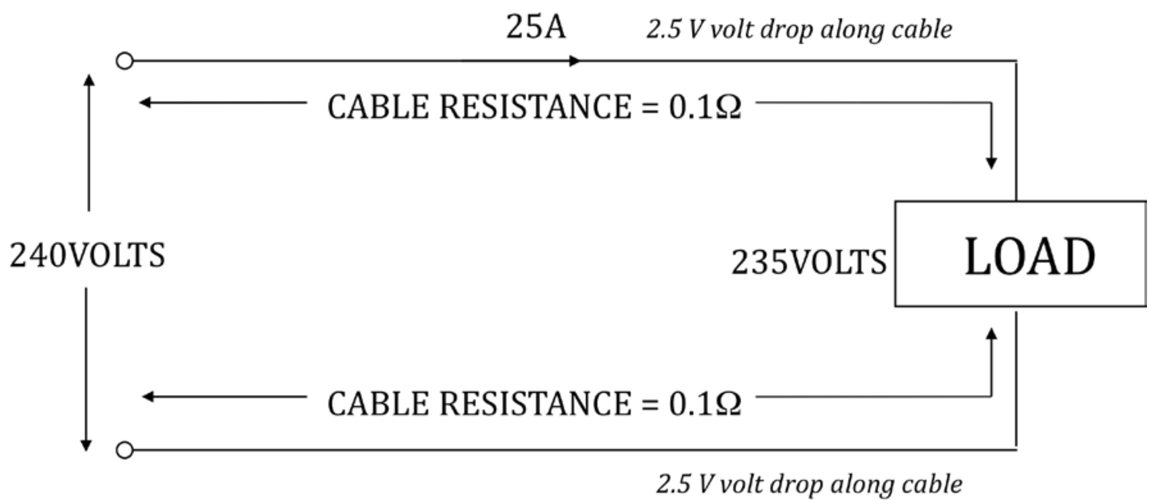
Volt Drops

Consider a cable that connects a supply onto a load, say a motor. The cable will possess resistance, which in turn, due to the current that is flowing in the cable, will produce a volt drop along the cable.

In the diagram below, the volt drop along one length of cable will be

$$25 \times 0.1 = 2.5V$$

There will be a similar volt drop along the return leg, giving a total volt drop of 5V between the supply and the load. The voltage on the load will therefore be 235V.



Voltage Drop Example

Volt drops may well be observed at the terminals of a load and the terminal voltage may well be adequate for the load. In the event of severe volts drops the load terminal voltage may be too low and the equipment fails to operate satisfactorily.

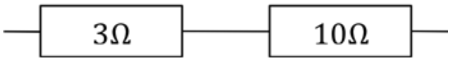
Typical causes of excessive volt drops.

- undersized cable
- extra resistance in the supply wiring due to poor (loose or worn) connections
- unnecessarily long cable
- fault in the load causing over-current

EXERCISE

Calculate the total resistance of the following resistor networks

1.



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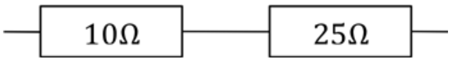

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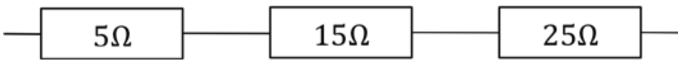

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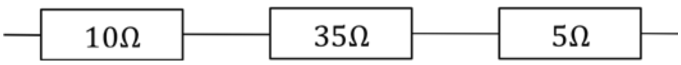

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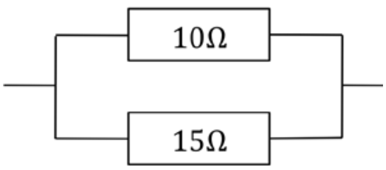

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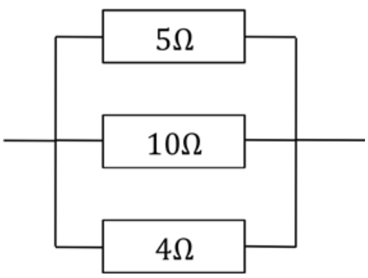

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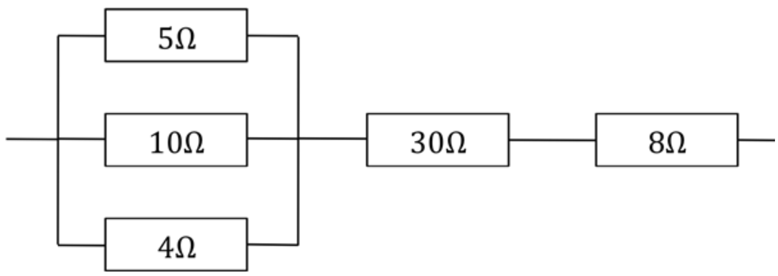

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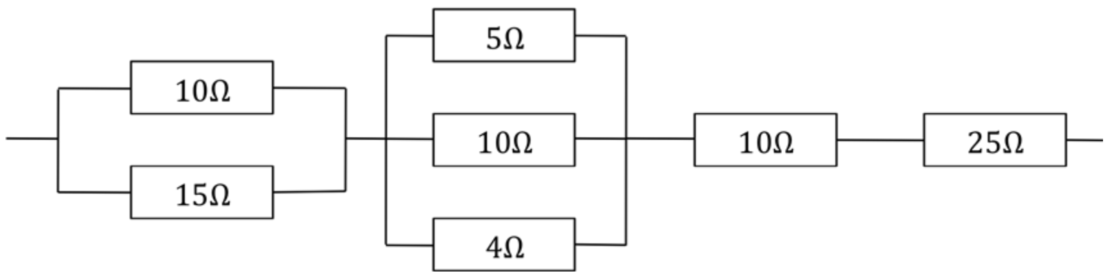
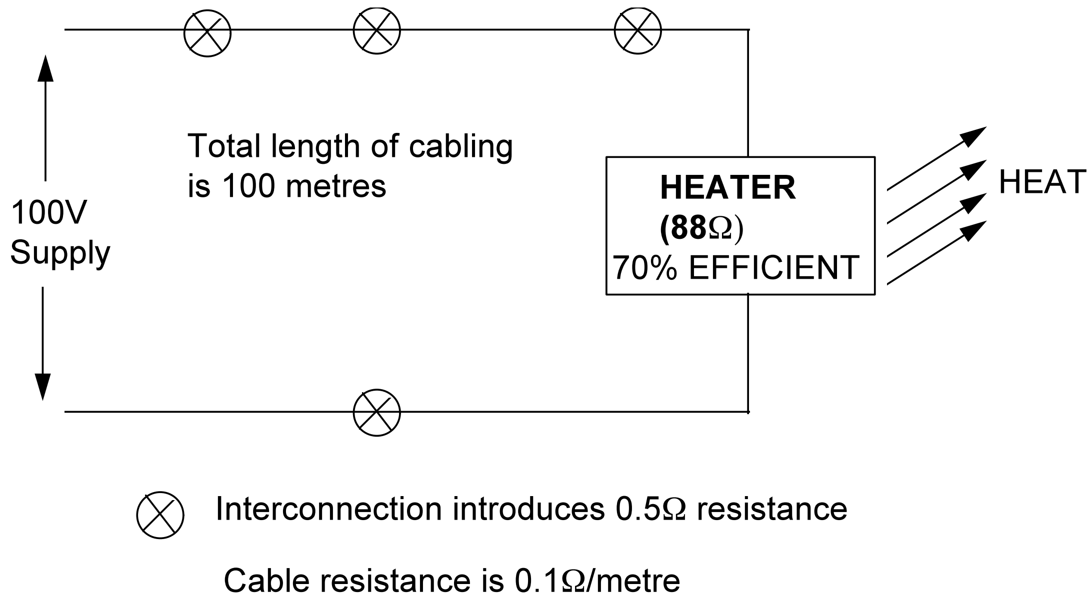


VOLT DROP EXERCISE



9.

Calculate the terminal voltage on the heater

10.

The heating process requires a minimum of 75W of heat. Will the process be operating satisfactorily under these conditions.

Chapter 3

DC Supplies

At the end of this section you will have an understanding of

- Dry and wet cells
- Electronic DC power supply units

DC Supplies

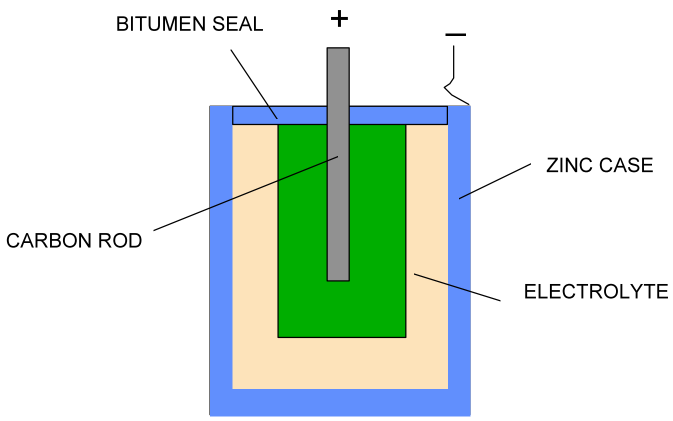
A DC supply is one in which the polarity of the supply does not change. It will have a positive and a negative line and the polarity of connection will in many instances be very important. A DC supply will essentially be generated from two different sources

- a battery
- a mains power supply unit

Batteries

Primary Cell

The principle of a primary cell is that two dissimilar metals are immersed in solution of acid or salt, called an electrolyte, an emf will be produced across the two metals. This emf can be used as a source to supply a load but it can only do so for a limited period of time as the electrolyte will deteriorate.



Dry Cell

The Secondary Cell

The secondary cell consists of positive and negative electrodes with an electrolyte of dilute sulphuric acid housed in an acid proof container. The electrodes are made of several plates separated by insulating materials.

When an external load is connected to the terminals of the cells, electrical energy is delivered to the load. During this discharge period, a chemical reaction takes place and a layer of lead sulphate is deposited on the plates. This process successively weakens the electrolyte until the cell is unable to deliver any more energy.

If a DC supply is then connected to the cell terminals and a current passed through it, the lead sulphate is converted back to sulphuric acid and restores the cell to it's original position. This process is known as recharging.

Care and Maintenance of secondary Cells

When the chemicals of a cell have changed to the inactive form, they can be made active again by passing a charging current through the battery in the opposite direction to the discharge current. There are two methods of charging:

Constant voltage charging	A constant voltage is applied to the battery under charge. While the battery is charging, a steady increase occurs in the terminal voltage, so that the charging current tapers off to a lower value at the end of the charge compared to the beginning. It is recommended that lead acid batteries are not charged in this way and a constant charge rate is better.
Constant current charging	This system uses an adjustable voltage source or a variable resistance so that the charging current can be kept constant throughout the charge.

Charging and maintenance requirements of lead acid and alkaline cells are quite different.

Lead-acid cells

These cells are the most widely used due to their comparatively low cost and higher voltage per cell. They consist of two plates of lead in a electrolyte solution of dilute sulphuric acid. They can be damaged by charging or discharging too quickly, overcharging and leaving in the discharged state. Healthy cells can only be maintained in condition either by keeping them fully charged or by periodically charging them. A lead acid cell will lose it's charge if left standing over a period of a few months. The constant current method of charging is preferred and the value of current would vary with the type of cell. A common value is one-tenth of the ampere-hour capacity. It is important not to overcharge.

There are three methods by which the state of charge can be determined.

Colour of plates	Fully charged cells should have clear light-grey negative plates and rich brown positive plates
Terminal voltage	Open circuit voltage of a fully charged cell depends on the type, being from 2.1V to 2.3V
Specific gravity	This is the best method of determining the state of charge

Provided the lead acid cell is maintained regularly it will last for a long period. Weekly checks on it's condition are recommended.

Electrolyte Level

The level of the electrolyte should never be allowed to fall below the tops of the plates.

Specific Gravity

As a cell discharges the electrolyte becomes weakened it's specific gravity falls until the cell can no longer deliver energy. Water is produced on discharge which lowers the specific gravity. The state of charge can therefore be measured by the specific gravity. The table below indicates the values of specific gravity in relation to the charge.

Specific Gravity	% of Charge
1.28	100
1.25	75
1.22	50
1.19	25
1.16	0

Terminal Voltage

At the end of a discharge period the voltage per cell should be 1.85 V. A fully charged cell should indicate about 2.2V which falls to 2.0V when in use.

Cell Capacity

The capacity of a cell is quoted in ampere - hours. If a cell is capable of delivering 10A for 10 hours it will have a capacity of 100 ampere hours (Ah). If the current drawn from the cell is more than 10A it will supply this for less time.

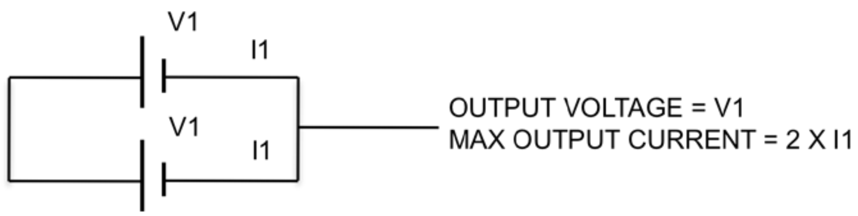
Combining Cells

Cells in Series

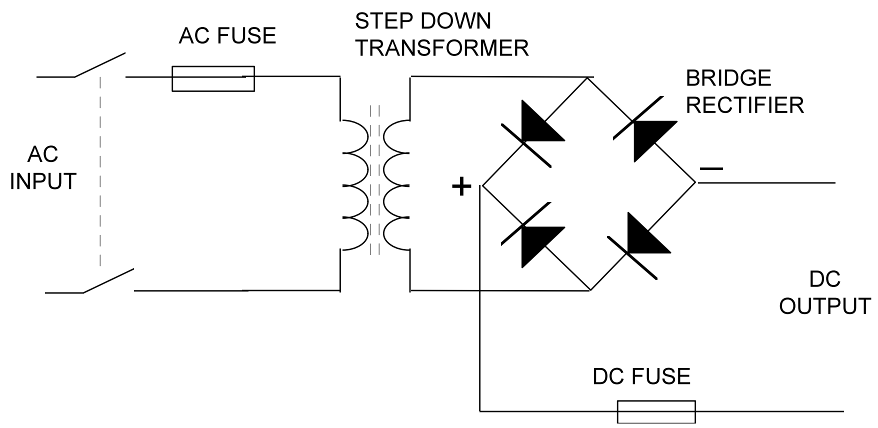
The combined voltage of connecting several cells in series will be the addition of the voltage of each cell. The current drawing capacity will be that of one cell.

Cells in Parallel

Assuming two cells of equal voltage are connected in parallel the overall voltage will be the same as one cell but the current capacity will be the sum of the two.



Linear DC Power Supply Unit



Power Supply Unit

The power input is from a single phase supply which is fused for protection purposes. The AC input is reduced to an appropriate level by a step down transformer. The output from the transformer supplies a bridge rectifier. The diodes in this circuit only allow current to pass in one direction. Consequently the output is unipolar i.e. DC. Fuses are often placed in the DC supply line to protect the circuitry being supplied.

Smoothing and Regulation

The DC output from this circuit will be poor in terms of it's smoothness and it's ability to remain constant regardless of the current being supplied. The following circuits would be added to the above circuit to create a more useful DC supply

Smoothing

This would remove any ripples of the AC that comes through to the DC.

Regulation

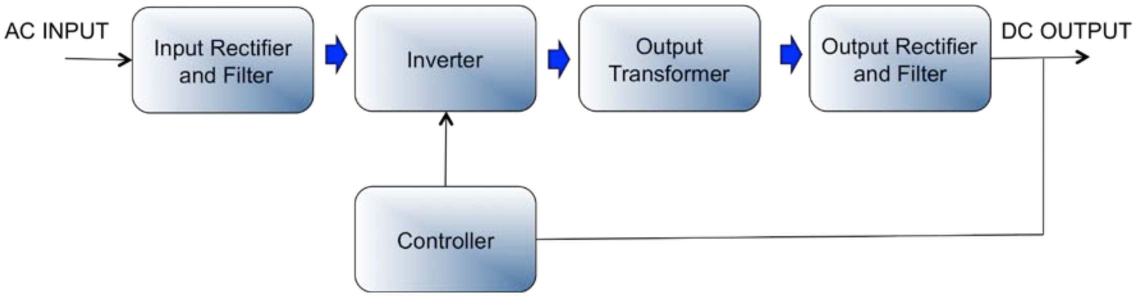
Ensuring that the output voltage remains constant regardless of the load. High current drawn would have a tendency to lower the output voltage whereas lower currents would have a tendency to increase the output voltage. Good regulation prevents this occurring.

Current Limit

Power supplies will often have a current limit which prevents the output current from increasing beyond a set limit. This will give protection against short circuits on the output.

Switched Mode Power Supplies

Switch mode power supplies provide a much more efficient method of generating a DC supply.



These power supplies offer the advantages of greater efficiency, smaller size and light weight but as such are more complex and can produce electrical noise.

The AC input is initially rectified to produce a high voltage DC. This DC is then switched by the inverter. An inverter is a circuit that converts DC to AC The rate of switching in terms of on time versus off determines the level of DC output. The more 'on' time gives a greater output. The switching voltage is then transformed and an output rectifier and filter removes the switching frequency. Feedback from the output to the inverter regulates the output to keep it constant.

EXERCISE

1 *Two 12V 4A power supplies are connected in series, what is the combined output*

- a 12V at 4A
- b 24V at 4A
- c 24V at 8A
- d 12 V at 8A

2 *Two 24V 3A power supplies are connected in parallel, what is the combined output*

- a 24V at 6A
- b 48V at 6A
- c 24V at 3A
- d 48V at 3A

3 *The purpose of smoothing in a DC power supply is to*

- a Protect the supply from delivering too much current
- b Ensure that the output stays constant with varying loads
- c Convert the AC to DC
- d Remove any AC ripples

4 *An inverter*

- a Converts AC to AC at a different voltage
- b Converts DC to DC at a different voltage
- c Converts AC to DC
- d Converts DC to AC

5 *A switched mode power supply compared to a linear supply is*

- a More efficient
- b Cheaper
- c More accurate
- d Much more widely available

Chapter 4

AC Supplies

At the end of this section you will have an understanding of

- how AC is generated
- how ac is measured
- phase and phase difference
- inductance
- capacitance

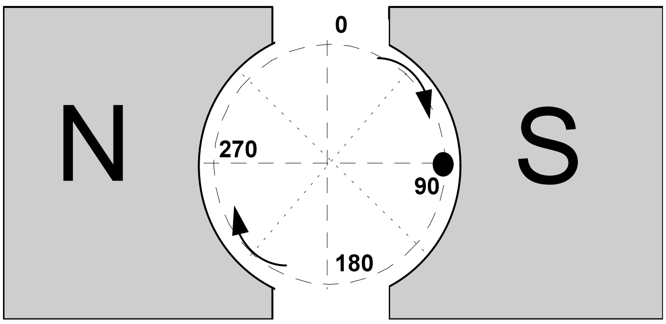
AC Supplies

Generation

Definition: emf - electromotive force – the force that makes electrons move

Faradays laws of electromagnetic induction says that if a conductor is moved within a magnetic field in such a way that it cuts across the lines of magnetic flux, then an emf (electro motive force) will be induced in that conductor. This emf is more commonly referred to as voltage. The maximum voltage will be induced when the conductor moves at right angles to the field. If the conductor moves along the field from pole to pole then no voltage will be induced. The polarity of the voltage will be determined by the direction of movement. If that conductor is connected to complete a circuit then current will flow. This is the principle of generation of electricity. A conductor is arranged to move within a magnetic field and the ends of the conductor form the output from which the power is delivered. Generators producing AC will be referred to as Alternators

Consider a single conductor that is moved in such a way that it rotates clockwise within a magnetic field.



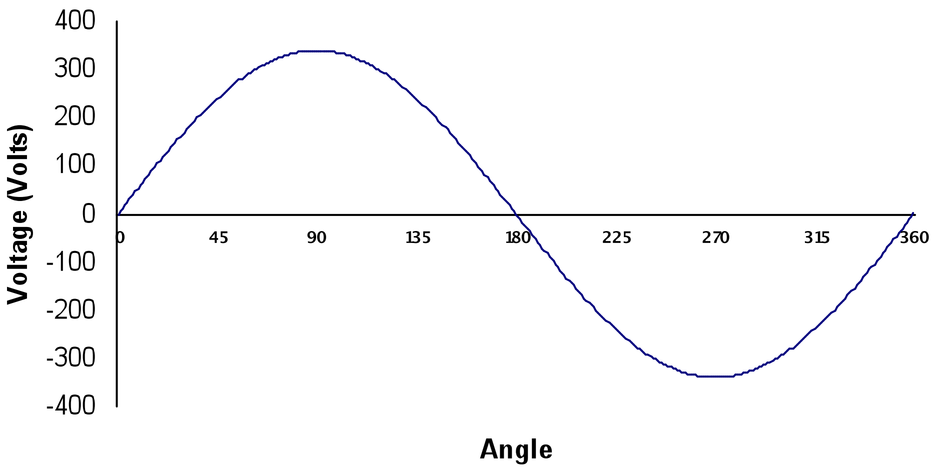
Simple Generator

At position 0º the conductor will be moving in a direction that is along the lines of magnetic flux and consequently there will be no emf induced at this instance. As the conductor rotates it will start to cut across the field and the emf induced will increase. At 90º the conductor will be cutting directly at right angles to the field which would induce the maximum possible emf. Further rotation moves the conductor such that the angle of cutting across the magnetic field is reducing and the emf induced will be reducing. This reduction of induced emf continues until at 180º the conductor is again moving along the lines of magnetic flux and no emf will be induced. The resultant generated voltage over this half cycle has started from zero at 0º, reached a maximum, referred to as a peak at 90º and has further fallen back to zero at 180º.

Faradays Laws also say that the direction of movement of the conductor determines the polarity of the induced emf. If the conductor is moved in a direction and the induced emf noted or measured and then the conductor reverses and moves across the field in the opposite direction, then the polarity of the induced emf is reversed.

Note that when the conductor that is rotating in the magnetic field passes through 180º, it's further movement through the field is in the opposite direction to that in which it was moving between 0º and 180º. Consequently the polarity of the induced voltage is reversed. In relation to the magnitude of the induced voltage, it will be noted that it again will increase to a maximum at 270º and reduce towards zero as it approaches 0º. At 0º the voltage is again zero and the cycle would start again.

The resultant generated voltage will therefore be sinusoidal in nature.



Generated AC Waveform - Voltage v Angle

The complete waveform is generated over 360° of rotation and can be described as starting from zero, rising to a positive peak, decreasing back to zero, rising to a negative peak and falling again back to zero once the conductor has completed the 360° of rotation.

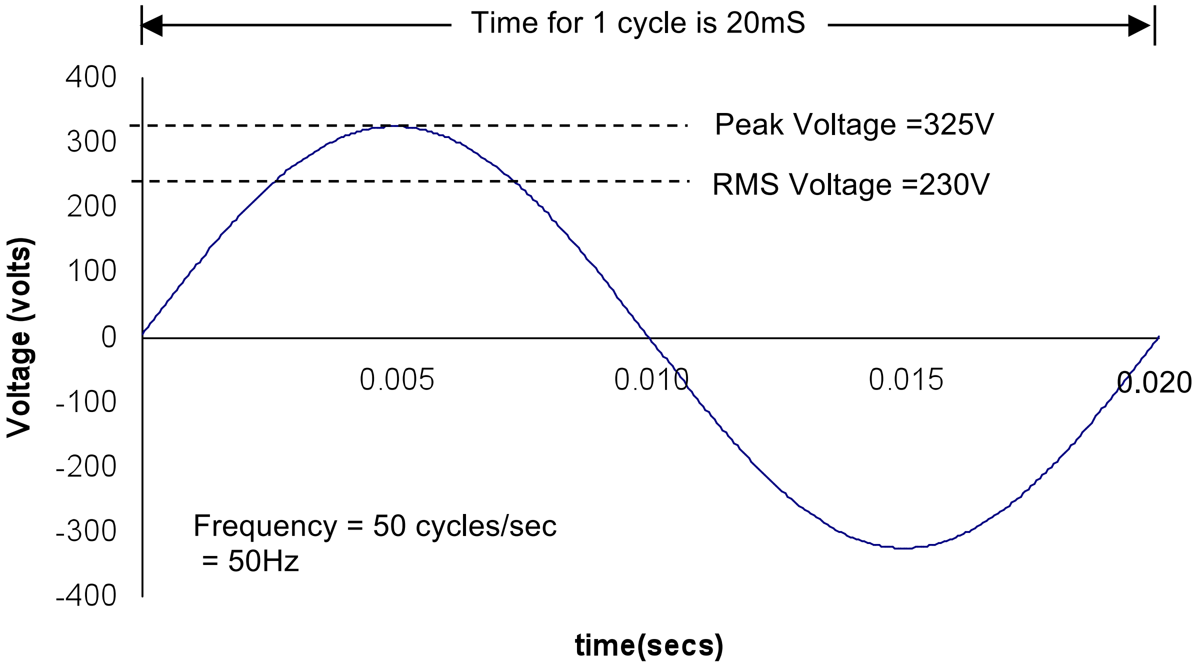
The magnitude or size of the voltage produced is dependant on several factors, namely

- the density of the magnetic field (B)
- the length of the conductor (l)
- the velocity at which the conductor is moved (v)

The relationship defining the magnitude of the emf produced (E) is

E = B x I x V volts

In a practical generator the conductor is a coil, which is rotated on a shaft and driven by a source of energy. Generation needs a source of energy to create movement to utilise this principle. That energy source may come from a steam turbine using gas, coal or oil as it's source. Alternative energy sources being utilised are wind, wave and solar. Smaller generators may be run from engines which in turn are driven by diesel or gas.



Generated AC Voltage - Voltage v Time

Units of measurement for AC

Voltage

The voltage can be measured in a number of ways

Peak Voltage

The voltage from the mid point of the waveform to the peak.

Peak to Peak Voltage

The magnitude of the voltage from the positive peak to the negative peak. This will be twice the peak voltage.

RMS Voltage

A 10V peak AC voltage would deliver less power than a 10V DC voltage simply because the DC level is constant at 10V whereas the AC value is not. RMS (Root Mean Square) is a corresponding value of voltage that would deliver the same power if it were DC. For example a 1.41V peak AC voltage would deliver the same power as a 1V DC voltage. Therefore the 1.41V AC is quoted as 1V RMS. It's value is calculated from

$$V_{rms} = 0.7071 \times V_{peak}$$

Example:

What is the peak value of a 230V RMS voltage

From

$$V_{rms} = 0.7071 \times V_{peak}$$

$$V_{peak} = \frac{V_{rms}}{0.7071}$$

$$V_{peak} = \frac{230}{0.7071} = 325V$$

All AC values are quoted as RMS and meters will all read RMS. This applies to currents and voltages and calculations would be carried out in the normal manner using RMS values.

Frequency

The time that it takes the voltage to pass through one complete wavelength is determined by the angular speed at which the conductor is being rotated (the angular speed of the generator). Clearly the faster the generator turns the less time the waveform will take to go through one cycle. This property of an AC waveform is referred to as it's frequency and is quoted as the number of cycles that the waveform will go through in a second. Frequency is measured in Hertz (Hz). In the UK the frequency of the generated mains is 50Hz.

Period

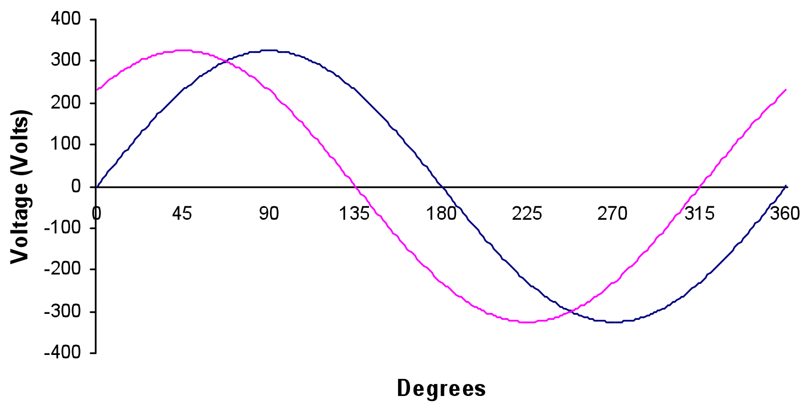
Period or periodic time is the time that it takes for the waveform to go through one cycle. Period is the reciprocal of frequency.

$$\text{Period} = \frac{1}{\text{Frequency}}$$

Phase

The X axis of an AC waveform can be considered as two possibilities. The angular position of the generator or time. Time on the graph would relate to the speed of rotation of the generator. One cycle would be 360° but the greater the speed of rotation then the shorter the time for one cycle. 3000 rpm is one cycle in 20mS, 1500rpm would be one cycle in 40mS.

Phase Difference



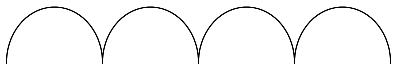
Phase Difference

Suppose two conductors were rotated in the magnetic field at the same speed of rotation and both conductors produced the same value of voltage but they were physically positioned with an angle between them. The two waveforms in the example shown would be produced where it can be seen that the two voltages do not have their peaks occurring at the same time. They have the same frequency and amplitude but are said to have a phase difference. This phase difference is quoted in degrees and in this instance a phase difference of 45º is shown. In many circuits the current flowing compared to the applied voltage will be out of phase. The term leading and lagging is used to indicate whether the current lags (ie comes after) the voltage or leads (comes before the voltage).

Reactive Components

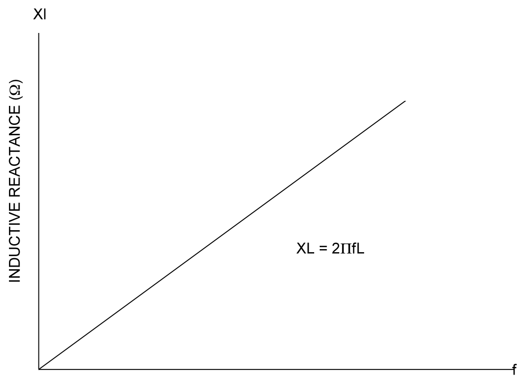
There are two other electrical properties that have a particular operation when they are connected to an ac supply.

Inductance



Consider a wire that is wound into a coil. This wire will possess resistance and therefore the coil will have resistance, even though it could be very small. If DC is applied to this coil then current will flow determined by Ohm's Law. It is a fact that when current flows through a conductor a magnetic field will be set up around that conductor. There are many applications that make use of this magnetic field such as a solenoid, motor and relay.

Consider AC being applied to this coil. As the current increases in one direction the magnetic field would grow around the coil. Once the current has peaked it will decrease and there will be a corresponding decrease of the magnetic field. When the current reaches zero the magnetic field would be zero but when the current commences to flow in the opposite direction the magnetic field will again grow but this time in the opposite direction. Consequently the magnetic field will be constantly changing around the coil. Increasing and decreasing in one polarity and then increasing and decreasing in the opposite polarity.
When there is movement between a conductor and a magnetic field then an emf is induced in the conductor. (It doesn't matter whether the conductor or the field moves as long as there is relative movement between them.) The polarity of this induced emf (according to the physicist Lenz) is opposite to the supply voltage. This means that there is a voltage acting which is opposing the supply which will reduce the effective voltage on the coil and reduce the current. Note that for DC this phenomena does not occur as the current is not changing.
The implication of this is that there is something else opposing the flow of current as well as resistance when AC is applied. It might be noted that if the rate of change of this magnetic field is increased the back emf is increased and therefore there is greater opposition. The rate of change of the magnetic field is determined by the rate of the change of the current which in turn is determined by the frequency of the applied voltage. Consequently this opposition to AC is proportional to frequency. This *AC opposition to current* is called reactance and in this case, inductive reactance (X_L).



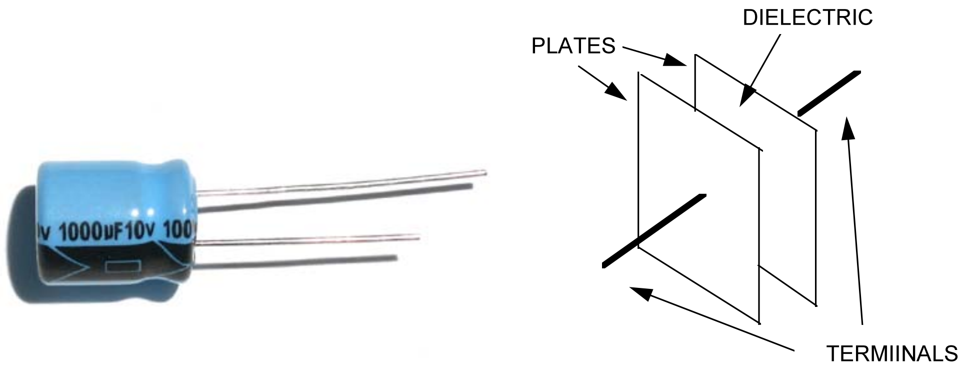
Inductive Reactance v. Frequency

In an inductor the current will lag the voltage by 90º

A coil that has the ability or indeed is used to create magnetic fields is called an inductor. Components in circuits (for example a radio receiver) will include inductors. Coils of motors, transformers etc are not particularly referred to as inductors. The unit of inductance is the henry (eg 100mH). The symbol for an inductor is L.

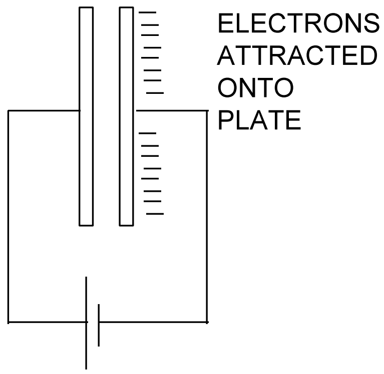
Capacitance

Capacitance is a property that occurs when two conductors lay in close proximity to one another. A capacitor as a component is created by having two plates of conductors close to each other but separated by insulation and is measured in Farads..



Capacitor Construction

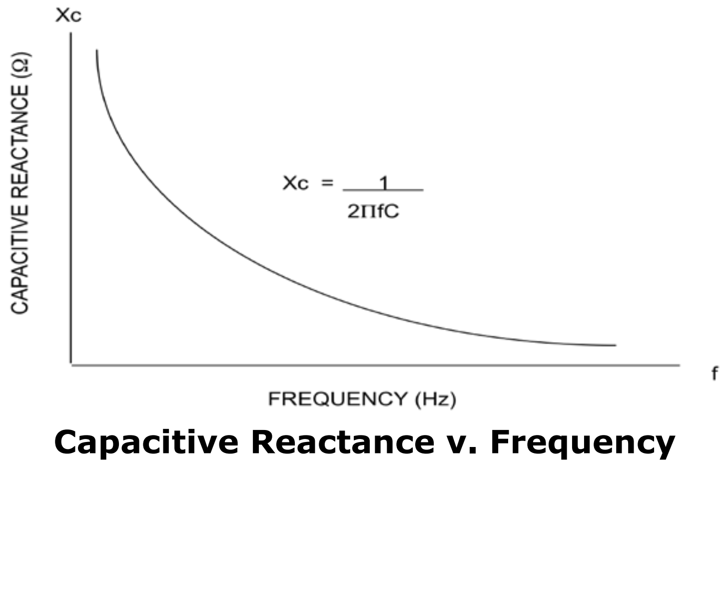
Consider a DC supply connected across the two terminals.



Charged Capacitor

The positive potential connected onto the left hand plate will attract electrons onto the right hand plate. This attraction will continue until the charge across the plates equals the charge of the supply. At this stage the capacitor is said to be charged. It is important to note that if the DC supply is removed the capacitor remains charged for a period of time and this will be apparent as a voltage on the capacitor terminals. Care must be taken if large capacitors are used as they will have the potential to give an electric shock after the supply has been disconnected. Equipment using large capacitors, that could hold a significant amount of charge, will often have a means to automatically discharge the capacitors when power has been removed

If AC is applied to a capacitor then it will continually charge and discharge as the supply is reversed. The capacitor is charged in one direction, then discharged, charged in the opposite direction and then discharged. This gives the affect that current will flow in the capacitor circuit when AC is applied.If the supply is reversed at a higher rate the capacitor will charge faster. This means that if frequency is increased more current will flow and therefore any opposition must have decreased. The opposition to AC current flow is called Capacitive Reactance (X_C)and decreases with frequency.



Capacitive Reactance v. Frequency

In a capacitor the current will lead the voltage by 90º.
A Farad would be a very large value of capacitance and therefore capacitors are usually in the region of μF (microfarads), pF (picofarads) and nF (nano farads). The symbol for a capacitor is C.

Impedance

The combined affect of resistance or reactance is called Impedance and is given the symbol Z. It is also measured in Ohms.

Note that when an alternating supply is connected to a circuit then Ohms Law becomes slightly modified to

$$\text{Current} = \frac{\text{Voltage}}{\text{Impedance}}$$

Note that in some cases the reactance will be much greater than the resistance and the value of impedance will be determined by reactance

UK Supply Voltage

In November 1998 the European electrical standards body CENELEC agreed on harmonisation of low voltage electricity supplies within Europe implemented by BS 7697 Nominal voltages for low voltage public electricity supply systems. The measure intended to harmonise mains electricity supplies at 230V within Europe.

The agreed voltage and tolerance is

230V (nominal) +10% / -10%, giving a permissible voltage range that lies from 207V to 253V.

The UK supply voltage previous to this has been 240V +6% / -6%, giving a range that lies between 226V and 254V. With existing equipment the UK supply would lie towards the top end of the latest standard. Over a period of time as equipment is replaced the UK supply will, gradually, be brought down to the nominal voltage of 230V.

EXERCISES

1 *The rotational speed of an alternator / generator determines primarily the*

- a phase
- b current
- c frequency
- d voltage

2 *A 200V peak to peak voltage would have an RMS value of*

- a 100V
- b 200V
- c 70.71V
- d 141.4V

3 *If the frequency is 100Hz, the periodic time is*

- a 10mS
- b 20mS
- c 5mS
- d 50mS

4 *Impedance is measured in*

- a henrys
- b farads
- c ohms
- d seconds

5 *The unit of capacitance is the*

- a ohm
- b farad
- c henry
- d volts

6 *Impedance is the combination of*

- a resistance and inductance
- b inductance and capacitance
- c resistance and reactance
- d resistance and capacitance

7 *According to the harmonised voltage level in Europe, the minimum L – N voltage would be*

- a 220V
- b 230V
- c 210V
- d 207V

8 *The higher the frequency, the higher the periodic time*

True ☐ False ☐

9 *When AC is applied to a circuit the current is determined by voltage divided by resistance*

True ☐ False ☐

10 *A meter when used to measure AC voltage will measure peak voltage*

True ☐ False ☐

Chapter 5

Three Phase Supplies

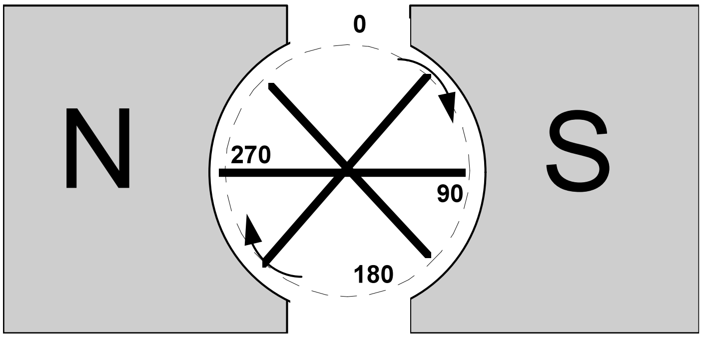
At the end of this section you will have an understanding of

- how three phase supplies are generated
- the voltages present in a three phase system
- how single phase supplies are produced from a three phase supply

Three Phase Supplies

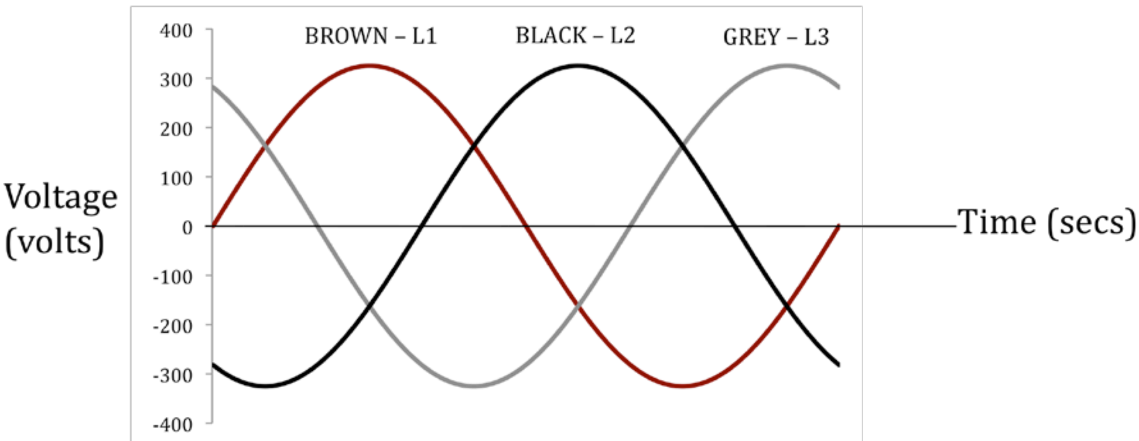
Generation

Single phase supplies are generated by rotating a single conductor in a magnetic field. Utilising several conductors fixed to a common shaft will allow several generating coils. The resulting generation would be referred to as polyphase. The most suitable polyphase is to use three conductors to generate three phase.



Three Phase Generation

Since three conductors are rotated within the magnetic they should be equally spaced. Consequently they will be spaced 120º apart. The resultant waveforms that are generated will have a phase difference of 120º. Since all generating coils are fixed on the same axis they will rotate simultaneously with the same angular velocity, therefore each voltage will have the same frequency. Assuming the coils are identical the amplitudes of the voltages will be identical.



Three Phase Voltage Waveform

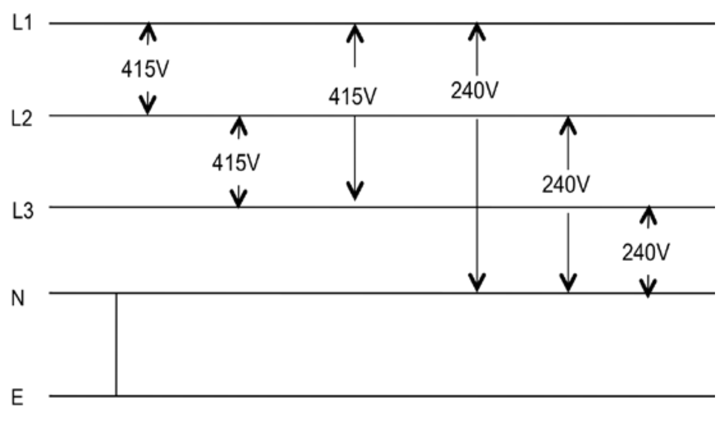
Whilst generators could be many phase, three is the optimum and the one that is used.. Within Europe the three phases are identified as Brown, Black and Grey in that order of phase rotation. The alphanumeric identifiers for the three phases is L1, L2 and L3.

Distribution

The three phase generated at the power station by a generator in the UK will be about 15000V. This will be transformed up for distribution to 133kV or 400kV. A transformer is used for this process which is a device that will increase or decrease the voltage of an AC supply. The transformer will not change power but simply change the level of the voltage. The high voltage is distributed across the country by pylons and cables through the National Grid. This voltage is transformed back down first to 33KV and then to 11KV. Industrial premises will receive this 33KV or 11KV as their incoming supply. This is then further transformed down to 230V for use on the factory floor.

Due to the phase difference between the phases the voltage between two phases is found to be 400V and is known as the Line Voltage. Between any live and neutral there will be 230V and this is referred to as the Phase Voltage. Control systems will typically have a three phase supply as the main feed and any items of equipment that require a single phase supply will be connected to one of the phases.

These voltages are shown below with the typical UK voltages of 415V and 240V

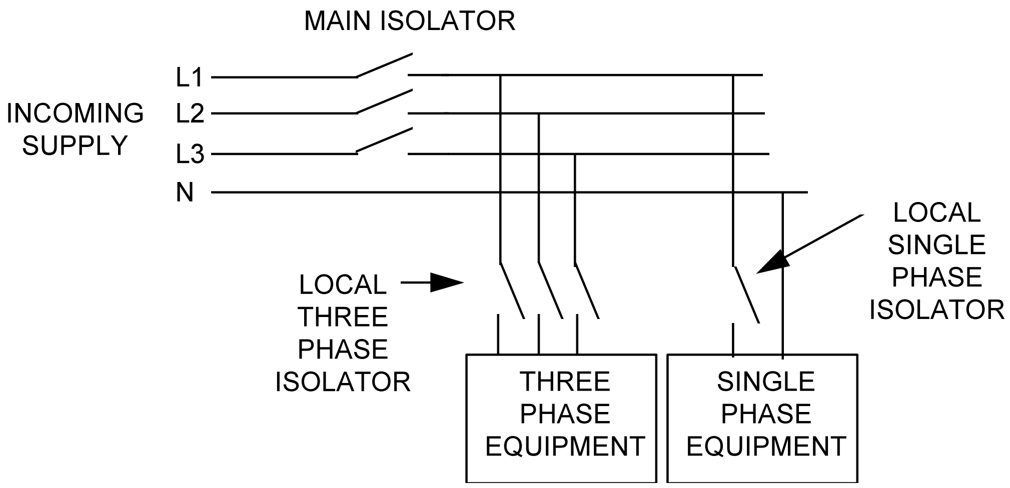


Three Phase Voltages

Note that since neutral is connected to earth the voltage of 240V is present between any live and earth. In the event of electric shock hazard a current path back to the supply will be created via the neutral to earth connection. In some instances a three phase supply does not contain a neutral and as such a 240V supply cannot be obtained without the use of a transformer.

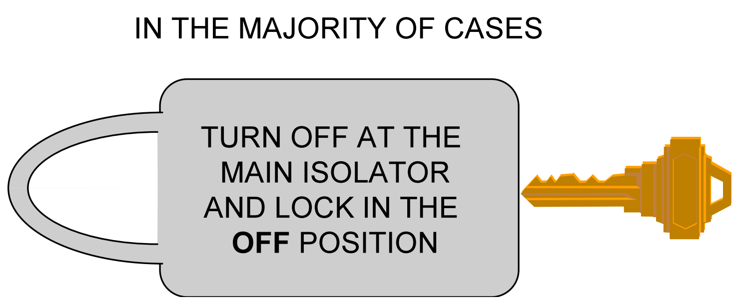
Isolation

Any electrical system has to be designed to provide a means of isolation to allow maintenance work to be carried out. The isolation will permanently disconnect electrical supplies. Isolators are designed to allow them to be locked in the off position. This is to ensure that they cannot be inadvertently switched back on by anyone else. Isolation may be provided by disconnected the whole of a supply to a machine or plant. This may be regarded as main isolation. Or individual items of equipment can be isolated known as local isolation.



Main and Local Isolation

Before commencing maintenance work on any work electrical isolation is imperative.



In some cases it may be acceptable to locally isolate a motor to allow it to be disconnected without removing power from the control system.

KNOW YOUR ISOLATION PROCEDURE BEFORE COMMENCING ANY WORK

EXERCISE

1 *The voltage between two phases of a three phase supply is*

- a 110V
- b 415V
- c 230V
- d 55V

2 *The voltage from phase to earth of a three phase supply is*

- a 230V
- b 415V
- c 110V
- d 55V

3 *The five wires in a three phase supply will be identified as*

- a L1, L2, L3, N. E
- b L1, L2, L3, L N
- c L1,L2,L3,L4,L5
- d L, N E L1, L2

4 *The European harmonised colours for a three phase supply are*

- a Red, yellow, blue
- b Brown, black, green
- c Brown, blue ,green
- d Brown, black, grey

5 *Three phase 415V is more dangerous than single phase 240V*

True ☐ False ☐

6 *Some three phase supplies might be supplied without a neutral*

True ☐ False ☐

7 *The higher the voltage between two phases; the lower the voltage from phase to neutral*

True ☐ False ☐

8 *The phase angle between the phases is 90°*

True ☐ False ☐

Chapter 6

Transformers

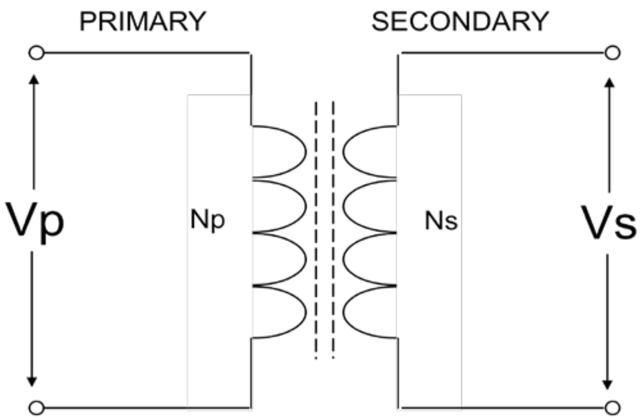
At the end of this section you will have an understanding of

- the principle of operation of a transformer
- how the output voltage relates to the secondary
- how transformers are connected
- centre tapped transformers

Transformers

Transformer Principles

A transformer consists of two coils that are wound on a core in close proximity. As AC current passes though the input coil referred to as the primary it causes a magnetic field to be created in the core. This magnetic field alternates with the supply current. Due to this changing magnetic field an emf is induced in the second coil referred to as the secondary.



$$\frac{Vs}{Vp} = \frac{Ns}{Np}$$

Transformer Circuit

The magnitude of the induced voltage is determined by the magnetic coupling between the primary and secondary coils. This is essentially determined by the number of turns on the primary and secondary coils. The simple relationship between secondary voltage and primary voltage is given by

$$\frac{Vs}{Vp} = \frac{Ns}{Np}$$

where Vs = secondary voltage

Vp = primary voltage

Ns = number of turns on the secondary

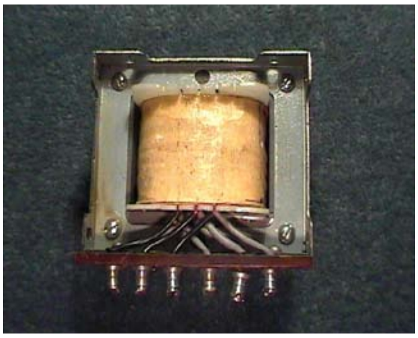
Np = number of turns on the primary

Where Ns > Np; Vs > Vp i.e. the secondary voltage is greater than the primary. This arrangement is known as a STEP UP transformer

Where Ns < Np; Vs < Vp i.e. the secondary voltage is less than the primary. This arrangement is known as a STEP DOWN transformer.

Where Ns = Np; Vs = Vp; the primary and secondary voltages are equal. In this arrangement the transformer is used to provide electrical isolation between primary and secondary. This may be known as an ISOLATION transformer.

It is important to appreciate that the transformer cannot magnify power. In an ideal transformer the power in the primary circuit is equal to the power in the secondary circuit. Efficiency is the measure of the power output from the transformer compared to the power input.

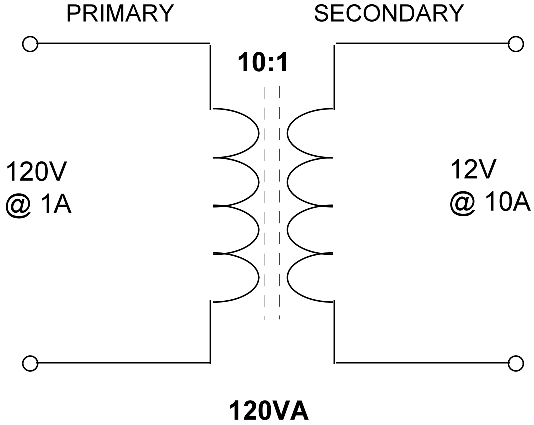


Low Power Transformer

Primary and Secondary Currents

Transformers are rated by their VA capacity i.e. the product of voltage and current

Suppose a transformer is rated at 120VA.

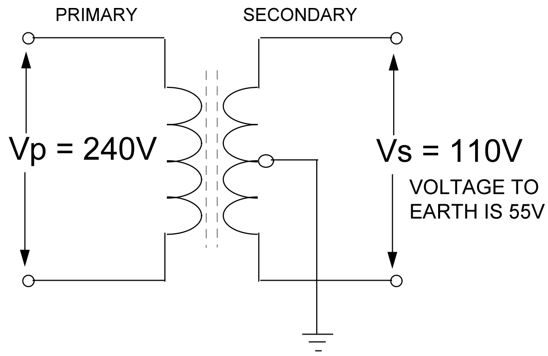


VA Ratings

If the primary voltage was 120 Volts, the 120VA power rating would limit the input current to 1A. The transformer being a 10:1 step down type, would give an output voltage of 12 Volts. The VA rating at the secondary being 120 VA would restrict the output current to 10A. Currents greater than this would create an overload. By a similar calculation it can be appreciated that a step up transformer would allow less secondary current than primary current.

Centre Tap Transformer

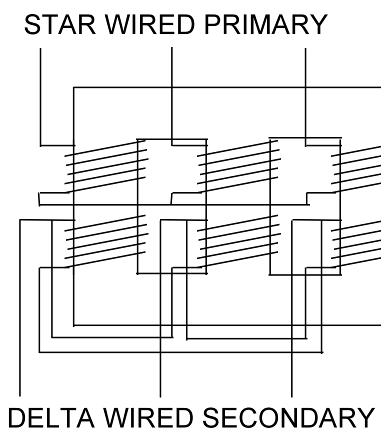
For safety reasons portable equipment has to be operated on safeworking voltages. This can be achieved by using a 110V transformer with a centre tap to earth.



Centre Tap to Earth

This ensures the maximum voltage will be 55 V to earth since the mid point of the 110 V is at earth potential.

Three Phase Transformer

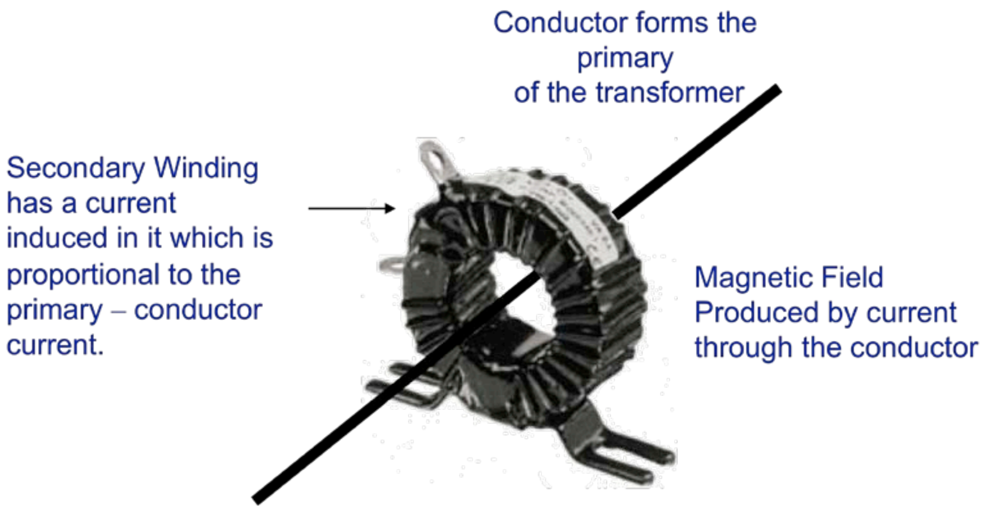


Star Delta Three Phase Transformer

The three phase transformer works on the same principle but has three sets of primary windings and three sets of secondary windings. The windings for both primary and secondary can be wired in either star or delta to suit the application. Consequently star-star, star-delta, delta-star and delta-delta configurations are possible.

Current Transformers (CTs)

Current transformers are used as a method to measure current in a conductor particularly when high currents are to be measured. Measuring a high current direct, by passing it through the measuring device, would not be easy. Using a CT means that current can be measured without interfering with the circuit.



The conductor passes through the centre of the CT and effectively forms the primary of the transformer. The magnetic field that is produced by the conductor causes a voltage to be induced across the ends of the secondary. This voltage is proportional to the current. The current that flows in the secondary will be greatly reduced compared to the primary. This secondary current can supply a meter which can be calibrated to show the conductor current. This method is widely used in power distribution to show the load currents.

EXERCISE

1 *Transformers are measured in*

a watts
b VA
c kilowatt hours
d joules

2 *A 10:1 step down transformer with a 240V input would produce*

a 24V
b 240V
c 2.4V
d 2400V

3 *The maximum current from 12V 120VA transformer would be*

a 12A
b 100A
c 1A
d 10A

4 *The voltage to earth on 110V centre tap transformer is*

a 55V
b 27.5V
c 240V
d 110V

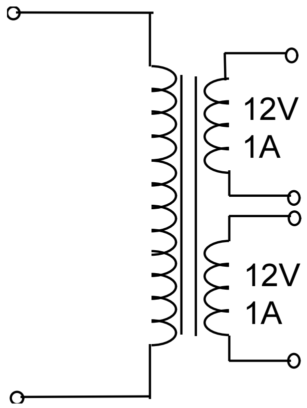
5 *CT stands for*

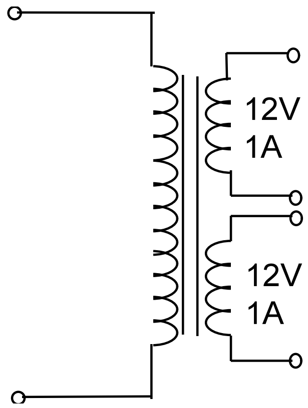
a circuit transformer
b cable transformer
c current transformer
d contactless transformer

Show how the transformer shown would be wired to give a secondary output of

(1) 12 V at 2A

(2) 24V at 1A





Chapter 7

Electrical Test Equipment

At the end of this section you will have an understanding of the operation of

- digital multimeters
- insulation testers
- clip on ammeters
- moving coil meters

Electrical Test Equipment

There are several items of test equipment that can be used to carry out tests on electrical equipment. Those instruments include

- Digital multimeter (DMM)
- Voltage Tester
- Clamp Meter
- Insulation Tester (commonly referred to as a megger)

Digital Multimeter

Multi Meter with Range selection

Auto Ranging Multimeter

Digital Multimeters (DMM)

Probably the most common test instrument to use when carrying out testing or fault finding on electrical equipment is the digital multimeter (DMM). This meter offers many advantages over its predecessor the analogue moving coil meter. These advantages include greater accuracy, more reliability, more robust, will cope with overloads better and will read when meter connections are the wrong way round.

The original AVOMeter took its name from a combined ammeter, voltmeter and ohmmeter. Most multimeters will at least measure these three quantities but some will have other operations that will rarely be used by the majority of users. The DMM will typically be used to measure voltage and resistance and will rarely be used to measure current.

Voltage measurements

The DMM is used to measure voltage by connecting the meter directly across the voltage supply that needs to be checked. It is obvious that when checking or reading voltage, the circuit under test has to be live. Therefore **EXTREME CAUTION SHOULD BE TAKEN TO ENSURE THAT YOU DO NOT COME INTO PERSONAL CONTACT WITH A LIVE SOURCE.** Probes will have a collar on them which guides the user to keep their fingers behind this collar away from the circuit.

Non Insulated Leads **Insulated Leads**

Probes that have long exposed tips such as those on the left need to be used with caution as when those tips are in contact with the live supply the whole of the exposed tip will be live. Probes with insulated ends are safer but can present a difficulty when trying to get into small recesses such as terminal strips or other connectors.

When the meter is placed across a voltage to obtain a reading, the meter should not, in anyway, affect the circuit or supply to which it has been connected. Therefore when a DMM has been set to measure voltage it will possess a very high impedance.

DC Measurements

When measuring DC the supply has a polarity with + and – terminals. If the meter probes are coloured red and black and indeed the red probe is inserted into the red socket on the meter the reading obtained on the meter would indicate the voltage on the red probe with respect to the black probe. If the meter probes are connected onto the DC supply with the red probe on the + the meter would read with no sign symbol inserted within the reading (the meter would read say 24.0 NOT +24.0). If the red probe is connected onto the – supply the meter would read the value with a – sign in front of the reading. (eg –24.0V). This would indicate that the red probe was reading less than the voltage on the black probe. Hopefully the value of voltage read would be the same whichever way the probes are connected.

AC Measurements

When measuring an AC voltage there is no polarity associated with the supply and therefore it does not matter which way around the meter probes are connected. There will never be a – sign produced when measuring AC.

AC / DC setting

On some instruments it is necessary set the meter to read AC or DC and it is important that this is done. There is no alternative other than knowing the type of voltage that you should be reading. It is worthwhile knowing that many instruments will give strange readings if they are set on the wrong type of voltage to what is being read.

Range setting

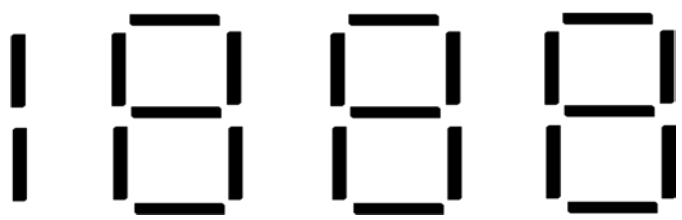
Some instruments will need to be set on the correct range. The lower the voltage being read the greater the accuracy of the reading. Eg Voltages in the range of 0 – 9.9 Volts could be read with an accuracy of say three decimal places, voltages in the range 10.00 – 99.99 could be read with an accuracy of two decimal places and voltages in the range 100.0 – 999.9 could be read with an accuracy of 1 decimal place. If the meter is set on a range that is too low for the voltage being read the meter will be overloaded and will indicate in some that an overload has occurred. Meters will vary on how they indicate this.

Autosetting / Autoranging

The easiest meter to use that automatically sets to read AC or DC when the probes are touched onto the circuit (Autosetting) and automatically sets the range to a setting that allows the most accurate reading (autoranging). Some instruments will also automatically select between voltage and resistance measurement depending upon whether voltage is detected or not.

Displays

The DMM will have a format of display that is used to show it’s readings. Clearly the more digits that are used to display the readings, then more accurate readings can be obtained. One type of format is the 3½ digit display.



3 ½ Digit Display

This display show as a maximum 1999. The decimal point can appear in various places and therefore could be showing 1.999 or 19.99 or 199.9. The scale for this type of display will have setting such as 2V, 20V or 200V. When the meter is set on the 2V range then the maximum value that can be displayed would be 1.999V. This type of instrument when overloaded will simply display the left 1 and no other displays will be visible.

Current

The meter will measure current by presenting a very low resistance which is inserted in series with the equipment being tested. Many instruments will have a set of terminals especially for measuring current. It is impractical to use the multimeter to measure current in many cases due to the fact that the meter has to be connected in series with the equipment. A Clamp Ammeter is normally to measure current.

Resistance

The meter measures resistance by applying a small voltage onto the test probes. This voltage will cause current to flow in the circuit or equipment under test. The meter will respond to this current and display the appropriate value of resistance. It is important that the current flow back into the meter is derived from the internal voltage that the meter places onto the meter probes.

THE CIRCUIT WHOSE RESISTANCE IS TO BE TESTED MUST BE DEAD

As with all readings but especially with resistance it is important to see if the instrument is displaying the units of the quantity being read. In some cases Ω may be displayed and therefore the reading is read as single units ohms. At other times KΩ or MΩ may be displayed. This factor is then taken into consideration with the value read on the display ie 2.54 with KΩ displayed is 2.54 KΩ.

When checking the resistance of a component in a circuit care needs to be taken to ensure that any other component or device that is connected in parallel with the device being tested does not give an erroneous reading.
Example:
A heater element has a resistance of 10Ω. In a circuit two of these elements are connected in parallel. A reading taken across either of these devices would give the effect of two 10Ω resistances in parallel and the meter reading would be 5Ω.

To be absolutely sure that there are no parallel paths disconnect one terminal of the device under test (or remove the device from the circuit completely).

Open Circuit Readings

An open circuit is a very large resistance (infinite) and therefore when the DMM detects an open circuit, the reading will technically overload the instrument. In other words the value that it is detecting is greater than it can display. Therefore an open circuit is shown on the meter as an overload. This will be seen as OL on some instruments and a single digit 1 on the left hand side of a 3½ digit display.

Continuity Testing

When measuring resistance the meter can be designed to emit an audible tone when a resistance of less than a set amount is measured. For example if the meter reads less than 30Ω the continuity tone will be emitted. Note it is important to appreciate the difference between measuring resistance and looking for continuity.

E.g. when testing a cable a continuity test would probably be suitable
when checking motor windings a resistance test is required.

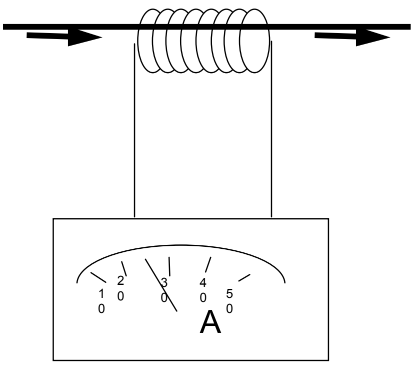
Voltage Tester

The voltage tester will illuminate LEDs according to the voltage measured. These are used for simple tests to indicate that a voltage is present but will not display the actual voltage.

Voltage Tester

Clamp Meter

Breaking into a circuit to measure current using a multimeter is rarely feasible and potentially dangerous therefore a clamp meter is used much more frequently to measure current. The clamp meter is essentially a coil of wire that is placed around the cable in which the current is to be measured. The current flowing in the test cable will induce a current in the test coil. This current is then calibrated to read the cable current.



Clamp Meter

It is worth noting that clamp meters may be capable of measuring DC and AC or in some cases AC only. When purchasing such an instrument check the type of current that can be read.

Insulation tester

Insulation Tester

An insulation tester is an instrument that is used to read low and high values of resistance. It is used to:

- check continuity of cables
- insulation between cables and cables and earth

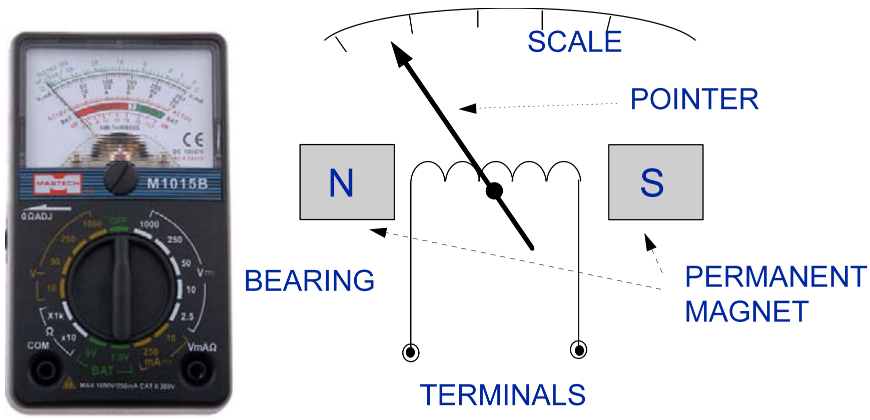
The insulation tester is essentially a resistance meter and measures resistance by applying a very high voltage typically 250V, 500V or 1000V. This voltage is necessary to allow current to trace across areas of high resistance or track across areas where exposed conductors are in close proximity to one another. For the sake of safety the insulation tester has a test button which when pressed will apply the high voltage onto the circuit under test. The circuit should be tested for at least the supply voltage under which it is normally operated. When checking insulation, BS7671-2008 wiring regulations give guidance on the value of insulation resistance that would be acceptable. Generally infinite resistance is the desired value but as a very broad rule insulation resistance ought never to be less than 1MΩ.

SAFETY
DO NOT TOUCH THE PROBES OF THE INSULATION TESTER WHILST PRESSING THE BUTTON. IT IS GOOD PRACTICE TO CLIP THE INSULATION TESTER TERMINALS ONTO THE CIRCUIT UNDER TEST BEFORE PRESSING THE BUTTON.

Moving Coil Meter

The moving coil meter (or analogue meter) is gradually disappearing from use. It's operation is briefly described here.

The moving coil meter as it's name suggests consists of a coil that moves within a magnetic field.



Moving Coil Meter

The terminals of the meter connect to the coil and once connected to a circuit current will flow through the coil. The coil is suspended in a magnetic field supplied by a permanent magnetic. When current flows through the coil a magnetic field is created around it. This interacts with the permanent magnetic field and a force is exerted on the coil. The coil is free to move since it is mounted on bearings and will rotate. The rotation acts against a spring in which tension builds as the spring coils. When the force on the coil equals the tension in the spring the coil comes to rest. The final rest position of the coil is dependant on the current in the coil. Connected to the coil is a pointer which moves over a calibrated scale. The moving coil meter will inherently measure current but can also be used to measure voltage, resistance and power.

This type of meter generally has a number of disadvantages such as:

- Delicate easily damaged by mishandling
- Cannot be autoranging
- Cannot be autosetting

- Does not tolerate overload easily

Key Points when using a Multi Meter

Ensure that the leads are in good condition – no damage to the insulation or connectors.

Ensure that the leads are operational – put the instrument on continuity and touch the probes together. The audible tone indicates the leads are working.

Check that the instrument is working correctly – use a regular calibration service or test the instrument on a known supply.

Ensure that the meter is set correctly – this tends to improve with experience of use but testing on a known supply can be helpful.

Ensure that the meter is in general good condition.

When working on live supplies use utmost vigilance to avoid bodily contact with live parts.

When measuring resistance ensure that the item under test is not connected to a live supply.

Beware of parallel resistances giving unexpected readings.

When using the meter to 'test for dead' check that meter is working on a known supply before and after the test for dead - a commonly defined method is to check the meter on a known supply and verify that it gives the correct reading thus proving that the instrument is working and is set correctly. Isolate the supply and test to prove that the circuit is dead. Check the meter again on a known supply to prove that it is still working and therefore the test for dead can be regarded as valid as the meter has been proven to be working before and after the 'test for dead' and therefore must have been working during the 'test for dead'.

EXERCISE

1 *DMM stands for*

- a dynamic multi meter
- b digital measuring meter
- c dual multi meter
- d digital multi meter

2 *Continuity testing is most useful for checking*

- a fuses
- b motor windings
- c tightness of terminals
- d leds

3 *An insulation tester should be used*

- a only by a qualified person
- b with caution due to high voltages
- c to check the resistance of motor windings
- d to test fuses

4 *A clamp meter measures*

- a current
- b voltage
- c resistance
- d insulation

5 *A 3 ½ digit display with one decimal place will have range settings up to*

- a 20V
- b 2V
- c 2000V
- d 200V

6 *A moving coil meter is more accurate than a DMM*

True ☐ False ☐

7 *A DMM cannot measure current*

True ☐ False ☐

8 *A voltage tester is useful to check to see if a supply is present*

True ☐ False ☐

Chapter 8

Contactors and Relays

At the end of this section you will have an understanding of

- the function and operation of a relay
- the function and operation of a contactor
- how to test relays and contactors
- how contactors are used in control circuits

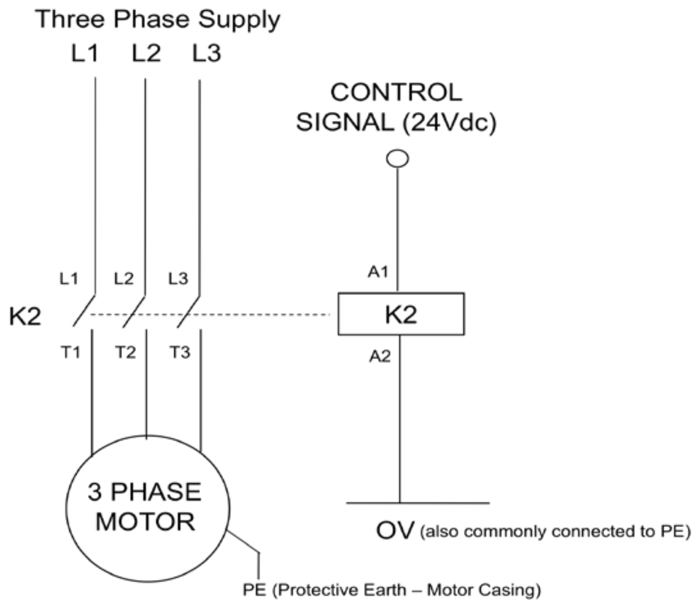
Contactors and Relays

Contactors

Contactor

Contactors are used to supply three phase power to a load. This is commonly a motor but not always as applications such as resistive heater banks may also be supplied with a three phase supply fed through a contactor.

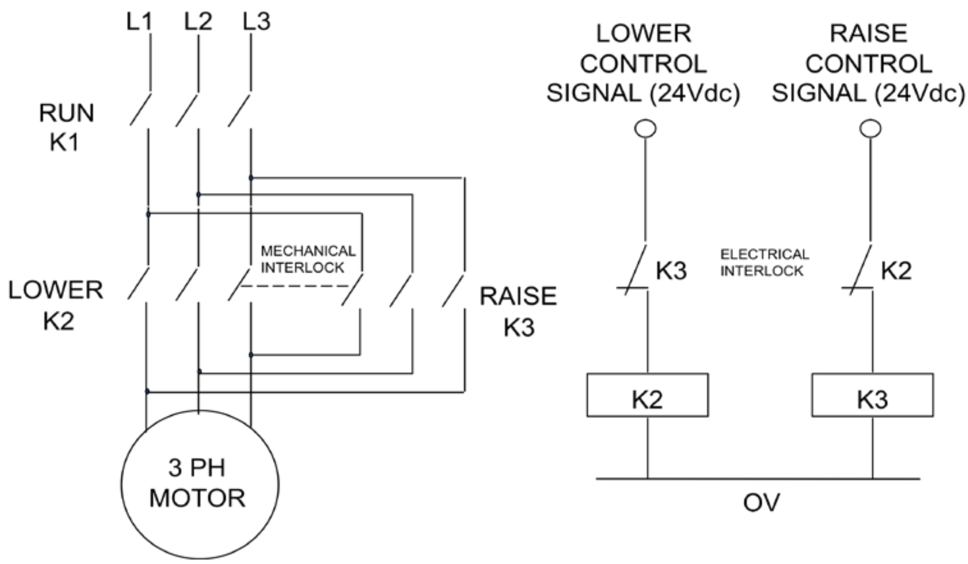
A contactor consists of a coil wound on an iron core and a contact assembly in which are mounted three or four contacts. When voltage is applied to the coil the core magnetises and the contact structure is moved due to magnetic attraction and the contacts close. In this state the contactor can be referred to as energised. The movement of the contacts is against tension in a spring and therefore when the coil voltage is removed, the core demagnetises and contacts separate due to the tension in the return spring. The coil voltage will vary from contactor to contactor with typical voltages being 24VDC, 24VAV, 110VAC, 230VAC and 400VAC. Current carrying capacity of the contacts is part of the specification for a contactor. Larger motors will require greater current rating. Generally there are three contacts for the three phase which are commonly marked as L1, L2 and L3 for the supply side of the connection and T1, T2 and T3 on the load side. On smaller contactors an auxiliary normally open contact is mounted on the same contact assemble and will therefore give another contact that can be used for control or indicating purposes. Additional auxiliary contact blocks can be mounted on the contactor for further contacts should the need arise.



Simple Contactor Circuit

An example of a contactor control circuit is shown in the diagram. The control voltage in this example is 24Vdc but could equally be any of the common voltages. When the control voltage is applied, the contactor is energised and the contacts will close. At this point 3 phase power is supplied to the motor. When the 24V control voltage is removed the spring return contacts will open and power is removed.

The second example shows how the contactor is used to reverse the phases and hence the direction of rotation of a three phase motor.



Three Phase Motor Direction Control

Interlocking

Electrical interlocking is the technique whereby contacts of a relay or contactor are used to inhibit an operation of control circuit. In the direction control of the three phase motor interlocking is included to ensure that the control system does not attempt to send the motor in both directions at the same time. This is an obvious impossibility but consider what would happen if both the up and down contactor were to energise at the same time. The result would be that two phases would be shorted together. This would clearly be unacceptable. Interlocking contacts are included into the circuit to ensure that this cannot happen. Interlocking may occur between two machines whereby if one machine stops or a jam occurs it would inhibit the operation of a preceding machine. Safety systems are interlocks where when a safety guard is moved out of position the machine will not operate.

Ratings

All contactors are rated in terms of

- the operating voltage for the coil

It is important that the correct rating used when replacing contactors. Using a contactor that has a rated voltage less then the control voltage would probably burn out the coil. Using a contactor with a rated voltage higher than the control voltage will probably cause non operation of the contactor

- the maximum contact current

The contacts of a contactor have a maximum current rating. This current rating like many other devices should not be exceeded. Exceeding this current will cause the contacts to overheat.

Testing

There is only one real test for a contactor in isolation and that is to test the continuity of the coil by using a multi-meter to check across the connections of the coil. These are marked A1 and A2. It is probably not possible to determine the reading that should be obtained. It is the best test that continuity is obtained. Open circuit reading would indicate that the coil has burnt out.

A contactor can be tested for it's operation by connecting the coil to the required voltage and checking that the coil energises. This is an acceptable test when the control voltage is low i.e. 24V but extreme caution should be exercised when connecting to a higher voltage.

Replacement

To replace a contactor switch off and isolate the power source. Remove connections from the contactor. Ensure that all connections are marked or identified in such a way that they can be replaced in the correct position. Care should be taken so as not to interchange any of the phase connections as this would result in the motor running in the opposite direction.

Ensure that the coil operating voltage is correct.

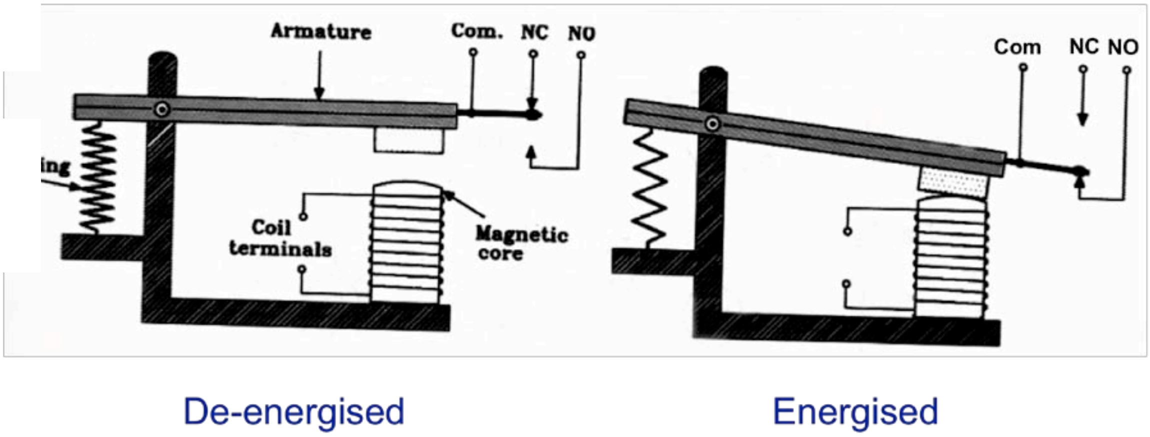
Current Rating Categories

AC1	Non Inductive or slightly inductive load
AC2	Starting of slip ring motors
AC3	Starting of squirrel cage motors and switching off only after motor is up to speed
AC4	Starting of squirrel cage motors with rapid stop start
AC11	Auxiliary Control Circuits

Relays

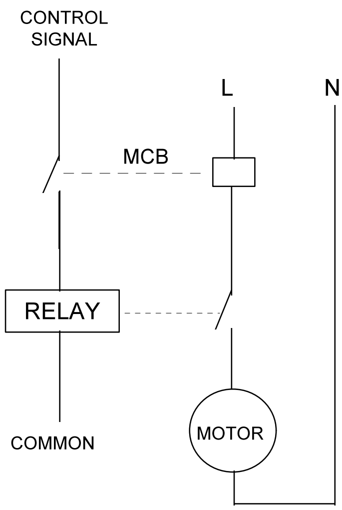
Electro magnetic relays are used to switch the supplies to devices such as motors and solenoids. The control signal is isolated from the supply so that, if required, a low voltage signal can be used to switch high voltage supplies.

Principle of Operation



Electromagnetic Relay

The control signal is connected to a coil so that when the signal is applied current passes through the coil. As a result a magnetic field is set up around the coil. The coil is wound on a core so as to increase the density of the magnetic field. An armature is placed in close proximity to the coil so that due to the magnetic field the armature is attracted to the electromagnet. Connected to the armature are the contacts that will open or close when the armature moves. In this state the relay is *energised*. Contacts on the coil can be normally open, normally closed or a combination of both. The armature is held in it's normal position by a spring and therefore will return to the normal position when the signal is removed from the coil. In this state the coil is *de-energised.*



Relay controlling a single phase motor

The figure shows a relay being used to control a single phase motor. The control signal, generated from a control system, which could be either DC or AC, energises the relay and switches the AC supply onto the motor. Relays are typically used on motors that carry low currents. The important characteristics of a relay are

The combination of contacts – how many, normally open, normally closed

The operating voltage of the coil

The current rating of the contacts

Timing Relays

Timing functions may often be required within a control circuit. It may be that after an operation is complete, there needs to be a delay before another operation takes place.

Example: Suppose a mechanism for gripping an object works by inflating an air bag to grip the container. A sensor may indicate that the gripper has moved into position and the sensor is used to open a valve to inflate the gripper. The next operation in the sequence would be to raise the gripper mechanism to lift the object. It would not be sensible to commence the lift operation at the same time as the inflation since the bag would need time to inflate. There would need to be a time delay in-between. The control system may be capable of generating this delay (especially if it comes from a PLC) but in a simple control system that does not use electronics then this may not be possible. Timing relays can be used to provide this timing operation.

Timing relays are generally available in two types

- Delay on energise

Delay on energise will produce a delay from the time that the coil is energised, which will be upon receipt of the control signal, to the relay energising. The relay will de-energise immediately once the control signal is removed.

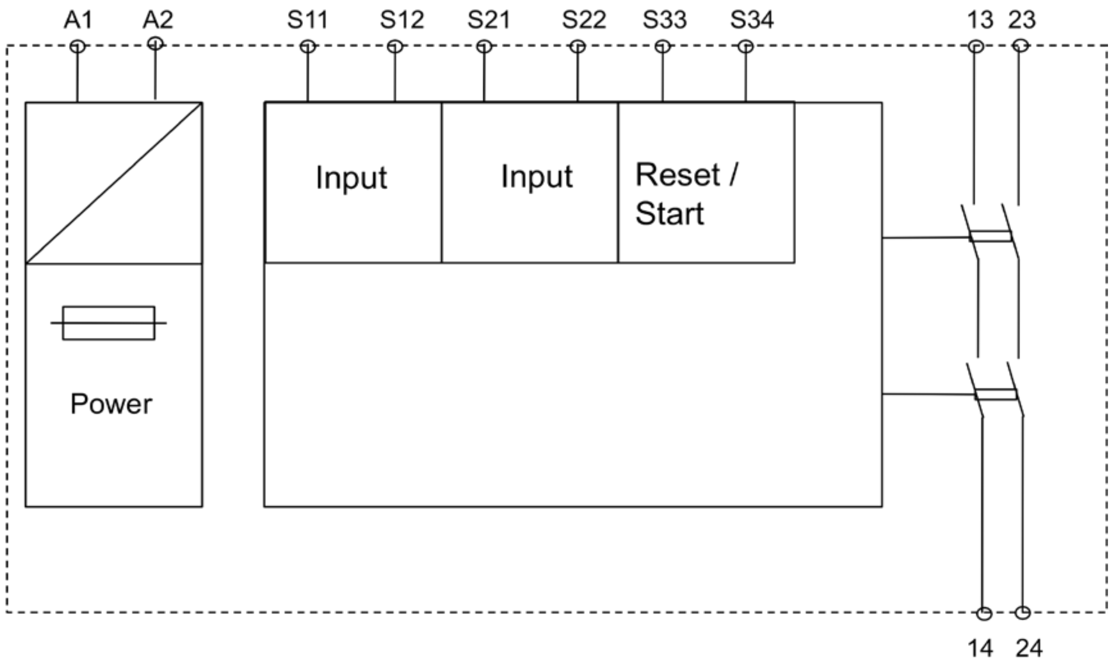
- Delay on de-energise

Delay on de-energise relays will energise immediately the control signal is applied but will produce a delay when the control signal is removed. The relay will stay energised for the time delay period and then de-energise upon expiry of the delay.

Delay settings are determined by a control on the relay cover and will be variable upon the type of device but usually can be in the range from seconds to hours.

Safety Relays

Safety relays such as those provided by Pilz are used in circuits where safety is the prime function. Such circuits include Emergency Stop and Safety interlock circuits. Such devices are manufactured to include high reliability thus maintaining the integrity of the circuit.



Safety Relay Connections

The devices would be powered with an input across A1 and A2 (various voltages are available). Two safety circuits, normally closed contacts can be wired across S11 and S12 and/or across S21 and S22. When wired across these inputs the relay is capable of detecting a short circuit fault condition across these inputs should it occur. The circuit to be de-energised in the event of a safety circuit interrupt would be supplied with power via 13 and 14 or 23 and 24.

In the event of a safety circuit interrupt the device would need to be reset and the reset switch would be a normally open contact across S33 and S34.

EXERCISE

1 *Which of the following is NOT part of a contactor*

a coil

b capacitor

c spring

d contacts

2 *Which of the following is not particularly important when selecting a contactor*

a manufacturer

b coil operating voltage

c number of contacts

d contact current

3 *When a control voltage has been applied to a contactor it is referred to as*

a set

b energised

c on

d activated

4 *The coil of a contactor is marked as*

a A2 and B2

b A1 and B2

c A1 and B1

d A1 and A2

5 *The power input terminals on a contactor are marked*

a L, L and L

b T1, T2 andT3

c L1,L2 and L3

d L N and E

6 *On a relay no stands for*

- a normally open ☐
- b normally off ☐
- c not open ☐
- d not off ☐

7 *A contactor is only used to supply power to a three phase motor*

True ☐ False ☐

8 *An light barrier would use a safety relay*

True ☐ False ☐

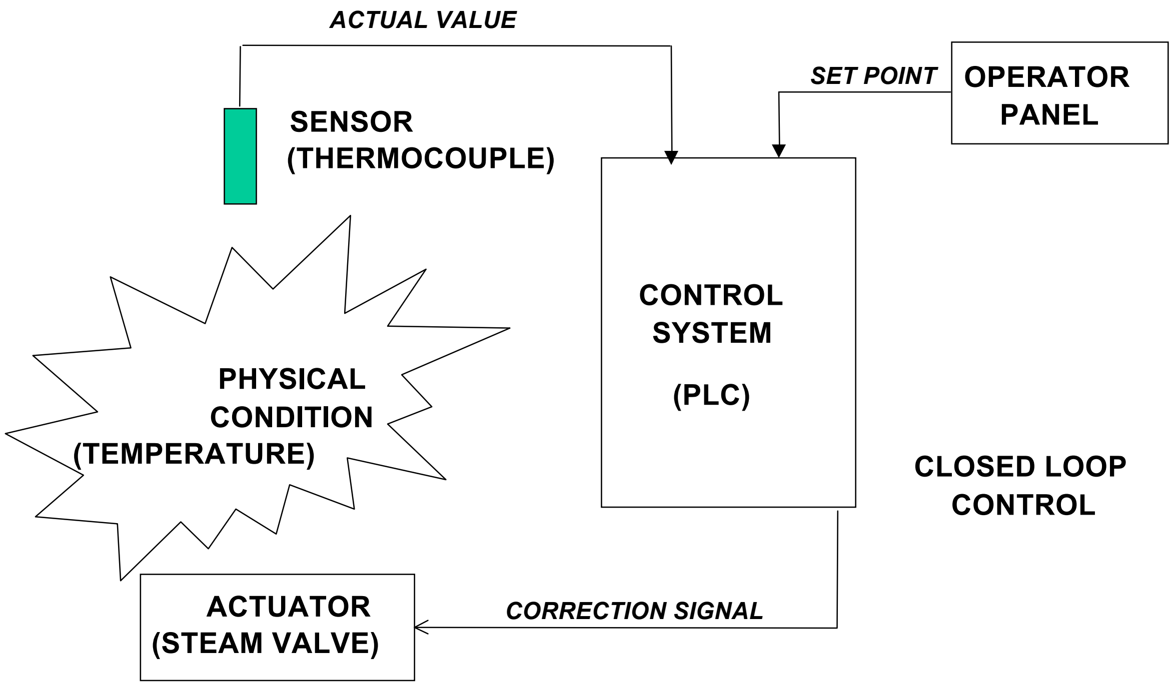
Chapter 9
Control Systems, Sensors and Circuits

At the end of this section you will have an understanding of

- the purpose of a control system
- the function of analogue sensors
- the operation of optical sensors
- the operation of inductive sensors
- the operation of capacitive sensors
- the main parameters of proximity sensors

Control Systems, Sensors and Circuits

Industrial control systems need to measure and then control a property. Such things would include position, weight, temperature, pressure etc. In order to control any property it first has to be measured and therefore a sensor is needed. The control system will be capable of receiving a signal from this sensor and respond to it accordingly. The response of the control system would be to output to an actuator that in turn would affect the property being controlled.



Example Control System

Actuator

The actuator will be a device that will bring about the necessary change in the property being controlled. Such examples will be a solenoid to open a valve that may vary the flow of steam for a heating process. A motor will run to move sections of a machine.

Analogue Sensors

Analogue sensors are those that sense a physical property such as weight, heat, pressure. The sensing occurs by the sensor reacting in some way to the property that it measuring. The reaction is incorporated electrically such that an electrical signal is produced that can be used by an electronic control system. Ultimately a voltage or current is produced that can be interpreted by the control system to represent the measured property.

Examples of analogue sensors

Thermocouple

A thermocouple is produced by having a junction of two dissimilar metals. A physical principle creates a voltage across this junction. It is found that this voltage varies with temperature and consequently this method can be used to measure temperature. There are different thermocouples available made from differing materials that can be used to sense temperatures over varying ranges. The voltage produced by the thermocouple is very small and consequently has to be amplified to a level suitable for the controller.

Load Cell

A load cell makes use of the principle of a strain gauge. This idea is based on the principle that the resistance of a material is determined by it's size and if that size changes then so too will the resistance. If a material is put under strain then it's size will vary and consequently a change of resistance will occur which is dependant on the load or force applied. It is important to appreciate that a load cell is designed to operate up to a maximum load. Over straining the load cell can cause the strain gauge elements to stretch beyond their limit and permanent damage would occur. Over straining a load cell could occur by standing directly on it.

Flow measurement

Flow measurement is achieved by using flow meters that could use different methods to detect flow. A turbine mounted in line with whatever flow is being measured would cause the turbine to rotate at a speed determined by the flow of the medium. This turbine would turn a generator which in turn produces a voltage represented flow rate. The disadvantage of this form of measurement is that the turbine has to be turned and therefore presents a resistance to the flow.
Alternative forms of measurement do not rely on contact with the medium. One such type uses ultrasonic measurement which transmits an ultrasonic signal across the flow and back again. The flow will affect the transmission rate aiding it when the signal goes with the flow and opposes it when the signal transmits against the flow. The flowmeter can compute these differences to determine the rate of flow of the medium.

Resistance Temperature Detector (RTD)

A resistance temperature detector commonly referred to as an RTD is a device that is used to measure temperature that makes use of the principle that some metals increase in resistance when the temperature increases. These devices have a linear response and tend to operate over a wide temperature range. They are categorised by their resistance at 0°C. Typical elements used are Nickel (Ni), Copper (Cu) but Platinum (Pt) is most commonly used for it's wide temperature range, accuracy and stability.

Thermistors

Thermistors (thermally sensitive resistors) are similar to RTDs in that they are electrical resistors whose resistance changes with temperature. Thermistors are manufactured from metal oxide semiconductor material which is encapsulated in a glass or epoxy bead.

Thermistors have a very high sensitivity, making them extremely responsive to changes in temperature. For example, a 2252 Ω thermistor has a sensitivity of -100 Ω/°C at room temperature. In comparison, a 100 Ω RTD has a sensitivity of 0.4 Ω/°C. Thermistors also have a low thermal mass that results in fast response times, but are limited by a small temperature range.

Thermistors have either a negative temperature coefficient (NTC) or a positive temperature coefficient (PTC). The first has a resistance which decreases with increasing temperature and the latter exhibits increased resistance with increasing temperature.

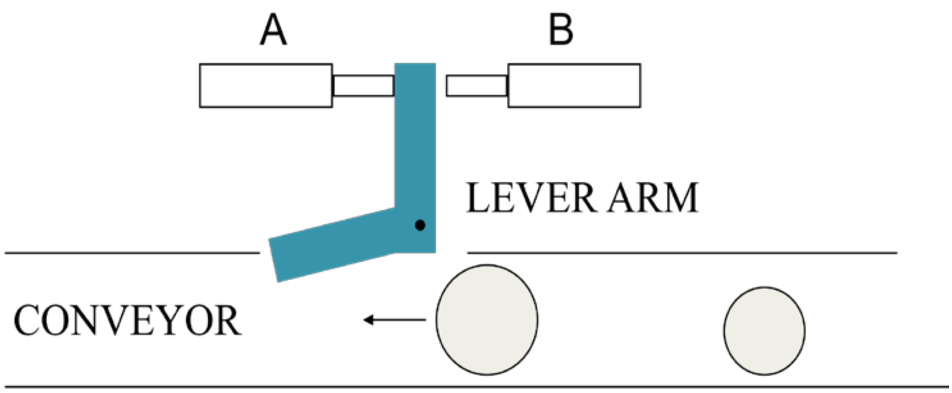
Proximity Sensors

Introduction

The sensing of the presence of a material is known as proximity detection. There are several forms of proximity detectors all of which are industrially important and feature to a considerable extent in automated equipment. The main use for proximity detectors range from the simple counting of objects by detecting their presence to checking for faulty assembly and ensuring that objects are positioned correctly for a subsequent operation.

Microswitches

The simplest form of proximity detection is touch detection, using a microswitch, often connected to a probe, to sense the position of an object. This has significant advantages in that it is not affected by the type of material, but does have the drawback that it is only confined to objects that have sufficient mass to operate the mechanism and for objects not to be damaged by being touched.



Simple Microswitch System

In the example system shown the objects pass along a conveyor. As they pass the lever arm objects may or may not touch it. Objects that are too small will not touch the lever arm and microswitch A will remain activated. If the object is of the right size then the lever arm will be operated and microswitch A will be deactivated. If the object is too large then the lever arm will be touched, microswitch A will be de-activated but also microswitch B will be activated. Any of these operations that has sensed an object that is the wrong size will trigger a reject mechanism.

This is a very simple mechanism for grading objects for a minimum and maximum tolerance.

Microswitches are almost universally of the changeover type so that either the opening or closing of the switch can be sensed.

Microswitches will also be used to sense the position of safety guards and cut off the power to a machine in the event of the safety guard being moved out of position.

Inductive Proximity Detectors

Proximity Sensors

Inductive proximity detectors consist of a coil which is mounted close to the sensing face of the device through which an alternating current is passed. This in turn creates a magnetic field in the area close to the sensing face. If a metal object comes into close proximity with the sensor eddy currents are created within that object. An eddy current is a current that is created due to electromagnetic induction. This eddy current circulating within the metal creates a magnetic field which reacts against the field created by the sensor and is capable of being detected. The change is usually designed to operate a switched output. The output switch action is predominantly normally open (NO), although a few types are normally closed (NC).

The overwhelming advantage of the inductive proximity switch is that no part of the switch needs to touch the object being sensed. Their disadvantage is that they sense metallic objects only and with a sensitivity that depends upon the type of metal used. The sensitivity is quoted in terms of the average sensing distance for an object of mild steel. Most inductive proximity sensors are DC operated , with the choice of current sink or current source. A current source will pass current into a load; a current sink will accept current to earth from a load. Current ratings are in the region 100-200mA at DC voltage levels of 5-30V.

Several inductive sensors will have a tell tale LED to indicate that sensing is occurring. This makes setting up the device easier since the load can and should be disconnected at this time.

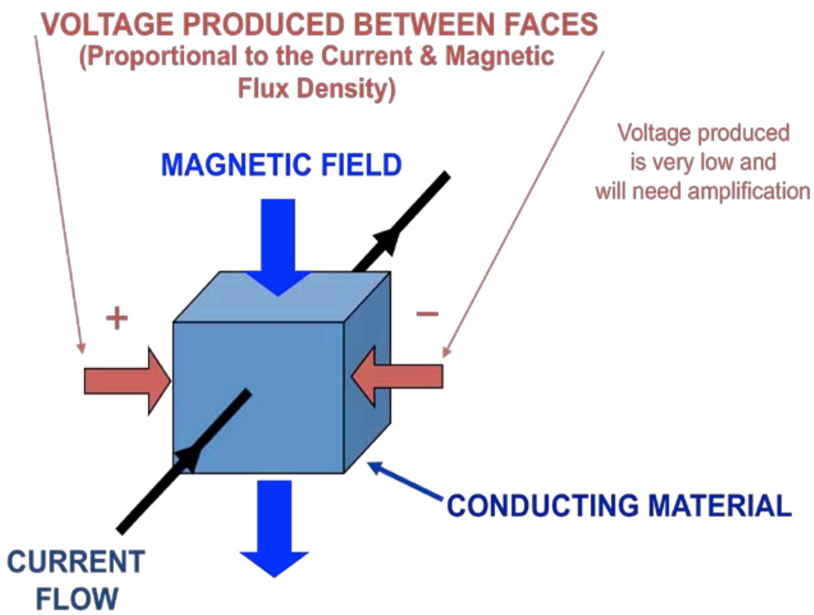
Another useful feature of inductive proximity sensors is their repetition rate that is typically in the order of 200Hz to 2kHz. Inductive sensors are more expensive than microswitches but carry the advantage of not having to make contact with the object being sensed.

Capacitive Proximity Sensors

Capacitive sensing makes use of the stray capacitance that exists between a metal plate and earth. This quantity can be altered by the presence of a non conducting material as well as earthed or isolated conducting material. A bridge or resonant circuit detection method can be used, although the resonant circuit is more common since stray capacitance is usually very small. A noticeable feature is that the detectable range is much higher than inductive types. Both DC and AC types are available.

Hall Effect Sensors

The Hall effect was discovered in 1879 by Edwin Hall. It was discovered that when a conductor is placed in a magnetic field and has current passed through it at a right angle to the field, a voltage will be developed across the other ends of the material.



Hall Effect Sensor

Hall effect sensors can therefore be used to sense current or magnetic field.

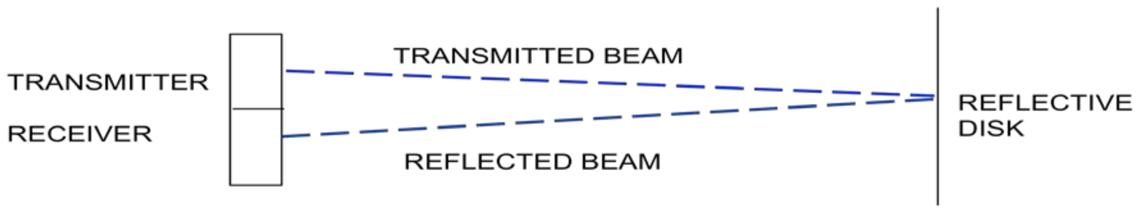
When used as a current sensor a magnetic field is provided through a permanent magnet within the device and the output voltage will be proportional to the current.

Hall effect sensors can also be used as proximity sensors that will detect on the presence of a magnet and hence a small magnet is used as the element to detect.

Optical

Optical Sensors use transmitted infra red light consisting of a transmitter and a receiver. The light is modulated such that ambient light does interfere with the sensor operation. There are a number of possibilities of how optical sensing can be achieved.

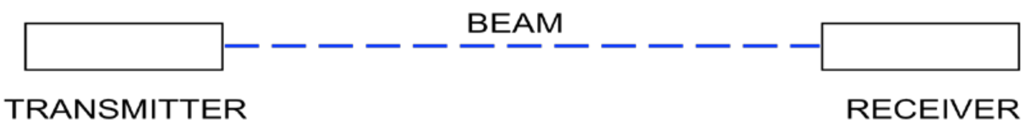
Transceiver



Transceiver Optical Sensor

Here the object to be sensed would pass between the transceiver unit and the reflector thus breaking the beam. The object to be sensed must be opaque to the infra red light for accurate sensing to be achieved.

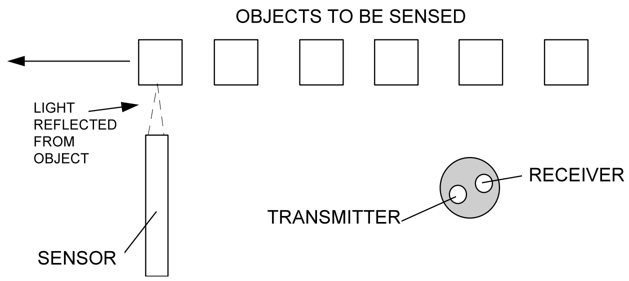
Transmitter and Receiver



Transmitter and Receiver Optical Sensor

The object to be sensed would pass between the transmitter and the receiver.

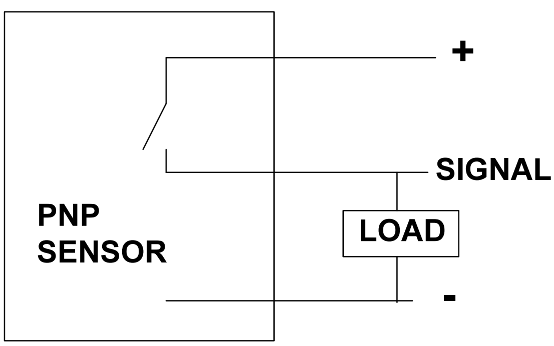
Reflection



Reflective Sensors

The sensor is sensing the reflection of the beam from the objects as they pass. This technique is particularly useful for counting objects.

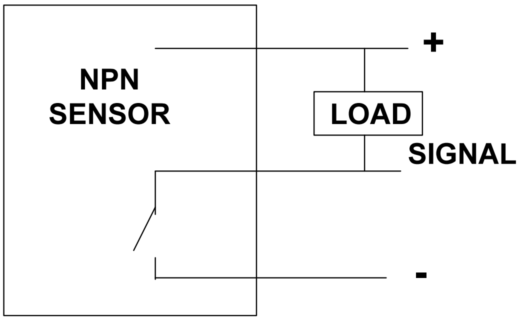
PNP Sensor



PNP Sensor – Switching Diagram

A PNP sensor switches the positive supply onto the load.

NPN Sensor



NPN Sensor – Switching Diagram

A NPN sensor switches the negative supply onto the load

NOTE: If a PNP sensor is mistakenly changed for a NPN sensor then the control system will not see the input from the sensor. The same would occur if a NPN is changed for a PNP.

Testing

Proximity sensors with tell tale indicators can generally be relied upon in as much as if the sensor is working the indicator will be functioning. If the indicator fails to show then the sensor has probably failed.

Testing the output from the sensor could be achieved by placing a meter across the terminals and causing the sensor to sense. The meter will show a change of state from a low voltage to a high or vice versa. Sensors where the connection of the leads is important will have coloured wires to identify the right connections. Where the sensor presents only a changing contact such as a microswitch, the polarity of the leads is unimportant and can be connected either way around.

In general coloured leads should always be connected as they were.

EXERCISE

1 *Which of the following would not be an analogue sensor*

a	a pressure switch	☐
b	thermocouple	☐
c	hall effect sensor	☐
d	load cell	☐

3 *With regard to a thermistor what does ptc mean*

a	positive pressure coefficient	☐
b	platinum tungsten control	☐
c	positive temperature coefficient	☐
d	preferred temperature control	☐

4 *A PNP sensor switches the live*

True ☐ False ☐

5 *A NPN sensor switches the live*

True ☐ False ☐

6 *A hall effect sensor can be used to measure current*

True ☐ False ☐

Chapter 10

Electrical Safety

At the end of this section you will have an understanding of

- how injury is caused through electric shock
- the levels of current sufficient to cause harm
- all electrical dangers
- first aid treatment
- safe working practices
- the principles and importance of earthing

Electrical Safety

The Dangers of Electricity

Most people think of electricity as being dangerous by virtue of it's ability to produce electric shock. However there are many other dangers which include

(a) Electric shock
(b) Electric burn
(c) Fires of electrical origin
(d) Electric arcing
(e) Explosions started or caused by electricity

1. Electric Shock

Electric shock is the effect on the nervous system of passing electricity through the human body. The current affects the normal control of the body muscles and the effects of this vary from a mild tingling sensation to death.

Effects of Electric Shock

Definition of Electric Shock

"A stimulation of nerve with a resulting contraction of muscles and feeling of concussion"

Whenever the human body comes into contact with a live electrical supply, (a voltage), then there is a possibility that a circuit will be formed and that current will flow through the body, Current flowing through the body produces the effect known as electric shock. The current may take multiple routes through the body with differing intensities in various parts of the body. These will be difficult to predict.

The minimum effect is the sensation of tingling or vibration. This may not be painful and if the current flow ceases then the person is unlikely to suffer any problem. Higher levels of current would cause a sensation that would be painful. If the levels are high enough muscles within the body will contract and spasm producing a locked muscle in a state of contraction (technically referred to as tetanus). This will induce severe pain within the individual. Violent muscle spasms can break or dislocate bones.

When current flows through a resistance heat is produced and therefore it is possible that the victim suffers burns. These burns may be more apparent at the points of contact due to increased resistance at these points. Generally the smaller the area of contact the greater the burning will be.

If current flows through greater areas of the body there is an increased possibility that internal organs of the body will suffer from the affects of being burnt. Burns to internal organs such as the liver or kidneys could cause failure of these organs.

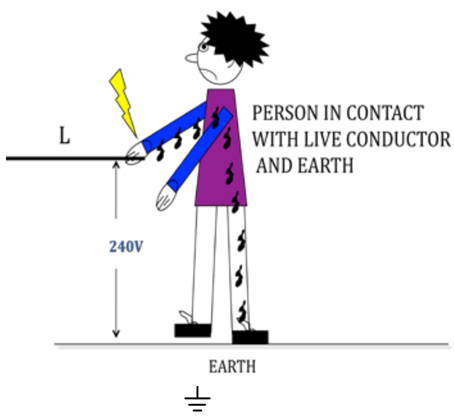
When current flows through the heart and is of sufficient size it may affect and cause a disturbance to the rhythm of the heart beat. Larger current levels can cause the heart to go into ventricular fibrillation. This is uncoordinated contraction of the cardiac muscles in the ventricles in the heart making them tremble rather than contract properly. If this condition continues for more than a few seconds blood flow will cease and death may occur within a few minutes. Similarly if current passes through the respiratory organs this may cause paralysis of the respiratory system and the victim stops breathing. If either of the two problems are not rectified the victim dies.

Blood clots can occur in the smaller veins and arteries. Damage to the smaller vessels is often followed by amputation.

There is also the possibility of damage to the central nervous system which can remain as a permanent disability. There are a range of progressive condition that potentially could occur some time after the shock with potential lesions in the spinal cord or brain. Temporary affects may include unconsciousness, amnesia and transient paralysis of the limbs.

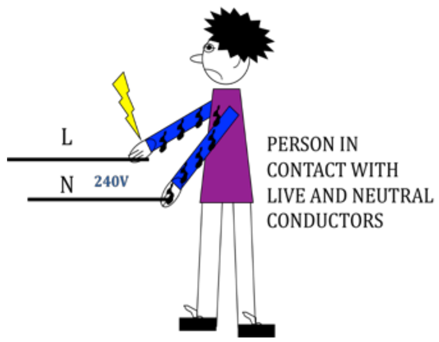
Causes of Electric Shock

- **Contact between the live conductor and earth**



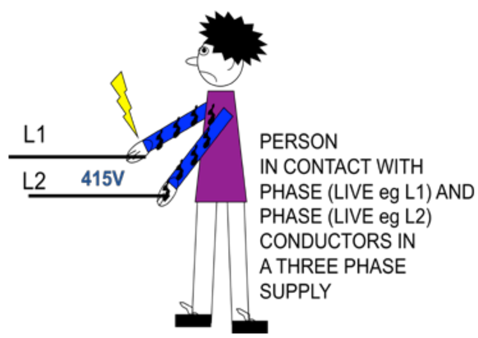
In the majority of electrical supplies in the UK the Neutral is connected to the earth and therefore if a nominal voltage of 230V exists between Live and Neutral then this same voltage will exist between Live and Earth. The contact with earth is the questionable item in this scenario and any insulation at this point will lessen the conductivity and reduce the effects of electric shock. Rubber soled shoes and rubber matting will all increase the safeness of the situation.

- **Contact between Live and Neutral in a single or three phase supply**



The nominal voltage between live and neutral in the UK is 230V and connection between Live and Neutral would be far more severe than that typically between Live and Earth. In the case of the diagram below a person touching both poles of the supply would receive a shock across the chest as this is the path of least resistance

- **Contact between Live and Live in a Three Phase Supply**



The nominal voltage present between any two lives in a three phase supply is 400V and this is the worst of the three examples given as direct contact with these would give rise to the greatest danger.

Factors affecting the severity of the shock

There are three factors that affect the severity of the electric shock

Factor 1: The Level of current.

The current that will flow will be determined by Ohms Law and therefore will be determined by the level of voltage and the resistance of the body.

$$\text{Current} = \frac{\text{Voltage}}{\text{Resistance}}$$

The greater the voltage; the greater the current; the greater the danger.
The less the resistance; the greater the current; the greater the danger.

Voltage

Typical voltages that will be present in an industrial environment are

12V 24V 110V 230V 400V	Voltages that exceed 50 volts are at levels that are considered to be hazardous as the likelihood of harm through electric shock is increased.

THE HIGHER THE VOLTAGE, THE GREATER THE DANGER
THE PUBLIC ELECTRICITY SUPPLY IN THE UK IS RATED AT 230V AND SHOULD ALWAYS BE CONSIDERED AS POTENTIALLY FATALLY DANGEROUS.

Body Resistance

This body resistance varies according to

- the physical condition of the body
- age
- situation
- weather

It is not possible to predict the resistance of the body and therefore it is not possible to predict exactly what will happen to the victim. Body resistance will vary with the amount of moisture.

A person is generally at greater risk in a damp or humid environment but perspiration can also contribute to this moisture

Effects of the levels of current

Current in mA	Effect
0.5 – 2.0	Threshold of perception with mild tingling
2-10	Painful sensation increasing with current
10-25	Cramp and inability to let go. Increase in blood pressure. Danger of asphyxiation from respiratory muscular contraction
15-80	Sever muscular contraction sometimes involving bone fracture. Increased blood pressure. Loss of consciousness from heart and/or respiratory failure
Over 80	Burns at the point of contact. Death from ventricular fibrillation

IT TAKES VERY LITTLE CURRENT TO CAUSE HARM !!

Increased currents will flow when the person is in good contact with earth or earthed equipment and or when the person is in damp or wet conditions.

Factor 2: The route that the current takes

The route that the current takes through the body will be determined by the points of contact although as previously stated will be unpredictable.

If a person brushes the back of their hand across a supply then the current flow could be across the hand and could be quite high and therefore result in burns but may not be fatal. If the points of contact are, say, from hand to hand then the current flow would be across the chest and could be through the heart.

Factor 3: The time for which the current flows.

The longer that the current flows for, the more harm is done. Certainly burning will continue for the period of current flow and therefore heat and burning will increase. A person who makes contact for a very short period of time may well tolerate a high current for that time.

This problem is highlighted when a person touches a supply but the hand and arm muscles spasm and the person grips hold of the supply. This is out of control of the victim but the effect would be to lengthen the time for which the current is flowing.

If a person is found in contact with an electrical supply, in the process of receiving electric shock and is unable to let go of the conductor it is imperative to disconnect the source of the supply immediately. The longer this situation exists the more harm will come to the victim.

If the source of the supply cannot quickly be recognised then another method should be used to physically remove the person from the supply. This could be in the form of using an insulated item (piece of wood) to 'knock or push' the person away from the supply.

AC versus DC

DC (direct current) is more likely to induce (tetanus) the freezing of the body and cause an individual to be locked onto an electrical supply thus prolonging the 'shock' with greater risk of injury.

AC is more likely to cause fibrillation of the heart. A stopped heart has a greater chance of starting and recovering whereas fibrillation is a condition that is not so easy to recover from.

2. Electric Burns

Electricity passing through any resistance liberates heat energy. The element of an electric fire for example has resistance to the flow of current and heats up as a consequence. In the same way, human tissue resists the flow of electric current and the heat liberated causes burns. Such burns are commonly associated with electric shock and often occur at the point of contact with the source of electricity.
In certain circumstances it is possible to suffer electrical burns without being in contact with an electrical source. High powered radio transmitters and microwave ovens, for example, can produce electrical burns due to high frequency electromagnetic waves.

3. Electrical Explosion

This literally means blowing a piece of electrical equipment apart due to electrical overload. A 12V car headlight, for example, will explode if mains voltage is connected across it.

4. Explosion Initiated by Electricity

Certain vapours, gases and fine dusts may explode if triggered by even tiny electric sparks. Examples are petrol, ether, methane, flour dust and talcum powder.

5. Arcing

The air is normally a good insulator, but under certain circumstances this insulation is broken down and sparks jump across air gaps. This is known as arcing. The most spectacular arcing is lightning, but you can see the effect quite clearly when you connect up a car battery. Arcing has it's own particular dangers

a) electrical burns
b) ultra violet radiation - this gives symptoms similar to that of sunburn. The radiation from an arc welder can be particularly dangerous to the eyes.
c) infra red heat or heat radiation - this will burn in the same way as putting your hand close to an electric fire
d) burns due to molten metal particles which often accompany arcing

6. Fire Caused by Electricity

Fires present a number of dangers. The most obvious is burning. But smoke or toxic fume inhalation are at least as dangerous. The main causes of fire are

a) overheating of cables and electrical equipment due to the passage of too much current
b) current leaking due to poor or inadequate insulation
c) overheating of inflammable materials placed too close to electrical equipment
d) the ignition of flammable materials by arcing, sparking or the scattering of hot particles from electrical equipment

Action in the Event of Electric Shock

Break contact with the supply by switching off, removing plug or by wrenching cable free. If this should not be possible, stand on some insulating material, such as dry wood or rubber and break contact by pushing the casualty free. In a place of work a First Aider should be summoned in the event of a person suffering from electric shock.

Treatment for Electric Shock

Reference should be made to an appropriate First Aid manual

- St Johns Ambulance
- St Andrews Ambulance Association
- The British Red Cross Society

Slight Shock

- Reassure the casualty and make them comfortable
- If in doubt refer to a medical practitioner
- Report the accident to the appropriate personnel

Burns

- Cool the tissue with cold water or other non flammable fluid close to hand
- Remove any smouldering clothing. Clothing that has caught fire but has cooled need not be removed
- Remove anything of a constrictive nature; rings, bangles, belts and boots
- Reassure the casualty
- Dress wounds to prevent infection
- Give sips of fluid to the casualty if conscious
- If the casualty is severely burned arrange for them to be taken to hospital without delay
- Report the accident to the appropriate personnel

Abrasions

- Clean and dress the wound to prevent further infection
- Reassure the casualty
- Arrange for medical help if necessary
- Report the accident to the appropriate personnel

Casualty Unconscious but breathing

- Loosen clothing about the neck, chest, and waist and place casualty in the recovery position
- Keep a constant check on breathing and pulse
- Arrange for medical help if necessary
- Report the accident to the appropriate personnel

Safe Working Practices

Introduction

Electricity is a killer. Make no mistake.

Death or injury can occur if you work on a piece of electrical equipment and you

- are not adequately trained in the dangers of working on such equipment
- do not have the necessary knowledge of electricity and the equipment being worked on
- are careless and negligent
- do not observe safety precautions

Remember that you do not only endanger yourself but also others. Causing death or suffering to others can not only be traumatic but could also have severe legal implications as a result of a breach of health and safety law.

Be extremely vigilant, disciplined and thorough. Do not take short cuts even if you are instructed to or under pressure from others. It is you who could be responsible should something go wrong.

Working on Live Systems

Making tests on live equipment

Electrical circuits may need to be tested live with the power applied. The Electricity at Work Regulations 1989 does make allowances for this activity by stating that equipment can be live when work is being carried out if it is unreasonable for it to be dead. Certain aspects of fault finding do require the system to be live. This is a hazardous situation that could result in a fatality. Remember if you can make an equivalent test with the circuit dead that method should be used in preference to a live circuit test.

Before making any tests on a live circuit you must

- **BE AWARE OF ALL THE VOLTAGES THAT YOU CAN ENCOUNTER WHILST WORKING ON A SYSTEM.**

Typically	12V DC
	24V DC
	110V AC
	230V AC
	400V AC

- **BE AWARE OF THE VOLTAGES THAT MAY BE GENERATED WITHIN A CIRCUIT THAT MAY BE HIGHER THEN AN INCOMING SUPPLY VOLTAGE**

  Typically through step up transformers

- **AT ALL TIMES YOU MUST BE FULLY ALERT TO THE PARTS THAT YOU ARE TOUCHING**

  Avoid leaning on parts

  Be totally vigilant concerning any part that you touch for support

- **ENSURE THAT ANY TOOLS AND EQUIPMENT THAT YOU USE ARE IN GOOD WORKING CONDITION AND OF THE CORRECT TYPE AND STANDARD FOR THE TASK BEING UNDERTAKEN**

- **IF IT IS APPROPRIATE DISCONNECT POWER, CONNECT THE TEST INSTRUMENT IN SUCH A WAY THAT IT CAN BE OPERATED HANDS FREE. POWER CAN BE RECONNECTED AND THE INSTRUMENT READ WITHOUT CONTACT. BEFORE REMOVING THE INSTRUMENT DISCONNECT THE POWER.**

- **IF A CIRCUIT IS INTERRUPTED TO MAKE A TEST ENSURE THAT IT IS RECONNECTED CORRECTLY.**
  Note connections before removal if necessary

- **ALWAYS ENSURE THAT EARTHS ARE CONNECTED**

  Any error that you make may endanger the lives of others.

Parts replacement on live systems

There are very rare situations where parts would be disconnected, removed and replaced on a system whilst it is live. These would need to be have been identified in advance, thorough risk assessments carried out and very special procedures would need to be in place.

IN VIRTUALLY ALL SCENARIOS POWER WOULD BE DISCONNECTED FROM A CIRCUIT BEFORE DISCONNECTING, REMOVING AND REPLACING PARTS.

Electrical Isolation

The way in which the electrical supply is connected to the equipment will affect the certainty of whether the supply is disconnected. Equipment fed from a connector such as plug can easily be observed as being disconnected and there ought to be little doubt that the equipment being worked on is disconnected from the supply. Switchable isolators can sometimes be difficult to locate or identify. These isolators should be easily accessible and clearly marked indicating the equipment to which it relates.

Isolation

The term isolation is defined here as disconnecting the supply and ensuring that it stays disconnected for the duration of the work being carried out. This is clearly to prevent inadvertent switching on of the supply at a time when the person working on the equipment is not aware. A typical scenario could be that the person working on the equipment leaves the work area (perhaps to collect parts or tools) and during the absence someone turns the equipment back on. It is hard to believe but there is always a possibility that someone with inadequate knowledge may indeed switch the supply on whilst the person is working.Precautions should be taken to prevent this reconnection of the supply during this time. Such precautions could include the use of lockable isolators which can be locked in the 'off' position. The person working on the equipment uses a padlock to lock the supply off and they hold the key to that padlock. In some instances where several people are working on equipment, the use of clasps that allow the padlocks of all those working to be fitted is good practice.

Isolator

Other precautions could include removing fuses and storing the fuses in a safe location. The use of warning signs and labels is a good practice to prevent accidental reconnection of the supply.

Working on equipment made dead

Whenever work is to be carried out the requires the assembly or disassembly of electrical equipment that equipment must be disconnected from it's source of supply. Such activities are likely to be done when equipment is being serviced, adjusted, repaired or modified with parts being removed and replaced. These parts include components, assemblies and cabling. The work to be carried out may not be classed as electrical. The person carrying out the work has to be absolutely sure that the supply has been disconnected and the equipment is dead. Extra tests should be carried out if there can be any doubt which may include

(a) observing for signs of the equipment being active,

(b) operating controls on the equipment

(c) testing with an appropriate test instrument.

If the person carrying out this work has any doubt over the state of the equipment assistance and clarification must be sought.

Stored Energy

In some cases electrical energy will be stored within the equipment even when the electrical supply has been isolated. One example of this is a capacitor which, in some applications, is designed to store charge. Dependent on the size of the capacitor (size relating to the amount of charge that can be stored which may well be reflected in the physical size of the capacitor) sufficient charge can be stored such that if it is discharged through a person the level of current flow could be significantly high. In the case where energy will be stored within a system there should be

(a) warning labels indicating this and

(b) an automatic means for this to be discharged when the power is removed

Replacing faulty items

- **POWER SHOULD ALWAYS BE REMOVED BEFORE ANY PART IS DISCONNECTED**

- **IDENTIFY THE METHOD OF ISOLATING A MACHINE FROM IT'S SUPPLY**

  Test the supply with a meter to ensure no voltage is present (having first established that the test instrument is working correctly)

- **ADEQUATE PRECAUTIONS SHOULD BE TAKEN TO ENSURE THAT THE SUPPLY CANNOT INADVERTENTLY BE RECONNECTED**

  Lock the isolator in the off position if this has been the method of disconnection. If the isolation method is done by removing a plug give some consideration to preventing the plug from being re-inserted by someone else.

- **BE AWARE OF ANY VOLTAGES THAT WILL REMAIN IN A CIRCUIT WHEN THE MAINS POWER IS REMOVED**

  Specifically on capacitors that have been charged with high voltage DC

- **NOTE CONNECTIONS BEFORE THEY ARE REMOVED**

  If necessary verify connections with a schematic diagram

- **NOTE ANY DAMAGE TO CABLES OR OTHER COMPONENTS**

  Signs of overheating
  Cut / damaged insulation

- **WHEN POWER IS RECONNECTED OBSERVE FOR ANY SIGNS OF A PROBLEM**

  Smoking
  Sparking
  Malfunction of machine

NOTE IF YOUR BUSINESS / COMPANY / EMPLOYER HAS A SPECIFIC ISOLATION PROCEDURE THIS SHOULD BE ADHERED TO AT ALL TIMES.

Earthing

The purpose of Earthing

In the United Kingdom the neutral of the supply is usually connected to earth. If therefore there is 230V between Live and Neutral there will be 230 V between Live and any earthed point. This in itself creates a danger as a person may well be in contact with earth (unless they are deliberately insulated from earth with good rubber soled shoes or standing on rubber matting) and they would therefore only need to make one point of contact with the Live.Wherever a live supply is in the vicinity of exposed electrical conductors (eg pipes, cabinets, chassis etc) the exposed conductors must be earthed. Without this earth it could be possible for a live conductor to inadvertently come into contact with the metal thus making it live. This would, of course, be a lethal hazard for anybody to come into contact with, since it would not be expected that the metalwork would present a danger. With the metalwork earthed any contact from a live source would cause over-current and the operation of the protective device such as fuse or circuit breaker. The resistance to earth through this path should be very low such that a large current tries to flow and the protective device (fuse or circuit breaker) operates almost simultaneously. For this reason the earth connection should be very securely made ensuring that solid contact is made with bare metal. It may well be necessary to ensure that any paint has been removed to enhance this contact. If for any reason this connection is removed it should be replaced before the equipment is turned on.

What not to earth.

The answer is simply a human body when it has made contact with a live supply. Since a body will normally be in contact with earth to some degree (i.e. standing on the ground) if that person touches a live supply a circuit will be formed with the path to earth. The better the earth connection the lower the resistance of the path and consequently the greater the current. It is therefore useful to inhibit the connection to earth wherever this is feasible. This can be achieved using thick rubber soled shoes or rubber mats. Avoid making good connections by wearing earth straps or holding earthed conductors.

EXERCISE

1 *What is the lowest level of current that could be fatal*

a 1A

b 10A

c 100mA

d 0.5A

2 *Electrical Isolation is*

a turning off an electrical supply

b turning off an electrical supply and ensuring that is stays off

c unplugging equipment

d switching off an isolator

3 *When working on a equipment made dead for the purpose of work being carried out which of the following is not appropriate as a safe working practice*

a ensure that you are earthed

b test the supply with a meter

c look for signs of the equipment being live

d operate controls

4 *What is the purpose of earthing*

a to provide a safe current path

b to trip a circuit breaker

c to ensure touchable conducting surfaces cannot become live

d to provide a return path for current

5 *A loose earth connection could*

a stop equipment working

b be nuisance

c create a potential danger

d catch fire

6 *Which of the following is not a typical industrial voltage*

a 110V ☐
b 415V ☐
c 275V ☐
d 24V ☐

7 *When disconnecting connections a good practice could be to*

a label/mark the wires ☐
b tape the wire ends up ☐
c connect them to ground ☐
d connect them together ☐

8 *230V should be considered as*

a an harmless voltage ☐
b a voltage that could be fatal ☐
c a voltage that will kill a person ☐
d nothing to be concerned about ☐

9 *Electric Shock is current flowing through the body*

True ☐ False ☐

10 *'Locking off' is a requirement of the Electricity at Work Regulations 1989*

True ☐ False ☐

Chapter 11

Cables and Protection

At the end of this section you will have an understanding of

- the factors affecting the choice of cables
- the principles of protection
- the operation of fuses
- the operation of miniature circuit breakers
- the operation of residual current circuit breakers

Cables and Protection

Cables and Cable Ratings

There is huge range of cables available to be used within any electrical system from the distribution of electrical supplies overground and underground, distribution of electrical supplies within buildings (industrial, commercial, business and residential), wiring of electrical control systems, carrying electrical data, signals from sensors etc. For any specific application there are factors that need to be taken into account to help decide the most appropriate cable for the task. In electrical control systems the most common cable found will be copper pvc insulated stranded cable.

Conductor Cross Sectional Area

The greater the cross sectional area the more current a cable will be capable of passing.

Insulation

Some type of insulation will be damaged at temperatures where no damage would occur to others. For example a p.v.c insulated cable at 2.5 square mm will be rated at 24A whereas the same size of mineral insulated conductor will be rated at 43A

Ambient Temperature

If the cable is installed in a hot environment it will not be able to dissipate the heat as easily as it would in cooler surroundings and will operate at higher temperatures.

Type of Protection

In the event of a fault or overload, the speed at which the protection device operates may vary depending upon the type of device used. The longer it takes a device to operate the greater the increase in temperature. Cables protected by rewireable fuses will be rated lower than those protected by HBC fuses or circuit breakers.

Grouping

Cables run together will not be able to radiate the heat and conduct as freely as if they were run separately. Cables run in groups are rated lower than those ran singularly.

Disposition

The physical area in which the cables lay may affect the ability to radiate heat. For example cables laid in moist earth will radiate heat more readily than one laid in air.

Type of Sheath

If the cable is protected with an outer sheath for protection purposes this will hinder the ability to radiate heat.

Contact with Thermal Insulation

A cable laid in an area surrounded by thermal insulation will not be able to radiate heat and will need to be rated lower.

General Guidelines

Cabling can be observed for signs of damage. Damage may constitute physical damage such as a cable being trapped with the insulation cut. This may expose the conductor with the possibility of coming into contact with another conductor or human limbs. Generally damaged cables should be replaced with a cable of the same rating and type. Overheating of cables may be observed by damage to the insulation. Again extensive overheating can damage the insulation to the extent that the conductor is exposed. If overheating has occurred the cause should be ascertained.

Overheating may occur when

- a motor has seized or become jammed
- the cable is the wrong size
- the ambient temperature has risen significantly
- there has been a short circuit

In all instances of cable overheating the cause should be rectified such that it does not occur again.

Preparing Cables for Termination

Whatever type of cable is being used the cable ends are terminated at a connector whether that it is plug, socket, terminal rail, equipment or component terminals. Correct and safe preparation of cables is important. The main aspect of cable preparation is to remove outer and inner insulation such that bare conductor is exposed for insertion into a terminal.

Removing Outer Insulation or Sheath

The use of the correct tool for removing the outer sheath is helpful to prevent any damage to the insulation of the cores. This tool has a cutter which is applied with sufficient pressure to cut the outer sheath but not the inner cores. If any damage occurs to the inner core insulation the end should be cut off and the process restarted.

Removing Inner Core Insulation

When removing insulation from cores to expose the conductor it is important not to damage the inner conductor. Stranded cable should not lose strands through this insulation stripping process. If any damage occurs to the conductors the ends should be cut off and the process restarted. Correct wire strippers should be used to help with this process.

Introduction to Over Current Protection

Electrical systems need to be protected electrically from overheating due to excessive current flow which in turn will cause

- fires and a risk to human life
- damage to equipment
- damage to cabling

Any current excessive in nature with regard to a specific situation can cause a conductor to become hot. Such overheating can continue until serious risks of injury and death are very real. The overheating of any conductor can give rise to fires which can lead to catastrophic situations and multiple casualties and deaths. It is this risk to human life that is the overriding factor in ensuring that excessive currents cannot flow in any conductor in an electrical system. The Electricity at Work Regulations 1989 state that ALL conductors in an electrical systems have to be protected from excessive current.

Secondary to the risk to life is the potential damage to equipment that can occur as a result of excessive current.

For a variety of reasons electrical equipment can develop problems which result in damage to equipment which might otherwise have been prevented. In a simple example it might be that the movement of a motor is hindered by an obstacle that has fallen. The motor will attempt to drive against this object and draw more current in an attempt to do so. This extra current could then cause the cables and the motor to overheat. This overheating can only continue for so long until a serious problem develops. Serious problems occur when materials melt due to excessive temperatures. Such materials are the insulation on the windings of motors or transformers. This will short out sections of a coil, which in turn will lower the coil resistance and create further current and further overheating. Obviously this destruction escalates until sections of the winding melt. During this process, the whole of the body of the unit become increasingly hot and due to expansion moving parts may cease. Ultimately the results of overheating have caused serious and expensive problems. Cables themselves will suffer when excessive currents are allowed to pass. The overheating will cause in the first instance the insulation to melt and finally the conductor in the cable to melt. Quite simply it is far better to prevent this build up of excessive current and prevent this damage.

Protection is easily achieved by breaking the supply to a circuit when overcurrent is detected.

Fuses

A fuse operates by disconnecting the supply through melting the fuse element

Fusing Factor

A fuse will have to pass, without problem, the normal operating current of the circuit. This will be termed the current rating of the fuse. The fuse should be capable of passing this current indefinitely. The minimum fusing current will be the current that will cause the fuse to melt.

The Ratio $\dfrac{\text{Minimum Fusing Current}}{\text{Current Rating}}$ is known as the Fusing Factor

Principle of Action

Every conductor is heated to a greater or less extent by the passage of current through it, the heating increasing with the square of the current and the resistance of the conductor.

E.g. If the resistance of a cable doubles the heat doubles. If the current through a cable doubles the heat will quadruple

If part of a circuit is reduced in cross sectional area it will, in normal circumstances, run hotter than the main part of the circuit. On the occurrence of an excessive current it will heat up much more quickly than the remainder of the circuit. If matters are arranged so that the reduced section melts when excessive current occurs, the molten metal is vaporised and an arc results. If the arc is extinguished the circuit is broken. A fuse is normally designed to carry out these operations which is commonly called blowing a fuse.

Anti surge fuses

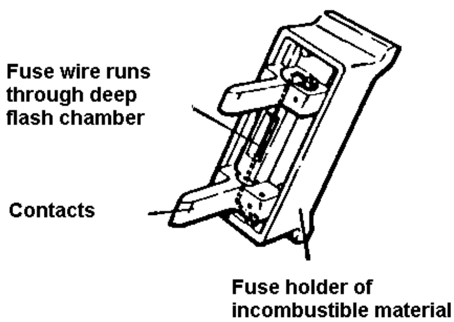
Anti surge fuses are designed to withstand a higher than normal current for a limited period of time before blowing. These are used in some electronic equipment when there may be a high surge current at switch on. During this time this is acceptable and it would be impractical for the fuse to blow. After this initial surge the current settles down to the normal operating current and currents continuously above this need to be prevented. In other words the surge current is acceptable for short period but not for sustained periods. The element of these fuses is constructed from a spring like coil attached to the fuse wire within the tube. A typical example of surge protection is ten times the current for 10mS.

Types of Fuses

There are three general types of fuse

- Rewireable
- Cartridge
- High Breaking Capacity

Rewireable



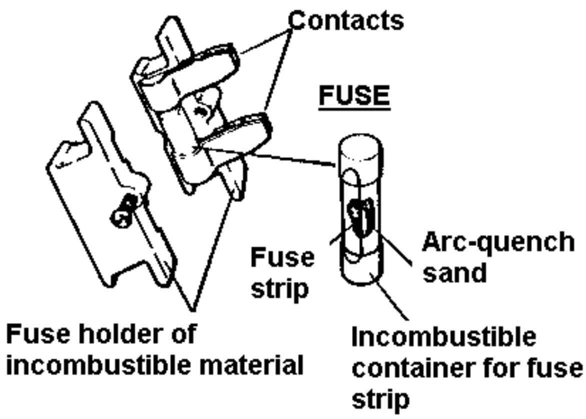
Rewireable Fuse

Advantage: These are both cheap in initial cost and cost to repair

Disadvantage: In can be repaired with incorrect size and fuse wire deteriorates with age

The fusing factor is about 2 and is classed as coarse excess current protection.

Cartridge



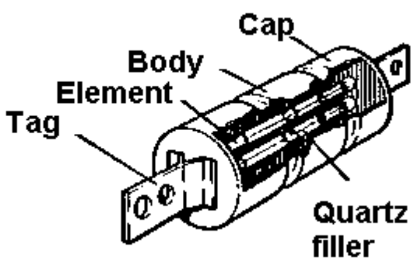
Cartridge Fuse

Advantage: More accurate current rating and does not deteriorate

Disadvantage: More expensive than rewireable.

The fusing factor is about 1.5 and will afford close excess current protection. This type of protection is used extensively in domestic equipment.

HBC Fuses (High Breaking Capacity)

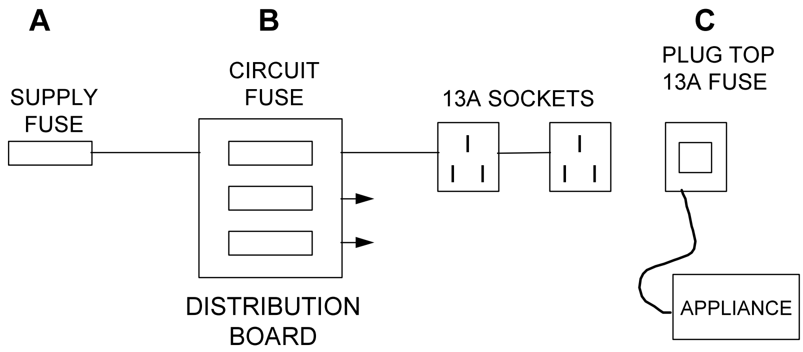


High Breaking Capacity Fuse

HBC are similar to cartridge fuses but they are more expensive. The body is made from high grade ceramic to withstand the shock of heavy current. It has an accurate fuse element usually made with silver plated end caps for good contact and fitted with an indicator to show that it has blown. Because of it's construction it is very reliable and is able to rupture with high currents without damage.

Discrimination

Where more than one fuse protects a circuit, it is sensible that the correct fuse should blow under fault conditions.



Discrimination

A fault on the appliance should cause fuse C to blow. If fuse B blew, although it would break the circuit to the faulty appliance, it would unnecessarily render the whole circuit dead. If fuse B blew it would pointlessly disconnect everything. Discrimination is the ability of the complete circuit to disconnect only the appropriate circuit. Typical installations should have a 2:1 ratio between fuse ratings. Incorrect replacement of fuses could cause unnecessary disconnections of circuits.

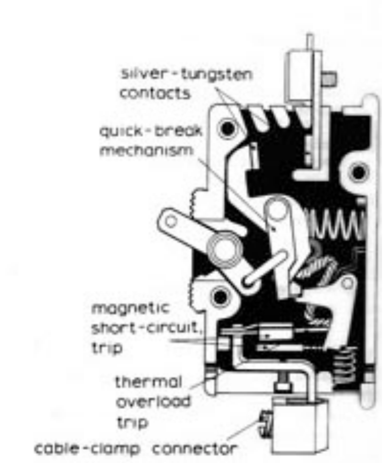
Thermal Fuse

A thermal fuse is a device that is intended to sense a rise temperature and break the supply. These devices operate on high temperature not current unless the current flow is high enough to cause high temperature. These devices may operate by using a meltable pellet that holds down a spring and when the rise in temperature causes the pellet to melt the spring breaks the connection.

Miniature Circuit Breakers (MCB’s)

The Miniature Circuit Breaker (MCB) protective devices have two elements, one thermal and one electromagnetic. The first looks after overloads and the second short circuits. Circuit breakers have one great advantage over the fuse in that once having operated, they can be reset. They are also very accurate and fast, therefore giving a high degree of discrimination.

Miniature Circuit Breaker



MCB Construction

The thermal operation will cause deflection of the bimetallic heater and the greater the overload becomes the faster the m.c.b. operates. This performance is followed by a more dramatic operation when a short circuit occurs. The in rush of current will cause the armature of the electromagnet to rapidly operate against the moving contact mechanism. The latch and spring arrangements work in conjunction with each other to separate very quickly.

Operating Characteristics

The rated value of the MCB is the value of current that they circuit breaker can pass indefinitely ie a 10A breaker will pass 10A forever.

A circuit breaker will trip when the current reaches a value for a period of time. The values of current that would cause instantaneous operation of the circuit breaker is shown in the tables. It can be seen that the type B is the most sensitive with type D being the least. Therefore circuits with equipment that take large surge currents at switch on would use Type D, whereas equipment with not so large surge currents would take Type C and equipment and circuits with the least value of surge current would use Type B. Equipment that takes a large surge currents as normal operation do not want to trip circuit breakers at start up and therefore Type C and D are used in these applications.

Reference to BS EN 60898 Type B Circuit Breakers would give the following information in relation to the tripping time versus level of current.

10A Breaker

Lowest value to trip the breaker is approx 18A and would trip after 10,000 secs (167 minutes)

20A would give a tripping time of 150secs

30A would give a tripping time of 35 secs

40A would give a tripping time of 20secs

Instantaneous tripping would occur at a current level of 50A

The higher the level of current flowing then the shorter the tripping time.

The tables shown state the instantaneous tripping times for Types B,C and D circuit breakers.

The following tables are used for illustrative purposes only to further explain the principles of circuit breakers and should not be used for reference purposes. Consult the appropriate standard for reliable and current data.

Time Current Characteristics Type B BS EN 60898			Time Current Characteristics Type C BS EN 60898	
Cuurent for time 0.1sec to 5 secs			Cuurent for time 0.1sec to 5 secs	
Rating	**Current**		**Rating**	**Current**
6A	30A		6A	60A
10A	50A		10A	100A
16A	80A		16A	160A
20A	100A		20A	200A
25A	125A		25A	250A
32A	160A		32A	320A
40A	200A		40A	400A
50A	250A		50A	500A
63A	315A		63A	630A
80A	400A		80A	800A
100A	500A		100A	1000A
125A	625A		125A	1250A

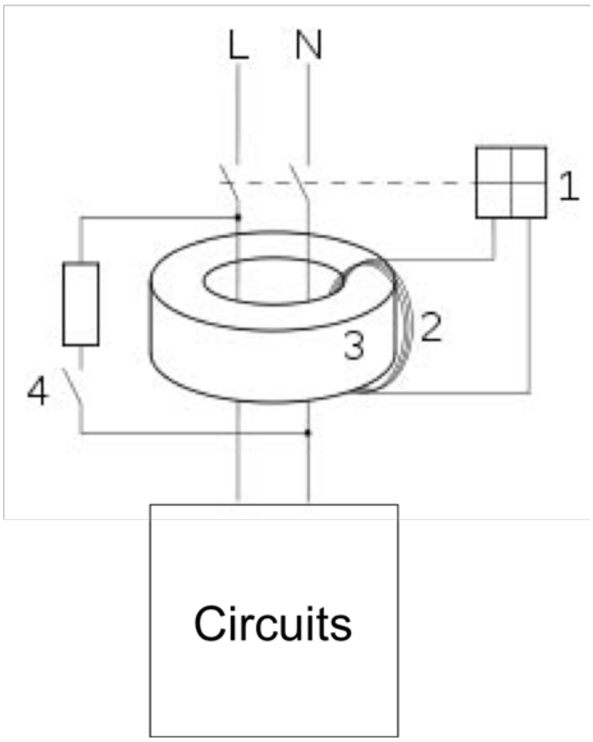
Time Current Characteristics Type D BS EN 60898	
Cuurent for time 0.1sec to 5 secs	
Rating	**Current**
6A	120A
10A	200A
16A	320A
20A	400A
25A	500A
32A	640A
40A	800A
50A	1000A
63A	1260A
80A	1600A
100A	2000A
125A	2500A

Note:

It can be observed from the values in these tables that to provide instantaneous tripping of a Type B circuit breaker a current of 5 times the rated current is required. A C type circuit breaker requires 10 times the rated current and a type D type requires 20 times the rated current.

Residual Current Circuit Breaker (RCCB)

A Residual Current Circuit Breaker is a device to protect against faults where there is current flow to earth. Normally there will be no current flowing to earth. Current flow in the live will equal current flow in the neutral. In the event of an earth fault being detected the trip will operate and the live and neutral supply will be disconnected.



Legend

1 Sensor that operates the trip

2 Sensing Coil

3 Transformer Core

4 Test Switch

L Live Conductor

N neutral Conductor

Residual Current Circuit Breaker

Current flows along the live and neutral and in a healthy situation the live current equals the neutral current in size but at any moment in time the currents are flowing in opposite directions. The result is that there is no residual magnetism, the transformer does not magnetise and the sensing coils is not excited. As soon as the live and neutral currents differ, the magnetic field from the live and neutral current are no longer equal and there is residual magnetism in the transformer core. This magnetism is sensed by the sensing coil and the breaker trips. The test switch causes an imbalance by diverting some current away from the live sensing section through the resistor and back along the neutral. The test switch is therefore a 'live test' that the device is functioning correctly.

This device would not offer protection in the event of an overload where phase and neutral currents, although high are equal. These devices would offer protection where any conducting path occurs between live conductors and earth. Such a condition would occur when a live conductor is touched by a human who is standing on earth.

These devices would offer protection for leakage currents in the order of 5 - 30mA.

IMPORTANTLY LESS THAN A POTENTIALLY LETHAL LIMIT OF 50mA.

In some applications it is possible for leakage to earth to occur as a natural effect of that system and therefore sensitive RCDs would result in 'nuisance' unwanted tripping. In these circumstances RCDs with a higher tripping current (100mA or more) would need to be used. This does result in a compromise between safety and effective system operation.

An RCCB (Residual Current Circuit Breaker) is a device without overcurrent protection.

An RCBO is a device with overcurrent protection included

EXERCISE

1 *When the ambient temperature is hot cables may need to be*

a grouped closely together

b of a greater csa

c be shorter

d be longer

2 *When a cable is run through thermal insulation it may need to*

a use a brightly coloured cable

b be run in conduit

c be longer

d have an increased csa

3 *Which of the following is the least sensistive MCB*

a type D

b type A

c type C

d type B

4 *What does MCB mean*

a miniature circuit breaker

b mains circuit breaker

c miniature current breaker

d mains current breaker

5 *What is the purpose of a circuit breaker*

a prevent over voltage

b to prevent over-current

c to prevent electric shock

d to detect loss of current

6 *What does RCD stand for*

a residual current detection ☐

b residual current detector ☐

c residual current device ☐

d residual current detecting ☐

7 *What is the purpose of an RCD*

a prevent over-current ☐

b prevent electric shock ☐

c to reduce the voltage to a safe level ☐

d to trip out the supply in the event of an overload ☐

8 *Fuses are more sensitive than circuit breakers*

True ☐ False ☐

9 *Over current can cause fires*

True ☐ False ☐

10 *An RCBO is a combined RCD and Circuit Breaker*

True ☐ False ☐

Appendix A

Electricity at Work Regulations 1989

The Electricity at Work Regulations 1989 were made under the Health and Safety at Work Act 1974 and reinforce the requirements of the HASAWA with respect to the use of electricity. The 1989 regulations apply to employers, the self employed and employees, all of whom will be responsible where matters are within their control.

A summary of the responsibilities called for under the 1989 regulations are given against the relevant regulation number.

4(1) to ensure at all times that the electrical system is of such construction as to make it safe

4(2) the electrical system is maintained so that it remains safe

4(3) that no person is in danger whilst using, operating, maintaining, or working near such a system

4(4) that any equipment provided for the purpose of protecting persons at work, on or near electrical equipment, shall be suitable for that purpose, shall be maintained and shall be properly used

5 that the system has sufficient strength and capability for any short circuit currents, overload currents and voltage surges etc. That can foreseeable occur

6 the equipment is suitable for any environmental conditions to which it may be reasonably and foreseeable be exposed

7 all conductors that can give rise to a danger to be insulated, protected or suitable placed so as not to cause a danger

8 precautions to be taken either by earthing or other suitable means to prevent a danger when any conductor (other than a circuit conductor) becomes charged (has a voltage

on it); the earthing conductor being capable of carrying any fault current without danger.

10 that every joint and connection in a system is mechanically and electrically suitable so as not to prevent a danger

11 that where necessary protection is provided to disconnect any excess current before danger can occur

12 that provision is made for cutting off the supply or isolating equipment as may be necessary to prevent danger

13 when equipment and conductors are made dead, suitable precautions must be taken to ensure that do not become electrically charged

14 that no person shall be allowed to work on or near any live conductor where a danger could arise unless:

a) it is unreasonable in all circumstances for the equipment or conductor to be dead and

b) it is reasonable in all circumstances for that person to be at work on or near it while it is live

15 that there is adequate working space, access and lighting for working on or near an electrical system

16 that no person is engaged in any work or activity unless they are competent for the duties they have to perform

Appendix B

The IEE Wiring Regulations (BS 7671 – 2008)

The IEE Wiring Regulations is the British standard that covers the safe design, installation and testing of electrical installations in building systems. In addition the regulations define special locations as

- Bathrooms
- Swimming Pools
- Hot Air Saunas
- Construction Sites
- Horticultural and Agricultural Locations
- Restrictive Conductive Locations
- Caravan and Camping Parks
- Marinas
- Exhibition shows and stands
- Solar Photo Voltaic Supply Systems
- Mobile and Transportable Units
- Caravans and Motor Caravans
- Amusement Devices, Fairgrounds and Circuses
- Floor and Ceiling Heating Systems

In the most simple form the wiring regulations are concerned with the following

- Use of good workmanship.
- Use of approved equipment and materials.
- Ensure that the correct type, size and current carrying capacity of cables are used.
- Ensure equipment is suitable for the maximum power demanded of it.
- Make sure conductors are insulated and sheathed or protected if necessary, or are placed in a position to prevent danger.
- Joints and connections should be properly constructed to be mechanically and electrically sound
- Always provide over current protection for every circuit in an electrical installation and ensure that protective devices are suitably chosen for their location and duty that they have to perform.
- Where there is a chance of metalwork becoming live owing to a fault, it should be earthed and the circuit concerned should be protected by an over current device or a Residual Current Device.
- Ensure that all necessary bonding of services is carried out.
- Do not place a fuse, or a switch or a circuit breaker unless it is a linked switch or circuit breaker in an earthed neutral conductor. The linked type must break all line conductors.
- All single pole switches must be wired in the line conductor only.
- A readily accessible means of isolation must be provided so that all voltages may be cut off from an installation or any of it’s circuits.
- All motors must have a readily accessible means of disconnection.
- Ensure that any item of equipment which may normally need operating or attending by persons is accessible and easily operated.

- Any equipment required to be installed in a situation exposed to weather or corrosion, or in explosive or volatile environments, should be of the correct type for such adverse conditions.

- Before adding to or altering an installation ensure that such work will not impair any part of the existing installation and that the existing installation is in a safe position to accommodate the addition.

- After completion of an installation or alteration to an installation, the work must be inspected and tested, so far as reasonably practical, that the fundamental requirements for safety have been met.

It is worth noting that although the wiring regulations are not statutory they may be used to claim compliance with statutory regulations such as the Electricity at Work Regulations, Health and Safety at Work Act and Part P of the building regulations.

Appendix C

Glossary of Electrical / Electronic Terms

Alternating Current	Current that reverses direction in response to a change in voltage polarity
Alternator	A rotating machine used to produce electrical energy
Amp	The unit of electrical current
Amplification	The process of increasing power, voltage or current of an electrical signal
Anode	The more positive terminal of a diode or other electronic device
Attenuation	The reduction in the level of power, current or voltage
Capacitor	A device capable of storing electrical charge or in AC circuits creating phase shifts
Cathode	The more negative terminal of a diode or other electronic device
Circuit Breaker	A protective device that will break the supply to a circuit in the event of excessive current
Contactor	An electromechanical device used to switch supplies on to equipment
Current	The rate of flow of electrons
Decibel	The unit of the logarithmic expression of a quantity
Diode	A two terminal electronic device that permits current flow in only one direction
DVM /DMM	Digital Voltmeter / Digital Multimeter

Electron	The basic particle of a negative electrical charge
Frequency	The measure of rate of change of an AC supply.
Full wave	The entire ac cycle consisting of both the positive and negative parts
Fuse	A protective device that will rupture in the event of excessive current in a circuit
Generator	An energy source for producing electrical signals
Giga	A prefix denoting 100,000,000 times abbreviated to G eg Ghz (gigahertz)
Ground	In electrical circuits the common reference points
Half wave	One half of an ac signal
Hertz (Hz)	The unit of frequency
Impedance	The total opposition to ac current
Inductor	An electrical device consisting of a coil of wire and having the capability to store energy in it's magnetic field
Kilo	A prefix designating one thousand (eg KW – kilowatts)
LED	Light emitting diode
Magnitude	The value of a quantity
Mega	A prefix designating one million (eg MΩ mega-ohm)
Megger	A common name for an insulation tester.
Micro	A prefix designating one millionth (eg μF microfarad)
Milli	A prefix designating one thousandth (eg mA milli-amp)
Nana	A prefix denoting a 1,000,000,000th (eg nm nano-metre)

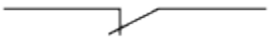
Noise	An unwanted signal
Ohm	The unit of resistance
Period	The time interval of one cycle of a periodic waveform
Phase	The angular displacement of one alternating signal with respect to another
Power	The rate of energy consumption
Protection	The equipment necessary in a circuit to prevent overcurrent
Rectifier	An electronic circuit that converts ac into dc
Relay	An electromechanical device used to switch signals
RCCB	Residual current circuit breaker
RCD	Residual Current Device
Resistance	The opposition to the flow of current
rms	Root mean square
Tera	A prefix denoting 1 million million times (eg Tbytes – terra Bytes
Three phase	A supply consisting of three ac voltages with a phase difference of 120º
Transistor	A semiconductor device used for amplification or switching
Volt	The unit of voltage
Voltage	The amount of energy, or driving force, available to move electrons from one point to another in a circuit path

Appendix D

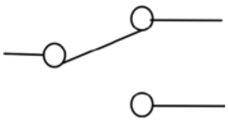
Electrical Symbols

Switches and Buttons

Normally open Contact
(N/O)



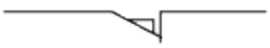
Normally Closed Contact
(N/C)



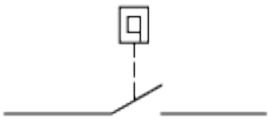
Change Over or 2 way Contact
Made position

Fused Switch Open Contact
(N/O)

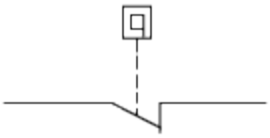
Limit Switch
(N/O)



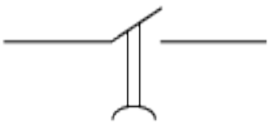
Limit Switch
(N/C)



Flow Switch
(N/O)



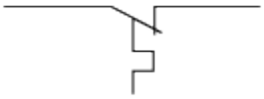
Flow Switch
(N/C)



Time Delay
(N/O)
Delay on Closing

Time Delay
(N/O)
Delay on re-opening

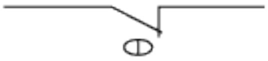
Thermal Switch - Overload
(N/O)



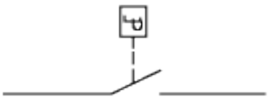
Thermal Switch - Overload
(N/C)

Normally Open PB
(N/O)

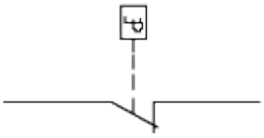
Temperature Switch
(N/O)



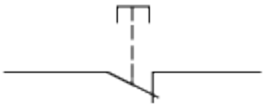
Temperature Switch
(N/C)



Pressure Switch
(N/O)

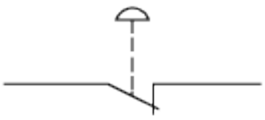


Pressure Switch
(N/C)

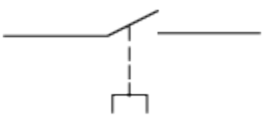


Normally Closed PB
(N/C)

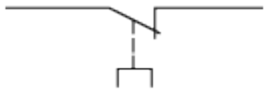
Emergency Stop PB
(N/O)
Indication Contact



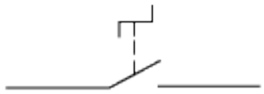
Emergency Stop PB
(N/C)



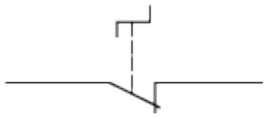
Pull Switch
(N/O)



Pull Switch
(N/C)

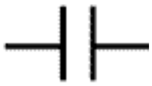


Turn/Rotary Switch
(N/O)

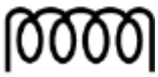


Turn/Rotary Switch
(N/C)

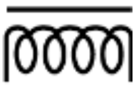
Components



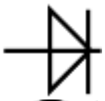
Capacitor, general symbol



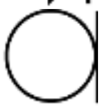
Inductor, coil, winding or choke



Inductor, coil, winding or choke with magnetic core



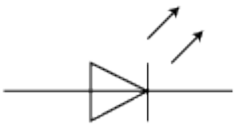
Semi Conductor Diode - general symbol



Microphone

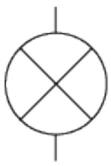
Loudspeaker

Antenna



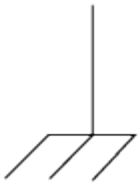
Light Emitting Diode

Fluorescent luminaire



Lamp

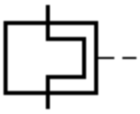
Earth Connection



Chassis Earth

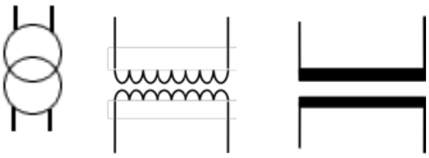
Ammeter

Voltmeter

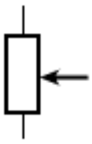


Thermal Overcurrent

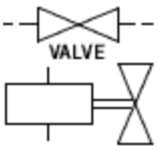
Mechanical Interlock



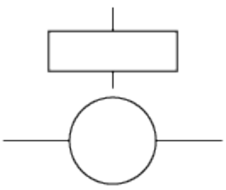
Transformer



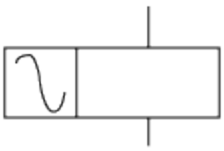
Potentiometer



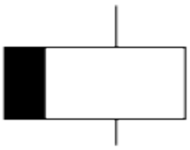
Solenoid Valve



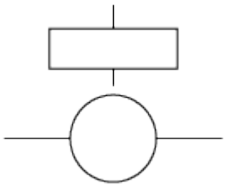
Contactor Coil



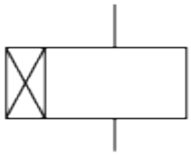
Relay with AC Supply



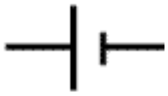
Slow Release Relay Delay Off



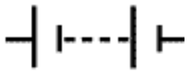
Relay Coil



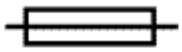
Relay delay On



Primary Cell – Long line Positive Short Line Negative



Battery



Fuselink rated in Amps

Letters used to identify Components

Component	Symbol / Letter
Motor	M
Contactor	K, C
Motor Contactor	KM
Relay	R , K
Lamps	H
Transformers	T
Fuses	F
Circuit Breakers	Q , F
Sensors	B
Solenoids	Y

Appendix E

Index of Protection (Ingress Protection) IP Rating

EN 60529 outlines an international classification system for the sealing effectiveness of enclosures of electrical equipment against the intrusion into the equipment of foreign bodies (i.e. tools, dust, fingers) and moisture. This classification system utilizes the letters "IP" ("Ingress Protection" or "Index of Protection") followed by two or three digits. (A third digit is optional. An "x" is used for one of the digits if there is only one class of protection; i.e. IPX4 which addresses moisture resistance only.)

The standard aims to provide users more detailed information than vague marketing terms such as "waterproof".

For example, an electrical socket rated IP22 is protected against insertion of fingers and will not be damaged or become unsafe during a specified test in which it is exposed to vertically or nearly vertically dripping water. IP22 or IP2X are typical minimum requirements for the design of electrical accessories for indoor use.

Degrees of Protection - First Digit

The first digit of the IP code indicates the degree that persons are protected against contact with moving parts (other than smooth rotating shafts, etc.) and the degree that equipment is protected against solid foreign bodies intruding into an enclosure.

Level	Description
0	No Special Protection
1	Protection against solid objects greater than 50mm dia
2	Protection against solid objects greater than 12mm dia
3	Protection against solid objects greater than 2.5mm dia
4	Protection against solid objects greater than 1.0mm dia
5	Dust protected
6	Dust tight

Degrees of Protection - Second Digit

The second digit indicates the degree of protection of the equipment inside the enclosure against the harmful entry of various forms of moisture (e.g. dripping, spraying, submersion, etc.)

Level	Description
0	No special protection
1	Protection from vertically dripping water
2	Protection from sprayed water up to 15° from the vertical
3	Protection from sprayed water up to 60° from the vertical
4	Protection from splashed water
5	Protection from water projected at low pressure in all directions from a nozzle
6	Protection from heavy seas or powerful water jets
7	Protection against immersion between 15cm and 1m for 30 minutes
8	Protection against complete continuous submersion in water

Third Digit – Optional

Level	Protection against access to hazardous parts with
A	Back of hand
B	Finger
C	Tool
D	Wire

Appendix F

BS7671-2008 Conductor Cable Colours

Function	Alphanumeric	Colour
Protective Conductor		Green and yellow
Functional earthing conductor		Cream
AC Power Circuits		
Line of single phase circuit	L	Brown
Neutral of Single or three phase circuit	N	Blue
Line 1 of three phase ac circuit	L1	Brown
Line 2 of three phase ac circuit	L2	Black
Line 3 of three phase ac circuit	L3	Grey
Two Wire unearthed DC Power Circuit		
Positive of two wire circuit	L+	Brown
Negative of two wire circuit	L-	Grey
Two wire earthed DC Power Circuit		
Positive (of negative earthed) circuit	L+	
Negative (of negative earthed) circuit	M	Brown
Positive (of positive earthed) circuit	M	Blue
Negative (of positive earthed circuit)	L-	Grey

Three Wire DC Power Circuit		
Positive of three wire circuit	L+	
Mid wire of three wire circuit	M	
Negative of three wire circuit	L-	

Appendix G

Electrical Colour Codes

Number	Colour
0	Black
1	Brown
2	Red
3	Orange
4	Yellow
5	Green
6	Blue
7	Violet
8	Grey
9	White

Appendix I

S I Units

Physical quantities are measured in units, have symbols to represent that quantity and will have an abbreviation for the unit when quoted. For example the quantity of voltage has the units of Volts, uses the symbol V to represent voltage in an equation and volts will be abbreviated to V when written down. There are considered to be 7 base quantities from which all other quantities are derived. For example from the base unit of length, area and volume can be derived. Area is two lengths multiplied together and volume is three lengths multiplied together. The SEVEN base units are

Quantity	Unit	Abbreviation	Symbol
Length	Metre	M	l
Mass	Kilogram	Kg	M
Time	Second	S	t
Electric current	Ampere	A	I
Temperature	Kelvin	K	T
Amount of a substance	Mol	Mol	mol
Luminous intensity	candela	cd	Iv

Electrical Quantities

Quantity	Unit	Abbreviation	Symbol
Voltage	Volts	V	V
Current	Amperes (amps)	A	I
Resistance	Ohms	Ω	R
Power	Watts	W	P
Capacitance	Farads	F	C
Inductance	Henrys	H	L
Reactance	Ohms	Ω	X
Impedance	Ohms	Ω	Z
Frequency	Hertz	Hz	f

Appendix J

Answers to Questions

Chapter 1

1	a
2	d
3	c
4	d
5	d
6	c
7	a
8	a
9	b
10	b

Chapter 2

1	13Ω
2	35Ω
3	45Ω
4	50Ω
5	6Ω
6	1.82Ω
7	39.82Ω
8	42.82Ω
9	88V
10	Yes

Chapter 3

1	b
2	a
3	d
4	d
5	a

Chapter 4

1	c
2	c
3	a
4	c
5	b
6	c
7	d
8	false
9	false
10	false

Chapter 5

1	b
2	a
3	a
4	d
5	true
6	true
7	false
8	false

Chapter 6

1	b
2	a
3	d
4	a
5	c

Chapter 7

1	b
2	a
3	a
4	d
5	true
6	true
7	false
8	false

Chapter 8

1	b
2	a
3	b
4	d
5	c
6	a
7	false
8	true

Chapter 9

1	a
2	b
3	c
4	true
5	false
6	true

Chapter 10

1	c
2	b
3	a
4	c
5	c
6	c
7	a
8	b
9	true
10	true

Chapter 11

1	b
2	d
3	d
4	a
5	b
6	c
7	b
8	false
	false
	true