Summary | Electrical Fundamentals

Introduction

Be sure to revise the Electricity unit of G.C.E. (A/L) Physics.

Charge

- measured in Coulomb (C) = 6.25×10^{18} number of electrons
- quantized
- conserved

Time invariant charge is denoted as Q. And time varying charge is denoted as q.

Current

Amount of charges (in C) flowing through a point in unit time. Conventional current (opposite to electron flow) flows from positive to negative potentials.

$$I = \frac{\mathrm{d}Q}{\mathrm{d}t}$$

Time invariant current (DC) is denoted as I. And time varying current (AC) is denoted as i.

Voltage

Voltage at a point is the work that must be done against the electric field to move a unit positive charge from infinity to that point.

1 volt is the potential difference between 2 points when 1 joule of energy is used to move 1 coulomb of charge from one point to the other.

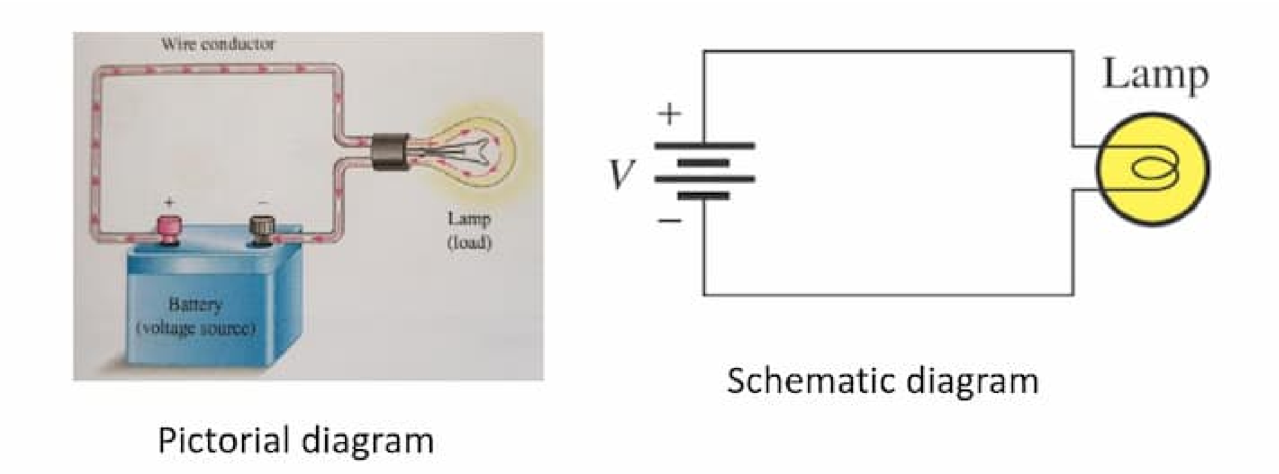
$$V = \frac{E}{Q}$$

Time invariant voltage is denoted as V. And time varying voltage is denoted as v.

Voltage difference is the work that must be done against the electric field to move a unit positive charge from one point to another.

$$V_{AB} = V_A - V_B$$

Electric Circuit



Pictorial diagram

Schematic diagram

Types of circuits

- Closed circuit - the electricity flows
- Open circuit - the electricity doesn't flow. current = 0 . ∞ resistance.
- Short circuit - very large current. 0 resistance.

Power

$$p = \frac{\mathrm{d}w}{\mathrm{d}t} = \frac{\mathrm{d}w}{\mathrm{d}q}\frac{\mathrm{d}q}{\mathrm{d}t} = vi$$

Total Work

$$w = \int_{t_0}^{t} p \, \mathrm{d}t = \int_{t_0}^{t} vi \, \mathrm{d}t$$

When v and i are constant

$$w = vi\int_{t_0}^{t} \mathrm{d}t = vi(t - t_0)$$

Electrical Load

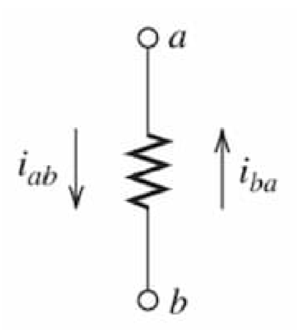
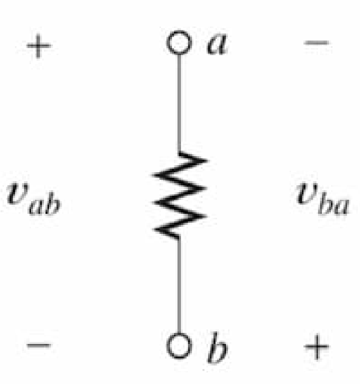
Something that consumes electrical energy.

Linear loads

Loads that can be expressed using a combination of resistors, capacitors and inductors only.

> ⓘ **Note**
>
> If a AC sinusoidal voltage is applied across a load, current through the load will also be sinusoidal **iff** the load is linear.

Double subscript notation

-	Current	Voltage
Double subscript		
Equation	$i_{ab} = -i_{ba}$	$v_{ab} = -v_{ba} = v_a - v_b$
Description	Current is flowing **from point a to point b**	Voltage is **higher at point a and lower at point b**

Common Terms

Branch

A branch represents a single element, such as a resistor or a battery.

Node

A node is the point connecting more than 1 branches. Denoted by a dot.

> **Note**
>
> All points in a circuit that are connected directly by ideal conductors can be considered to be a single node.

Two terminal element

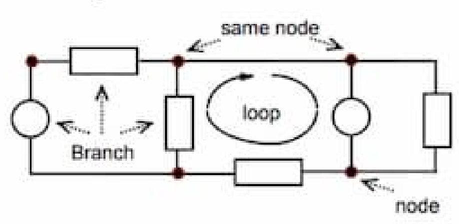
An element connected to two nodes. Branches are two terminal elements.

Loop

A loop is a closed path through a circuit in which no node is encountered more than once except for the same start/finish node.

Mesh

A mesh is a loop without having other loops inside it. Subset of loops.



Circuit elements

Two types of circuit elements.

- Active
- Passive

Active

Capable of generating electrical energy.

- Voltage sources
- Current sources

These can interchangeably be used.

Passive

Either consumes or stores electrical energy.

- Resistors
- Inductors
- Capacitors
- Any other elements

Voltage sources

- Batteries - electrochemical
- Solar cells - photo voltaic
- Generators - electromagnetic

Ideal voltage source

Constant voltage for any required currents. Does not exist.

Resistors

Resistance, in terms of physical dimensions:

$$R = \frac{\rho l}{A}$$

Here:

- l : length
- A : cross-sectional area
- ρ : resistivity

If a voltage V is applied across a conductor, then a given current I will flow through the conductor $V \propto I$. The proportionality constant is called resistance R.

$$R = \frac{V}{I}$$

Capacitors

Made of two conductive plates separated by an insulating (dielectric) layer.

Capacitance (C), in terms of physical dimensions:

$$C = \frac{\epsilon A}{d}$$

Here:

- d : distance between the plates
- A : area of a plate

In an ideal capacitor, the charge imbalance Q is proportional to the voltage V across the plates.

$$Q = CV$$

v and i

As C is constant, current i passing through the capacitor and the voltage v across the capacitor are related by:

$$i = C\frac{\mathrm{d}v}{\mathrm{d}t}$$

Energy stored

Suppose voltage across an initially uncharged capacitor rises from 0 to V during a time period of t.

$$e = \int_0^t p\,dt = \int_0^t vi\,dt = C\int_0^v v\,dv$$

$$E = \frac{1}{2}CV^2$$

Inductors

When there is a current in the inductor, a magnetic field is created. Any change in current causes the magnetic field to change, this in turn induces a voltage across the inductor that opposes the original change in current.

A length of wire turned into a coil works as a inductor.

Inductance (L)

For an ideal inductor:

$$v = L\frac{\mathrm{d}i}{\mathrm{d}t}$$

Here the v is the voltage difference between the inductor, and i is the current through the inductor.

The polarity is such as to oppose the change in current.

Energy stored

Assume voltage across an inductor rises from 0 to i during a time period of t seconds.

$$e = \int_0^t p\,dt = \int_0^t vi\,dt = L\int_0^i i\,di$$

$$E = \frac{1}{2}Li^2$$

Kirchhoff Laws

Kirchhoff Current Law

The algebraic sum of all the currents entering and leaving a node is zero. Based on principle of conversation of charge.

$$\sum_{\text{node}} I = 0 \implies \sum_{\text{in}} I = \sum_{\text{out}} I$$

Kirchhoff Voltage Law

The algebraic sum of voltages around a loop is zero. Based on principle of conversation of energy.

$$\sum_{\text{node}} V = 0$$

Voltage division

Series connection is used to divide voltage. Potentiometeres are commonly used to create voltage divider circuits.

Current division

Parallel connection is used to divide current.

Introduction to Waves

Waveform

Obtained by plotting instantaneous values of a time-varying quantity against time.

Periodic Waveform

A pattern repeats after T time. Periodic time is T and frequency f is $\frac{1}{T}$.

Alternating Waveform

A waveform that changes in magnitude and direction with time. Is also a periodic waveform.

Sinusoidal Waves

Same as $\sin\theta$ vs θ (in rad). Also called sine waves or sinusoid.

$$y = Asin(\omega t + \phi)$$

When ϕ is:

- > 0 - the wave is said to be **leading** by ϕ
- $= 0$ - the wave is the **reference**
- < 0 - the wave is said to be **lagging** by ϕ

Sinusoidal voltages are be easily generated using rotating machines.

Complex Waveforms

Periodic non-sinusoidal waveforms can be split into its fundamental and harmonics.

Fundamental Waveform

$$f_0 = f_{\text{complex}}$$

Harmonics

Sine waves with higher frequencies which is a multiple of f_0.

$$f_{\text{harmonic}} = n \cdot f_0 \ ; n \in \mathbb{Z}$$

Harmonics are grouped into:

- **odd harmonic** when n is odd.
- **even harmonic** when n is even.

Definitions in AC Theory

> **Note**
>
> Only sinusoidal AC supply are considered in s1.

Say v is alternating as in $v = V_m sin(\omega t + \phi)$.

Peak value

Maximum instantaneous value. V_m in the example.

Peak-to-peak value

Maximum variation between maximum positive and negative instantaneous values. $2V_m$ in the example.

For a sinusoidal waveform, this is twice the peak value.

Mean value

$$v_{\text{mean}} = \frac{1}{T} \int_{T_0}^{T_0+T} v(t) \mathrm{d}t$$

Here:

- T_0 is the starting time of a cycle
- T is the periodic time

For any symmetric waveform, mean value is 0.

Average value

Mean value of the rectified version of a waveform.

For symmetric waveforms, half-cycle mean value is taken as the average value.

$$v_{\text{average}} = \frac{2}{T}\int_{T_0}^{T_0+\frac{T}{2}} v(t)\,\mathrm{d}t$$

For sinusoidal waveforms, from the example:

$$v_{\text{average}} = \frac{2}{T}\int_{T_0}^{T_0+\frac{T}{2}} V_m sin(\omega t+\phi)\,\mathrm{d}t$$

$$= \frac{2}{\pi}V_m = 0.637V_m$$

Effective value or rms (root mean square) value

$$v_{\text{rms}} = \sqrt{\frac{1}{T}\int_{T_0}^{T_0+T} v(t)^2\,\mathrm{d}t}$$

For sinusoidal waveforms:

$$v_{\text{rms}} = V_m\sqrt{\frac{1}{T}\int_{T_0}^{T_0+T} sin^2(\omega t+\phi)\,\mathrm{d}t} = \frac{V_m}{\sqrt{2}}$$

> **Note**
>
> i_{rms} is the equivalent current that dissipates same amount of power across a resistor R in time T as $i(t)$. Similar for voltage.

> **Note**
>
> rms value is always used to express the magnitude of a time varying quantity.

Instantaneous power

$$P = vi = i^2R$$

Form factor

$$\text{Form factor} = \frac{\text{rms value}}{\text{average value}} = \frac{V_m}{\sqrt{2}} \times \frac{2}{\pi V_m} = 1.111$$

Peak factor

$$\text{Peak factor} = \frac{\text{peak value}}{\text{rms value}} = V_m \times \frac{\sqrt{2}}{V_m} = 1.412$$

Phasor Representation

Phasor (phase vector) is a vector representing a sinusoidal function.

- Magnitude of the phasor: rms value of the wave
- Angle of the phasor: The angular position ϕ, with respect to a reference direction

Can also be represented by a complex number.

Representation

- Polar form: $A = |A|\angle\phi$
- Cartesian or rectangular form: $A = A_x + jA_y$

Here:

- $|A| = A_{\text{rms}} = \sqrt{A_x^2 + A_y^2}$
- $A_x = |A| \cos \phi$
- $A_y = |A| \sin \phi$
- $j = \sqrt{-1}$
- $\tan \phi = \frac{A_y}{A_x}$

Impedance & Admittance

Impedance (Z)

$$Z = \frac{V}{I} = R + jX$$

Here:

- R : Resistance
- X : Reactance

Admittance (Y)

Inverse of impedance.

$$Y = \frac{1}{Z} = \frac{I}{V} = G + jB$$

Here:

- G : Conductance
- B : Susceptance

From the definitions:

$$G = \frac{R}{R^2 + X^2} \ \wedge B = -\frac{X}{R^2 + X^2}$$

For simple circuit elements

Resistor

Let $i = I_m \sin{(\omega t + \phi_0)}$ is applied across a resistor with resistance R. From Ohm's law:

$$v = RI_m \sin{(\omega t + \phi_0)} \implies Z_R = R$$

No changes in frequency, phase angle. v is in phase with i. R doesn't have reactance.

Inductor

Let $i = I_m \sin{(\omega t + \phi_0)}$ is applied across an inductor with inductance L.

$$v = L\omega I_m \sin{(\omega t + (\phi_0 + \frac{\pi}{2}))} \implies Z_L = j\omega L$$

Reactance of the inductor is $X_L = L\omega$.

> **Note**
>
> v leads i by $\frac{\pi}{2}$. No changes in frequency.

Capacitor

Let $i = I_m \sin{(\omega t + \phi_0)}$ is applied across an capacitor with capacitance c.

$$v = \frac{I_m}{c\omega} \sin{(\omega t + (\phi_0 - \frac{\pi}{2}))} \implies Z_C = -j\frac{1}{c\omega}$$

Reactance of the capacitor (capacitive reactance) is $X_c = -\frac{1}{c\omega}$.

> **Note**
>
> v lags i by $\frac{\pi}{2}$. No changes in frequency.

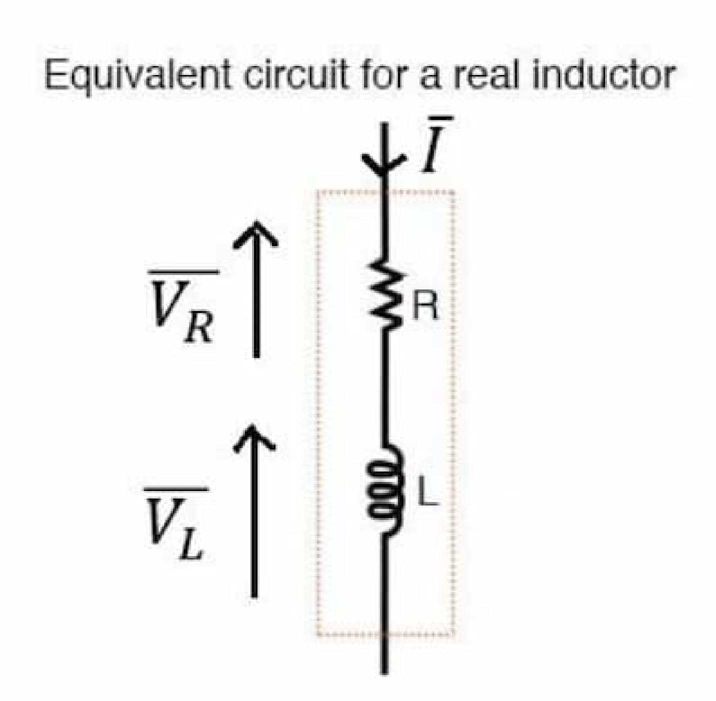
Note

If v:

- lags i - circuit is capacitive
- leads i - circuit is inductive

For complex circuit elements

Real Inductor



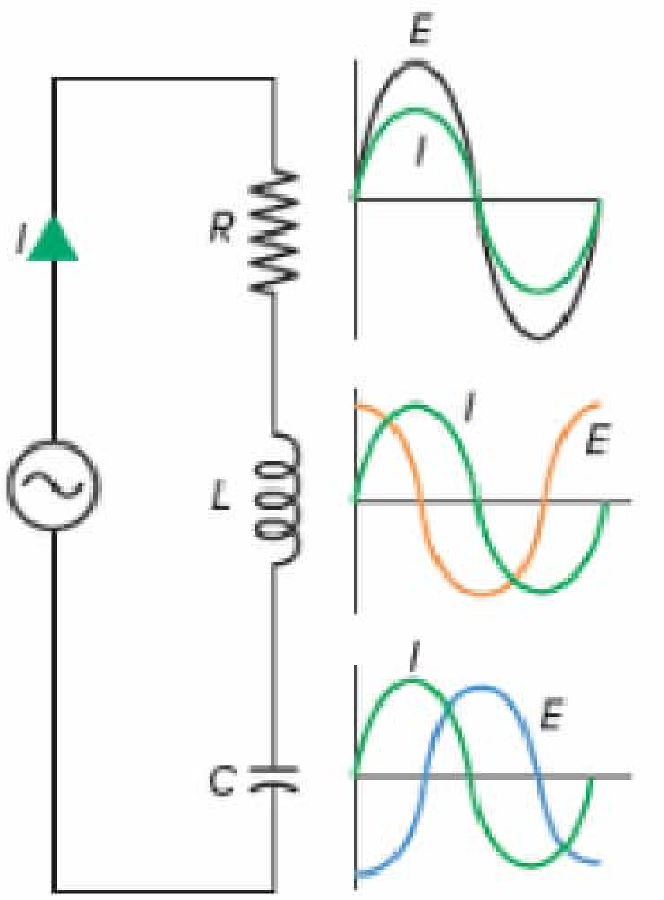
Take $\overline{I}$ as the reference. We get:

$$\overline{V} = \overline{I}(R + j\omega L)$$

From here $\overline{Z}$ can be written (in cartesian or polar form):

$$\overline{Z} = R + j\omega L = |\overline{Z}|\angle\phi$$

RLC series circuit



Complex impedances are added up to find the total impedance of a series circuit.

$$\overline{Z} = R + j(\omega L - \frac{1}{\omega C})$$

For a series circuit

Total impedance is the sum of each component's impedance.

For a parallel circuit

Total admittance is the sum of each component's admittance.

Power and Power factor

- In a purely resistive AC circuit, the energy delivered by the source will be dissipated in the form of the heat by the resistance.
- In a purely capacitive or purely inductive circuit, all of the energy will be stored during one half of each cycle, and then returned to the source during the other half cycle – there will be no net conversion to heat.
- When there is both a resistive component and a reactive component, some energy will be stored, and some will be converted to heat during each cycle.

Power equations

Purely resistive circuit

Suppose a circuit with load R resistance is supplied a voltage of $v(t) = V_m \cos \omega t$.

Instantaneous power dissipated by the load is given by:

$$p(t) = \frac{V_m^2}{R} \cos^2 (\omega t)$$

Always: $p(t) > 0$.

$$\text{Average power} = \frac{1}{2} \text{Peak power} = \frac{V_m^2}{2R}$$

Purely inductive circuit

Suppose a circuit with inductor L is supplied a voltage of $v(t) = V_m \cos \omega t$.

Instantaneous power dissipated by the load is given by:

$$p(t) = \frac{V_m^2}{2\omega L} \sin (2\omega t)$$

Purely capacitive circuit

Suppose a circuit with inductor L is supplied a voltage of $v(t) = V_m \cos \omega t$.

Instantaneous power dissipated by the load is given by:

$$p(t) = -\frac{V_m^2 \omega C}{2} \sin(2\omega t)$$

Power of a general load

Consider a general load with both resistive and reactive components. Depending on how inductive or capacitive the reactive component, the phase shift between voltage and current phasor lies between 90° and -90°.

Suppose the circuit is supplied a voltage of $v(t) = V_m \cos(\omega t)$. And the current phasor shifts in θ phase angle.

$$i(t) = I_m \cos(\omega t - \theta)$$

This ends up with:

$$p(t) = \frac{1}{2} V_m I_m \left[\cos\theta + \cos\left(\omega t - \frac{\theta}{2}\right)\right]$$

Average of over 1 cycle

$$P_{\text{avg}} = \frac{1}{T} \int_{t_0}^{t_0+T} p(t)\,\mathrm{d}t = V_{\text{rms}} I_{\text{rms}} \cos\theta$$

Types of power

Reactive Power

Power delivered to/from a pure energy storage element is known as reactive power.

- Average power consumed by a pure energy storage element is zero.
- Current associated with it is **not** 0. Transmission lines, transformers, fuses, etc. must all be designed to be capable of withstanding this current.
- Loads with energy storage elements will draw large currents and require heavy duty wiring even though little average power is consumed.
- In all electrical and electronic systems, it is the true power (the resistive power) that does the work, the reactive power simply shuttles back and forth between the source and the load.
- This means that the apparent power supplied is a combination of the true and the reactive power.

$$Q_{\text{reactive}} = V_{\text{rms}} I_{\text{rms}} \sin\theta$$

Active power

$$P = V_{\text{rms}} I_{\text{rms}} \cos\theta$$

Apparent power

$$S = V_{\text{rms}} I_{\text{rms}} = \sqrt{P^2 + Q^2}$$

The apparent power is essentially the effective power that the source “sees”

The Beer Analogy

- Beer - Active power
  Liquid beer is useful power. The power that does the work.
- Foam - Reactive power
  Wasted or lost power. The power that does the work.
- Mug - Apparent power
  Demand power, that is being delivered by the utility.

Power factor

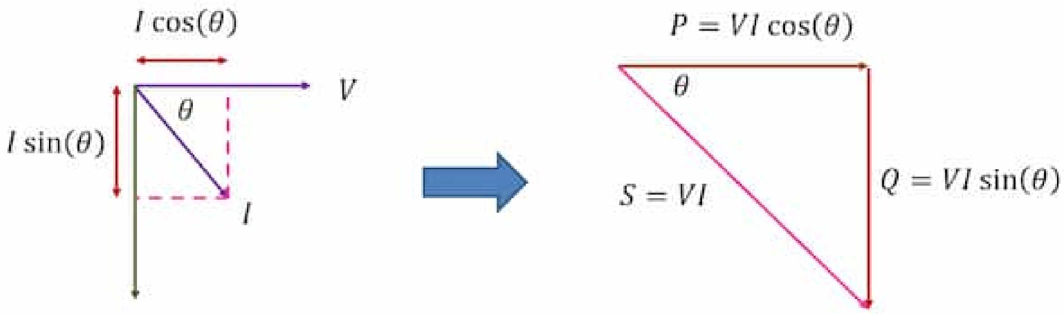
In the above equation of P_{avg}, the $\cos\theta$ is called the power factor.

$$\cos\theta = \frac{\text{Active power}}{\text{Apparent power}}$$

Power factor is:

- leading when I leads V
- lagging when I lags V

Power triangle



- Take V phasor as the reference.
- Draw V and I phasors.

Power systems

An electric power system consists of 3 principle sections

- Power stations: electricity is generated
- Transmission: voltage is stepped to high voltage
- Distribution: voltage is stepped down to medium voltage for distribution over a relatively small region

Variable load

Load on a power station changes with to uncertain demands of consumers. This is called the **variable load**.

Load vs time curve is called the **load curve**. Area under this curve is the **total energy requirement**.

Power grid

Nation-wide, massive, geographically distributed system for electrical power supply network.

Sri Lankan Voltage Levels

- High voltage $220\ \mathrm{kV}$
- Medium voltage $11\ \mathrm{kV}$
- Nominal voltage $230\ \mathrm{V}$
- Nominal line-to-line $400\ \mathrm{V}$

3-Phased System

Why 3-phase?

- The current can be distributed into 3 wires instead of just 1.
  There is a maximum limit of how much current a wire can carry.
- Economical as less amount of wires.
  3-phase system requires 4 wires (3 if balanced) while single phase system requires 6 .

The phases are denoted by $\mathrm{R}, \mathrm{Y}, \mathrm{B}$ in that order.

Balanced 3-phase

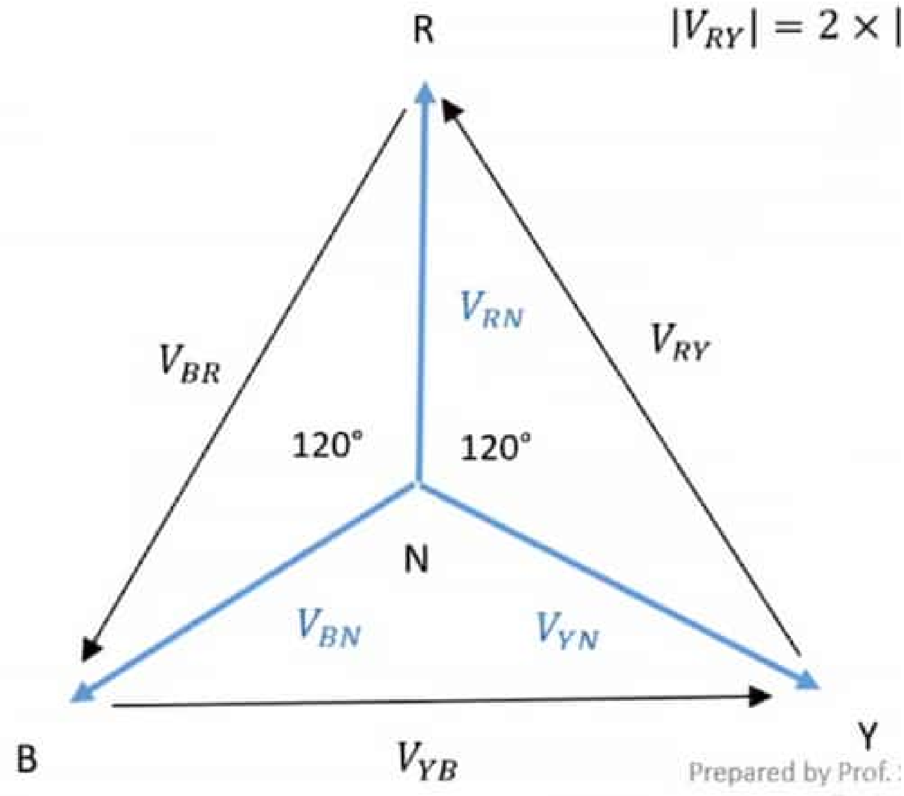
A 3-phase system is said to be balanced **iff**:

- Supply is balanced
- Loads are the same in each phase

Power source

A 3-phase power source which produces 3 phase voltages of equal rms value, but with 120° phase difference.

Phasor diagram



Phase voltage

Voltage between a phase wire and the neutral wire.

$V_{\mathrm{RN}}, V_{\mathrm{YN}}, V_{\mathrm{BN}}$ are the phase voltages.

Line-to-line voltage

Voltage between any 2 phase wires. Line-to-line voltages also have a 120° phase difference.

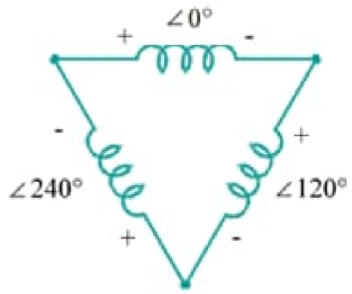
$V_{\mathrm{RY}}, V_{\mathrm{YB}}, V_{\mathrm{BR}}$ are the line-to-line voltages or line voltages.

$$\left|V_{\mathrm{BR}}\right| = 2 \times \left|V_{\mathrm{BN}}\right| \cos(30^\circ) = \sqrt{3}\left|V_{\mathrm{BN}}\right|$$

> ⓘ **Note**
>
> In a 3-phase system, line-to-line voltage is mentioned.

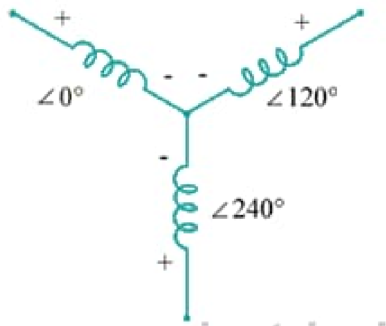
Connection types

Delta connection

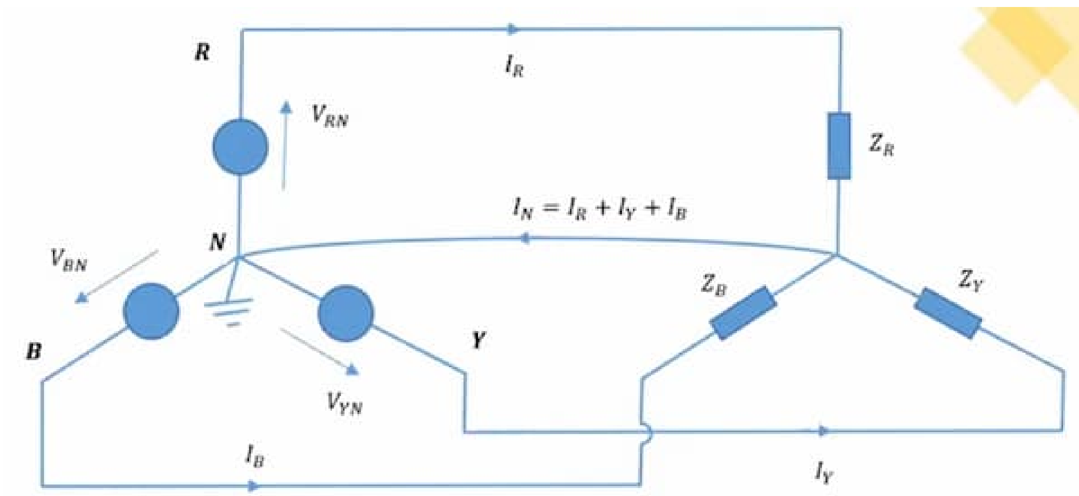


Doesn't have a neutral wire. Neutral point is imaginary.

Star connection



Analysis



$$I_N = E\left[\frac{1\angle 0^\circ}{z_R} + \frac{1\angle -120^\circ}{z_Y} + \frac{1\angle 120^\circ}{z_B}\right]$$

When the loads are balanced: $z_R = z_Y = z_B = z, I_N = 0$

In this case, neutral wire is optional and can be eliminated. $I_N = 0$ have to be maintained so that the voltage is equal to ground voltage in neutral wire. This makes sure there are no power losses in neutral wire.

Real-life Usage

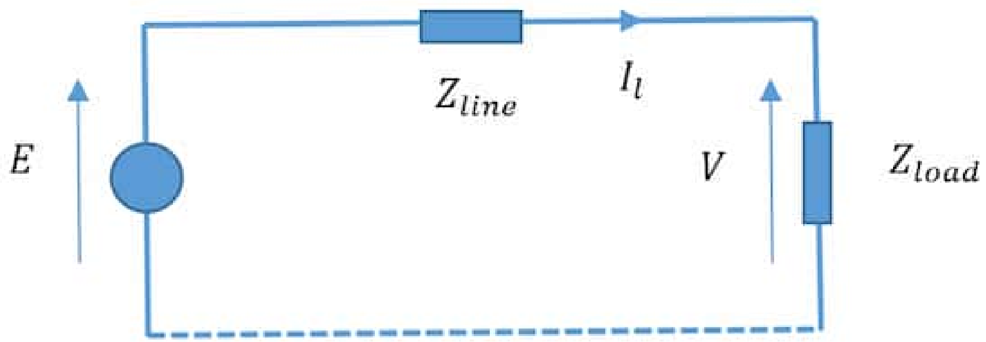
Most domestic loads are single-phase. In case of 3-phase domestic wiring, the single-phase loads are distributed among the 3 phases at the main distribution board.

Devices that have a 3-phase power input, doesn't require a neutral line.

Per-phase Equivalent Circuit

Power, voltage, current, power factor are same for all 3 phases.

When a 3-phase system is balanced, it is sufficient to consider only a single phase. The diagram showing the single-phase equivalent of the power system using standard symbols.



Here:

- E - voltage across the source
- V - voltage across the load

$$\text{Per-phase power} = |V_p||I_l|\cos\theta = \frac{1}{3} \times \text{3-phase power} \quad \wedge \quad |V_l| = \sqrt{3}|V_p|$$

$$\implies \text{3-phase power} = \sqrt{3}|V_l||I_l|\cos\theta$$

Here:

- V_p - phase voltage
- V_l - line voltage
- I_l - line current
- $\cos\theta$ - power factor
- The power can either be source power, load power, transmission power losses.

Unbalanced 3-phase system

A 3-phase system becomes unbalanced, when load distribution among the phases is equal. $I_N \neq 0$. Highly undesirable. Neutral wire is the return path for the line currents.

Large currents in the neutral wire could cause:

- If neutral wire have significant impedance, different points of the neutral wire will have different voltage
- Series voltage unbalances can happen if the neutral wire is broken

Each phase will be different. Complete system has to be considered when analyzing the circuit.

Electrical Installations

An assembly (connected as a complete set) of associated electrical equipment to fulfill a specific purpose and having certain coordinated characteristics.

Electrical equipment

Any item used in generation, transmission, distribution and utilization of electrical energy.

Examples: generators, transformers, measuring instruments, protective devises, wiring materials, etc.

Overcurrent

Current that exceeds the rated value. Includes overload and fault current.

Current carrying capacity

The rated value of current, for conductors.

Faulty current

Can be subdivided into:

- short-circuit current
- earth fault current

Most common types of faults

Short-circuit fault

Large current will flow. Over heating will occur. Damages may occur to wires, insulators, switches, etc. Aka. phase-neutral fault.

Insulation failure

Fault between phase conductor and non-current carrying metallic parts. High voltages may appear on the frames of electrical equipment.

Protection for safety

Protecting livestock and electrical equipments from electric faults.

- Prevent damage by fire or shock
- Maintain supply continuously
- Minimize the system interruptions under faulty conditions.
- Against direct contact: Relates to live parts.
- Against indirect contact: Relates to exposed parts. Conductive but not normally live. Made live by fault.

Properties of protective equipment

- Certainty and reliability of operation under normal, fault, non-operational conditions
- Discrimination
- Rapidity of operation: how fast the equipment responses
- Simplicity
- Low initial and maintenance cost
- Easy adjustment and testing

Protection methods

- Earthing of equipments
- Use of circuit breakers/fuses
- Use of residual current circuit breakers

Fuses

A device for opening a circuit by means of a conductor designed to melt when an excessive current flows along it. Simple. Relatively cheap.

When overcurrent flows through a fuse, the fuse element melts and followed by arcing.

Fuse element

Part of a fuse. Designed to melt and open the circuit when overcurrent flows.

Fuse link

Part of a fuse, which comprises a fuse element and a cartridge (or other container) and is capable of being attached to the fuse contacts.

Current rating

Maximum current, which the fuse can carry for an indefinite period.

Fusing current

Minimum current that will cause the fuse element to heat up melt or blow.

Fusing factor

The ratio of the fusing current to current rating.

Rupturing capacity

Product of maximum current and supply voltage.

Types of fuses

Semi-enclosed fuse

Consist of a fuse holder made up of a fuse base and a fuse carrier. The fuse carrier contains the fuse element usually in wire form. “Rewireable” because the elements are directly replaceable. Cheap. Low rupturing capacity.

But not recommended nowadays because of these disadvantages:

- Deterioration with time due to oxidation - may operate at lower currents than expected due to the reduction in cross sectional area and hence increase in resistance
- Very easy for an inexperienced person to replace a blown fuse-element with a wire of incorrect size or type
- **Slow**: time taken for the fuse to blow may be as long as several seconds during which time considerable electrical and physical damage may result to the circuit conductors and the equipment being protected.
- **Not accurate**: calibration of re-wirable fuse can never be accurate
- Unsuitable for circuits which require discriminative protection. i.e. it is possible in certain circuit conditions for the 15 A rated fuse element to start melting before the 10 A rated element completes fusing
- Not capable of differentiating between a transient high current and a continuous fault current
- Has an associated fire risk
- When the fault current is particularly high, though the fuse works, an arc may still be maintained by the circuit voltage (through air and metallic vapour)

Fully enclosed (catridge) fuse

Developed to overcome the disadvantages of the re-wirable type of fuse. Fuse wire is enclosed in a evacuated glass tube with metal end chips. Expensive compared to semi-enclosed fuses. Low rupturing capacity.

> **Note**
>
> Both semi-enclosed and fully-enclosed fuses are generally used in house-hold, commerical and small scale industrial applications.

High-rupturing capacity (HRC) fuses

Used for high current applications. Expensive.

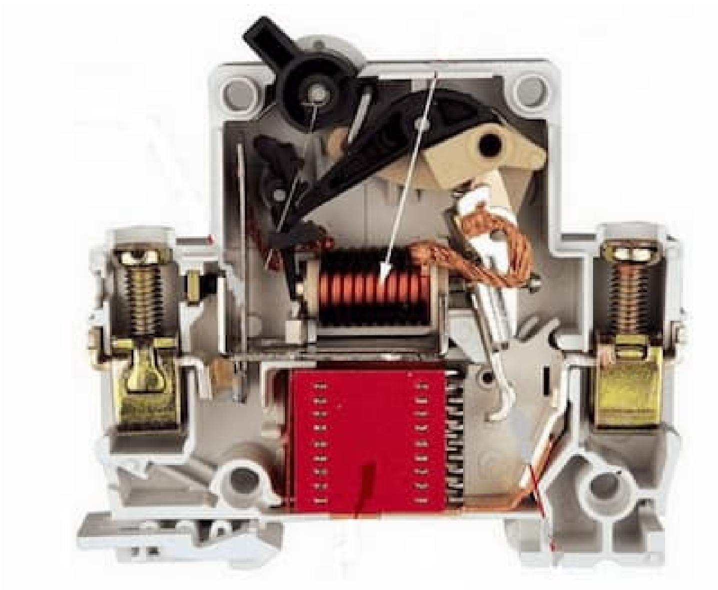
Circuit Breaker

A device for making and breaking a circuit. Operated by hand or automatically. Can be used to isolate part of a circuits. More accurate protection compared to semi-enclosed or fully-enclosed fuse.

Things to consider when choosing a circuit breaker:

- the normal current it will have to carry
- the amount of current it will have to interrupt

MCB

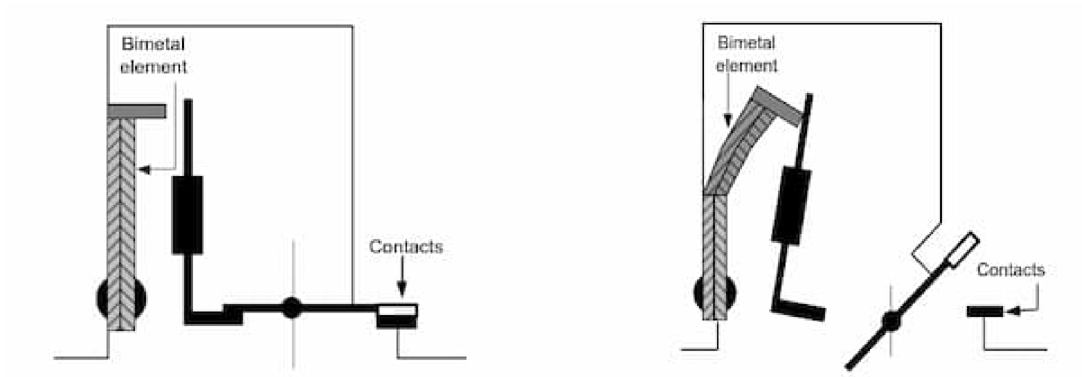


MCB is short for miniature circuit breaker. Not main circuit breaker.

Has 4 functional components:

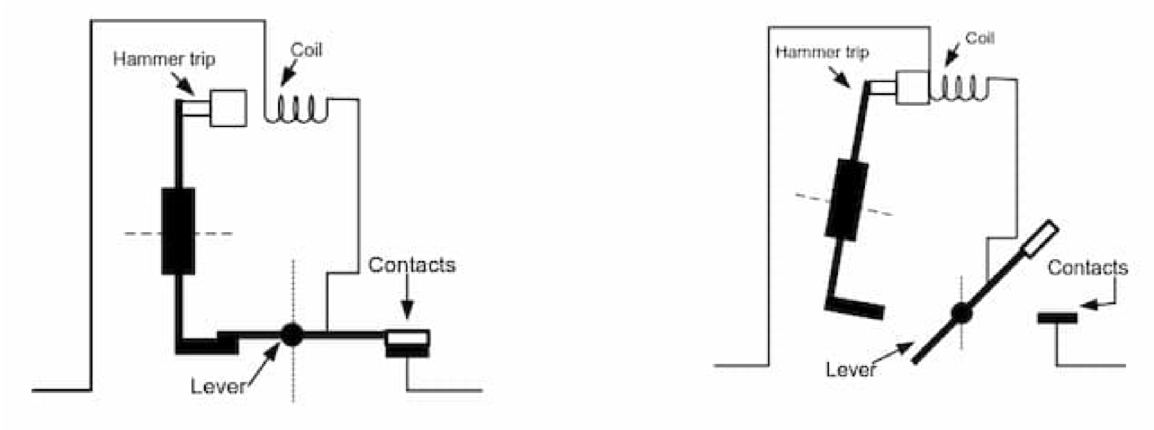
- A thermal overload trip (bi-metal)
- An electromagnetic short-circuit trip
- A switching mechanism with contacts
- Arc exhausting system

Function of the thermal device



The overload trip depends on the operation of the thermally operated bi-metal strip. When heated by the current passing through, the bi-metal strip is deflected due to the difference in expansion. The deflection thus depends on the intensity of heat dependent on the intensity of the current flow and the duration. As can be seen from the figure, after the deflection (or temperature) exceeds a predetermined amount, the tripping mechanism is activated

Function of the EM device



Electromagnetic trip consists essentially of a solenoid coil through which the load current flows. In this coil, there is a fixed iron-core with a movable armature. When the current exceeds a predetermined value, the coil exerts sufficient electromagnetic force to attract the armature against the force of the spring. A switch mechanism is activated by the lever, to open the contacts.

Advantages

Advantages of a MCB over fuses:

- Non-destructive determination of tripping characteristics
- Shorter tripping times under moderate overcurrents
- Immediate indication of faulty current
- Reclosing can be effected at once after the fault has been cleared
- No stock of fuses required
- Can be used as a circuit control switch

Protection

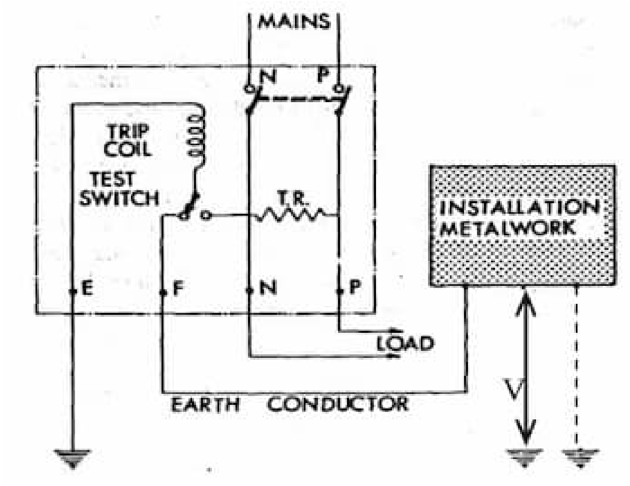
Earth leakage current

Can be used to detect electrical faults to earth in electrical.

- Voltage operated protection - Earth Leakage Circuit Breaker (ELCB)
- Current operated protection - Residual Current Circuit Breaker (RCCB) or Residual Current Device (RCD)

The earth leakage protection device is called as trip switch.

ELCB



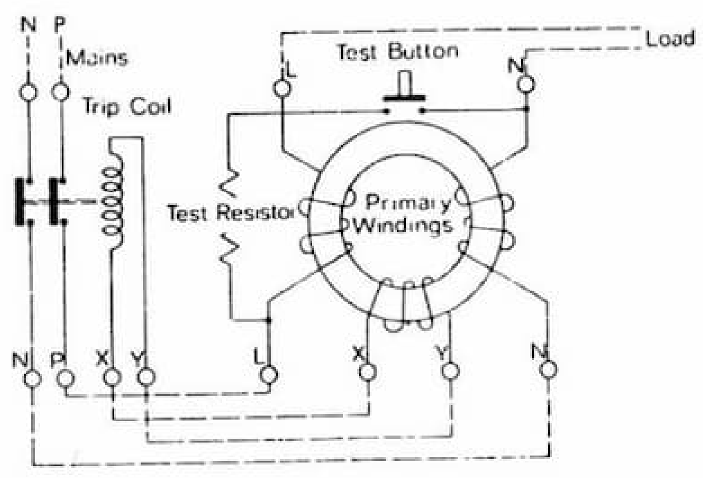
2 earth terminals are required for the proper operation of a ELCB.

- Frame earth to which all non-conducting metallic parts of equipment are connected
- The ELCB reference earth

The ELCB will normally operate when the voltage across the coil, which corresponds to the voltage of the frame earth with respect to the reference earth, exceeds about 40 V. Up to about 50V has been traditionally considered as a safe voltage.

However, it is now known that what is important is the current that may pass through the human body rather than the voltage, and that too is time dependent. Thus the RCCB is now preferred to the ELCB.

RCCB



Trips when line current and neutral current are different.

The current difference between line and neutral currrents is used to energize the solenoid, which causes the switch to open. Under normal operating conditions, two identical windings, m1 and m2, will carry the main current. Since the currents are equal and opposite through the two windings, there is mmf balance and there will be no induced emf on the detector winding. Thus the operating coil will not be energized. However, in case of a fault the line and neutral currents will not equal and the trip coil will be energized due to the induced currents in the detector winding.

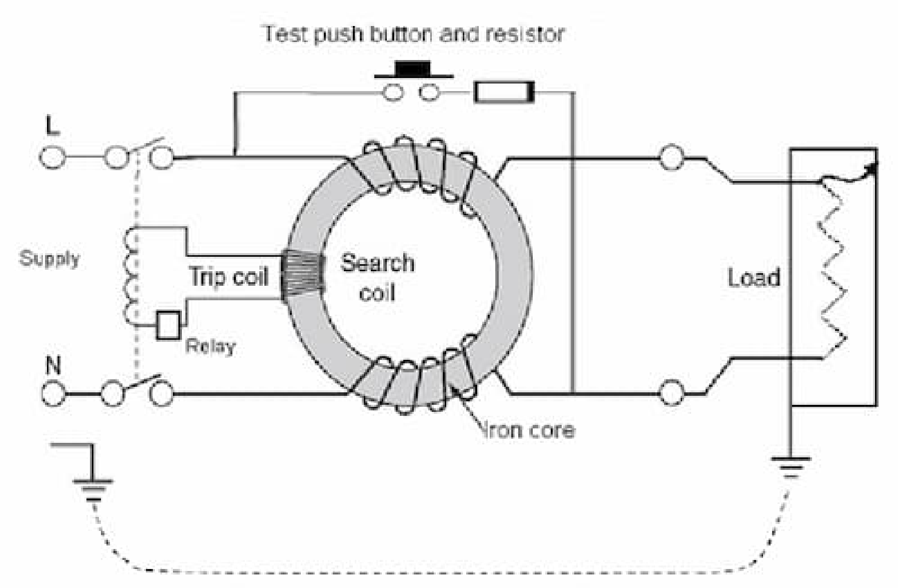
> ⓘ **Note**
>
> In both ELCB and RCCB, a test switch is provided to create an artificial fault.

Advantages of RCCB

Suppose the live wire is exposed. If somebody touches it, they may get a shock if a current passes through them.

In the case of voltage-operated ELCB, this earth current is not going through the tripping coil and will cause danger. But in the case of RCCB, the return path is going to loose part of the current, which passed through the human body, which in turn would cause a resultant flux within the ring energizing the tripping circuit.

Residual Current Device (RCD)



If there is an out of balance, as what happens when part of the current from the live flows to earth at the fault, an out of balance flux is produced, causing operation of the relay and opening of the main contacts. Highlight

Earthing

An effective earthing system avoids having dangerous potentials on the equipment even during electrical faults and also ensures the proper operation of electrical protection equipment during fault condition.

Potential of an installation is measured with respect to earth.

Earthing is done for 2 purposes.

Neutral Earthing

Limiting the voltage of current carrying conductors forming a part of the system.

This is important because the performance of the system in terms of short circuits, stability, protection, etc., is greatly affected by the state of the neutral conductor. When the neutral is properly grounded, voltages of the phases are limited to near phase to ground voltage.

Equipment Earthing

Limiting the potential of non-current carrying metal work associated with equipment, apparatus and appliances in the system.

Refers to grounding of all non-current carrying metal work of equipment. Governed by various regulations such as the IEE regulations. The objectives of this grounding are:

- To ensure effective and rapid operation of the protective gear in the event of earth fault currents. Otherwise, those currents might be undetected, cause fire
- Protect against danger to life through shock due to installation metal work being maintained at a dangerous potential relative to earth

Types of earthing arrangements

In the regulations for electrical installations, the types of earthing systems are identified as follows, depending on the relationship of the source (supply authority network) and of the exposed conductive parts of the installation, to earth.

- TN - earthing of the installation is done to that supplied by the supply authority
- TT - supply authority earth and the installation earth is independent
- IT - supply authority has effectively an isolated neutral and the installation has an independent earth

Above the first letter means:

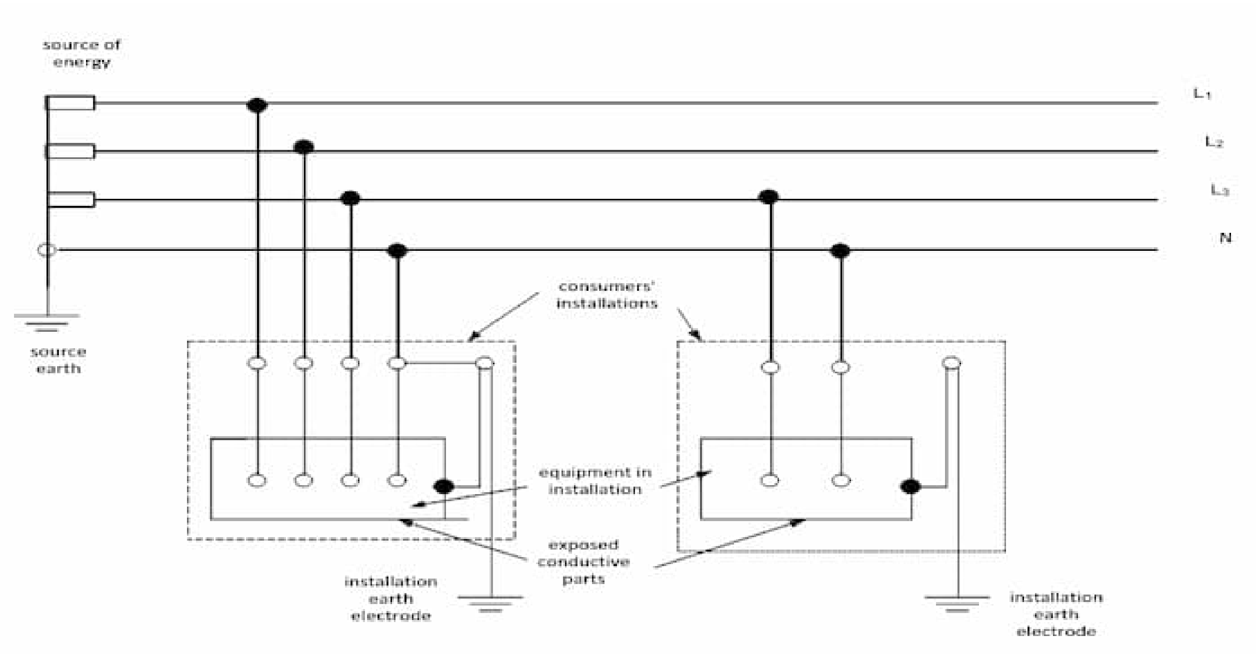
- **T** - Short for terra. Refers to one or more points of the source to earth
- **I** - Short for isolated. Indicates either:
  - (i) all live parts are isolated from earth
  - (ii) one point of live is connected to earth through high impedance

Above the second letter means:

- **T** - Denotes a direct connection from exposed parts of consumer installation to earth, independently of any point of the supply authority side
- **N** - Denotes a direct electrical connection of the exposed conductive parts to the earthed point of the supply authority side (which is usually the neutral point)

TT system

Used in Sri Lanka. Supply is earthed at the source end. All exposed conductive parts of the installation are connected to earth (independent earth electrode) at consumer end.



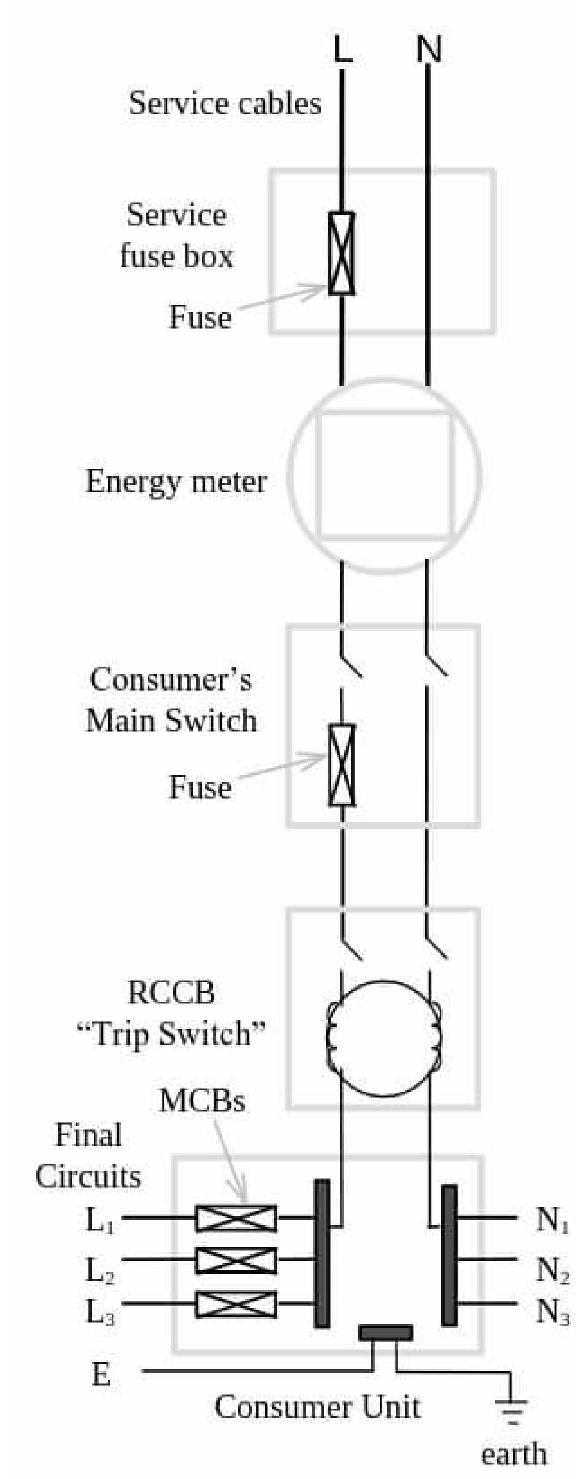
ⓘ **Note**

In domestic systems, the earthing circuit is usually earthed by connecting to metallic water pipes buried in ground. The resistance of this electrode to earth also depends on the condition of soil and may have values in excess of 100 . Thus in the TT system of earthing, it is now essential to use an RCCB for protection.

The normal earthing practice is to provide a circuit protective conductor throughout every installation. A circuit protective conductor connects exposed conductive parts of equipment to the main earthing terminal.

Basic Domestic Installations

Most domestic installations in Sri Lanka use single phase and is supplied at 230V line to neutral.

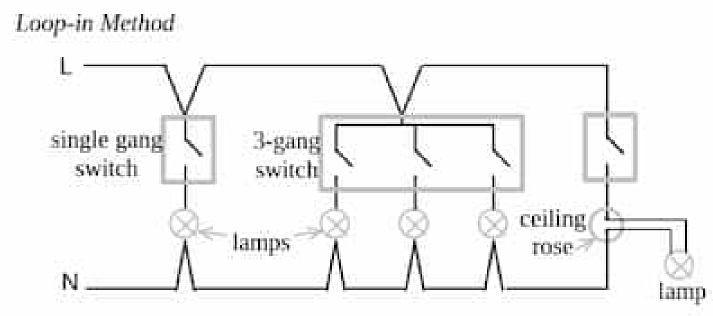


Up to the energy meter belongs to the supply authority. Consumer's installation starts from the main switch.

Final circuits are taken from the consumer unit (or distribution unit).

Wiring a final circuit

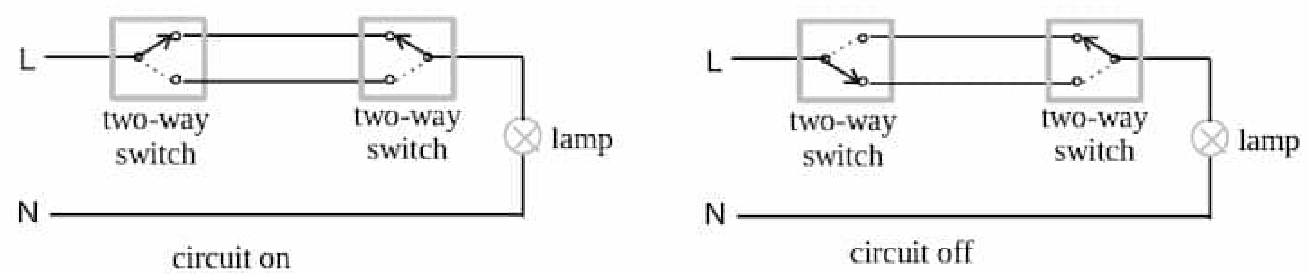
Loop-in method



Enables all joints and terminations in a single final circuit to be made at ceiling roses, switches or other accessories. This makes all joints accessible for testing and alterations. Each final circuit has both its live and neutral conductors terminating at the consumer unit. Wires are usually laid in PVC conduits.

> **Note**
>
> Lamp circuits do not normally need an earth wire unless there is a metallic fitting which needs to be earthed for safety.

Two-way switches

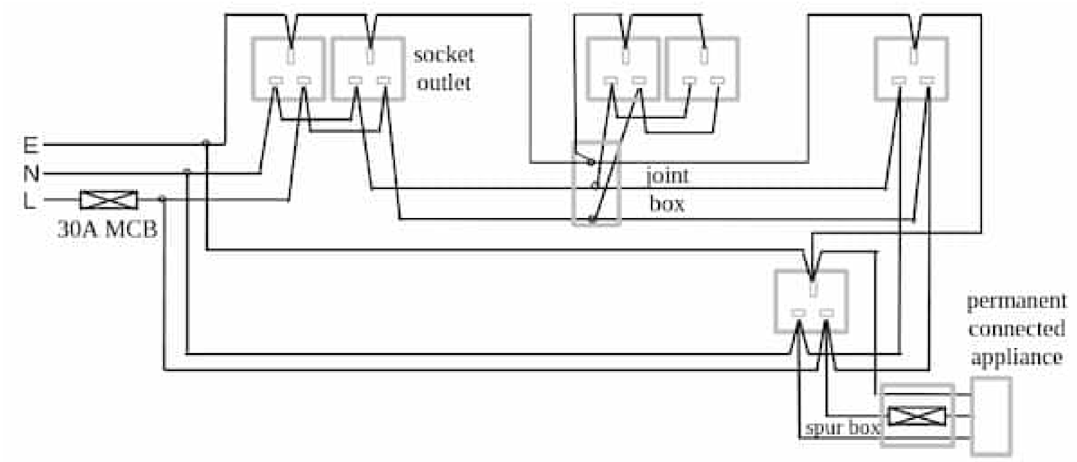


Used when it's necessary to operate an equipment from 2 positions.

Final circuits for socket outlets

Socket outlets are wired in 2 ways.

Ring circuit



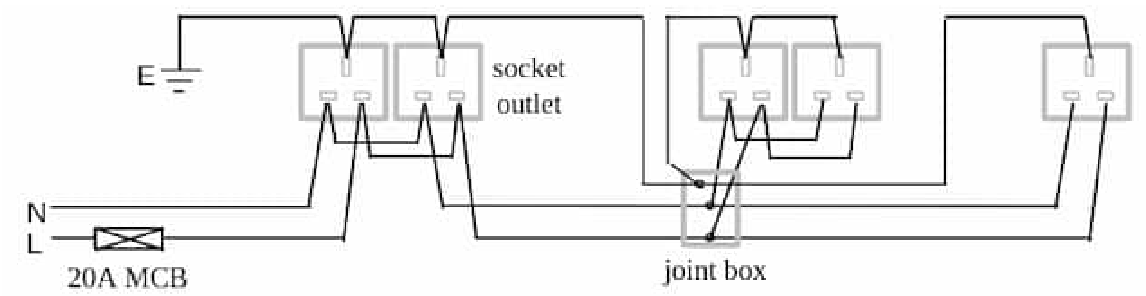
Each circuit commences from consumer unit (or distribution board) through an MCB (or fuse) of specific rating usually 30 A, loops into each socket outlet and returns to the same MCB (or fuse) in the consumer unit (distribution board).

Looping must be done for the live, neutral and the protective conductors in separate rings.

A ring circuit can only be used when:

- The floor area served by the ring does not exceed $100\,\mathrm{m}^2$
- Maximum demand of the circuit doesn't exceed the MCB (or fuse) rating

Radial connection



Each circuit commences from consumer unit (or distribution board) through an MCB (or fuse), loops into each socket outlet and ends at a socket outlet.

Protection Tests

After an electric installation is done, it must be tested for faults, to ensure the safety of users and electrical appliances.

Insulation test

To make sure there are no short circuits and the circuit is properly insulated.

Procedure

1. All main circuit breaker, MCBs, RCCBs are turned off
2. Turn on the required MCB and switch
3. All appliances are unplugged
4. Appropriate scale is set on the tester
5. One probe is connected to the earth bus bar
6. Other probe is connected to the live of the load
7. Circuit is tested
8. If the reading is higher than $1\,\mathrm{M\Omega}$, test is passed

Continuity test

To check if current passes through 2 points of the circuit continuously.

Procedure

1. Installation is disconnected by turning off main switches, MCB, RCCB
2. All appliances are unplugged
3. All switches are in on state
4. Appropriate scale is set on the tester
5. One probe is connected to the earth bus bar
6. Other probe is connected to the earth of the socket
7. Circuit is tested
8. If the reading is less than $10\,\Omega$, test is passed

Electric Shock

Electric shock is when a current flows through the human body.

Ventricular fibrillation

Prevention of the heart to act as an effective pump. Stops blood circulation to all parts of body. Causes death in a very short time.

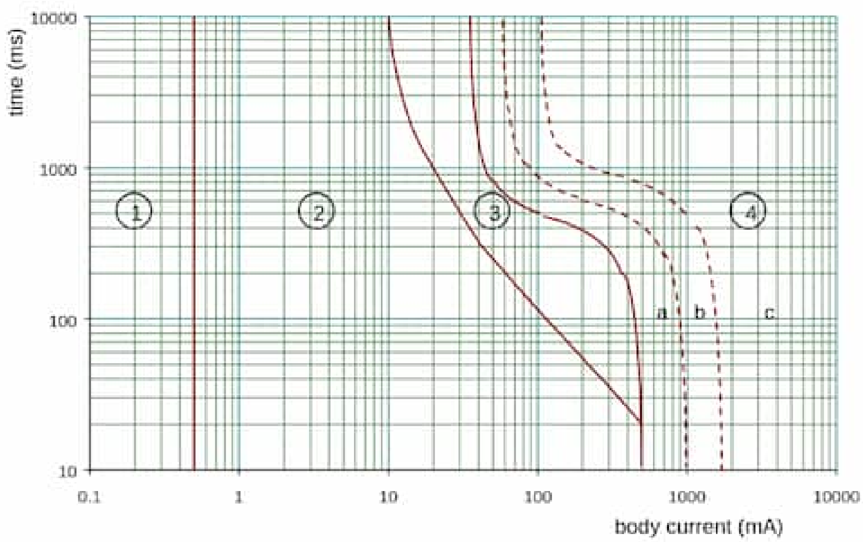
Degree of danger

Depends on

- Value of the body current
- Time for which the current flows

Zones

The below chart shows the time/current zones of effects of 50 Hz current on the human body:



Zone	Description
Zone 1	No sensation
Zone 2	Perceptable. Not harmful. 10mA is the threshold of let-go
Zone 3	Mascular contractions and difficulty in breathing. Usually no danger of ventricular fibrillation. (0.5% possibility)
Zone 4	Probability of ventricular fibrillation increases. (a - up to 5%, b - up to 50%, c - more than 50%)

Note

From the above chart, 30mA never goes into zone 4. Thus typically used in residual current devices for the safety of people.