1. Balanced Three Phase system of EMFs

→ Balanced 3 Phase system of EMFs is set of 3 EMFs which are of equal magnitude / amplitude and displaced in phase in one another by 120°.

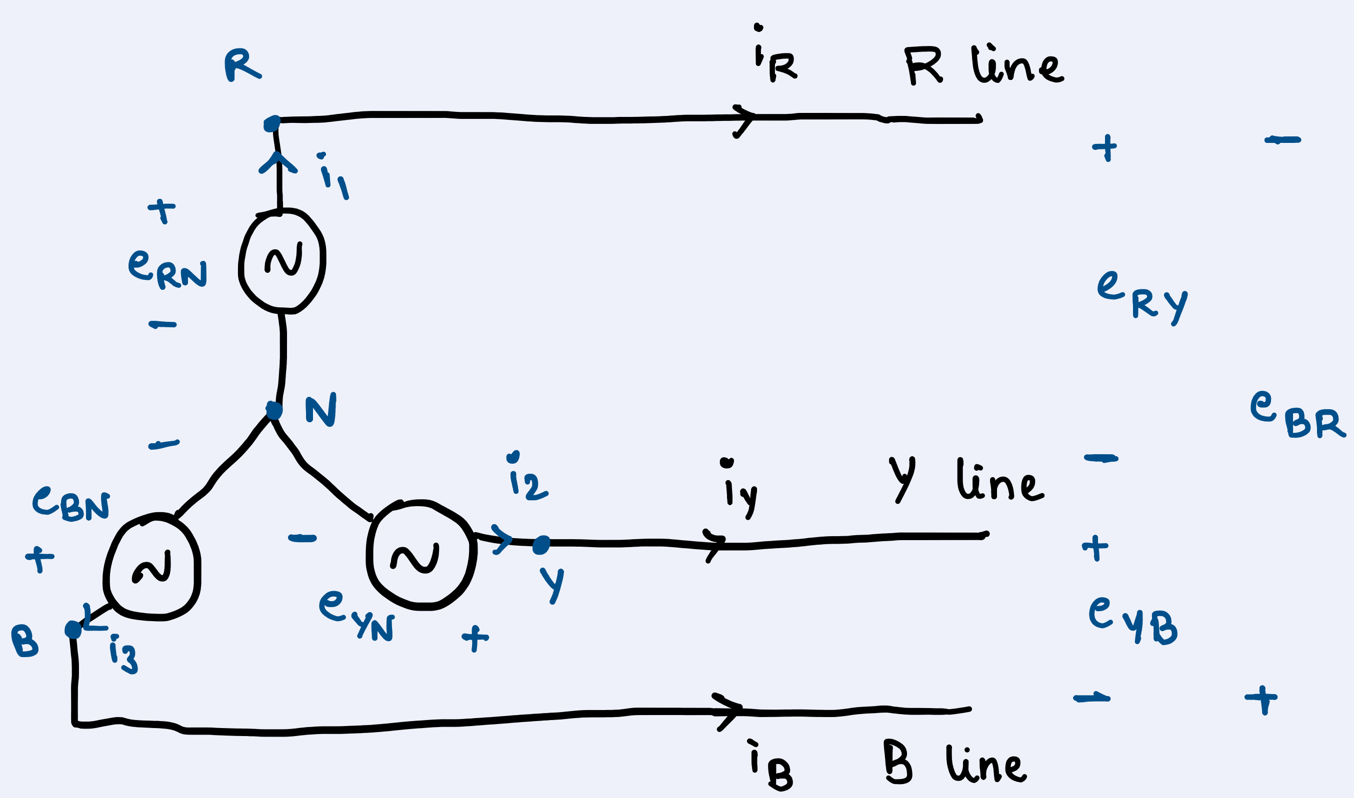
$$e_1 = E_m \sin(\omega t)$$
$$e_2 = E_m \sin(\omega t - 120)$$
$$e_3 = E_m \sin(\omega t - 240)$$

→ Balanced 3 Phase system of EMFs

$$e_1 - e_2 = 0 - (-120) = 120$$
$$e_2 - e_3 = -120 - (-240) = 120$$
$$e_3 - e_1 = -240 + 0 = -240 + (360) = 120$$

→ They are generated in a machine called '3 Phase Generator' / 'Alternator'

2. Balanced star system

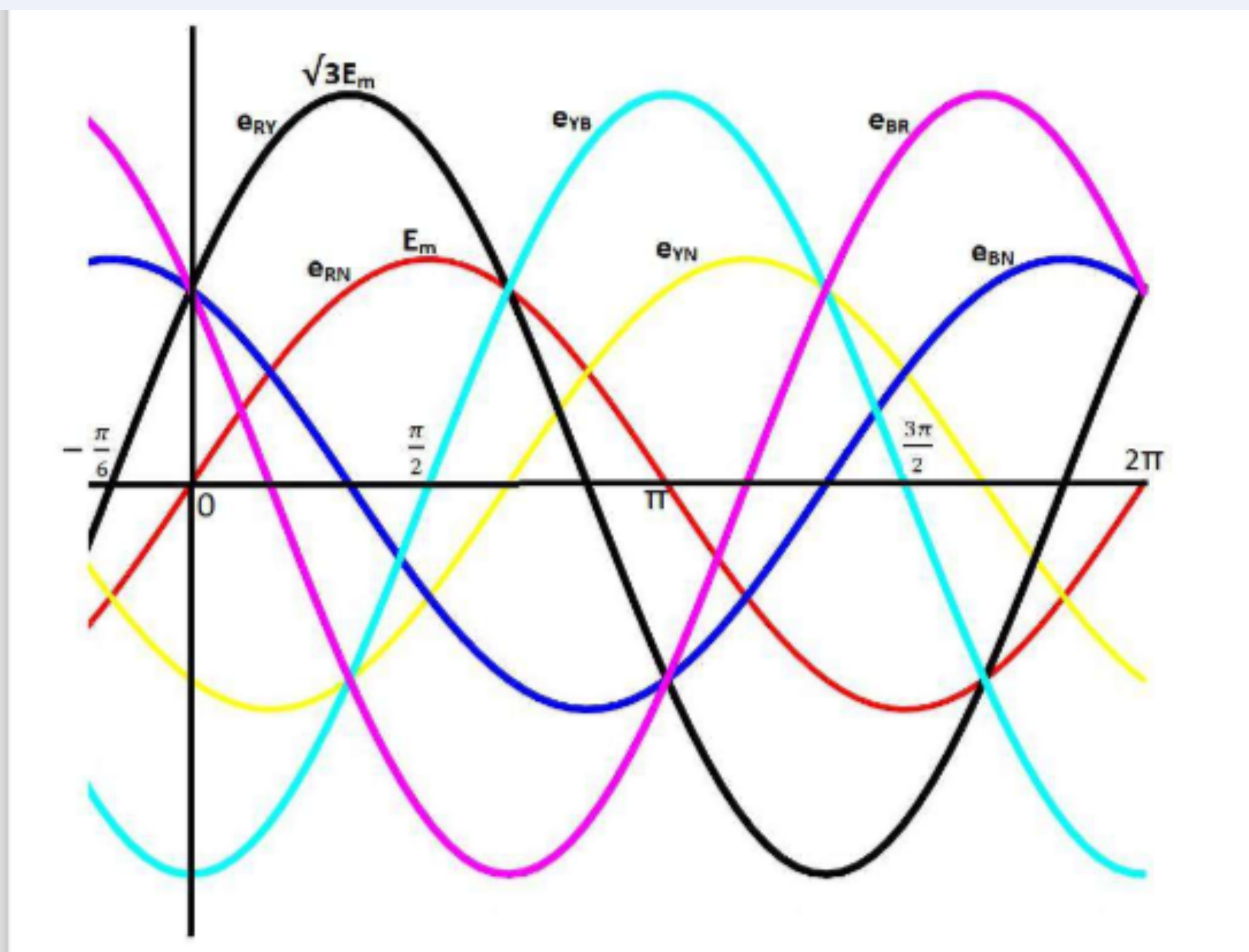


$\underbrace{i_1 \ , \ i_2 \ \& \ i_3}$ → Represent Phase Currents

$\underbrace{i_R \ , \ i_y \ , \ i_B}$ → Represent Line Currents

$\underbrace{e_{RN} \ , \ e_{YN} \ , \ e_{BN}}$ → Represent Phase Voltages

$\underbrace{e_{YR} \ , \ e_{YB} \ , \ e_{BR}}$ → Represent Line to Line Voltages



Relation b/w line & phase currents

→ Line current = Phase current

$i_1 = i_R \ ; \ i_2 = i_y \ ; \ i_3 = i_B$

→ Applying KVL on RYNR,

$$-e_{RY} - e_{YN} + e_{RN} = 0$$

$$e_{RY} = e_{RN} - e_{YN}$$

$$\bar{E}_{RY} = \bar{E}_{RN} - \bar{E}_{YN}$$

$$= \frac{E_m}{\sqrt{2}} \angle 0 - \frac{E_m}{\sqrt{2}} \angle -120$$

$$= E_{ph} \angle 0 - E_{ph} \angle -120$$

$$= E_{ph} \left(\frac{3}{2} + j\frac{\sqrt{3}}{2} \right)$$

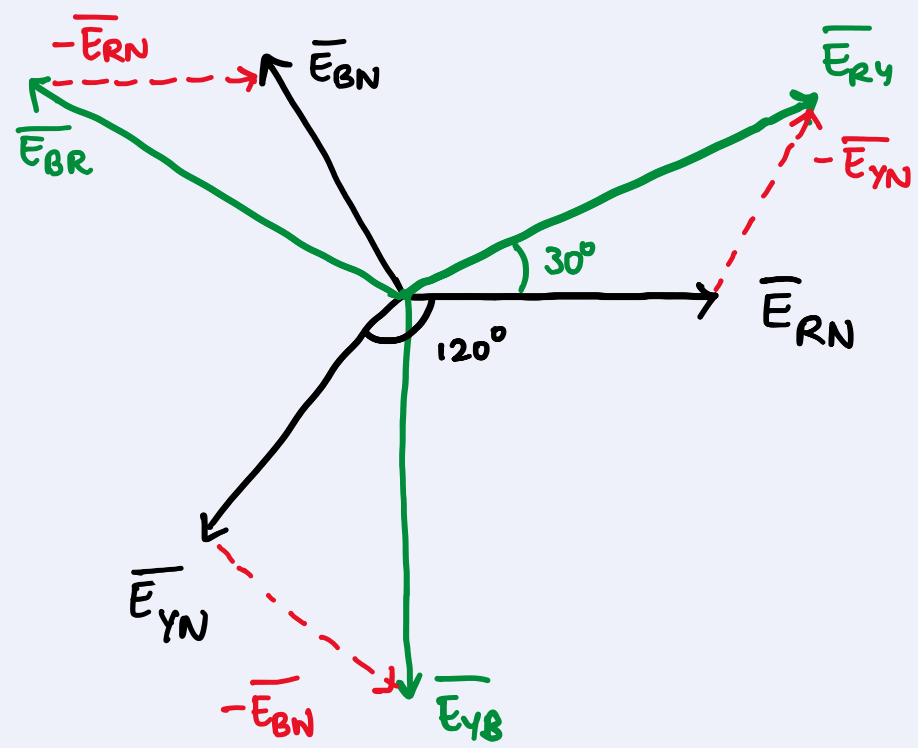
$$= \sqrt{3} E_{ph} \angle 30°$$

Similarly, $\bar{E}_{YB} = \bar{E}_{YN} - \bar{E}_{BN} = \sqrt{3} E_{ph} \angle -90$

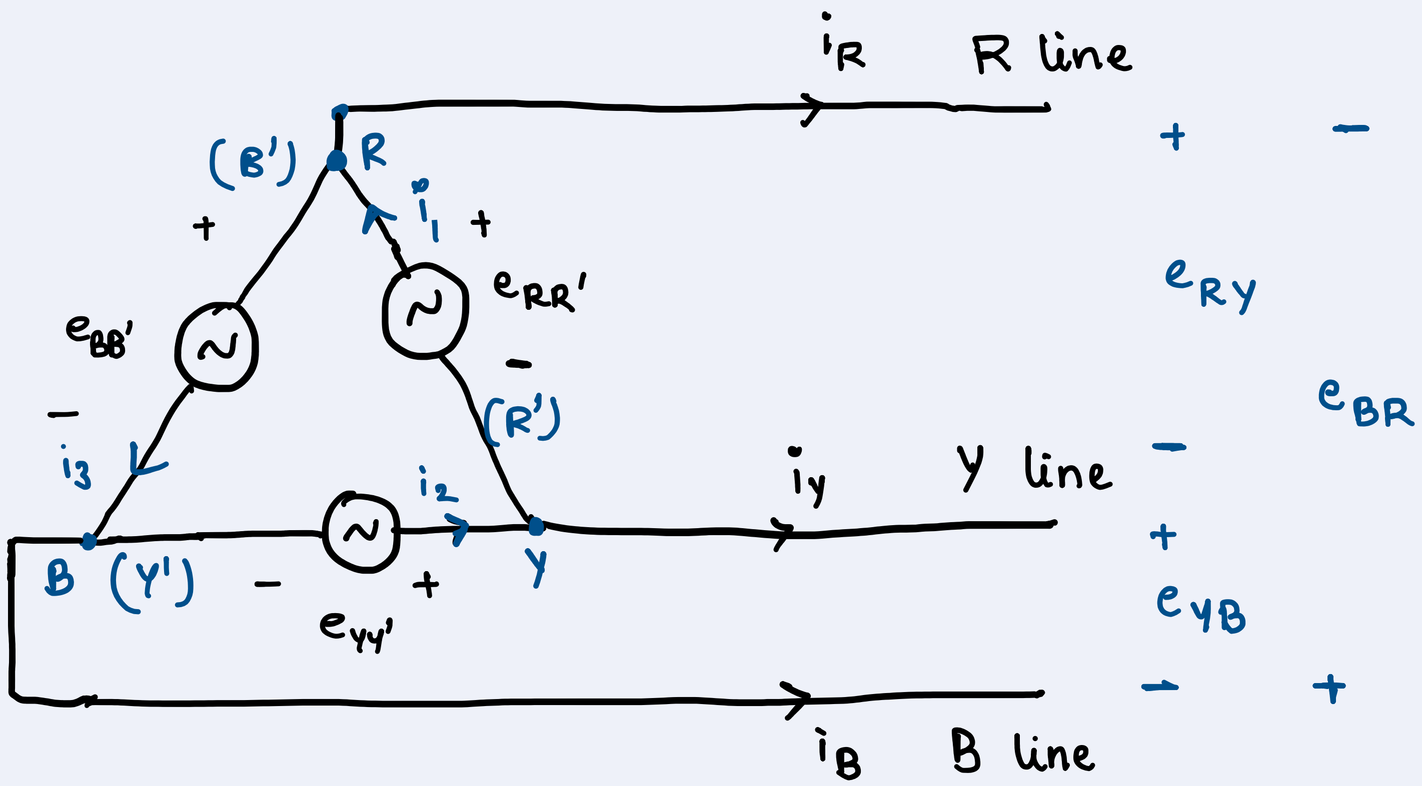
$\bar{E}_{BR} = \bar{E}_{BN} - \bar{E}_{RN} = \sqrt{3} E_{ph} \angle -210$

→ Magnitude of RMS Voltage = $\sqrt{3}$ (Magnitude of Phase Voltage)

→ Line voltage leads phase voltage by 30°

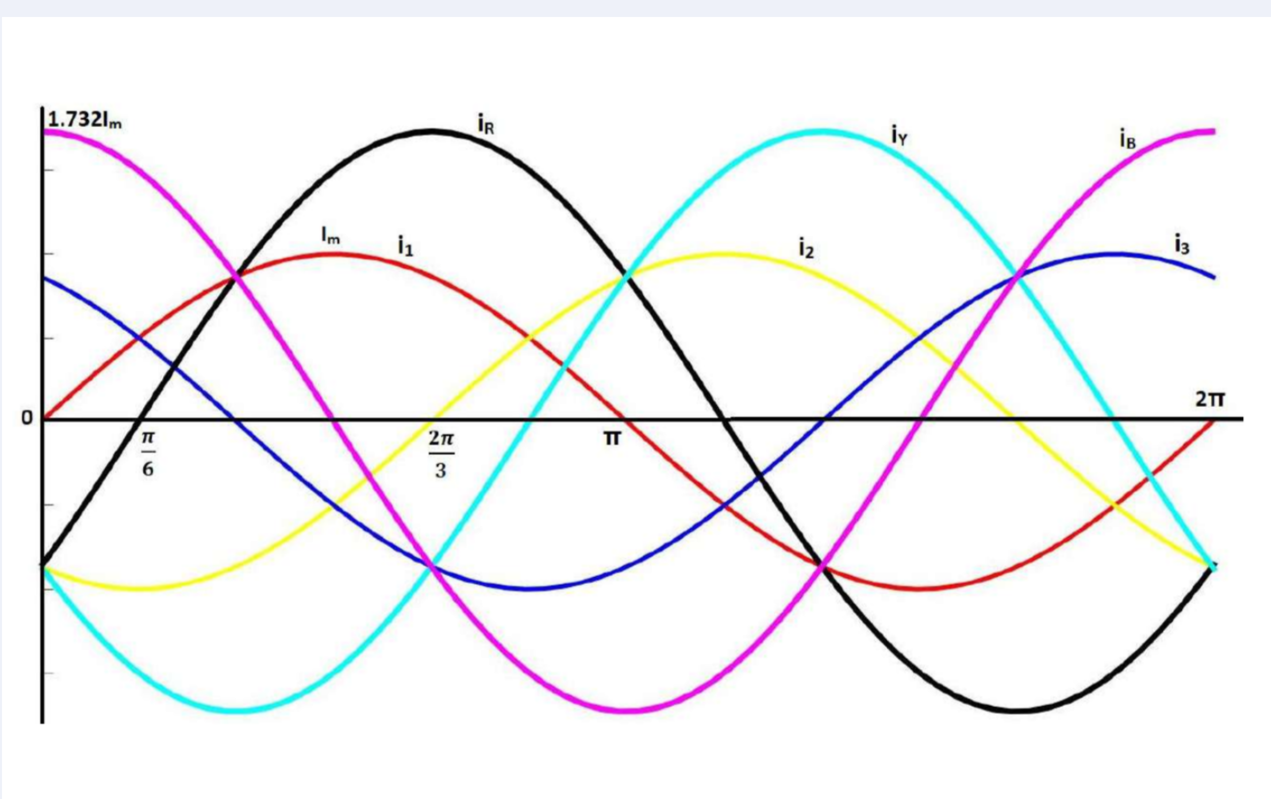


3. Balanced Delta System



$\underbrace{e_{RR'},\ e_{yy'},\ e_{BB'}}_{\text{Phase Voltages}}$ $\qquad$ $\underbrace{e_{RY},\ e_{YB},\ e_{BR}}_{\text{Line Voltages}}$

$\underbrace{i_1,\ i_2,\ i_3}_{\text{Phase Currents}}$ $\qquad$ $\underbrace{i_R,\ i_Y,\ i_B}_{\text{Line Currents}}$



Relation b/w line & phase currents

→ $e_{RR'} = e_{RY}$; $e_{YY'} = e_{YB}$; $e_{BB'} = e_{BR}$

→ Applying KCL at R,

$$i_1 = i_R + i_3$$

$$i_R = i_1 - i_3$$

$$= \frac{I_m}{\sqrt{2}}\angle 0 - \frac{I_m}{\sqrt{2}}\angle -240$$

$$= I_{ph}\angle 0 - I_{ph}\angle -240$$

$$= I_{ph}\left(\frac{3}{2} - \frac{\sqrt{3}}{2}i\right)$$

$$= \sqrt{3}\, I_{ph}\angle -30$$

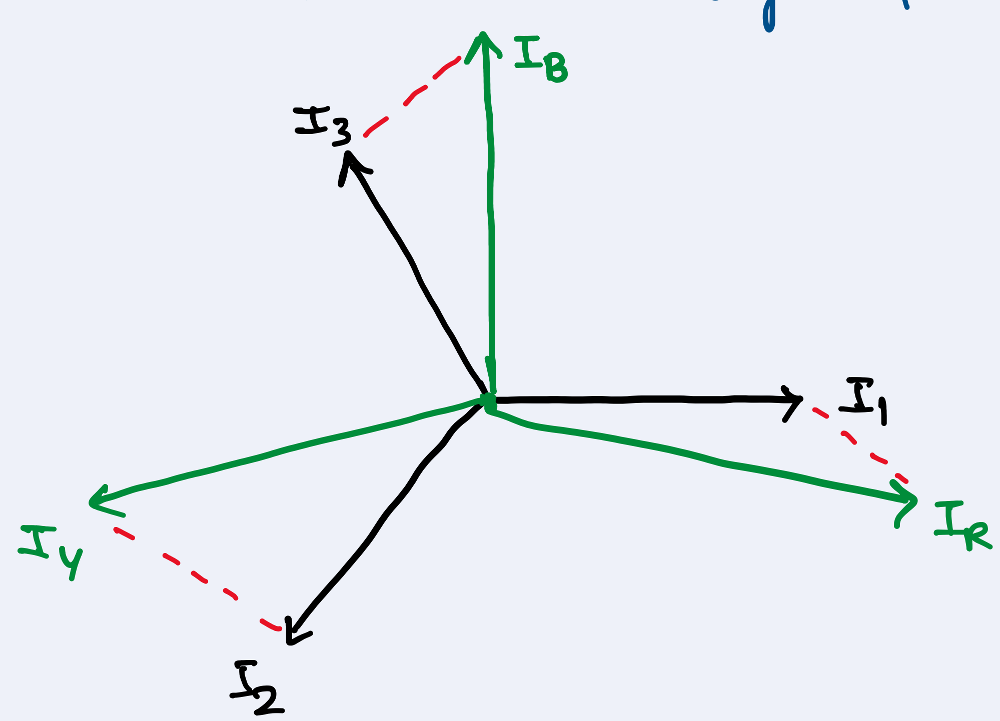
Similarly,

$$I_B = i_3 - i_2 = \sqrt{3}\, I_{ph}\angle 90$$

$$I_Y = i_2 - i_1 = \sqrt{3}\, I_{ph}\angle -150$$

→ Magnitude of RMS Current $= \sqrt{3}$ (Magnitude of Phase Current)

→ Line current lags phase current by $30°$



4. Summary of star & delta

- Star ⇒ $V_L = \sqrt{3}\, V_{ph}$; $I_L = I_{ph}$
- Delta ⇒ $V_L = V_{ph}$; $I_L = \sqrt{3}\, I_{ph}$
- Total active power = 3 x Active power for each phase

$P = 3 V_{ph} I_{ph} \cos\phi$

Star ⇒ $P = 3 V_{ph} I_{ph} \cos\phi$
$= \sqrt{3} V_{ph} \cdot \sqrt{3} I_{ph} \cos\phi$
$= \sqrt{3} V_L I_L \cos\phi$ $(V_L = \sqrt{3} V_{ph} ; I_L = I_{ph})$

Delta ⇒ $P = \sqrt{3} V_{ph} \sqrt{3} I_{ph} \cos\phi$
$= \sqrt{3} V_L I_L \cos\phi$ $(V_L = V_{ph} ; I_L = \sqrt{3} I_{ph})$

$Q = \sqrt{3} V_L I_L \sin\phi$
$S = \sqrt{3} V_L I_L$

$Z = \frac{V_{ph}}{I_{ph}}$

$P = 3 I_{ph}^2 R$
$Q = 3 I_{ph}^2 (X_L - X_C)$
$S = 3 I_{ph}^2 |Z|$

Q. A Balanced 3 Phase load circuit consists of 3 coils each of 4Ω resistance & 0.02H inductance. Determine total active power & reactive power when coils are connected in a star, if supply voltage = 400 V & f = 50Hz

A. $L = 0.02H$
$X_L = 6.28\,\Omega$
$Z = R + jX_L\ \Omega = 4 + 6.28i\ \Omega$
$V_L = 400\text{ V}$
$V_{ph} = \frac{V_L}{\sqrt{3}} = 230.94\text{ V}$

$I_{ph} = \frac{230.94\angle 0}{4+6.28i} = 31.02\angle -57.5^\circ$

$\phi = \angle V - \angle I = 0 - \angle -57.5 = 57.5^\circ$ lag
$P = 3 V_{ph} I_{ph} \cos\phi$
$= 11.547\text{ KW}$
$Q = 3 V_{ph} I_{ph} \sin\phi$
$= 18.125\text{ KVAR}$

Q. A balanced delta connected 3 phase inductive load draws real & apparent powers of 16KW & 20KVA from a balanced 3 phase 400V, 50Hz supply. Find V_L, Z, P.F, X_L

A. $V_{ph} = V_L = 400\text{ V}$
$P = 16000\text{ W}$
$S = 20000\text{ VA}$ $\cos\phi = 0.8$
$P = S\cos\phi$
⇒ $\cos\phi = 36.87^\circ$
$Z = \frac{V_{ph}}{I_{ph}}$
$P = \sqrt{3} V_L I_L \cos\phi$
$\frac{16000}{\sqrt{3} \times 400 \times \frac{16}{20}} = I_L = 28.86A \angle -36.86$ ⇒ $I_{ph} = 16.67$
$Z = \frac{400}{16.67\angle -36.86} = 19.2 + 14.4j$
$X_L = 14.4j$
$= 0.045\text{ H}$

Q. A balanced 3 phase star connected load of 100KW takes a leading current of 80A when connected to 3 phase 1.1KV, 50Hz supply. Find Q, Z & C of load per phase. Also Calculate P.F

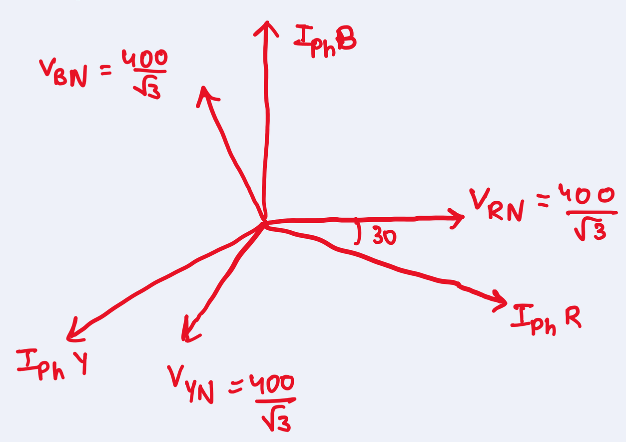
A. $V_L = 1.1KV$ $f = 50Hz$ $I_L = 80A$
$P_{3P} = 100KW$
$= \sqrt{3} V_L I_L \cos\phi$
$100000 = \sqrt{3} \times 1100 \times 80 \times \cos\phi$
$\cos\phi = 0.65$
$\phi = 49.45^\circ$
$Q_{3P} = \sqrt{3} V_L I_L \sin\phi$
$= 115815\text{ VAR}$
$V_{ph} = \frac{1100}{\sqrt{3}} = 635.08\text{ V}$
$I_{ph} = 80\angle 49.45$
$Z = 5.16 - 6.03j$
$X_C = 6.03$
$\frac{1}{2\pi f C} = 6.03$ ⇒ $C = 5.27 \times 10^{-4}\text{ F}$
$= 527\ \mu F$

Q. A balanced 3 phase star connected load is supported from a symmetrical 3 phase 400 V system. The current in phase is 30A & lags by 30° behind voltage. Find Z, P & Phasor diagram

A. $I_L = 30A \angle -30$
$V_L = 400V$
$V_{ph} = \frac{400}{\sqrt{3}} = 230.94V$

$Z = 6.67 + 3.84i$

$P = \sqrt{3} V_L I_L \cos\phi$
$= \frac{3}{2} \times 400 \times 30 = 18\text{ KW}$



Q. 3 similar elements are connected in delta across 2000V, 50Hz 3 phase supply. Power absorbed is 300 KW. Current taken is 100A leading. Find values of circuit parameters

A. $V_L = V_{ph} = 2000V$
$P = 300KW$
$I_L = 100A$ ⇒ $I_{ph} = 57.73$
$\cos\phi = \frac{300 \times 10^3}{200 \times 10^3 \times \sqrt{3}}$ ⇒ $\phi = 30^\circ$ ⇒ $\cos\phi = 0.86$ lead
$Z = \frac{2000}{57.73} = 30 - 17.3j$
$X_C = 17.32$
$C = \frac{1}{2\pi f \times 17.32}$ ⇒ $183.78\ \mu F$

Q. A balanced delta connected load consumes 2KW of power when connected to 3 phase, 400V & 50Hz supply, the same load when connected to a 3 phase 230V, 50Hz supply draws a current of 2A at lagging power factor. Determine load power factor & R, L per phase

A. Case i) $P = 2000\text{ W}$
$V_L = 400V = V_{ph}$

$I_{ph} = \frac{V_{ph}}{|Z|} = \frac{400}{200} = 2A$

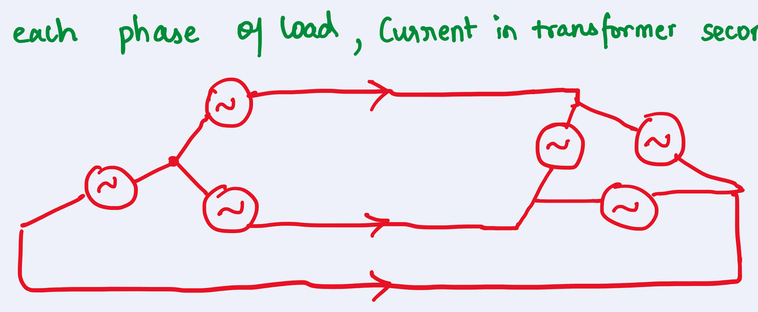
$I_L = 3.46A$
$\cos\phi = \frac{2000}{\sqrt{3} \times 400 \times 2}$
$\cos\phi = 0.83$
$\phi = 33.55$ lag
$\frac{V_{ph}}{I_{ph}} = \frac{400}{2\angle -33.55} = 166.68 + 110.53j$

$L = \frac{110.53}{100\pi} = 0.352\text{ H} = 352.2\text{ mH}$

Case ii) $V_L = V_{ph} = 230V$
$I_L = 2A$
$I_{ph} = 2/\sqrt{3} = 1.154\text{ A}$
$|Z| = \frac{V_{ph}}{I_{ph}} = \frac{230}{1.154} = 200\,\Omega$

Q. A 3 phase delta connected load, each phase has an impedance of $(28+40j)\,\Omega$. The load is fed from the secondary 3 phase star connected transformer which has phase voltage of 240V. Draw the circuit diagram & calculate current & voltage in each phase of load, Current in transformer secondary winding & Power

A.



Star: $V_{ph} = 240V$
$V_L = \sqrt{3} V_{ph} = 415.69$
$V_{LR} = 415.69\angle 30$
$V_{LY} = 415.69\angle -90$
$V_{LB} = 415.69\angle -210$

Delta: $I_{ph_R} = \frac{V_{ph_R}}{Z} = \frac{415.69\angle 30}{28+40i} = 8.81\angle -28\text{ A}$

$I_{ph_Y} = \frac{V_{ph_Y}}{Z} = \frac{415.69\angle -90}{28+40i} = 8.81\angle -148\text{ A}$

$I_{ph_B} = \frac{V_{ph_Y}}{Z} = \frac{415.69\angle 210}{28+40i} = 8.81\angle -268\text{ A}$

$I_{LR} = 8.81\sqrt{3}\angle -28-30 = 15.25\angle -58$
$I_{LY} = 8.81\sqrt{3}\angle -148-30 = 15.25\angle -178$
$I_{LB} = 8.81\sqrt{3}\angle -268-30 = 15.25\angle -298$

$P = 3(I_{ph})^2 R$
$= 3(8.81)^2 \times 25$
$= 5821.2\text{ W}$
$= 5.82\text{ KW}$

Q. A 3 Phase motor operating on a 400V supply is developing an output power of 25 HP at an efficiency of 87% power & PF = 0.82. Calculate a) V_L b) I_{ph} if delta connection

A. $\eta = \frac{P_o}{P_I}$ $25\text{ HP} = 25 \times 0.746\text{ KW}$
$= 18650\text{ W}$
$P_I = \frac{18650}{0.87} = 21436.78\text{ W}$

$P = \sqrt{3} V_L I_L \cos\phi$
$I_L = \frac{21436.78}{\sqrt{3} \times 400 \times 0.82} = 37.73\text{ A}$

$I_{ph} = \frac{I_L}{\sqrt{3}} = 21.78\text{ A}$

Q. The load connected to a 3 Phase supply comprises of 2 similar coils connected in star. The line current is 25A, the real & apparent powers are 11KW & 20KVA. Find the line voltage, resistance of reactance of each coil. If the coils are connected in delta, find the line current & P.F

A. $S = \sqrt{3} V_L I_L$ ⇒ $V_L = \frac{20 \times 10^3}{\sqrt{3} \times 25} = \frac{800}{\sqrt{3}} = 461.88\text{ V}$

$V_{ph} = \frac{V_L}{\sqrt{3}} = \frac{800}{3} = 266.67V$
$P = \sqrt{3} V_L I_L \cos\phi$
$\cos\phi = \frac{11 \times 10^3}{20 \times 10^3} = 0.55$

$\phi = 56.63^\circ$
$Z = \frac{V_{ph}}{I_{ph}} = \frac{266.67}{25\angle -56.63} = 5.867 + 8.9i\ \Omega$
$X_L = 8.9$
In delta: $Z = \frac{V_{ph}}{I_{ph}} = \frac{V_L}{I_L/\sqrt{3}} = 5.867 + 8.9$

$I_L = \frac{\sqrt{3} V_L}{5.86 + 8.9i} = \frac{\sqrt{3} \times 461.88}{5.86 + 8.9i} = 75.07\angle -56.63\text{ A}$

$P = \sqrt{3} V_L I_L \cos\phi = \sqrt{3}(461.88)(75.07)(0.55) = 33.03KW$
$Q = \sqrt{3} V_L I_L \sin\phi = \sqrt{3}(461.88)(75.07)(0.835) = 50.154\text{ KVAR}$
$S = \sqrt{3} V_L I_L = 60\text{ KVA}$

Q. A Balanced delta connected to 3 phase inductive load draws real & apparent powers of 6KW & 10KVA from a balanced 3 phase 400V, 50Hz supply. Determine V_L, Z, PF, R & L

A. $P = 6KW$
$S = 10KVA$
$\cos\phi = 0.6$
$\phi = 53^\circ$
$V_L = 400V$ ⇒ $V_{ph} = \frac{400}{\sqrt{3}}$
$P = \sqrt{3} V_L I_L \cos\phi$
I_L ⇒ $14.43\angle -53^\circ$

$Z = \frac{V_{ph}}{I_{ph}} = 9.63 + 12.78j\ \Omega$

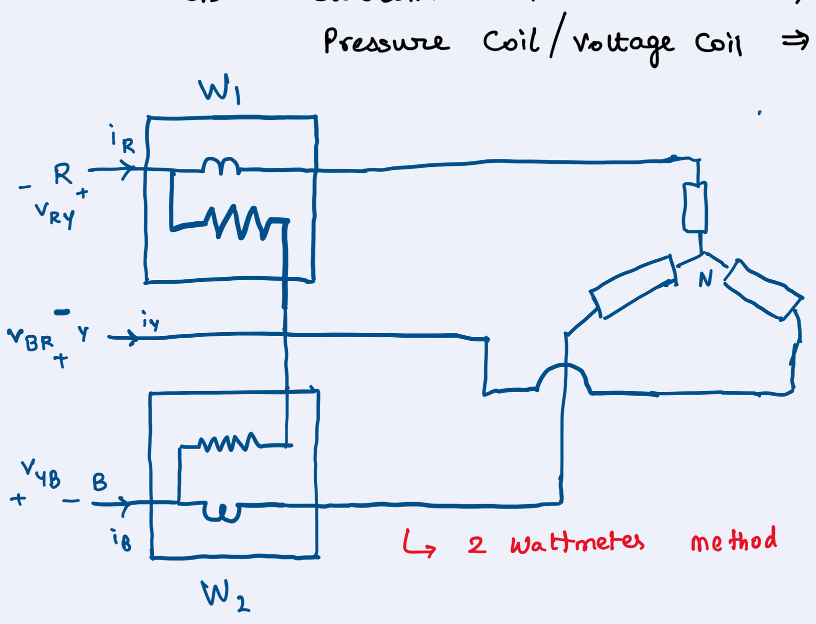
$X_L = 2\pi f L$
$L = 0.04H$

5. Wattmeter

→ Power measuring instrument

→ Consists : Current Coil ⇒ Fixed coil (CC)

Pressure Coil / Voltage Coil ⇒ Moving coil (PC)



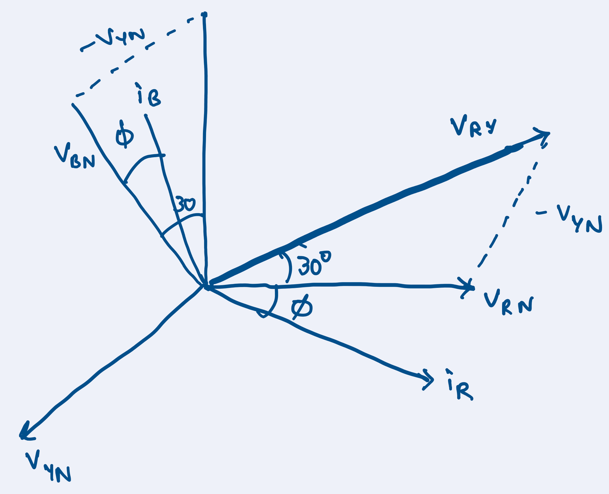
↳ 2 wattmeters method circuit diagram

For Star Load

$W_1 = V_{RY} \cdot I_R \cos \angle V_{RY} I_R = V_L I_L \cos(30+\phi)$

$W_2 = V_{BY} I_B \cos \angle V_{BY} \cdot I_B = V_L I_L \cos(30-\phi)$

$\overline{V}_{RY} = \overline{V}_{RN} - \overline{V}_{YN}$



$W_1 + W_2 = V_{RY} I_R + V_{YB} I_B$

$= V_L I_L \left(\cos(30+\phi) + \cos(30-\phi)\right)$

$= V_L I_L (\cos 30 \cos\phi - \sin 30 \sin\phi + \cos 30 \cos\phi + \sin 30 \sin\phi)$

$= V_L I_L \left(2 \times \frac{\sqrt{3}}{2} \times \cos\phi\right) = \sqrt{3} V_L I_L \cos\phi = P_{3\phi}$

$W_2 - W_1 = V_L I_L \sin\phi \Rightarrow \sqrt{3}(W_2 - W_1) = \sqrt{3} V_L I_L \sin\phi = Q_{3\phi}$

$\frac{Q_{3\phi}}{P_{3\phi}} = \tan\phi = \frac{\sqrt{3}(W_2-W_1)}{(W_2+W_1)} \Rightarrow \phi = \tan^{-1}\left(\frac{\sqrt{3}(W_2-W_1)}{W_1+W_2}\right)$

ϕ	PF	W_1	W_2	Comments
0	1	$\frac{\sqrt{3} V_L I_L}{2}$	$\frac{\sqrt{3} V_L I_L}{2}$	$W_1 = W_2$
30	0.86	$\frac{V_L I_L}{2}$	$V_L I_L$	$W_1 = \frac{W_2}{2}$
60	0.5	0	$\frac{\sqrt{3} V_L I_L}{2}$	$W_1 = 0$, $W_2 = P_{3\phi}$
> 60°	< 0.5	−ve	+ve	$W_1 = -ve$, $W_2 = +ve$

For Delta Load

$W_1 = V_L I_L \cos(30-\phi)$

$W_2 = V_L I_L \cos(30+\phi)$

$W_1 + W_2 = V_L I_L \left(\cos(30-\phi) + \cos(30+\phi)\right)$

$= \sqrt{3} V_L I_L \cos\phi = P_{3\phi}$

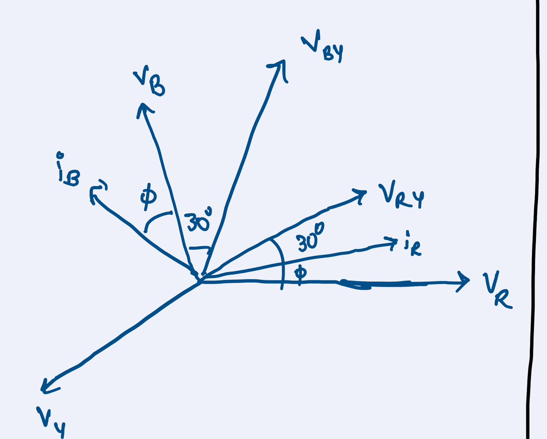
$W_1 - W_2 = V_L I_L \left(\cos(30-\phi) - \cos(30+\phi)\right)$

$= V_L I_L \sin\phi$

$\sqrt{3} W_1 - W_2 = \sqrt{3} V_L I_L \sin\phi = Q_{3\phi}$

$\frac{Q_{3\phi}}{P_{3\phi}} = \tan\phi = \frac{\sqrt{3}(W_1-W_2)}{W_1+W_2}$

$\phi = \tan^{-1}\left(\frac{\sqrt{3}(W_1-W_2)}{W_1+W_2}\right)$



ϕ	PF	W_1	W_2	Comments
0	1	$\frac{\sqrt{3} V_L I_L}{2}$	$\frac{\sqrt{3} V_L I_L}{2}$	$W_1 = W_2$
30	0.86	$V_L I_L$	$\frac{V_L I_L}{2}$	$W_1 = 2W_2$
60	0.5	$\frac{\sqrt{3} V_L I_L}{2}$	0	$W_2 = 0$, $W_1 = P_{3\phi}$
> 60°	< 0.5	+ve	−ve	$W_1 = +ve$, $W_2 = -ve$

Q1. In a 2 Wattmeter method of measuring 3 phase power, it is observed that wattmeter readings are in ratio 3:1. Determine power factor of load

A. $\frac{W_1}{W_2} = \frac{3}{1} \Rightarrow W_1 = 3W_2$

$\cos\phi = \cos\left[\tan^{-1}\left[\frac{\sqrt{3}(W_1-W_2)}{W_1+W_2}\right]\right]$

$= \cos\left[\tan^{-1}\left[\frac{\sqrt{3}(-2\cancel{W_2})}{4\cancel{W_2}}\right]\right]$

$= 0.7559$ lag

Q2. 2 Wattmeters are connected to measure an input to a balanced 3 ϕ circuit indicate 2000W & 500W respectively. Find power factor when:

i) Both readings are +ve

ii) Latter reading is obtained after reversing its CC.

A. i) $W_1 = 2000W$

$W_2 = 500W$

$\cos\phi = \cos\left[\tan^{-1}\left[\frac{\sqrt{3}(W_2-W_1)}{W_1+W_2}\right]\right]$

$= 0.693$ lag

ii) $W_1 = 2000W$

$W_2 = -500W$

$\cos\phi = \cos\left[\tan^{-1}\left[\frac{\sqrt{3}(W_2-W_1)}{W_1+W_2}\right]\right]$

$= 0.327$ lag

Q3. 3 Coils each having a resistance of 20Ω & reactance 15Ω are connected in star across a 3ϕ 400V, 50Hz supply. Calculate the readings of 2 wattmeters connected to measure the power input. If coils are connected in delta across same supply, calculate new wattmeter readings

A. $Z = 20 + 15i\ \Omega$

$V_L = 400V$

For star,

$V_{ph} = \frac{V_L}{\sqrt{3}} = \frac{400}{\sqrt{3}} = 230.94\ V$

$I_{ph} = \frac{V_{ph}}{Z} = 9.23\angle{-36.87}\ A$

$W_1 = V_L I_L \cos(30+\phi)$

$= 400 \times 9.23 \times (66.87)$

$= 1.45 KW$

$W_2 = V_L I_L \cos(30-\phi)$

$= 400 \times 9.23 \times (-6.87)$

$= 3.665 KW$

For delta,

$V_{ph} = V_L = 400V$

$I_{ph} = \frac{V_{ph}}{Z} = 16\angle{-36.87}\ A$

$I_L = 27.71\ A$

$W_1 = V_L I_L \cos(30-\phi)$

$= 4.354\ KW$

$W_2 = V_L I_L \cos(30+\phi)$

$= 11.004\ KW$

Q4. 2 Wattmeters are connected to measure power in a 3ϕ circuit. The reading of one of the wattmeters is 5KW when the load P.F = 1. If the P.F of load is changed to 0.707 lag w/o changing total input power, calculate new readings of wattmeter

A. $W_1 = 5000W$

case I : $\cos\phi = 1$

$\cos\phi = \cos\left(\tan^{-1}\left(\frac{\sqrt{3}(W_2-W_1)}{W_1+W_2}\right)\right)$

$\frac{\sqrt{3}(W_2-W_1)}{W_1+W_2} = 0 \Rightarrow W_2 = W_1 = 5000W$

$P = W_1 + W_2 = 10000W$

case II : $\cos\left(\tan^{-1}\left(\frac{\sqrt{3}(W_2-W_1)}{W_1+W_2}\right)\right) = 0.707$

$\sqrt{3}(W_2-W_1) = 10000(1)$

$W_2 - W_1 = 5773.5$

$W_2 + W_1 = 10000$

$W_2 = 7.886\ KW$

$W_1 = 2.114\ KW$

Q5. A 3ϕ balanced load connected across a 3ϕ 400V AC supply draws a line current of 10A. 2 Wattmeters are used to measure input power. The ratio of 2 wattmeter readings is 2:1. Find the readings of 2 wattmeters

A. $\frac{W_1}{W_2} = \frac{2}{1}$; $\phi = 30°$; $W_1 = V_L I_L$; $W_2 = \frac{V_L I_L}{2}$

$V_L = 400V = V_{ph}$

$I_L = 10A$

$W_1 = 4000 = 4KW$

$W_2 = \frac{400 \times 10}{2} = 2000\ W = 2KW$

$\cos\phi = \cos\left[\tan^{-1}\left[\frac{\sqrt{3}(W_2-W_1)}{W_1+W_2}\right]\right] = 0.866$

$W_1 = V_L I_L \cos(30+\phi)$

$= 400 \times 10 \times \cos 60$

$= 2KW$

$W_2 = V_L I_L \cos(30-\phi)$

$= 400 \times 10 \times 1$

$= 4KW$

Q6. Calculate readings of 2 Wattmeters connected to measure total power for a balanced delta connected load, fed from 3ϕ, 200V balanced supply with phase sequence as RYB. Also find line of phase currents, power factor, total power total reactive VAR & total VA

A. $V_L = 200V = V_{ph}$; $I_{ph} = \frac{V_{ph}}{Z} = \frac{200}{14-14i} = 10.1\angle 45$

$I_L = 10.1\sqrt{3} = 17.49\ A$

$\phi = -45° \Rightarrow PF = 0.707$ lead

$P_{3\phi} = \sqrt{3} V_L I_L \cos\phi$

$= \sqrt{3} \times 200 \times 17.49 \times 0.707$

$= 4.284\ KW$

$Q_{3\phi} = \sqrt{3} V_L I_L \sin\phi = -4.284\ KVAR$

$S = \sqrt{P^2 + Q^2} = 6.06\ KVA$

Q7. One of the wattmeters read 10KW when load power factor is 0.5. When load PF changes to 0.8, total power remains unchanged. Find new readings of wattmeters

A. $\cos\phi_1 = 0.5 \Rightarrow \phi_1 = 60°$

$\cos\phi_2 = 0.8$

$W_1 = 10KW$

for ϕ_1, $W_1 = 0$, $W_2 = 10KW = P_{3\phi}$

$\cos\phi_2 = 0.8 \Rightarrow \phi_2 = 36.87$

$P_{3\phi} = W_1 + W_2$

$\cos\phi = \cos\left(\tan^{-1}\left(\frac{\sqrt{3}(W_2-W_1)}{W_1+W_2}\right)\right) = 0.8$

$= \frac{\sqrt{3}(W_2-W_1)}{10000} = 0.75$

$W_2 - W_1 = 4330.12$

$W_1 + W_2 = 10000$

$W_1 = 2.834\ KW$

$W_2 = 7.165\ KW$

Q8. A 400V, 3ϕ motor has a full load output of 20 hp, the efficiency being 88%. & power factor being 0.8 lagging. Find reading on each of 2 wattmeter connected to measure input

A. $V_L = 400V$

$P_{out} = 20hp = 20 \times 0.746KW = 14.914\ KW$

$\eta = 88\% = 0.88$

$\eta = \frac{P_{out}}{P_{in}} \Rightarrow P_{in} = \frac{14.914}{0.88} = 16.947\ KW$

$\cos\phi = 0.8$ lag $\Rightarrow \phi = 37°$

$P = W_1 + W_2 = 16.947$

$0.75 \overset{!}{=} \frac{\sqrt{3}(W_2-W_1)}{W_1+W_2}$

$\Rightarrow W_2 - W_1 = 7.34$, $W_2 + W_1 = 16.947$ → $W_1 = 4.8\ KW$, $W_2 = 12.143\ KW$

Q9. 3 Impedences $(6+8i)\ \Omega$ each are connected in delta across a balanced 3ϕ 400V, 50Hz supply, determine: i) line current ii) Readings of 2 wattmeters connected to measure input power

If this delta load is reconnected as star load & supply voltage is reduced to 200V, Determine new values of line current & wattmeter readings

A. Delta,

$V_L = V_{ph} = 400\ V$

$I_{ph} = \frac{V_L}{Z} = \frac{400}{6+8i} = 40\angle{-53}\ A$

$I_L = 69.28\angle{-53}\ A$

$\cos\phi = 0.6 = \cos\left(\tan^{-1}\left(\frac{\sqrt{3}(W_2-W_1)}{W_1+W_2}\right)\right)$

$1.327 = \frac{\sqrt{3}(W_2-W_1)}{W_1+W_2}$

$P = \sqrt{3} V_L I_L \cos\phi = 28.89\ KW$

$= W_1 + W_2$

$W_2 - W_1 = \frac{1.327 \times 28.89}{\sqrt{3}}$

$= 22.13 KW$

$W_2 = 25.51 KW$

$W_1 = 3.38 KW$

Star,

$V_L = 200V$

$V_{ph} = V_L/\sqrt{3} = 115.47V$

$I_{ph} = \frac{V_{ph}}{Z} = 11.54\angle{-53}$

$0.6 = \cos\left(\tan^{-1}\left(\frac{\sqrt{3}(W_2-W_1)}{W_1+W_2}\right)\right)$

$1.327 = \frac{\sqrt{3}(W_2-W_1)}{P}$

$P = \sqrt{3} V_L I_L \cos\phi$

$= \sqrt{3} \times 200 \times 11.54 \times \cos 53$

$= 2.398\ KW$

$W_2 - W_1 = 1.837 KW$

$W_1 = 0.28\ KW$

$W_2 = 2.118\ KW$

Q10. 2 Wattmeters connected to measure 3ϕ power for a balanced star connected 3ϕ load measures 10KW & 5KW respectively. If the line current is 20A & a lagging power factor. Determine V_L, V_{ph}, R & L

A. $W_1 = 10KW$ $W_2 = 5KW$ $I_L = I_{ph} = 20A$

$\cos\phi = \cos\left(\tan^{-1}\left(\frac{\sqrt{3}(W_2-W_1)}{W_1+W_2}\right)\right) \Rightarrow \cos\left(\tan^{-1}\left(\frac{\sqrt{3}(-5)}{15}\right)\right) = 0.866$; $\phi = 30°$

$P = \sqrt{3} V_L I_L \cos\phi \Rightarrow 15 = \sqrt{3}\, V_L \times 20 \times 0.866 \Rightarrow V_L = 500V$

$V_{ph} = \frac{V_L}{\sqrt{3}} = 288.68V$

$Z = \frac{V_{ph}}{I_{ph}} = \frac{288.68}{20\angle{-30}} = 12.5 + 7.217i\ \Omega$

$R = 12.5\Omega$

$X_L = 7.217\Omega$

$2\pi f L = 7.217 \Rightarrow L = 22.9mH$

Q11. A balanced 3ϕ star connected load is supplied from a symmetrical 3ϕ 400V, 50Hz system. The current in each phase of load is 10A & lags by 60° behind phase voltage. Determine Z, R, L, P. Consider R-phase voltage as reference, draw phasor diagram representing all phase voltage & phase currents. Consider RYB phase seq

A. $V_L = 400V$, $V_{ph} = 230.94\ V$

$Z = \frac{V_{ph}}{I_{ph}} = \frac{230.94}{10\angle{-60}}$

$= 11.547 + 20i\ \Omega$

$L = \frac{20}{100\pi} = 0.0636\ H = 63.6mH$

$P = \sqrt{3} V_L I_L \cos\phi = \sqrt{3} \times 400 \times 10 \cos 60 = 3.464KW$

$Q = \sqrt{3} V_L I_L \sin\phi = \sqrt{3} \times 400 \times 10 \sin 60 = 6\ KVAR$

Q12. 2 Wattmeters are connected to measure the power input 15HP, 50Hz, 3ϕ induction meter at full load. The full load efficiency & P.F are 0.9 & 0.8 lag respectively. Find the 2 Wattmeters

A. $P_{out} = 15HP = 11.19\ KW$

$\eta = \frac{P_{out}}{P_{in}} \Rightarrow P_{in} = \frac{11.19}{0.9} = 12.43\ KW$

$P = W_1 + W_2$

$\cos\phi = 0.8$ lag $= \cos\left(\tan^{-1}\left(\frac{\sqrt{3}(W_2-W_1)}{W_1+W_2}\right)\right)$

$\frac{\sqrt{3}(W_2-W_1)}{12.43} = \frac{3}{4} \Rightarrow W_2 - W_1 = 5.38\ KW$

$W_1 = 3.525\ KW$

$W_2 = 8.905\ KW$

Q13. When 3 identical star-connected coils are supplied with 440V, 50Hz, 3ϕ supply. The 1ϕ wattmeter whose current coil is connected in line R & pressure coil across the phase R & neutral reads 6KW by the ammeter connected in R-phase reads 30A. Assuming RYB phase sequence, find R, X, PF, Q

A. $V_L = 440V$; $V_{ph} = 254.03V$

$W_2 = 6KW = V_L I_L \cos(30-\phi)$

$I_{ph} = I_L = 30A$;

$\cos(30-\phi) = 0.45$

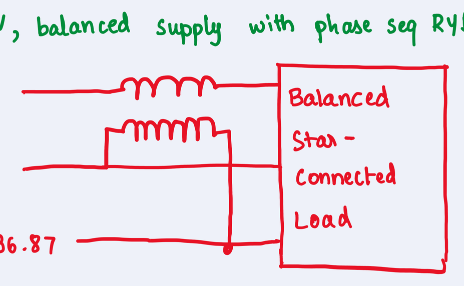
$\phi = -32.96$

$\cos\phi = 0.84$ lag

$Z = \frac{V_{ph}}{I_{ph}} = \frac{254.03}{30\angle{-32.96}} = 7.1 + 4.6j\ \Omega$

$Q = \sqrt{3} V_L I_L \sin\phi = -12.44\ KVAR$

Q14. Calculate the reading of the wattmeter(W) connected as shown in the figure. The load is balanced-star connected one, with impedance of $(20+15i)\ \Omega$ per phase fed from a 3ϕ, 400V, balanced supply with phase seq RYB



A. $Z = 20 + 15i\ \Omega$

$V_L = 400V$

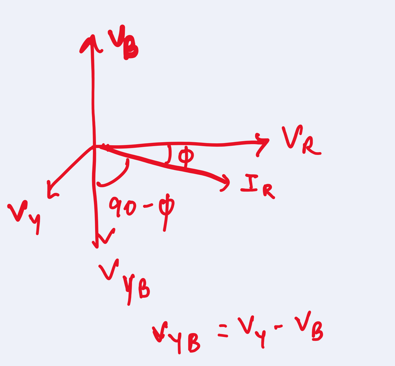
$V_{ph} = 230.94V$

$I_{ph} = \frac{V_{ph}}{Z} = \frac{230.94}{20+15i} = 9.23\angle{-36.87}$

$W = V_{YB} I_R \cos\angle V_{YB}, I_R$

$= 9.23 \times 400 \times \cos(90-\phi)$

$= 2.214\ KW$



$V_{YB} = V_Y - V_B$

Q15. Calculate the reading of the 2 wattmeters W_1 & W_2 connected to measure the power for a balanced 3 phase load. The supply voltage is 200V for a star-connected balanced load with $(9-5i)\ \Omega$ per phase. The connection of wattmeter W_1 - current coil is in R, line, voltage coil is across R & Y lines. The connection of wattmeter W_2 current coil is in B line & voltage coil is across B & Y lines

A. $V_L = 200V$

$V_{ph} = 115.47V$

$Z = 9 - 5i$

$I_{ph} = \frac{V_{ph}}{Z} = 11.21\angle 29.05 = I_L \Rightarrow \phi = -29.05$

$Q = V_L I_L \sin\phi = -29.05\ KW$

$W_1 = V_L I_L \cos(30-\phi) = 2.241\ KW$

$W_2 = V_L I_L \sin(30-\phi) = 1.153\ KW$

6. Advantages of 3 phase over 1 phase

Advantages

1) For certain amount of power to be transmitted over certain distance, 3 phase system requires less conductor material compared to single phase

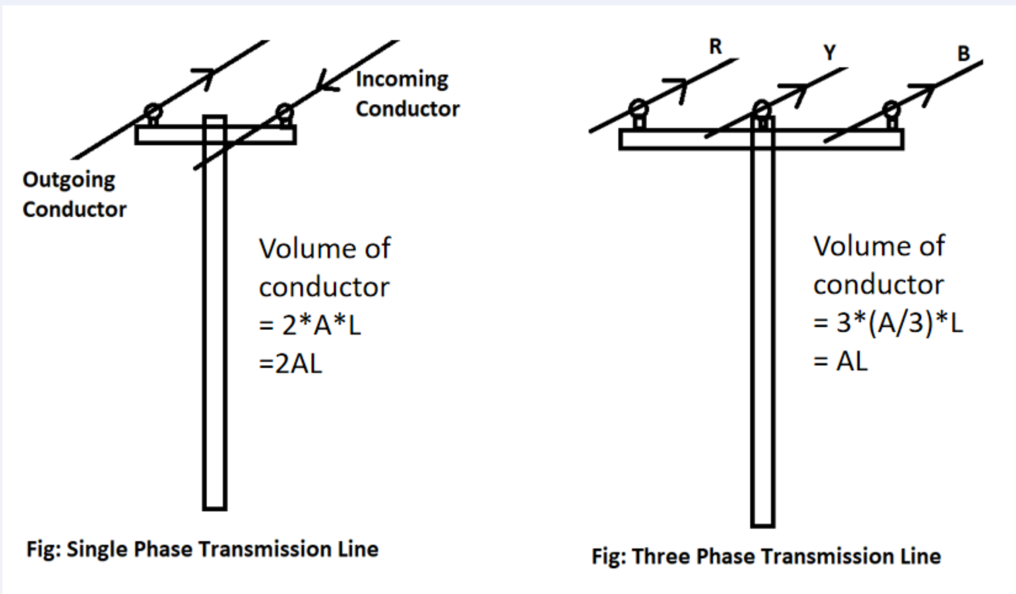


Fig: Single Phase Transmission Line

Fig: Three Phase Transmission Line

2) For same frame size, 3ϕ can handle higher amount of power compared to 1ϕ counterpart

$P_{1\phi} = V_L I_L \cos\phi \qquad P_{3\phi} = \sqrt{3}\, V_L I_L \cos\phi$

3) 1ϕ power is pulsating in nature

3ϕ power is almost constant at every instant ⇒ smoother, less noisy & better lifespan

4) 3ϕ induction motors are self starting

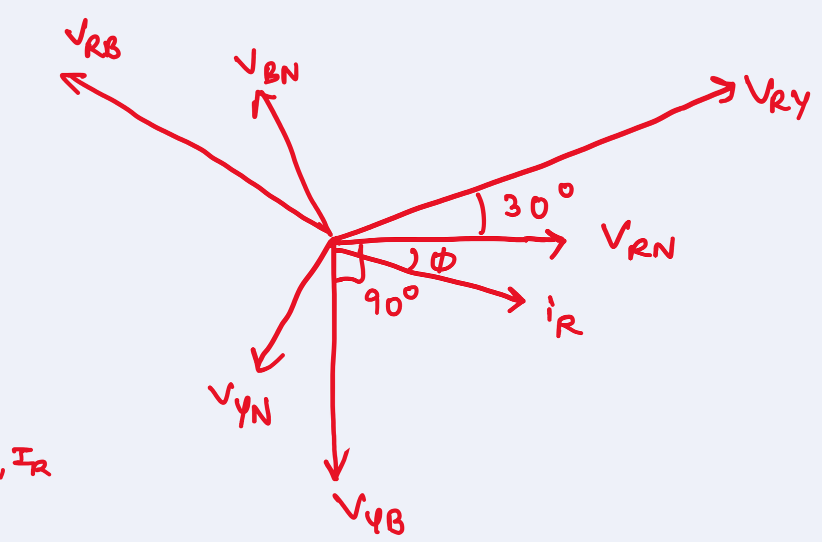
1ϕ induction motors aren't,

So, 3ϕ widely popular in industrial drives

Q. A 3ϕ, Y connected balanced load with lagging PF is supplied at 400 V (b/w the lines). A wattmeter when connected with its current coil in R-line & voltage coil b/w R & Y lines gives a reading of 6KW. When the same terminals of the voltage coil are switched over to Y & B lines, the current coil connections remains the same

A. $V_L = 400V = V_{YB} = V_{RY} = V_{BR}$

$V_{Ph} = \frac{V_L}{\sqrt{3}} = 230.94\ V = V_{YN} = V_{RN} = V_{BN}$



$W_2 = 6\ KW = V_{RY} I_R \cos\angle V_{RY}, I_R$

$W' = 6\ KW = V_{YB} I_R \cos\angle V_{BY}, I_R$

$W_2 = W' \Rightarrow V_{RY} I_R \cos\angle V_{RY}, I_R = V_{YB} I_R \cos\angle V_{BY}, I_R$

$\cos\angle V_{RY}, I_R = \cos\angle V_{BY}, I_R$

$\cos(30+\phi) = \cos(90-\phi)$

$30+\phi = 90-\phi$

$\phi = 30$

$PF = \cos 30 = 0.866$ lag

$W = V_{RY} I_R \cos(30+\phi) = 6000$

$\Rightarrow I_R = \frac{6000}{400 \times \cos 60} = 30A = I_L$

Q The following table gives average consumption hours in typical household

S. No	Name of Appliance	Wattage	Avg. Consumption hours (in a day)
1	AC	2000 W	1
2	TV	50 W	8
3	3 LED Bulbs	20W each	6 (each)
4	2 Ceiling Fans	75W each	8 (each)
5	Refrigerator	100 W	24
6	Water Pump	750W	30 mins

Considering a 30 day month determine :

i) Total no. of units consumed in a month

ii) Monthly bill for above consumption units considering a domestic connection of 5KW sanctioned load with tariff details listed below :

S.No.	Type of Charge	Tariff Details
1	Fixed charges for sanctioned load	Rs 85/- for first KW Rs 95/- for every additional KW
2	Energy consumption charges	0 – 50 units – Rs 4/- per unit 51 – 100 units – Rs 5.55/- per unit 101 – 200 units – Rs 7.1/- per unit 200+ units – Rs 8.15/- per unit
3	Fuel adjustment charges	@ 14 paisa per unit of energy consumed

Consider an overall tax of 9% on energy consumption charges

A. i) Appliance   Units (in KW) → Wattage x Consumption x No. of appliances

Appliance	Units (in KW)
AC	2
TV	0.4
3 Bulbs	0.36
2 Fans	1.2
Fridge	2.4
Pump	0.375
	6.735 units/day

⇒ 6.735 x 30 = 202.05 units/month

ii) Fixed charges ⇒ For first KW ⇒ 85 x 1

For rest KWs ⇒ 95 x (5 − 1) = 95 x 4

85 x 1 + 95 x 4 = 85 + 380 = 465 Rs

Energy Consumption ⇒ 0-50 → 50 x 4.1 = 205

51-100 → 50 x 5.55 = 277.5

101-200 → 100 x 7.1 = 710

200+ → 2.05 x 8.15 = 16.7

1209.2 Rs

Fuel Adjustment ⇒ 0.14 x 202.05 = 28.287 Rs

9% Tax on E.C = 1209.2 x 109% = 1318.02 Rs

Total = 465 + 1318.02 + 28.287 = 1811.307 Rs

Q

S.No.	Appliance	Wattage	Consumption/Day
1	Geyser	2000 W	1 hr
2	TV	50 W	6 hrs
3	4 LED	20 W each	6hrs each
4	3 Fans	75W each	8hrs each
5	Fridge	100W	24 hrs
6	Pump	1500W	20 mins

30 Days month

i) Total Units ii) Monthly Bill ; Sanctioned Load = 5KW

1	Fixed	100/- First KW 110/- Additional KW
2	Energy Consumption (Tax 9%)	0 – 50 – ₹4.15/unit 51 – 100 – ₹5.6/unit 101 – 200 – ₹7.15/unit 200 + – ₹8.2/unit
3	Fuel Handling	Nil

A.

Appliance	Units (in KW)
AC	2
TV	0.3
3 Bulbs	0.48
2 Fans	1.8
Fridge	2.4
Pump	0.5
	7.48 Units perday

Per month (x30) = 224.4 Units/Month

I. Fixed : 100 x 1

+ 110 x 4

540Rs Fixed Charges

II Energy Consumption : 0 - 50 ⇒ 50 x 4.15 = 207.5

51 - 100 ⇒ 50 x 5.6 = 280

101 - 200 ⇒ 100 x 7.15 = 715

200 + ⇒ 24.4 x 8.2 = 200.08

1402.58

With Tax ⇒ 1402.58 x 1.09 = 1528.8122 Rs

III Fuel ⇒ 0

Total = I + II + III = 540 + 1528.8122 + 0 = 2068.8122 Rs

UNIT 3

ELECTRICAL INSTALLATIONS

What is a Fuse?

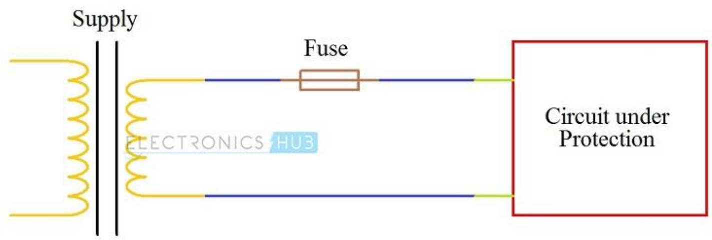
A Fuse or an Electric Fuse is an Electrical / Electronic device that protects the circuit from different electrical faults like over current and overload. Fuses can be considered as a sacrificial element in the circuit as they act as a weak link in the entire circuit. This is because, a fuse scarifies itself and reliably opens the circuit when there is an excessive current in the circuit or the circuit is under over load and if there is any short circuit.

The principle of a fuse is based on the heating effect of the electric current. A simple fuse consists of a small conductive material with low resistance and it is placed in series with the circuit.

The cross-section area of this conducting material is designed such that it allows a certain amount of current that is permitted to flow in the circuit.

When the current in the circuit exceeds this permitted value (which may be caused due to overload, short circuit or load mismatch), this excessive current will melt the conductive element in the fuse and opens the circuit.

This will disconnect the power supply and thus, the rest of the circuit is protected from being damaged. The following image shows a block diagram of how a fuse is connected in the circuit.



Fuses are very simple and cheap devices that are being used for over hundred years as protective equipment. For electrical drawings and circuits, there are three symbols of fuses we can use. The following image shows the symbols of fuse along with their standards.

Characteristics of a Fuse

There are different types of Fuses available in the market for different types of applications like residential, industrial, automotive, etc. All the fuses are often characterized by the following characteristics.

- Current or Ampere Rating
- Melting Time
- Voltage Rating and
- Interrupting Rating or Breaking capacity
- I^2T Value of the Fuse
- Packaging
- Temperature

The first two i.e., Current Rating and Melting Time of the Fuse are generally associated with the Thermal Characteristics of the fuse whereas the Voltage and Interrupting Rating are classified under Interrupting Characteristics of the fuse.

As the amount of current in the circuit increases, the melting time of the conducting element in the fuse decreases. This is because, as the current increases, the power dissipation (determined by I2R) will increase and the temperature of the element increases rapidly.

If there are any inductive components in the circuits, then melting of the conductive element in the fuse is not enough for interrupting the current. Even though the element in the fuse melts, there is a chance of arc in the fuse before the current is completely disconnected.

During this period, the fuse must hold the transient voltages and hence, any fuse must be given a clearing time.

Till now, we have spoken only about the current ratings of the fuse but haven’t brought up the voltage rating. All the fuses are rated with a maximum voltage that they can be operated with.

Current Rating or Current Capacity of Fuse

Current Rating or the Current Capacity of a Fuse defines the maximum amount of current a fuse can hold without blowing or melting. This is usually mentioned in Amperes i.e., 2A, 4A, 600A etc.

Voltage Rating of Fuse

Along with Current Rating, a fuse will also be specified with the maximum voltage it can be supplied with. Based on the Voltage Rating, Fuses are again classified in to Low Voltage (LV) Fuses and High Voltage (HV) Fuses (and even miniature fuses).

I^2T (Ampere Squared Seconds)

I^2T value of a Fuse measures the heat energy in the fuse. This heat energy is due to current flow and also the arc produced when the fuse is blown.

Breaking Capacity of Fuse

Breaking Capacity of the Fuse is also known as the Interrupting Rating or Short Circuit Rating. Breaking Capacity will specify the maximum safe current that the fuse can interrupt at a voltage less than the maximum rated voltage.

Types of Fuses

There are many types of fuses available for a variety of applications. The main category of Fuses is based on the type of circuit they are used in i.e. AC Fuses and DC Fuses. Again, AC Fuses are divided in to High Voltage (HV) Fuses and Low Voltage (LV) Fuses.

High Voltage (HV) AC Fuses are used for voltages above 1000V and Low Voltage (LV) AC Fuses are used for voltages less than 1000V. Low Voltage (LV) Fuses are again classified in to Cartridge Fuses (Totally Enclosed Type), Rewirable Fuses (Semi – Enclosed Type), Switch Fuses, Drop out Fuses and Striker Fuses.

High Voltage (HV) Fuses are further divided in to Cartridge Type HRC (High Rupturing Capacity) Fuses, Liquid Type HRC Fuses and Expulsion type Fuses.

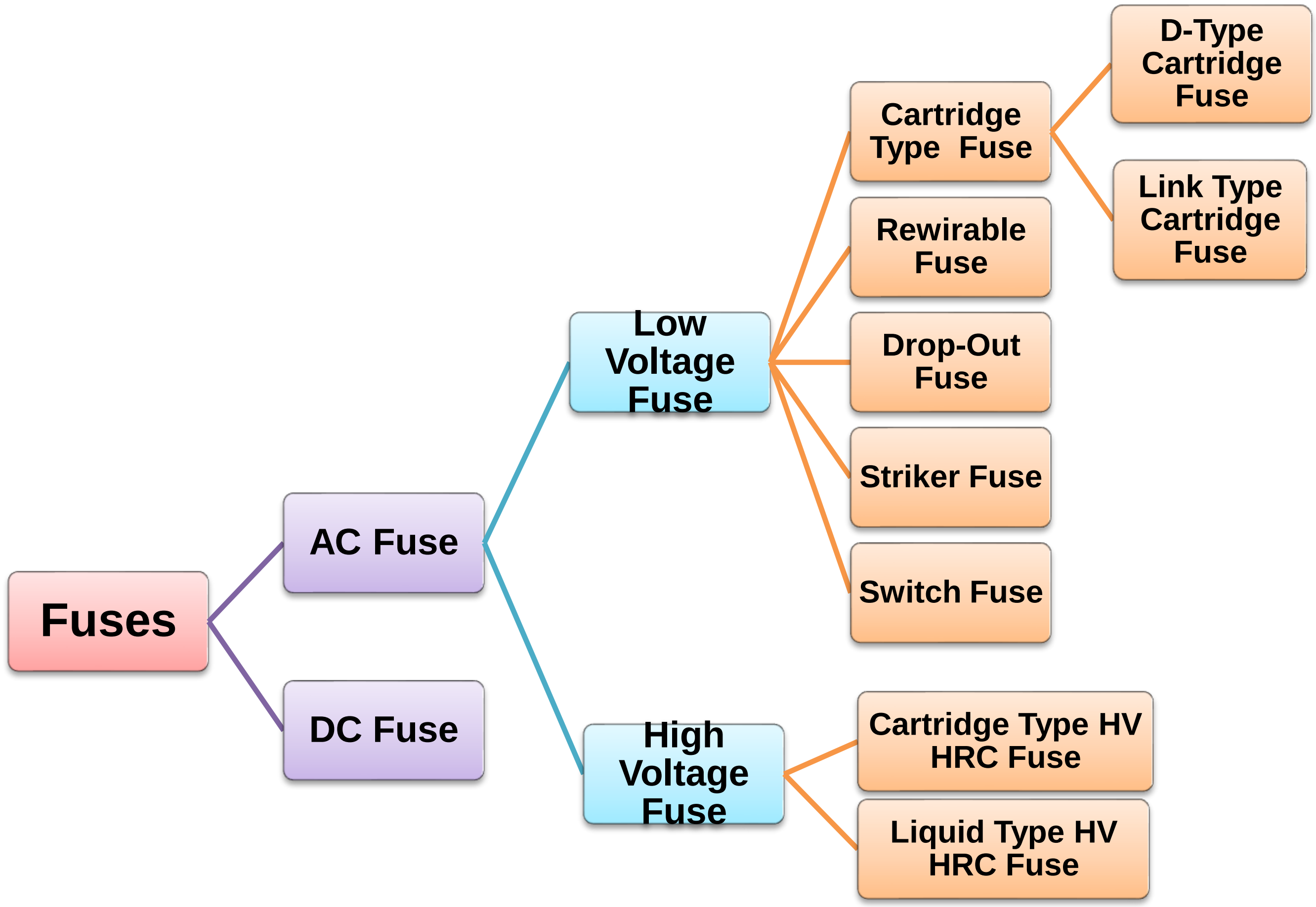
DC Fuses

The main difference between the DC Fuses and AC Fuses is the size of the fuse. In a DC circuit, when the current exceeds the limit, the metallic wire in the fuse melts and disconnects the rest of the circuit from power supply.

Since DC is constant value and is always above 0V, there is a chance of an electric arc between the melted wires, which will be difficult to avoid and turn off. Hence, usually, the electrodes of the DC Fuses are placed at larger distance when compared to the AC Fuses.

This will minimize the chance of arc and since the distance between the electrodes is increased, the size of the DC Fuses is comparatively large.

The following image shows the chart of fuses divided based on the AC and DC currents.



AC Fuses

We know that AC current (and voltage) oscillates as 50 or 60 times per second and in this the amplitude of the signal varies from minimum to maximum. At one point of this oscillation, the AC Voltage touches the 0V and hence the arc between the melted electrodes can be easily terminated.

As a result, the size of the AC Fuses can be much smaller when compared to the size of DC Fuses.

Cartridge Type Fuses or Totally Enclosed Type Fuses

As the name indicates, Cartridge or Totally Enclosed Fuses have a completely closed structure with the Fuse Links enclosed in the container. This type of design and construction will help in keeping the arc within the container at the event of blown fuse.

Cartridge Type Fuses are a very important category of fuses that are used in almost all types of applications like Low Voltage (LV), High Voltage (HV) and miniature fuses.

Cartridge Type Fuses are again further divided in to D Type Cartridge Fuses and Link Type Cartridge Fuses.

Fig: Cartridge Type Fuses

Rewireable Fuses

Rewireable or Kit – Kat Type Fuses are a type of Low Voltage (LV) Fuses. They are most commonly used in house wiring, small industries and other small current applications.

Rewireable Fuses consists of two main parts: A Fuse Base, which contains the in and out terminal, and a Fuse Carrier, which holds the Fuse Element. The Fuse Base is generally made up of Porcelain and the Fuse Element is made up of Tinned Copper, Aluminum, Lead, etc.

The Fuse Carrier can be easily plugged in or removed from the Fuse Base without the risk of any electric shock. When the fuse is blown due to over current, we can easily remove the Fuse Carrier and replace the fuse wire. This is the main advantage of rewireable Fuses.

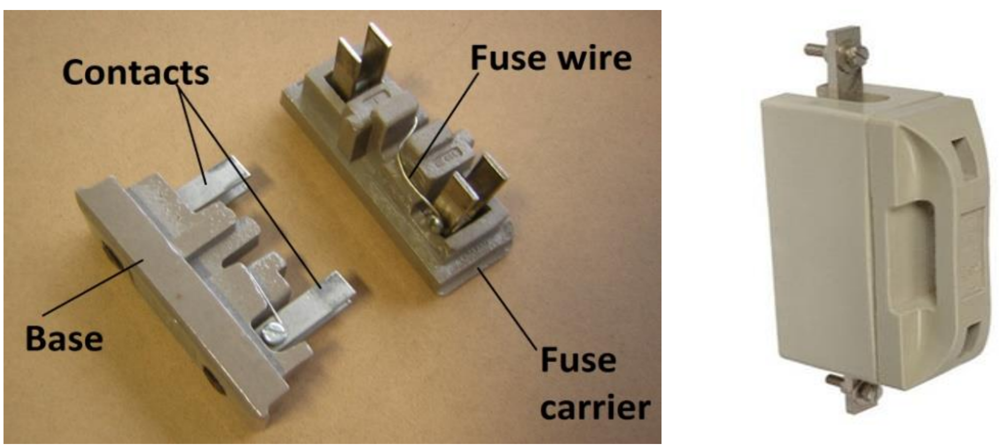


Fig: Kit – Kat Type Fuse

Drop Out Fuse

High-voltage drop-out fuse mounting plate is fixed in the middle of the support insulator. Support the insulator has the upper and lower terminals for the connection wire. Upper and lower terminals attached to the upper and lower static contact. The fuse tube is made of phenolic paper tube or laminated glass cloth tube, lined with arc-extinguishing tube; both ends are equipped with upper and lower moving contact, after the fuse penetrates the fuse tube, using the tension of the fuse, Move the contact taut so that the fuse remains closed.

When operating. Insert the lower moving contact of the fuse tube into the lower terminal with the high voltage insulated rod and make it come into contact with the lower stationary contact, then insert the pull hook of the high voltage insulated rod into the operating ring of the fuse tube to drive the fuse tube the upper moving contact pushed into the terminal, contact with the static contact, the circuit connected.

Fig: Drop Out Type Fuse

After the fuse is blown the upper and lower movable contact of the fuse tube loses the tension and loosens, the movable contact slides downward under the action of the spring, the fuse tube falls by its own weight, the fuse is in the disconnected state, and the obvious fracture occurs when a line or device fails. The fault current causes the fuse to fuse quickly and create an arc. Arc extinguishing tube produces a lot of gas under the action of the electric arc, so that the tube to form a great pressure, the gas jet out at high speed, this powerful air flow, the arc quickly elongated and extinguished.

Switch Fuse

Such type of switches is used for low and medium voltages circuit. The rating of the fuse unit is in the range of 30, 60, 100, 200, 400, 600, and 800 amperes. The fuse unit is available as 3-pole and 4-pole unit. The making capacity of such type of fuses is up to 46 kA. They can safely break depending upon rating currents of the order of 3 times the load current.

Fig: Switch Fuse

High Voltage HRC Fuses

The HRC fuse element carries the short circuit or faults current for the specific interval of time. And if the fault removes in that specific period then the fuse element remains safe and it does not melt or breaks. The fuses element is kept inside the airtight container. The HRC fuse has inverse time characteristic, i.e., if the magnitude of the fault current is high, then their rupturing time is low and for low magnitude fault current the rupturing time is high.

When the fault current passes through the fuse, the fuse element melt and break. The enclosure in which the fuse element is placed is filled with the chemical powder. The vapors of fuse element and the powder together form the high resistive substance which extinguishes the arc.

High Voltage Fuses are generally used in power systems and are typically rated for voltages above 1500V and up to 138000 V. High Voltage (HV) Fuses are used to protect transformers, either small power transformers or instrument transformers, where circuit breakers might not guarantee the protection.

The fuse element in High Voltage (HV) Fuses are made up of either Silver or Copper (sometimes even Tin is used), in order to provide reliable and stable performance. In Expulsion type High Voltage (HV) Fuses, the Fuse Link Chamber is filled with Boric Acid.

Cartridge Type HV High Rupturing Capacity (HRC) Fuse

The construction of the fuse element is similar to the low voltage fuses. In this type of fuse, the fuse element is wound in the shape of the ring for removing the corona effect.

In some of the HRC fuses the two fuse elements are used. These fuse elements are connected parallel to each other. The one element is used for the flows of the normal current, and the other is used for short circuit current. The fuse element for heavy current is made of tungsten metal because of high resistance property.

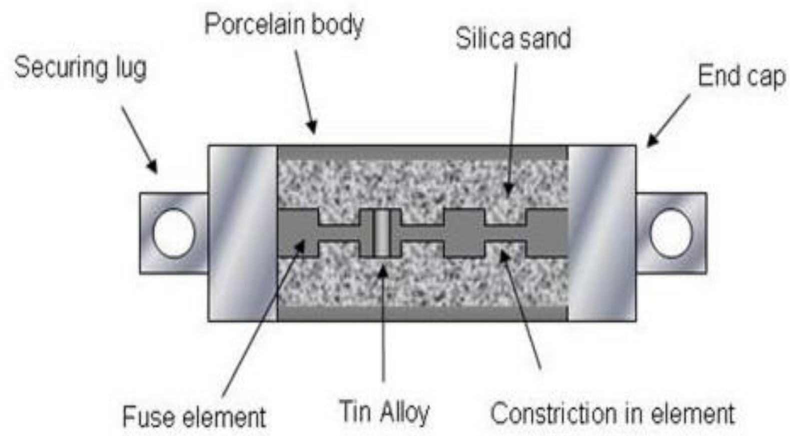
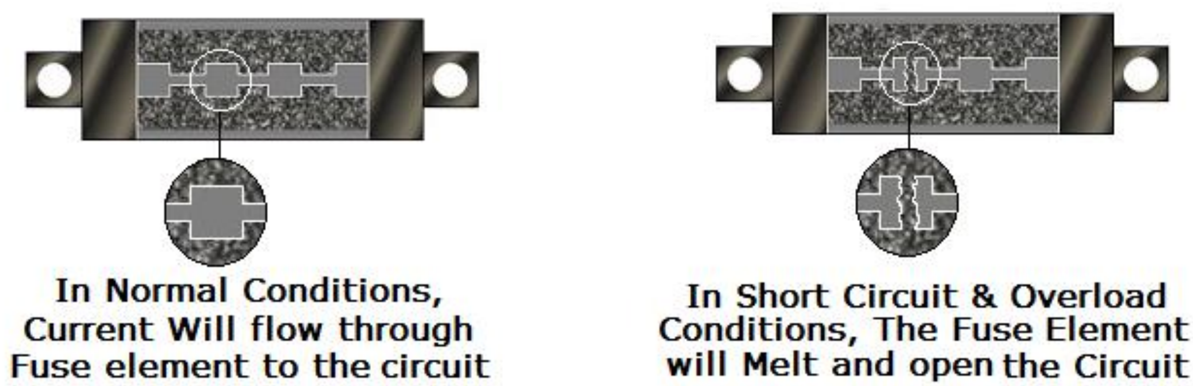


Fig: Cartridge Type HV HRC Fuse



Liquid Type HV HRC Fuse

The liquid type HV HRC fuse is mostly used in the high voltage circuit. It is used for the transformer protection or for the circuit having a rating higher than 400A.

The fuse has the glass tube which fills with carbon tetrachloride. The fuse element places inside the glass tube. The one end of the tube is sealed, and another fix at the end of the glass tube by the help of the phosphorous bronze wire.

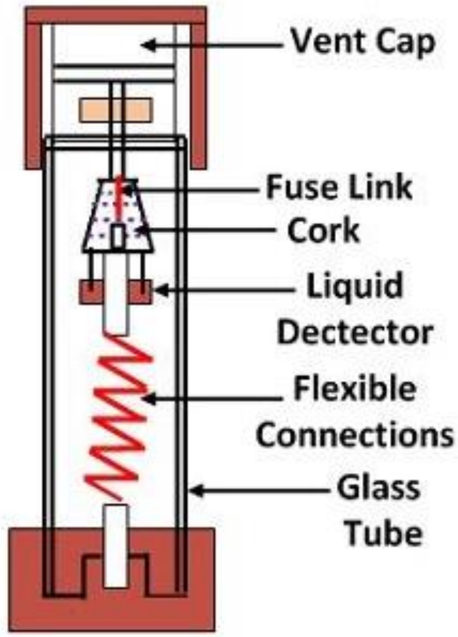


Fig: Liquid Type HV HRC Fuse

When the fault occurs, the short circuit current passes through the fuse element. The fuse element becomes melts and breaks. The small quantity of gas generated at the time of fusion. The liquid uses in the fuse extinguish the arc.

Such type of fuse is used as the backup protector of the circuit breaker. The HRC fuses increase the short circuit capacity of the circuit breaker.

Miniature Circuit Breaker

Nowadays we use more commonly miniature circuit breaker or **MCB** in low voltage electrical network instead of fuse.

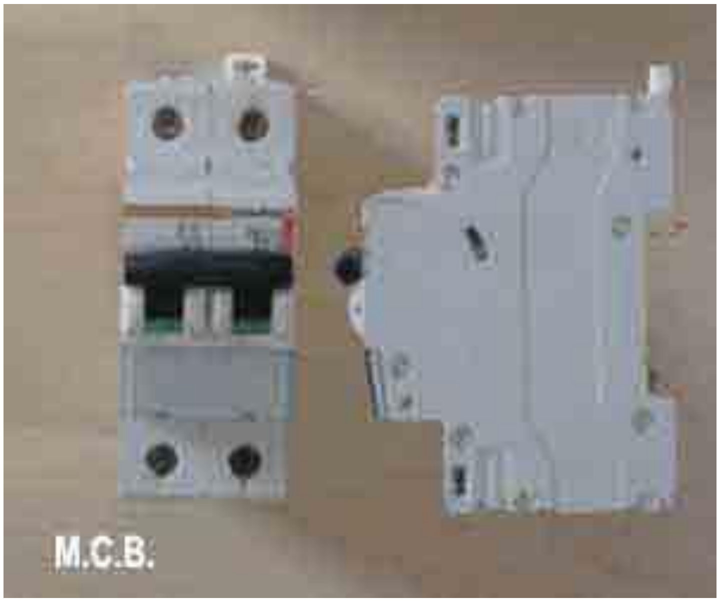
The MCB has some advantages compared to fuse.

1. It automatically switches off the electrical circuit during abnormal condition of the network means in over load condition as well as faulty condition. The fuse does not sense but miniature circuit breaker does it in more reliable way. MCB is much more sensitive to over current than fuse.

2. Another advantage is, as the switch operating knob comes at its off position during tripping, the faulty zone of the electrical circuit can easily be identified. But in case of fuse, fuse wire should be checked by opening fuse grip or cutout from fuse base, for confirming the blow of fuse wire.

3. Quick restoration of supply cannot be possible in case of fuse as because fuses have to be rewireable or replaced for restoring the supply. But in the case of MCB, quick restoration is possible by just switching on operation.

4. Handling MCB is more electrically safe than fuse. Because of too many advantages of MCB over fuse units, in modern low voltage electrical network, miniature circuit breaker is mostly used instead of backdated fuse unit. Only one disadvantage of MCB over fuse is that this system is more costly than fuse unit system.



Working Principle Miniature Circuit Breaker

There are two arrangement of operation of miniature circuit breaker**.** One due to thermal effect of over current and other due to electromagnetic effect of over current. The thermal operation of miniature circuit breaker is achieved with a bimetallic strip whenever continuous over current flows through MCB; the bimetallic strip is heated and deflects by bending. This deflection of bimetallic strip releases mechanical latch. As this mechanical latch is attached with operating mechanism, it causes to open the miniature circuit breaker contacts.

But during short circuit condition, sudden rising of current, causes electromechanical displacement of plunger associated with tripping coil or solenoid of MCB. The plunger strikes the trip lever causing immediate release of latch mechanism consequently open the circuit breaker contacts. This was a simple explanation of miniature circuit breaker working principle**.**

Miniature Circuit Breaker Construction

Miniature circuit breaker construction is very simple, robust and maintenance free. Generally, a MCB is not repaired or maintained, it just replaced by new one when required. A miniature circuit breaker has normally three main constructional parts. These are:

Frame of Miniature Circuit Breaker

The frame of miniature circuit breaker is a molded case. This is a rigid, strong, insulated housing in which the other components are mounted.

Operating Mechanism of Miniature Circuit Breaker

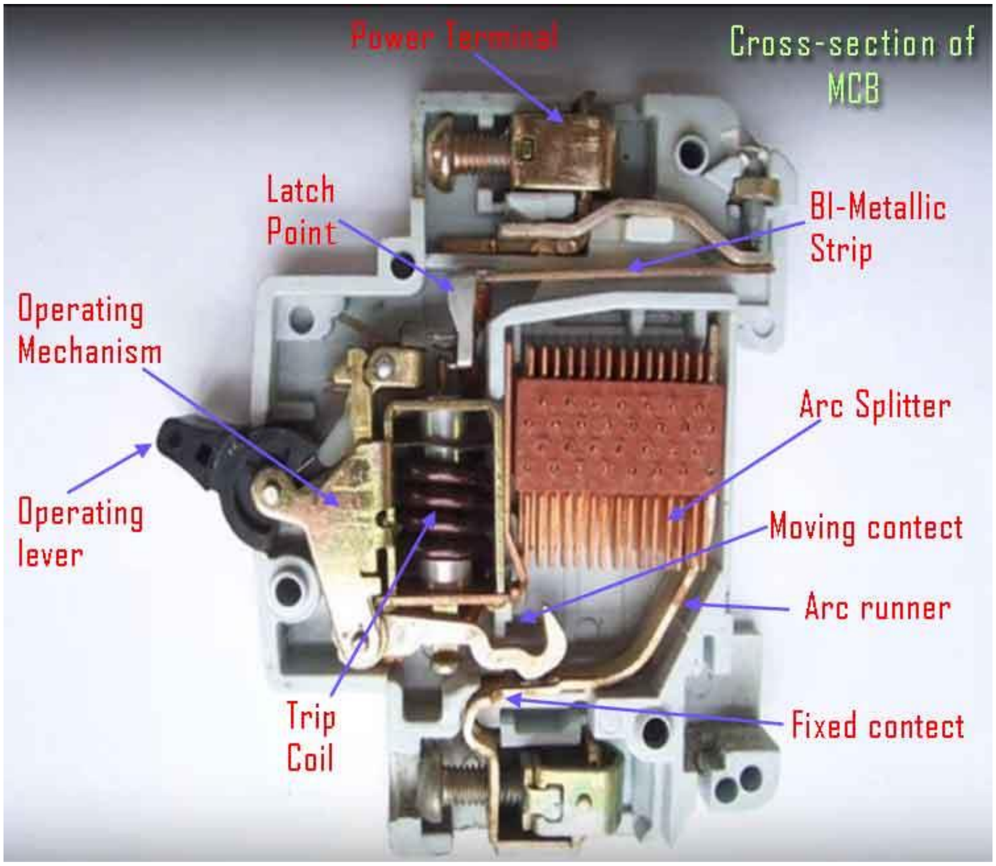
The operating mechanism of miniature circuit breaker provides the means of manual opening and closing operation of miniature circuit breaker. It has three-positions "ON," "OFF," and "TRIPPED". The external switching latch can be in the "TRIPPED" position, if the MCB is tripped due to over-current. When manually switch off the MCB, the switching latch will be in "OFF" position. In close condition of MCB, the switch is positioned at "ON". By observing the positions of the switching latch one can determine the condition of MCB whether it is closed, tripped or manually switched off.

Trip Unit of Miniature Circuit Breaker

The trip unit is the main part, responsible for proper working of miniature circuit breaker**.** Two main types of trip mechanism are provided in MCB. A bimetal provides protection against over load current and an electromagnet provides protection against short-circuit current.

Operation of Miniature Circuit Breaker

There are three mechanisms provided in a single miniature circuit breaker to make it switched off. If we carefully observe the picture beside, we will find there are mainly one bi - metallic strip, one trip coil and one hand operated on-off lever. Electric current carrying path of a miniature circuit breaker shown in the picture is like follows. First left-hand side power terminal - then bimetallic strip - then current coil or trip coil - then moving contact - then fixed contact and - lastly right had side power terminal. All are arranged in series.



If circuit is overloaded for long time, the bi - metallic strip becomes over heated and deformed. This deformation of bi metallic strip causes displacement of latch point. The moving contact of the MCB is so arranged by means of spring pressure, with this latch point, that a little displacement of latch causes, release of spring and makes the moving contact to move for opening the MCB. The current coil or trip coil is placed such a manner that during short circuit fault the mmf of that coil causes its plunger to hit the same latch point and make the latch to be displaced. Hence the MCB will open in same manner. Again, when operating lever of the miniature circuit breaker is operated by hand, that means when we make the MCB at off position manually, the same latch point is displaced as a result moving contact separated from fixed contact in same manner. So, whatever may be the operating mechanism, that means, may be due to deformation of bi - metallic strip, due to increased mmf of trip coil or may due to manual operation, actually the same latch point is displaced and same deformed spring is released, which ultimately responsible for movement of the moving contact. When the moving contact separated from fixed contact, there may be a high chance of arc. This arc then goes up through the arc runner and enters into arc splitters and is finally quenched. When we switch on an MCB, we actually reset the displaced operating latch to its previous on position and make the MCB ready for another switch off or trip operation.

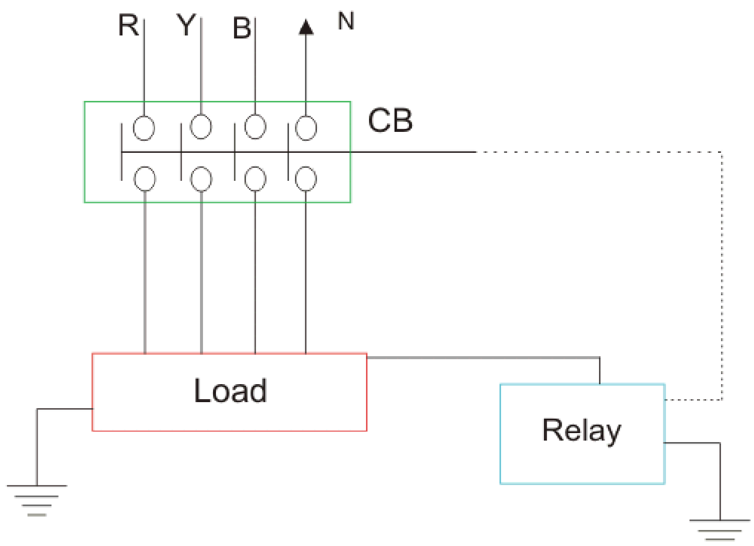
Earth Leakage Circuit Breaker or ELCB

If any current leaks from any electrical installation, there must-be any insulation failure in the electrical circuit, it must be properly detected and prevented otherwise there may be a high chance of electrical shock if-anyone touches the installation. An earth leakage circuit breaker does it efficiently. Means it detects the earth leakage current and makes the power supply off by opening the associated circuit breaker. There are two types of **earth leakage circuit breaker**, one is **voltage ELCB** and other is **current ELCB**.

Voltage Earth Leakage Circuit Breaker

The working principle of voltage ELCB is quite simple. One terminal of the relay coil is connected to the metal body of the equipment to be protected against earth leakage and other terminal is connected to the earth directly.

If any insulation failure occurs or live phase wire touches the metal body, of the equipment, there must be a voltage difference appears across the terminal of the coil connected to the equipment body and earth. This voltage difference produces a current to flow the relay coil.



If the voltage difference crosses, a predetermined limit, the current through the relay becomes sufficient to actuate the relay for tripping the associated circuit breaker to disconnect the power supply to the equipment. The typicality of this device is, it can detect and protect only that equipment or installation with which it is attached. It cannot detect any leakage of insulation in other installation of the system.

Current ELCB or RCCB or Residual Current Circuit Breaker

The working principle of current earth leakage circuit breaker or RCCB is also very simple as voltage operated ELCB but the theory is entirely different and residual current circuit breaker is more sensitive than ELCB.

Actually, ELCBs are of two kinds, but it is general practice to refer voltage based ELCB as simple ELCB. And current based ELCB is referred as RCD or RCCB.

RCCB (Residual Current Circuit Breaker)

It falls under the category of wide range of circuit breakers. As we know there are several types of miniature circuit breakers like MCCB which works on different operational principle and has different safety purpose.

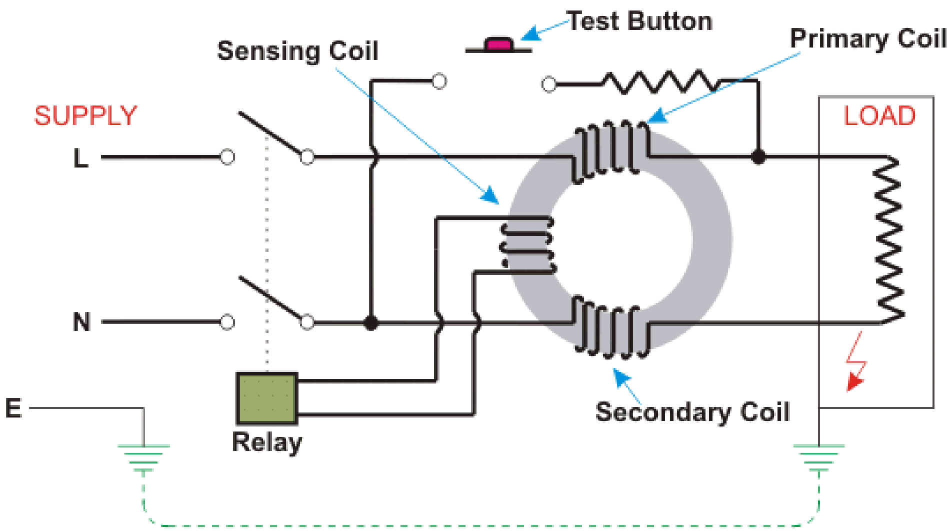
Function: Residual Current Circuit Breaker is essentially a device which senses current and disconnects any low voltage (unbalanced current) circuit whenever there is any fault occurs.

Purpose: Residual Current Circuit Breaker basically is installed to prevent human from shocks or death caused by shocks. It prevents accidents by disconnecting the main circuit within fraction of seconds.

How Residual Current Circuit Breaker Works?

It has very simple working based on Kirchhoff's Current Law i.e. the incoming current in a circuit must be equal to the outgoing current from that circuit. This circuit breaker is made such that whenever a fault occur the current balance of line and neutral did not matches (imbalance occurs, as the fault current finds another earthing path of current). Its circuit is made such that every instance it compares the value of incoming and outgoing circuit current. Whenever it is not equal, the residual current which is basically the difference between the two currents actuates the circuit to trip/switch off.

Working Principle of Residual Current Circuit Breaker



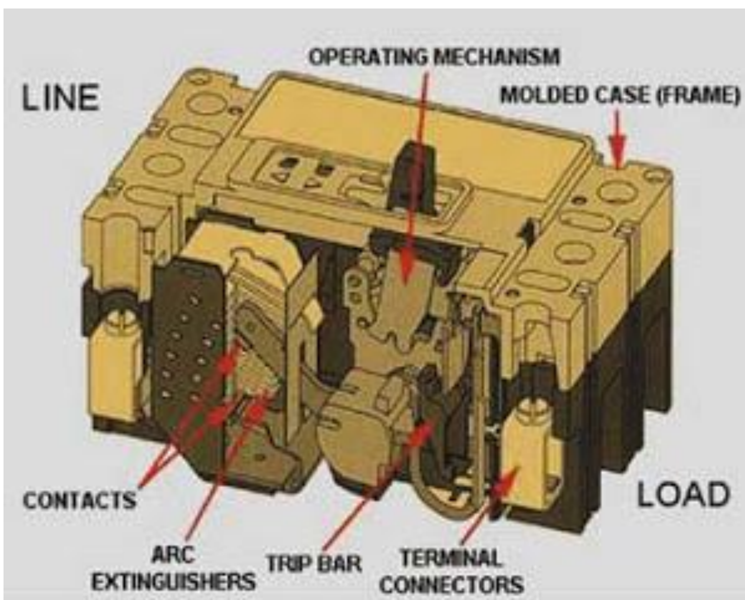
Working Principle of Residual Current Circuit Breaker

The basic operating principle lies in the Toroidal Transformer shown in the diagram containing three coils. There are two coils say Primary (containing line current) and Secondary (containing neutral current) which produces equal and opposite fluxes if both currents are equal. Whenever in the case there is a fault and both the currents changes, it creates out of balance flux, which in-turn produces the differential current which flows through the third coil (sensing coil shown in the figure) which is connected to relay.

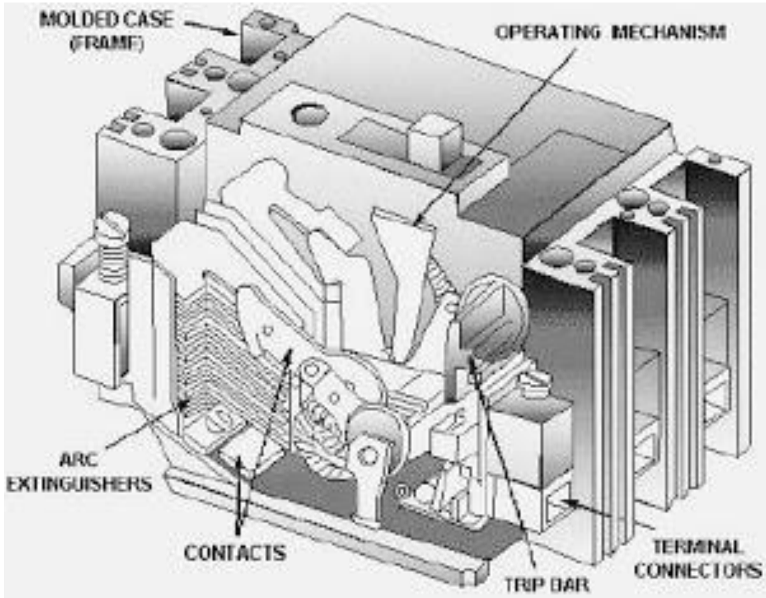
The Toroidal transformer, sensing coil and relay together is known as RCD - Residual Current Device. **Test Circuit:** The test circuit is always included with the RCD which basically connects between the line conductor on the load side and the supply neutral. It helps to test the circuit when it is on or off the live supply. Whenever the test button is pushed current starts flowing through the test circuit depending upon the resistance provided in this circuit. This current passes through the RCD line side coil along with load current. But as this circuit bypasses neutral side coil of RCD, there will be an unbalance between the line side and neutral side coil of the device and consequently, the RCCB trips to disconnect the supply even in normal condition. This is how the test circuit tests the reliability of **RCCB**.

MCCB

Molded Case Circuit Breakers are electromechanical devices which protect a circuit from Over current and Short Circuit. They provide Over current and Short Circuit Protection for circuits ranging from 63 Amps up to 1000 Amps.



Their primary functions are to provide a means to manually open a circuit and automatically open a circuit under overload or short circuit conditions. The over current, in an electrical circuit, may result from short circuit, overload or faulty design.



MCCB is an alternative to a fuse since it does not require replacement once an overload is detected. Unlike fuse, a **MCCB** can be easily reset after a fault and offers improved operational safety and convenience without incurring operating cost.
Molded case circuit breakers generally have a

- Thermal element for over current and
- Magnetic element for short circuit release which has to operate faster.

MCCBs are manufactured such that end user will not have access to internal workings of the over-current protection device. Generally constructed of two pieces of heavy-duty electrically insulated plastic, these two halves are riveted together to form the whole. Inside the plastic shell is a series of thermal elements and a Spring-loaded trigger. When the thermal element gets too warm, from an over current situation, the spring trips, which in turn will shut off the electrical circuit.

Summary

MCB (Miniature Circuit Breaker)
Characteristics
Rated current not more than 100 A.
Trip characteristics normally not adjustable.
Thermal or thermal-magnetic operation.

MCCB (Molded Case Circuit Breaker)
Characteristics
Rated current up to 1000 A.
Trip current may be adjustable.
Thermal or thermal-magnetic operation.

RCD (Residual Current Device / RCCB (Residual Current Circuit Breaker)

Characteristics

Phase (line) and Neutral both wires connected through RCD. It trips the circuit when there is earth fault current. The amount of current flows through the phase (line) should return through neutral. It detects by RCD any mismatch between two currents flowing through phase and neutral detect by RCD and trip the circuit within 30Miliseconed. RCDs are an extremely effective form of shock protection the most widely used are 30 mA (milliamp) and 100 mA devices. A current flow of 30 mA (or 0.03 amps) is sufficiently small that it makes it very difficult to receive a dangerous shock. Even 100 mA is a relatively small figure when compared to the current that may flow in an earth fault without such protection (hundreds of amps)

ELCB (Earth Leakage Circuit Breaker)

Characteristics
Phase (line), Neutral and Earth wire connected through ELCB.
ELCB is working based on Earth leakage current.
<u>Operating Time of ELCB:</u>
The safest limit of Current which Human Body can withstand is 30ma sec.
Suppose Human Body Resistance is 500Ω and Voltage to ground is 230 Volt.
The Body current will be 500/230=460mA.
Hence ELCB must be operated in 30maSec/460mA = 0.65msec

Difference between ELCB and RCCB

ELCB is the old name and often refers to voltage operated devices that are no longer available and it is advised you replace them if you find one.

RCCB or RCD is the new name that specifies current operated (hence the new name to distinguish from voltage operated). The new RCCB is best because it will detect any earth fault. The voltage type only detects earth faults that flow back through the main earth wire so this is why they stopped being used. The easy way to tell an old voltage operated trip is to look for the main earth wire connected through it. RCCB will only have the line and neutral connections.

ELCB is working based on Earth leakage current. But RCCB is not having sensing or connectivity of Earth, because fundamentally Phase current is equal to the neutral current in single phase. That's why RCCB can trip when the both currents are deferent and it withstand up to both the currents are same. Both the neutral and phase currents are different that means current is flowing through the Earth. Finally both are working for same, but the thing is connectivity is difference. RCD does not necessarily require an earth connection itself (it monitors only the live and neutral).In addition it detects current flows to earth even in equipment without an earth of its own. This means that an RCD will continue to give shock protection in equipment that has a faulty earth. It is these properties that have made the RCD more popular than its rivals. For example, earth-leakage circuit breakers (ELCBs) were widely used about ten years ago. These devices measured the voltage on the earth conductor; if this voltage was not zero this indicated a current leakage to earth. The problem is that ELCBs need a sound earth connection, as does the equipment it protects. As a result, the use of ELCBs is no longer recommended.

Electrical Wires & Cables

More often than not, the terms wire and cable are used to describe the same thing, but they are actually quite different. Wire is a single electrical conductor, whereas a cable is a group of wires swathed in sheathing. The term cable originally referred to a nautical line of multiple ropes used to anchor ships, and in an electrical context, cables (like wires) are used to carry electrical currents.

Whether indoors or outdoors, proper wire and cable installation is of paramount importance - ensuring a smooth electricity supply, as well as passing electrical inspections. Each wire and cable need to be installed carefully, from the fuse box to the outlets, fixtures and appliances. The National Electrical Code (NEC) and Local Building Codes regulate the manner of installation and the types of wires and cables for various electrical applications.

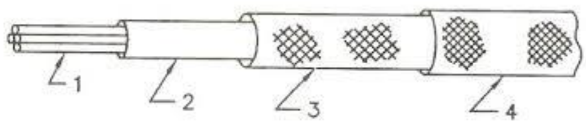
- Wires/cables are conducting materials which are made of copper, aluminum, silver, iron, and alloyed metals like nichrome wire, constantan, and German silver wire.
- It is used to conduct power from the point where it is generated to the point where it is used.
- Wires/cables are all electric conductors but not all conductors are wires. These wires are either made of solid or stranded. Most wires are round although square and rectangular forms are also used in specific applications. These wires are manufactured with or without insulation depending upon the application.
- Copper or aluminum wires without insulation are usually used for grounding connection and also for high tension or high voltage transmission lines.
- Nichrome wire, constantan, manganin, and German silver wires are used as resistance wires in electrical equipment and appliances.
- All wires/cables have resistances that oppose the unlimited flow of current and causes voltage drop resulting in the eventual heat developed in the wire. The heat developed varies according to the square of the current in amperes.
- There is a limit to the degree of heat that various types of wire insulation and sizes can safely withstand. They should not be allowed to reach a temperature that might cause a fire.
- The Electrical Code specifies the maximum current-carrying capacity in amperes that is safe for wires of different with different insulations and under different circumstances and conditions.

Types of Wires

- Vulcanised Indian Rubber wire (V.I.R)
- Tough Rubber Sheathed wire (T.R.S)
- Poly Vinyl Chloride wire (P.V.C.)
- Lead Alloy Sheathed wire
- Weather Proof wires
- Mineral Insulated Copper Covered wire

Vulcanised Indian Rubber wire (V.I.R)

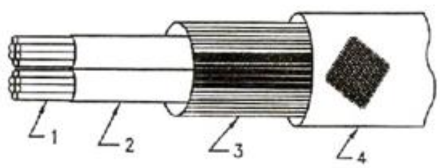
- A VIR wire mainly consists of a tinned conductor having rubber coating.
- Tinning of the conductor prevents the sticking of rubber to the conductor.
- Thickness of the rubber mainly depends on the operating voltage to which the wire is designed.
- Cotton braiding is done over the rubber insulation to protect the conductor from the moisture.
- Finally, the wire is finished with the wax for cleanliness.
- They are suitable for low and medium voltage only.
- Now a days this type of wires is not in use since a better-quality wire are available at cheaper rate



1. CONDUCTOR 2. RUBBER INSULATION 3. BRAIDING
4. SECOND LAYER OF BRAIDING

Cabe tyre sheath wire (CTS)/Tough Rubber Sheathed wire (T.R.S)

- This type of wire is modification of VIR wire. It consists of the ordinary rubber coated conductors with additional sheath of tough rubber.
- This layer provides better protection against moisture and wear and tear. Also it provides an extra insulation.
- These wires are generally available in single conductor,2 conductor or 3 conductors

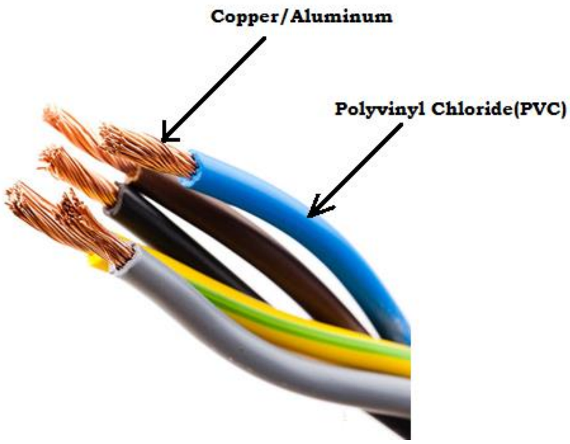


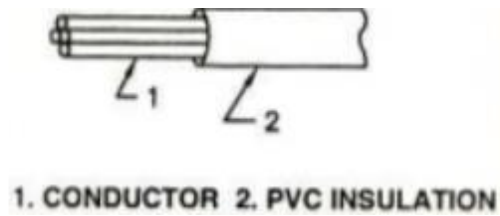
1. CONDUCTOR 2. RUBBER INSULATION 3. RUBBER SHEATH
4. BRAIDING

Poly Vinyl Chloride wire (P.V.C.)

- This is most commonly used wire for wiring purpose.
- Conductor is insulated by poly vinyl chloride (insulating material)
- PVC has following properties:
  - Moisture free
  - Tough
  - Durable
  - Chemically inert
  - High life
  - High dielectric strength
  - No disturb in vibration

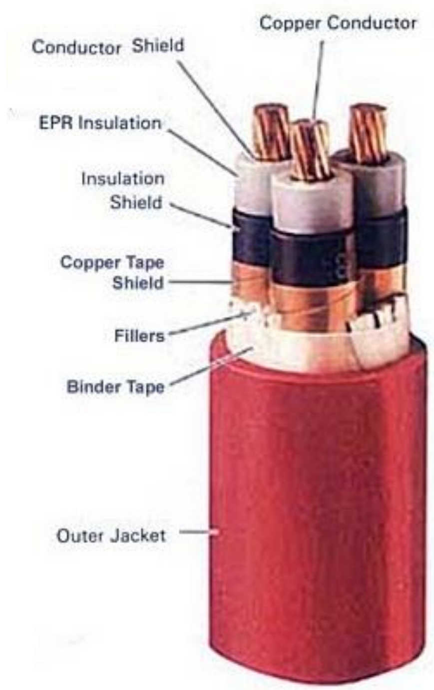
- But it softens at high temperatures therefore not suitable for connection to heating appliances
- Available in 600V,660V,1100V, widely used long life durable against water, heat, oil, UV light





Lead Alloy Sheathed wire

- The ordinary wires can be used only at dry places but for damp places these wires are covered with continuous lead sheaths.
- The layer of lead covering is very thin like 0.12 cm thick.
- These wires provide little mechanical protections to the wires.



Weather Proof wires

- These types of wire are used outdoors i.e. providing a service connection from overhead line to building, etc.
- In this type of wire the conductor is not tinned and the conductor is covered with three braids of fibrous yarn and saturated with water proof compound.

Fig: Weather Proof wires

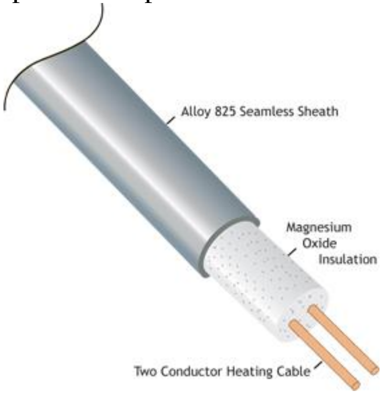


Fig: MICC wire

Mineral Insulated Copper Covered (MICC) wire

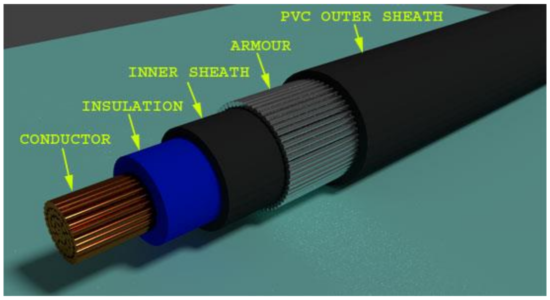
In this type wire copper conductor is coated with magnesium oxide and after that copper coating is done on it. In case of moisture weather PVC coating (serving) is coated on it. It is used in mines, factory, furnace, boiler, rolling mills, etc. magnesium oxide is used for avoiding moisture problems.

Cables

A power cable is an assembly of two or more electrical conductors, usually held together with an overall sheath. The assembly is used for transmission of electrical power. Power cables may be installed as permanent wiring within buildings, buried in the ground, run overhead, or exposed. Flexible power cables are used for portable devices, mobile tools and machinery.

Construction

The power cable mainly consists of three main components, namely, conductor, dielectric, and sheath. The conductor in the cable provides the conducting path for the current. The insulation or dielectric withstands the service voltage and isolates the conductor with other objects. The sheath does not allow the moistures to enter and protects the cables from all external influences like chemical or electrochemical attack, fire, etc. The main components of electrical power cables are explained below in details.



Conductor

Coppers and aluminum wires are used as a conductor material in cables because of their high electrical conductivity. Solid or number of bare wires made of either copper or aluminum is used to make a power cable.

Insulation

The most commonly used dielectric in power cables is impregnated paper, butyl rubber, polyvinyl chloride cable, polyethylene, cross-linked polyethylene. Paper insulated cables are mostly preferred because their current carrying capacity is high, generally reliable and having a long life. The dielectric compound used for the cable should have following properties.

- The insulator must have high insulation resistance.
- It should have high dielectric strength so that it does not allow the leakage current to pass through it.
- The material must have good mechanical strength.
- The dielectric material should be capable of operating at high temperature.
- It should have low thermal resistance.
- It should have a low power factor.

Inner Sheath

- It is used for protecting the cable from moistures which would affect the insulation. Cable sheath is made up of lead alloy, and these strengths withstand the internal pressures of the pressurized cables. The material used for inner sheath should be nonmagnetic material.
- The aluminum sheath is also used in a power cable because it is cheaper, smaller in weight and high mechanical strength than the lead sheath. In oil-filled cables and telephone, cables corrugated seamless aluminum sheath is used because it has better-bending properties, reduced thickness, and lesser weight.

Armouring

Armouring is the process in which layers of galvanized steel wires or two layers of metal tape are applied over sheath for protecting it from mechanical damage. The steel wires are normally used for armouring because it has high longitudinal strength. Armouring is also used for earthing the cable. When the fault occurs in the cable (due to insulation failure) the fault current flows through the armour and get earthed.

Over Sheath

It gives the mechanical strength to the cables. It protects the cable from overall damage like moisture, corrosion, dirt, dust, etc. The thermosetting or thermoplastic material is used for making over the sheath.

Classification Based Upon Voltage Rating of the Cable

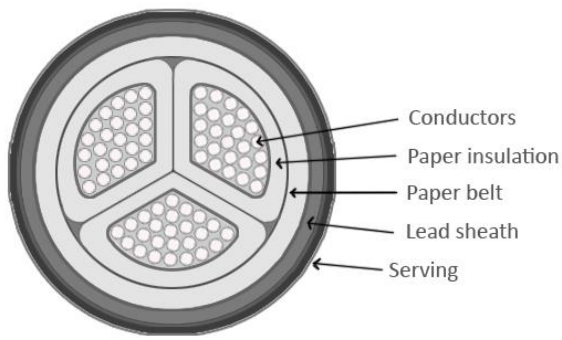
1. **Low tension cables**: These have a maximum voltage handling capacity of 1000 V (1 kV)
2. **High tension cables**: These have a maximum voltage handling capacity of 11 kV.
3. **Super tension cables**: These have a maximum voltage handling capacity of 33 kV.

4. **Extra high-tension cables**: These have a maximum voltage handling capacity of 66 kV.
5. **Extra super voltage cables**: These are used for applications with voltage requirement above 132 kV.

Classification Based Upon Construction of the Cable

1. Belted Cable

In such cables, the conductors (usually three) are bunched together and then bounded with an insulating paper 'belt'. In such cables, each conductor is insulated using paper impregnated with a suitable dielectric. The gaps between the conductors and the insulating paper belt are filled with a fibrous dielectric material such as Jute or Hessian. This provides flexibility as well as a circular shape. As we discussed earlier (in Construction of Cables), the jute layer is then covered by a metallic sheath and armouring for protection. One particular specialty of this cable is that its shape may not be perfectly circular. It is kept non-circular to use the available space more effectively.



There are some limitations of such construction. Since the electric field is tangential, the insulation provided is stressed. As a result, the dielectric strength falls over time. Hence, such construction isn't preferred for voltage levels above 11 kV.

2. Pressure Cables

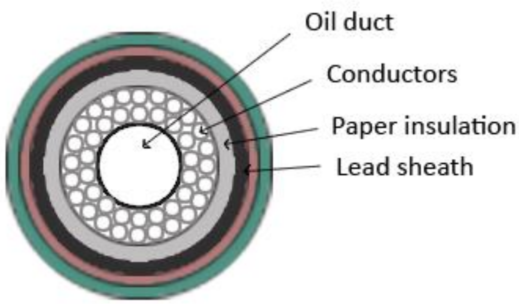
For voltages beyond 66 kV, the electrostatic stresses in the cables exceed the acceptable values and solid cables become unreliable. This occurs mainly because voids are created when voltages exceed 66 kV. Hence, instead of solid cables, we use Pressure cables. Typically, such cables are either oil filled or gas filled.

- **Oil Filled Cables**

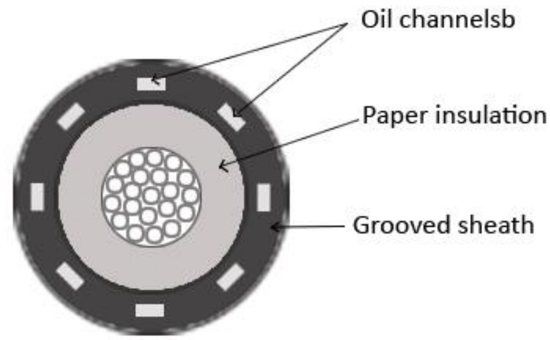
Oil is circulated under suitable pressure through ducts provided for such purpose. This oil supply and pressure are maintained through reservoirs kept at proper distances. The oil used is the same that is employed for impregnation of paper insulators.

- **Gas Filled Cables**

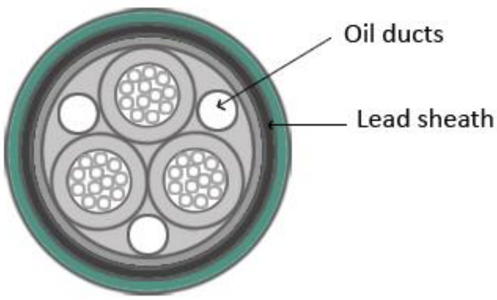
Pressurized gas (usually dry nitrogen) is circulated around cables in an air-tight steel pipe. Such cables are cable of carrying higher values of load current and can operate at higher values of voltage. But the overall cost is more.



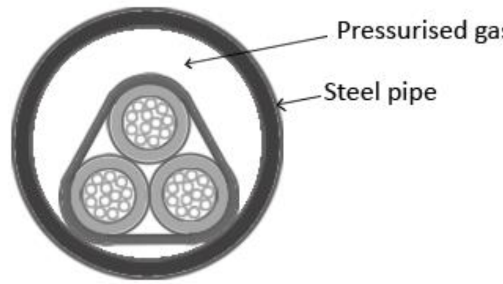
Single core conductor channel oil filled cable



Single core sheath channel oil filled cable



Three core oil filled cable



Three core gas pressure cable

Earthing

Earthing or grounding is the process of transferring the immediate discharge of electricity directly to the earth plate, by means of low resistance electrical cables or wires. Earthing really is one of the most important aspects of electric networks, since it makes the most readily available and dangerous source of power much safer to use.

In case of a short circuit due to leakages arising from weak insulation or damage, the grounding wire safely removes excess electricity and passes it on to the ground

Earthing or Grounding in an electrical network works as a safety measure to protect human life as well as equipment, the main objective of the Earthing system is to provide an alternative path for dangerous currents to flow so that accidents due to electric shock and damage to the equipment can be avoided.

Metallic parts of equipment are grounded or connected to the earth and if the equipment insulation fails for any reason, then the high voltages that can be present in the equipment covering or outer box need some path to get discharged. If the equipment is not earthed, these dangerous voltages can be transferred to anyone who touches it resulting in an electric shock.

The circuit gets shorted and the fuse will blow immediately, in case a live wire touches the earthed case.

Why Do You Need an Earthing System in an Electrical Network?

This question generally arises when you have all the right equipment, wires, sockets and well maintained electrical devices. Yet, why is there a need for an Earthing system?

The answer is very simple…

Earthing system makes the equipment electrically shock free and gives you a safe place to stay.

Here are some advantages of the Earthing system:

1. **Safety for Human Life, Electrical Devices and Buildings**

It saves the human life from the danger of electrical shock which can cause death, by blowing a fuse. It protects your electric equipment or devices. It provides a safe path for lighting and short circuit currents and saves the building from structural damage.

2. **Voltage Stabilization**

Electricity comes from many sources, every transformer can be considered as a separate source. If there is no point which will act as a common point, then it is impossible to make a calculation between these sources.

In an electrical distribution system, Earth is the omnipresent conductive surface, which makes it a universal standard for all-electric systems.

3. Over Voltage Protection

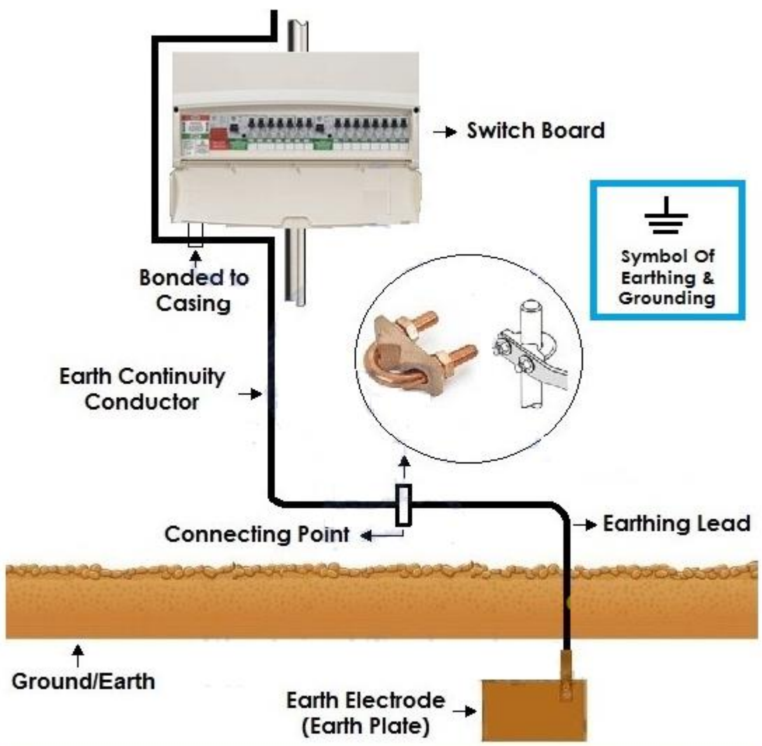
Earthing System provides an alternative path in the electrical system to minimize the dangerous effect in the electrical system which happens at the time of lighting and unintentional contact with high voltage lines.

Now that you have got an idea of the Earthing system, it is time to know how to set up an Earthing or Grounding system at your home, office or shop.

Components of Earthing System

A complete electrical earthing system consists on the following basic components.

- Earth Continuity Conductor
- Earthing Lead
- Earth Electrode



Components of an Earthing/Grounding System

Earth Continuity Conductor or Earth Wire

That part of the earthing system which interconnects the overall metallic parts of electrical installation e.g. conduit, ducts, boxes, metallic shells of the switches, distribution boards, Switches, fuses, Regulating and controlling devices, metallic parts of electrical machines such as, motors, generators, transformers and the metallic framework where electrical devices and components are installed is known as earth wire or earth continuity conductor as shown in the above fig.

The resistance of the earth continuity conductor is very low. According to IEEE rules, resistance between consumer earth terminal and earth Continuity conductor (at the end) should not be increased than 1Ω. In simple words, **resistance of earth wire should be less than 1Ω**.

Size of Earth Continuity Conductor

The cross-sectional area of the Earth Continuity Conductor should not be less than the half of the cross sectional area of the thickest wire used in the electrical wiring installation.

Earthing Lead or Earthing Joint

The conductor wire connected between earth continuity conductor and earth electrode or earth plate is called earthing joint or "Earthing lead". The point where earth continuity conductor and earth electrode meet is known as "connecting point" as shown in the above fig.

Earthing lead is the final part of the earthing system which is connected to the earth electrode (which is underground) through earth connecting point.

There should be minimum joints in earthing lead as well as lower in size and straight in the direction. Generally, copper wire can be used as earthing lead but, copper strip is also used for high installation and it can handle the high fault current because of wider area than the copper wire. A hard drawn bare copper wire is also used as an earthing lead. In this method, all earth conductors connected to a common (one or more) connecting points and then, earthing lead is used to connect earth electrode (earth plat) to the connecting point.

To increase the safety factor of installation, two copper wires are used as earthing lead to connect the device metallic body to the earth electrode or earth plate. I.e., if we use two earth electrodes or earth plats, there would be four earthing leads. It should not be considered that the two earth leads are used as parallel paths to flow the fault currents but both paths should work properly to carry the fault current because it is important for better safety.

Size of the Earthing Lead

The size or area of earthing lead should not be less than the half of the thickest wire used in the installation.

Earthing Electrode or Earth Plate

A metallic electrode or plate which is buried in the earth (underground) and it is the last part of the electrical earthing system. In simple words, the final underground metallic (plate) part of the earthing system which is connected with earthing lead is called earth plate or earth electrode.

A metallic plate, pipe or rode can be used as an earth electrode which has very low resistance and carry the fault current safely towards ground (earth).

Size of Earthing Electrode
Both copper and iron can be used as earthing electrode.

The size of earth electrode (In case of copper)
2×2 (two foot wide as well as in length) and 1/8 inch thickness i.e. 2’ x 2’ x 1/8”. (600x600x300 mm)
In case of Iron
2’ x2’ x ¼” = 600x600x6 mm
It is recommended to bury the earth electrode in the moisture earth. If it is not possible, then put water in the GI (Galvanized Iron) pipe to make possible the moisture condition.

In the earthing system, put the earth electrode in vertical position (underground) as shown in the above fig. Also, put a 1 foot (about 30cm) **layer of powdered charcoal and lime mixture** around the earth plate (don’t confuse with earth electrode and earth plate as both are the same thing).

This action makes the possible increase in the size of the earth electrode which leads a better continuity in the earth (earthing system) and also helps to maintain the moisture condition around earth plate.

General method of Earthing / Proper Grounding Installation (Step by Step)

The usual method of earthing of electric equipments, devices and appliances are as follow:

1. First of all, dig a 5x5ft (1.5×1.5m) pit about 20-30ft (6-9 meters) in the ground. (Note that, depth and width depend on the nature and structure of the ground)

2. Bury an appropriate (usually 2’ x 2’ x 1/8” (600x600x300 mm) copper plate in that pit in vertical position.

3. Tight earth lead through nut bolts from two different places on earth plate.

4. Use two earth leads with each earth plate (in case of two earth plates) and tight them.

5. To protect the joints from corrosion, put grease around it.

6. Collect all the wires in a metallic pipe from the earth electrode(s). Make sure the pipe is 1ft (30cm) above the surface of the ground.

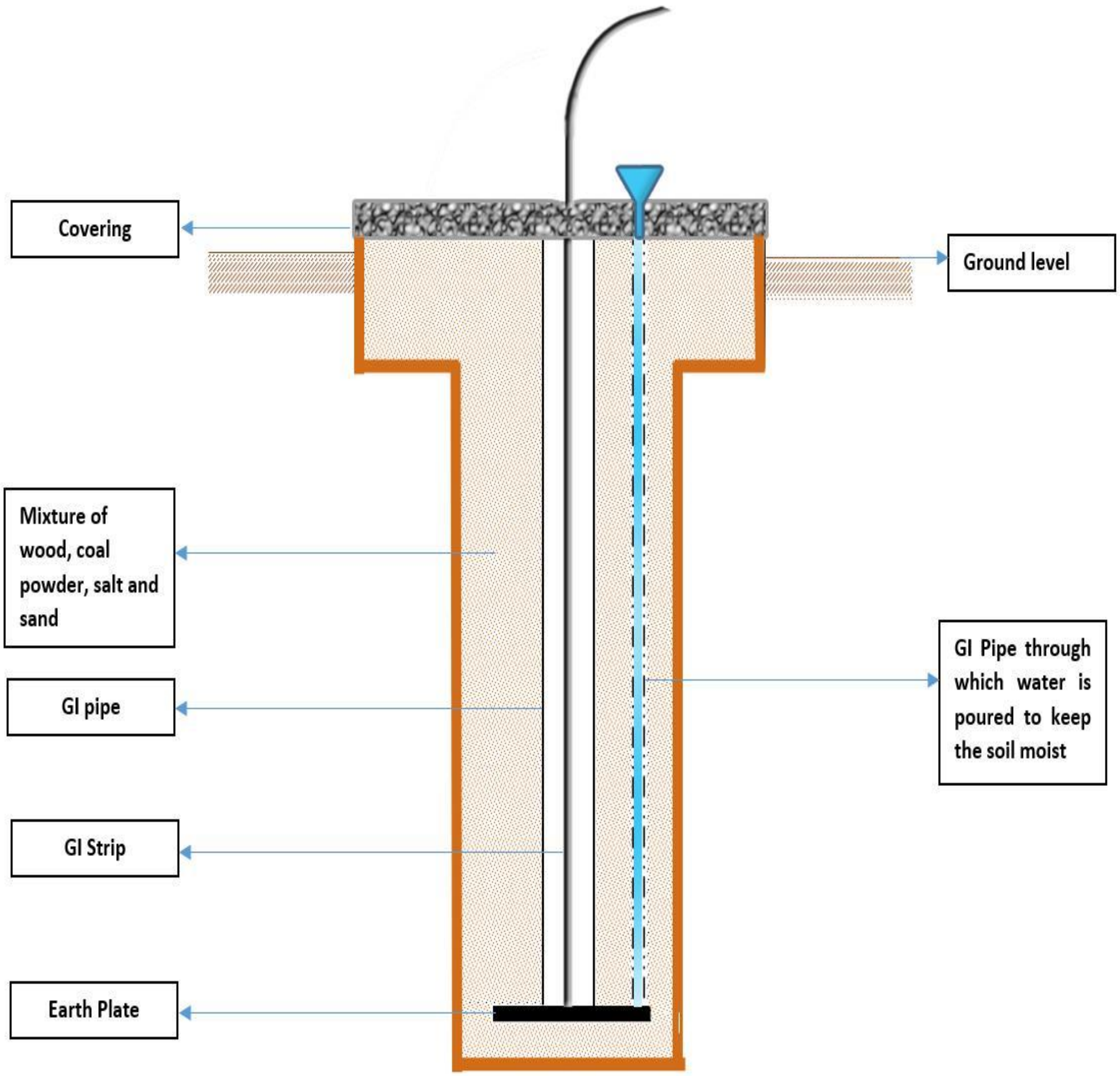
7. To maintain the moisture condition around the earth plate, put a 1ft (30cm) layer of powdered charcoal (powdered wood coal) and lime mixture around the earth plate of around the earth plate.

8. Use thimble and nut bolts to connect tightly wires to the bed plates of machines. Each machine should be earthed from two different places. The minimum distance between two earth electrodes should be 10 ft (3m).

9. Earth continuity conductor which is connected to the body and metallic parts of all installation should be tightly connected to earth lead.

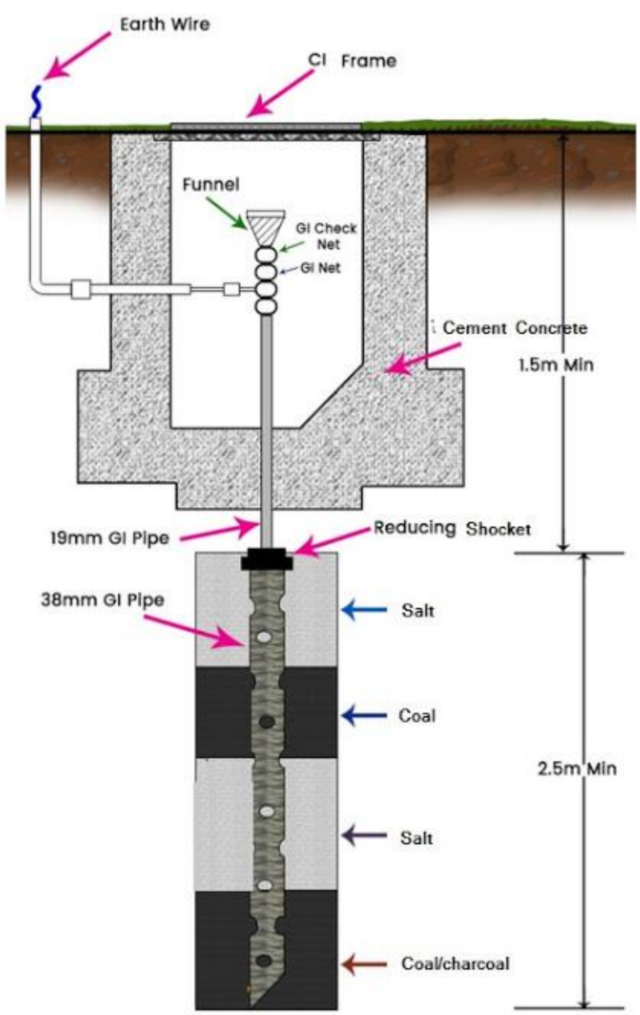
10. At last (but not least), test the overall earthing system through earth tester. If everything is going about the planning, then fill the pit with soil. The maximum allowable resistance for earthing is 1Ω. If it is more than 1 ohm, then increase the size (not length) of earth lead and earth continuity conductors. Keep the external ends of the pipes open and put the water time to

time to maintain the moisture condition around the earth electrode which is important for the better earthing system.



PROCEDURE FOR PIPE OR ROD ELECTRODE EARTHING

- Make a borehole of 500 mm diameter and 3.5 meters deep or as per the approved design and drawing.
- Lower the Pipe electrode made of a 65 mm diameter GI perforated pipe of 3.0-meter length attached at the top with a funnel covered with wire mesh. A G.I. strip is fixed to the electrode to act as an earthing connection. For rod earthing, a copper rod of required diameter is used in place of the pipe.
- Fill the annular space between the electrode and borehole walls with alternating layers of coke or charcoal and common salt.
- Inspection chamber: Construct brick chamber of size 450 x 450 x 450 mm with 100 mm thick brick walls over a P.C.C. layer. Keep 100 mm of the chamber above ground level. Cover the top with a cast iron (CI) cover.
- Follow the approved design and drawing for fixing and laying of earth wires or GI/copper strips between the earth electrode and the electrical room.



SUGGESTED ITEM DESCRIPTION FOR G.I. PIPE ELECTRODE EARTHING:

Supply and erection of G.I. earth pipe electrode 65 mm diameter, at least 3.0 meter below ground with 40 Kg alternate layers of charcoal and salt with and with wire mesh funnel for watering, 230 brick masonry chamber (450 mm x 450 mm x 450 mm), C.I. cover 300mm x 300mm (10 Kg) complete with necessary length of double G.I. earth wire no. 6 SWG bolted with lug to the plate and covered in 12 mm dia G.I. pipe 3.0 meter long complete connected to the nearest switchgear with end socket and duly tested by earth tester and recording the results.

Calculation of Energy Consumption

Step 1

- Calculate Watts per day consumption.

Step 2

- Convert to KilloWatts per day consumption.

Step 3

- Calculate energy uses over a month period.

Step 4

- Figure out the cost considering the rate.

Electrical Energy consumed is recorded by the energy meter.

Energy consumed = (Power consumed)*(No. of hours in operation)

The unit of energy consumed is KilowattHour (KWHr) which is often referred to as ‘UNIT’

1 UNIT = 1KWHr = 1000WHr

For example,

- **An appliance ‘A’ rated at 1KW if used for 1 hour,**

  Energy consumed = 1KW*1 Hr = 1KWHr = 1 Unit

- **An appliance ‘B’ rated at 100W if used for 10 hours,**

  Energy consumed = 100W*10Hr = 1000WHr = 1KWHr = 1 Unit

- **An appliance ‘C’ rated at 2000W if used for half-an hour,**

  Energy consumed = 2000W*(1/2)Hr = 1000WHr = 1KWHr = 1 Unit

RATE SCHEDULE

LT-2(a)(i) : Applicable to areas coming under Bruhat Bangalore Mahanagara Palike (BBMP), Municipal Corporations and all other Urban Local Bodies.

Fixed charges per month	For the first KW	Rs.100 per KW
	For every additional KW up to and inclusive of 50 KW	Rs.110 per KW
	For every additional KW above 50 KW	Rs.175 per KW
Energy charges	For 0 - 50 units (Lifeline consumption)	415 paise/unit
	51 to 100 units	560 paise/unit
	101 to 200 units	715 paise /unit
	Above 200 units	820 paise /unit

ಬೆಂಗಳೂರು ವಿದ್ಯುತ್ ಸರಬರಾಜು ಕಂಪನಿ ನಿಯಮಿತ

ವಿದ್ಯುತ್ ಬಿಲ್ / ELECTRICITY BILL

GSTN No: 29AACCB1412G1Z5

O/o.AEE(Ele.) W6-BYATARAYANAPURA

Account Details

ಆರ್.ಆರ್.ಸಂಖ್ಯೆ/ RR No MSW6LG60725 — Revenue Register Number

ಖಾತೆ ಸಂಖ್ಯೆ/Acc Id 2354729550

ಮಾ.ಓ. ಸಂಕೇತ/ M.R Code 14003318

- -

Personal Details

ಹೆಸರು ಮತ್ತು ವಿಳಾಸ/Name and Address

- -

Connection Details

ಜಕಾತಿ /Tariff 1LT2A1-N — Tariff Category

ಮಂ. ಪ್ರಮಾಣ/Sanc Load 5KW+0HP — Sanctioned Load of your building

- -

Billing Details

ಬಿಲ್ ಅವಧಿ/Bill Period 02/05/2022 - 02/06/2022

ರೀಡಿಂಗ್ ದಿನಾಂಕ/Rdng. Date 02/06/2022

ಬಿಲ್ ಸಂಖ್ಯೆ/Bill No 142319226020358

- -

Consumption Detail

ಇಂದಿನ ಮಾಪನ/Pres. Rdg. 4214

ಹಿಂದಿನ ಮಾಪನ/Prev. Rdg. 3969 — Two consecutive readings

ಮಾಪನ ಸ್ಥಿರಾಂಕ/Constant 1

ಬಳಕೆ/Consumption(Units) 245 — Consumption in Units (KWh)

ಸರಾಸರಿ/Average

ಪವರ್ ಫ್ಯಾಕ್ಟರ್/Power Factor 1.0

ಸಂ.ಪ್ರಮಾಣ/Connected Load 0.0KW

Connection Details

ಜಕಾತಿ /Tariff	1LT2A1-N
ಮಂ. ಪ್ರಮಾಣ/Sanc Load	5KW+0HP

Billing Details

ಬಿಲ್ ಅವಧಿ/Bill Period	02/05/2022 - 02/06/2022
ರೀಡಿಂಗ್ ದಿನಾಂಕ/Rdng. Date	02/06/2022
ಬಿಲ್ ಸಂಖ್ಯೆ/Bill No	142319226020358

Consumption Detail

ಇಂದಿನ ಮಾಪನ/Pres. Rdg.	4214
ಹಿಂದಿನ ಮಾಪನ/Prev. Rdg.	3969
ಮಾಪನ ಸ್ಥಿರಾಂಕ/Constant	1
ಬಳಕೆ/Consumption(Units)	245
ಸರಾಸರಿ/Average	
ದಾಖಲಿತ ಬೇಡಿಕೆ/Recorded MD	1KW
ಪವರ್ ಫ್ಯಾಕ್ಟರ್/Power Factor	1.0
ಸಂ.ಪ್ರಮಾಣ/Connected Load	0.0KW

ನಿಗದಿತ ಶುಲ್ಕ/Fixed Charges (Unit, Rate, Amount)

1 KW	100	100.00
4 KW	110	440.00

ವಿದ್ಯುತ್ ಶುಲ್ಕ/Energy Charges (Unit, Rate, Amount)

50	4.15	207.50
50	5.6	280.00
100	7.15	715.00
45	8.2	369.00

ಇಂಧನ ಹೊಂದಾಣಿಕೆ ಶುಲ್ಕ/FAC Charges (Unit, Rate, Amt)

245	0	0.00

Additional Charges

ರಿಯಾಯಿತಿ/ Rebate	0.00
ಪಿ ಎಫ್ ದಂಡ/PF Penalty	0.00
ಹೆ.ಲೋ.ದಂಡ/Ex.Load/MD Penalty	0.00
ಬಡ್ಡಿ/Interest	0.00
ಇತರೇ/Others	0.00
ತೆರಿಗೆ/Tax	141.44
ಬಿಲ್ ಮೊತ್ತ/Bill Amt	2252.94
ಬಾಕಿ/Arrears	0.00
ಜಮೆ/Credits & Adjustment	0.00
ಸರ್ಕಾರದ ಸಹಾಯಧನ/GOK Subsidy	0.00

ಪಾ ಮೊತ್ತ/Net Amt Due	₹ 2253.00
ಪಾವತಿಗೆ ಕಡೇಯ ದಿನಾಂಕ/Due Date	16/06/2022

QUESTION:

The list of loads and average consumption hours per day of a typical household is given below:

S.No.	Name of the Appliance	Wattage	Average consumption hours per day
1.	**Four LED Bulbs**	**15 W each**	**14 hours**
2.	**Four Ceiling fans**	**75 W each**	**12 hours**
3.	**Geyser**	**1 kW**	**1 hour**
4.	**Refrigerator**	**100 W**	**24 hours**
5.	**Television**	**50 W**	**8 hours**
6.	**Mixer Grinder**	**750 W**	**15 minutes**
7.	**Water Pump**	**750 W**	**30 minutes**

Considering a 30-day month, Determine

i) Total number of units consumed in a month

ii) Monthly bill for the above consumption units considering a domestic connection of 5 kW sanctioned load with the tariff details given below:

S.No	Type of Charges	Tariff Details
1.	**Fixed Charges for the sanctioned load**	**100/- - For first kW** **110/- - For every additional kW**
2.	**Energy consumption Charges**	**0 – 50 Units @ 4.15/- Per Unit** **51 – 100 Units @ 5.6/- Per Unit** **101 – 200 Units @ 7.15/- Per Unit** **Above 200 Units @ 8.2/- Per Unit**
3.	**Fuel Adjustment Charges**	**@ 0 Paise per unit consumed**
4.	**Tax applicable only for units consumed**	**@ 9% (Note: Only applicable for Units consumed and not for Fixed charges and fuel adjustment charges)**

CALCULATIONS

Sl.No.	Name of the Appliance	Wattage	Avg consumption hours/ day	Units consumed per day
1.	**Four LED Bulbs**	**15 W each**	**14 hours**	**4*15*14 = 0.84 kWhr = 0.84 Units**
2.	**Four Ceiling fans**	**75 W each**	**12 hours**	**4*75*12 = 3600 Whr = 3.6 units**
3.	**Geyser**	**1 kW**	**1 hour**	**1 kW*1 Hr = 1 unit**
4.	**Refrigerator**	**100 W**	**24 hours**	**100 W*24 hrs = 2400 Whr = 2.4 units**
5.	**Television**	**50 W**	**8 hours**	**50*8 = 400 Whr = 0.4 units**
6.	**Mixer Grinder**	**750 W**	**15 minutes**	**750*(15/60) =187.5Whrs = 0.1875 units**
7.	**Water Pump**	**750 W**	**30 minutes**	**750*(1/2) =375Whrs = 0.375units**

- Total units consumed per day = 8.192 Units per day
- Total units consumed per month = 30 x 8.192 = 245.76 units per month = Rounding off to 245 Units

TARIFF DETAILS AND CALCULATIONS

Sl.NO	TYPE OF CHARGES	TARIFF DETAILS	TARIFF CALCULATIONS
1.	Fixed Charges for the sanctioned load	100/- - For first kW 110/- - For every additional kW	(100*1) + (110*4) = 540.00
2.	Energy consumption Charges	0 – 50 Units @ 4.15/- Per Unit 51 – 100 Units @ 5.6/- Per Unit 101 – 200 Units @ 7.15/- Per Unit Above 200 Unit @ 8.2/- Per Unit	50 * 4.15 = 207.50 50 * 5.6 = 280.00 100 * 7.15 = 715.00 45 * 8.2 = 369.00 Total = 1571.50
3.	Fuel Adjustment Charges (FAC)	@ 0 Paise per unit consumed	0 * 245 = 0.00
4.	Tax applicable only for units consumed	@ 9% On 245 units consumed	0.09 * 1571.50 = 141.44

Monthly bill = 540.00 + 1571.50 + 141.44 = 2252.94 = Rs. 2253.00