Handwritten Notes

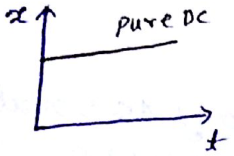
On

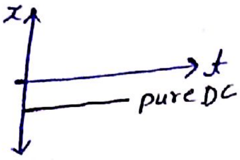
Alternating Current

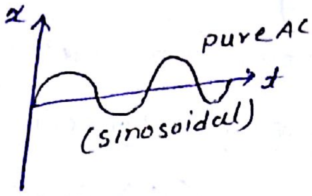
'ALTERNATIN CURRENT'

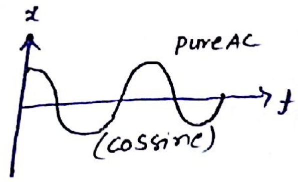
Electrical signal

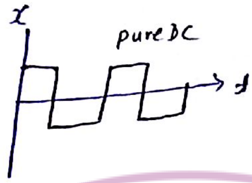
- → Direct (unidirectional, ϕ const)
- → Alternating (Bidirectional, periodic, positive peak equal to negative peak position.)

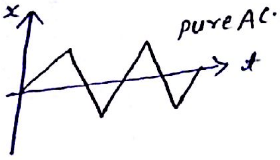


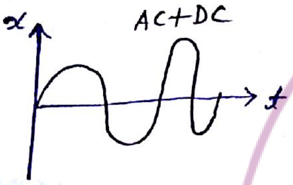












Imp
* AC Measured by Hot wire Instrument
  → Heating Effect of current prove AC.

Imp
* DC measured by Moving coil galvanometer.
  → proved by magnetic Effect of current.

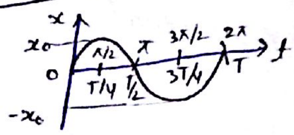
Fundamental Alternating signal.

$\boxed{x = x_0 \sin(\omega t \pm \phi)}$

x → Instantaneous value
x_0 → peak value
$2x_0$ → peak to peak value
Phase Angle → $\omega t + \phi$
ω → Angular frequency.

ϕ = phase difference b/w current & voltage.

case-I $x = x_0 \sin \omega t$



$\boxed{2\pi = T}$

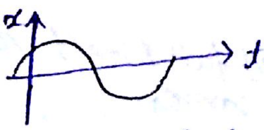
Eg → $\frac{\pi}{3} = \frac{T}{6}$

$\frac{\pi}{4} = \frac{T}{8}$

$\frac{\pi}{6} = \frac{T}{12}$

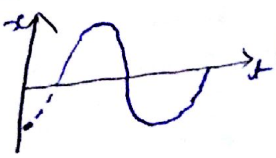
→ In one cycle direction change twice
→ 0 − T/2 ⊕ve Half cycle.
→ T/2 − T ⊖ve half cycle.

case-II $x = x_0 \sin(\omega t + \phi)$



left shifted sign wave.

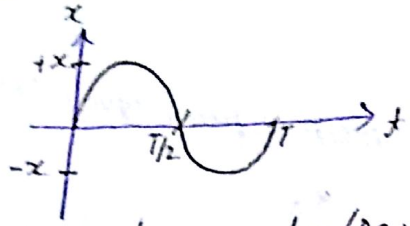
case-III $x = x_0 \sin(\omega t - \phi)$



Right shifted sign wave

Fundamental Alternating signal

$x = x_0 \sin \omega t$



|1| → Average/Mean value/DC voltage

case-I → For complete cycle.

$$\langle x \rangle = \frac{1}{T}\int_0^T x\,dt$$

$$= \frac{1}{T}\int_0^T x_0 \sin \omega t\, dt$$

$$\boxed{\langle x \rangle_T = 0}$$

NOTE → For any AC signal Average for one cycle is always zero.

case-II → For Half cycle

$$\langle x \rangle_{+1/2} = \frac{1}{T/2}\int_0^{T/2} x \cdot dt$$

$$= \frac{2}{T}\int_0^{T/2} x_0 \sin \omega t\, dt$$

$$\langle x \rangle_{+1/2} = \frac{2x_0}{\pi}$$

*

$$\boxed{\begin{aligned} \langle x \rangle_{+1/2} &= +\frac{2x_0}{\pi} \\ \langle x \rangle_{-1/2} &= -\frac{2x_0}{\pi} \end{aligned}}$$

NOTE → For Half cycle Average value for sinosoidal voltage is may be ⊕ve, ⊖ve, zero.

*

Average voltage/current

$\langle \vec{V} \rangle_{cycle} = 0$

$\langle i \rangle_{cycle} = 0$

|2| → Root Mean square velocity (rms, Apparent, Effective, virtual)

$$x_{rms} = \left\{\frac{1}{T}\int_0^T x^2\, dt\right\}^{1/2}$$

$$x_{rms} = \left\{\frac{1}{2} \cdot \int_0^T x_0^2 \sin^2 \omega t\, dt\right\}^{1/2}$$

$$\boxed{x_{rms} = \frac{x_0}{\sqrt{2}}}$$

NOTE → rms of full & Half cycle is same.

POWER LOSS

$$P_{inst} = VI = V_0 \sin(\omega t) \cdot I_0 \sin(\omega t + \phi)$$
$$= \frac{V_0 I_0}{2}\left[\cos\phi - \cos(2\omega t + \phi)\right]$$

$$\langle P_{avg} \rangle_{cycle} = \frac{V_0 I_0}{2} \cos\phi = \frac{V_0}{\sqrt{2}} \cdot \frac{I_0}{\sqrt{2}} \cos\phi$$
$$= V_{rms} \cdot I_{rms} \cdot \cos\phi$$

$P = I^2 R$
$H = I^2 R t$

NOTE → * If Nothing is mentioned then given AC voltage consider rms only.
* For Heat & power calculation only RMS value is used.

Imp! * 220 volt AC is more dangerous than 220 volt DC b/c peak value of AC is 311. (बीच-2 मे आ के झटके मारेगो·)

Form Factor (FF)

$$FF = \frac{x_{rms}}{x_{average}} = \frac{\frac{x_0}{\sqrt{2}}}{\frac{2x_0}{\pi}} = \boxed{\frac{\pi}{2\sqrt{2}}}$$

NOTE →
* $\langle \sin\omega t \rangle_T = 0$
* $\langle \cos\omega t \rangle_T = 0$
* $\langle \sin^2\omega t \rangle_T = 0$
* $\langle \cos^2\omega t \rangle_T = 0$

* $\langle \sin^2\omega t \rangle_T = 1/2$
* $\langle \cos^2\omega t \rangle_T = 1/2$

EX → $I = I_1 + I_2 \sin\omega t$

Short trick

(i) Average for one cycle

$$\boxed{\langle I \rangle_T = \langle I_1 + I_2 \sin\omega t \rangle_T = I_1 + I_2 \times 0 = I_1}$$

(ii) rms for one cycle

$$\boxed{I_{rms} = \left\{\langle I^2 \rangle_T\right\}^{1/2}}$$
$$= \left\{\langle I_1^2 + I_2^2 \sin^2\omega t + 2 I_1 I_2 \sin\omega t \rangle\right\}^{1/2}$$
$$I_{rms} = \left\{I_1^2 + \frac{I_2^2}{2} + 0\right\}^{1/2}$$
$$= \sqrt{I_1^2 + \frac{I_2^2}{2}}$$

*** Phase

When a physical parameter changes ~~sinuslo~~ sinusoidaly with sign then it can be represented by a arrowheaded straight line & this representation is called phase. Where length of line represent peak value.

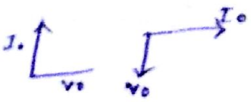
Phaser diagram

It is diagram having phase current & voltage Both.

Ex → $V = V_0 \sin\omega t$
$I = I_0 \sin(\omega t + 30)$

Ex → $V = V_0 \sin\omega t$
$I = I_0 \sin(\omega t - 45°)$

Ex → $V = V_0 \sin\omega t$
$I = I_0 \sin\omega t$

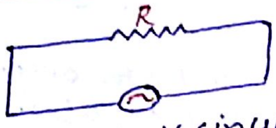


Phase difference (ϕ) → It is difference b/w phase of V & I.

$$\boxed{\text{power factor} = \cos\phi}$$

AC CKtS

|1| → pure Resistive ckt (R)



V = Vo sin ωt

|i| → phase diagram $\xrightarrow{I_o \;\; V_o}$

|ii| → Phase difference = 0

|iii| → power factor $\cos\phi = 1$ (max)

('R' consume the total power of ckt).

By KVL at any Instant.

* $\boxed{I = \frac{V}{R}} = \frac{V_o}{R} \sin\omega t$

$$\boxed{I = I_o \sin\omega t}$$

|2| → pure Inductive ckt (L)

V = Io sin ωt

Inductive Reactance (XL)

* $X_L = \omega L = 2\pi f L$
* $X_L \propto f$

* unit → ohm (R, XL, XC)

By KVL

* $\boxed{I = I_o \sin(\omega t - \pi/2)}$

R → Resistance = R

L, C] Reactance (X) < XL, Xc

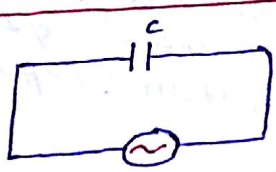
⇓

Z = Impedence

* [General term that include both Resistone & Reactance.]

* voltage leading the current by $\boxed{\pi/2}$
* phase difference = $\boxed{\pi/2}$
* Phaser diagram $V_o \uparrow \; \rightarrow I_o$
* power factor = $\cos\phi = 0$
* power = $V_{rms} I_{rms} \cos\phi = 0$

|3| → pure capacitive ckt (C)



V = Vo sin ωt

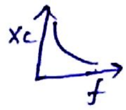
$V = \frac{q}{c} = 0$

$q = CV$

* $\boxed{I = I_o \sin \omega t + \pi/2}$

capacitive Reactance (Xc)

* $X_C = \frac{1}{\omega c} = \frac{1}{2\pi f c}$
* unit → ohm
* $X_C \propto \frac{1}{f}$

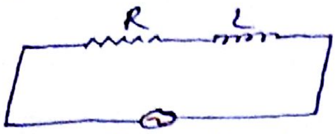


* voltage laging by current by $\boxed{\pi/2}$ angle

so $\boxed{\phi = \pi/2}$

* Phase diagram $\rightarrow I_o$, $V_o \downarrow$

|4| → Series RL →



$I = I_0 \sin\omega t$

current

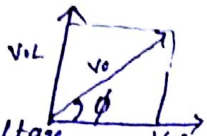
Let, $I = I_0 \sin\omega t$

$V_R = V_{0R} \sin\omega t$

$V_L = V_{0L} \sin(\omega t + \pi/2)$

When $\left[\begin{array}{l} V_{0R} = I_0 R \\ V_{0L} = X_0 X_L \end{array}\right]$

Phase Diagram



Voltage triangle

$\Rightarrow$

XL Impedence triangle.

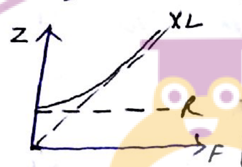
*|i| → $\boxed{V_0 = \sqrt{V_{0R}^2 + V_{0L}^2}}$

**|ii| → Impidence (Z)

$\boxed{Z = \sqrt{R^2 + X_L^2}}$

**|iii| → unit = $\boxed{\text{ohm}}$

|iv| → Z v/s f



* $\boxed{\begin{array}{l} f = 0 \Rightarrow X_L = 0 \Rightarrow Z = R \\ F(\uparrow) \Rightarrow X_L(\uparrow) \Rightarrow Z(\uparrow) \\ F(\infty) \Rightarrow X_L(\infty) \Rightarrow Z(\infty) \end{array}}$

Imp * 'V' Leading

* phase difference(ϕ) = Acute Angle

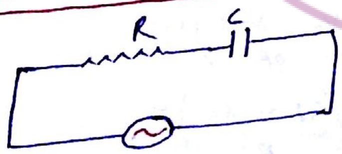
$$\boxed{\phi = \tan^{-1}\left(\frac{V_{0L}}{V_{0R}}\right) = \tan^{-1}\left(\frac{X_L}{R}\right)}$$

* powerfactor $= \cos\phi = \frac{V_{0R}}{V_0} = \boxed{R/Z}$

Imp * Equation of supply voltage

$$\boxed{V_{supply} = V_0 \sin(\omega t + \phi)}$$

|5| → Series RC



Let, ckt current

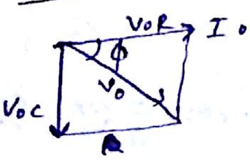
$I = I_0 \sin\omega t$

$\boxed{V_R = V_{0R} \sin\omega t}$

$\boxed{V_C = V_C \sin(\omega t - \pi/2)}$

When $\left[\begin{array}{l} V_{0R} = I_0 R \\ V_{0C} = X_{0C} \end{array}\right]$

Phase diagram



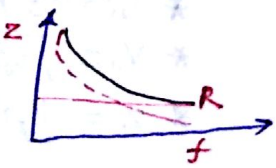
* $\boxed{V_0 = \sqrt{V_{0R}^2 + V_{0C}^2}}$

* Impidence (Z)

$\boxed{Z = \sqrt{R^2 + X_C^2}}$

** Z v/s f

$\left[\begin{array}{lll} * f = 0 & X_C = \infty & \Rightarrow Z = \sqrt{R^2 + X_C^2} = \infty \\ * f(\uparrow) & X_C = \downarrow & \Rightarrow Z \downarrow \\ * f = \infty & X_C = 0 & \Rightarrow Z = R \end{array}\right]$



* Voltage laging.
* Phase difference (ϕ) => Acute Angle.

$$\boxed{\phi = \tan^{-1}\left(\frac{V_{oC}}{V_{oR}}\right) = \tan^{-1}\left(\frac{X_C}{R}\right)}$$

* Power factor

$$\boxed{PF = \cos\phi = \frac{V_{oR}}{V_0} = \frac{R}{Z}}$$

* Equation of power supply

$$\boxed{V_{supply} = V_0 \sin(\omega t - \phi)}$$

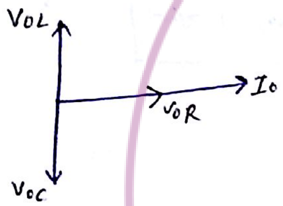
161 → Series RLC

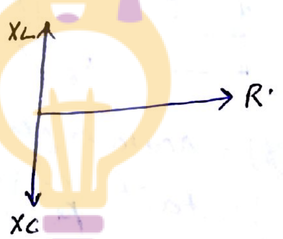
Let $I_{ckt} = I_0 \sin\omega t$

$V_R = V_{oR} \sin\omega t$

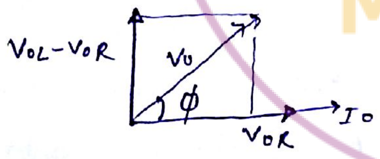
$V_L = V_{oL} \sin(\omega t + \pi/2)$

$V_C = V_{oC} \sin(\omega t - \pi/2)$





Case-I If $V_{oL} > V_{oC}$



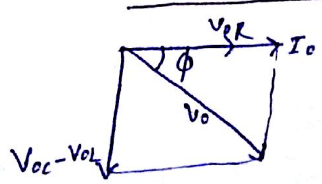
* Series R-L behaviour.
* $V_0 = \sqrt{V_{oR}^2 + (V_{oL} - V_{oC})^2}$
* $Z = \sqrt{R^2 + (X_L - X_C)^2}$
* Voltage leading.
* $\phi = \tan^{-1}\left(\frac{V_{oL} - V_{oC}}{V_{oR}}\right)$

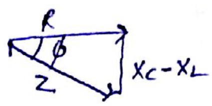
$= \tan^{-1}\left(\frac{X_L - X_C}{R}\right)$

* power factor

$P.F = \cos\phi = \frac{V_{oR}}{V_0} = \boxed{\frac{R}{Z}}$

Case-II → If $V_{oC} > V_{oL}$





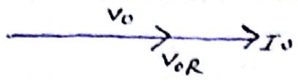
* Power factor $\cos\phi = \frac{V_{oR}}{V_0} = R/Z$

* Series R-C behaviour
* $V_0 = \sqrt{V_{oR}^2 + (V_{oC} - V_{oL})^2}$
* $Z = \sqrt{R^2 + (X_C - X_L)^2}$

* 'V' Laging
* $\phi = \tan^{-1}\left(\frac{V_{oC} - V_{oL}}{V_{oR}}\right)$

$= \tan^{-1}\left(\frac{X_C - X_L}{R}\right)$

Case – III → Voltage Resonance ($V_{oL} = V_{oC}$)



* pure 'R'
* $V_o = V_{oR}$
* $\phi = 0$
* power factor $= \cos\phi = 1$ (Max)
* $Z = R$ (min)
* $I = \frac{V}{Z} = \frac{V}{R}$ (Max)

At Resonance

$(X_L)_r = (X_C)_r$

$\rightarrow (V_{oL})_r = (V_{oC})_r$

$(I_o X_L)_r = (I_o X_C)_r$

$(\omega L)_r = \left(\frac{1}{\omega C}\right)_r$

$\boxed{\omega_r = \frac{1}{\sqrt{LC}}}$ (Rad/sec)

$\boxed{F_r = \frac{1}{2\pi\sqrt{LC}} \text{ (Hz)}}$

⇒ Z v/s f

|i| → f = 0
$R = R$
$X_L = 0$
$X_C = \infty$
$Z = \infty = X_C$

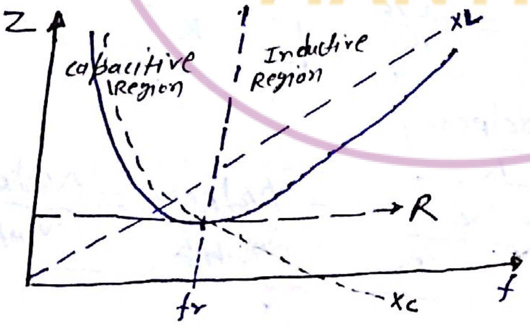
|ii| → $0 < f < f_r$
$R = R$, $X_L = \uparrow$, $X_C = \downarrow$] $X_C > X_L$] series R–C

|iii| → $f = f_r$
$R = R$, $X_L = X_C$] pure 'R'

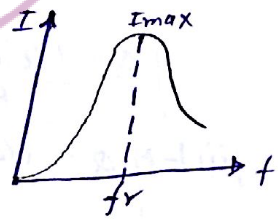
|iv| → $f_r < f < \infty$
$R = R$, $X_L > X_C$] series R–L

|v| → $f = \infty$
$R = R$, $X_L = \infty$, $X_C = 0$] $Z = \infty = X_L$, pure 'L'

⇒

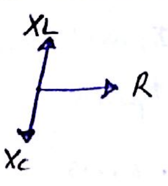


Graph
$I = V/Z$

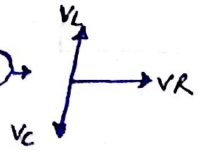


General Knowledge

① → Resistance = R
Reactance = X < $X_L = \omega L$, $X_C = \frac{1}{\omega C}$] Z ⇒



② →

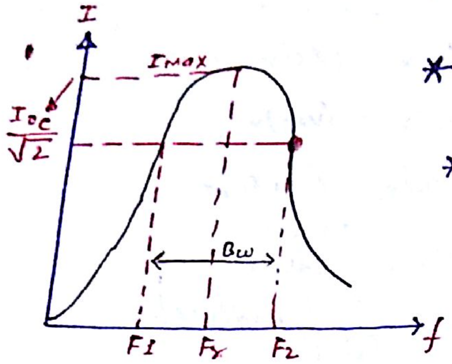


③ → $\phi = \tan^{-1}\left(\frac{V}{R}\right)$

|4| → $\cos\phi = \left(\frac{R}{Z}\right)$ = Powerfactor.

Half power frequency

At this freq. current become $1/\sqrt{2}$ times of I_{max} . so power become Max.



* $f_1 = f_r - \frac{R}{4\pi L}$
* $f_2 = f_r + \frac{R}{4\pi L}$

* Bandwidth (Bw)

$$\Delta f = f_r - f_1$$

$$\Delta f = \frac{R}{2\pi L} \text{ (Hz)}$$

$$\Delta \omega = \frac{R}{L} \text{ (Rad/sec)}$$

* Fractional Band width

$$\frac{\Delta f}{f_r} = \frac{\Delta \omega}{\omega_r}$$

$$\frac{R/L}{1/\sqrt{LC}}$$

$$= \boxed{R\sqrt{\frac{C}{L}}}$$

* Quality factor (Q)

→ Measure of sharpness of 'I' v/s 'f' curve.

→ If 'Q' ↑ ⇒ sharpness ↑

'Q' ↓ ⇒ sharpness ↓

→ It is inverse of fractional Bandwidth.

(i) → $Q = \frac{1}{f_r \cdot Bw} = \boxed{\frac{1}{R}\sqrt{\frac{L}{C}}}$

(ii) → $Q = \frac{\omega_r}{\Delta\omega} = \frac{\omega_r}{R/L} = \frac{\omega_r L}{R} = \boxed{\frac{(X_L)_{resonance}}{R}}$

$$\boxed{Q = \frac{(X_L)_{reso}}{R} = \frac{(X_C)_{reso}}{R}}$$

(iii) → $\boxed{Q = \frac{(V_L)_{reso}}{V_R} = \frac{(V_C)_{reso}}{V_R} = \frac{(V_L)_{reso}}{V_{supply}} = \frac{(V_C)_{reso}}{V_{supply}}}$

power in AC ckt

(i) → $P_{inst} = V_{inst} \cdot I_{inst}$.

(ii) → $P_{peak} = V_{peak} \cdot I_{peak}$

(iii) → $P_{Apparent} = V_{rms} \cdot I_{rms}$

(iv) → Real/Average power of ckt.

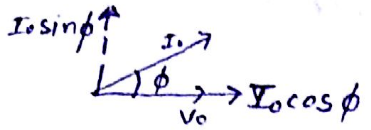
$$\boxed{P = V_{rms} I_{rms} \cos\phi}$$

$$\boxed{P = I_{rms}^2 R = \left(\frac{V_R}{R}\right)^2 R}$$

* ckt voltage & current
$P = V_{rms} I_{rms} \cos\phi$
* $P = I_{rms}^2 R = \frac{V_R^2}{R}$
↳ Resistance voltage.

Wattless current / Workless current / Powerless current

It is part of ckt current which is not Responsible for any power consumption.



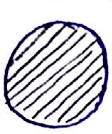
**

* $I_{Wattless} = I_{rms} \sin\phi$
* $I_{wattfull} = I_{rms} \cos\phi$
* I_{ckt} = pythigorous of both.

*** Skin Effect →

* High freq. AC does flow near the surface of wire.
* So, AC coble is made by multible wire of smaller cross-sectional Area rather than thick cable.

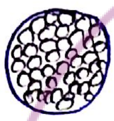
Single Stand Wire



$R = \frac{\rho l}{A}$ $\because A(\downarrow\downarrow\downarrow) \Rightarrow Res.(\uparrow\uparrow\uparrow)$

$\therefore \boxed{\text{power Loss} = I^2 R \text{ Loss}(\uparrow\uparrow)}$

Multi strand Wire



$A_{eff}(\uparrow) \Rightarrow R_{eff}(\downarrow)$

$\boxed{P_{Loss} \Rightarrow \downarrow}$

Hot Wire Ammeter & voltmeter

(i) → Moving coil galvanometer does not work on AC ckt. since its Reverced direction continuosly.

So, Measure AC, A device is made based on Heating effect of current called Hot wire Ammeter & voltmeter.

* Its direction is direction Independent.

$\boxed{\text{Deflection } \theta \propto H}$ *

$\left[\begin{array}{l} \theta = i^2_{rms} \\ \theta \propto V^2_{rms} \end{array}\right]$ $\left[\begin{array}{l} H \propto i^2_{rms} \\ H \propto V^2_{rms} \end{array}\right]$

(ii) → It measure r.m.s value.

(iii) → It has non-linear scale.

(iv) → It can work in AC & DC Both.

NOTE → (i) → In case of Resonance in R-L-C ckt

Amplitude of current is max.

For max Amplitude $\boxed{X_C = X_L}$

Resonance Angular Frequency → $\boxed{\omega = \frac{1}{\sqrt{LC}}}$ *

Linear Frequency → $\boxed{f = \frac{1}{2\pi\sqrt{LC}}}$ *

(ii) → Avg Power

$\boxed{P_{avg} = \frac{V^2_{rms} \cdot R}{|Z|^2}}$

$\cos\phi$ → power factor.

* pure 'R' $\Rightarrow \phi = 0$, $\cos\phi = max = 1$
* pure 'L' or C $\Rightarrow \phi = \frac{\pi}{2}$ or $-\pi/2$, $\cos\theta = 0$ (Watless current found in ckt).

* In India	* In USA
220V	110 V
50 Hz	60 Hz

* 1 unit = 1KWH = $1000 \times 60 \times 60 = 3.6 \times 10^6$ Jule.
* Any scalar quantity come with phase diff. in physics then vector addition occur. not simple addition.

* R → power खाता है।
* L, C → power नहीं खाते हैं।
* L–C → झगड़ा करते हैं

Phase & Amplitude Relation for Alternating current & voltage.

SYMBOL	Impedance	Phase of current	Phase Angle (ϕ)	Amplitude Relation
R	R	Inphase $\bar{c}$ V_R	0°	$V_R = IR$
C	X_C	Leads V_C by 90°	−90°	$V_C = IX_C$
L	X_L	Lags V_L by 90°	+90°	$V_L = IX_L$

Mnemonic ⇒ designed to assist the memory.
↳ 'ELI the ICE man'

* L ⇒ Inductance
* C ⇒ capacitance
* E ⇒ voltage
* I ⇒ current.

* In Inductive ckt (ELI) → the current (I) lags the voltage (E)
* In capacitive ckt (ICE) → the current leads the voltage.