

Basic Electrical & Electronics Engineering

Part A: Basic Electrical Engineering

UNIT- I: DC & AC Circuits

AC Circuits:

- A.C. Fundamentals: Equation of AC Voltage and current,
- waveform, time period, frequency, amplitude,
- phase, phase difference,
- average value, RMS value,
- form factor, peak factor,
- Voltage and current relationship with phasor diagrams in R, L, and C circuits,
- Concept of Impedance, Active power, reactive power and apparent power,
- Concept of power factor (Simple Numerical problems)

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BEEE - PART-A - UNIT-1 DC & AC CIRCUITS

A.C CIRCUITS

A.C Fundamentals

Equation of AC voltage and current

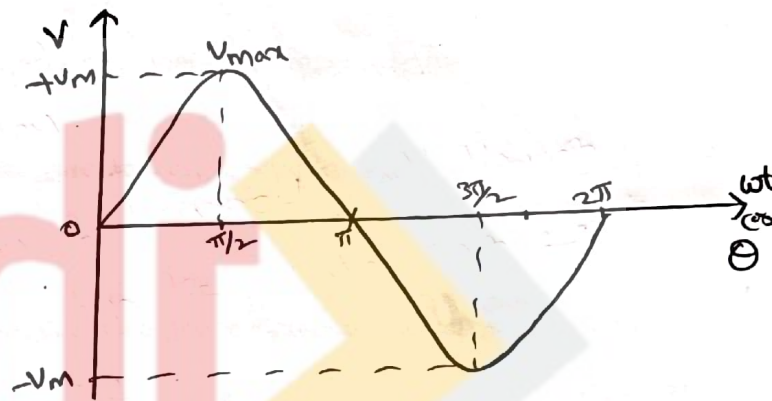
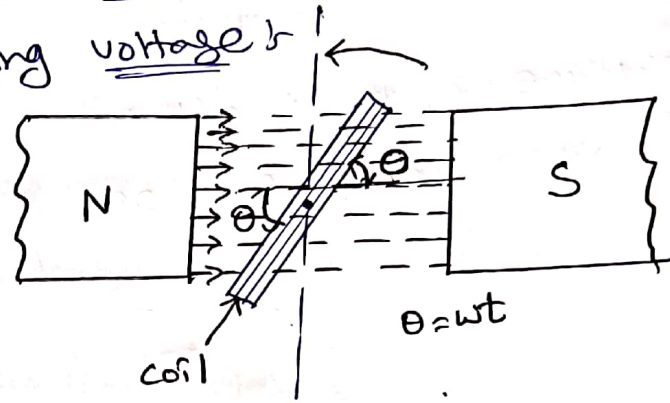
Generation of Alternating voltage

Let N = be the no. of turns in the coil

B = magnetic flux density (or) field strength (Wb/m^2)

A = Area of the coil

θ = angle between the magnetic field and the normal to the plane of the coil.



According to Faraday's law "when ever a conductor cuts the magnetic flux an emf is generated, if the coil is closed circuit then induced current will flow".

From the above figure coil is rotated in anticlockwise direction with angular velocity ωt , then the magnetic flux (ϕ) through one turn of the coil is given by $\phi = B \cdot A \cos \theta$.

The total magnetic flux through the coil with N turns is $\phi_{\text{total}} = NBA \cos \theta$.

The induced EMF (E) is given by Faraday's law

$$E = -\frac{d\phi}{dt}$$

→ If the coil rotate with angular velocity ω , then $\theta = \omega t$

thus $E = -\frac{d\phi}{dt} = -NBA \frac{d}{dt} \cos \omega t$

$$E = -NBA \omega (-\sin \omega t) = NBA \omega \sin \omega t \quad \text{--- (1)}$$

maximum value of 'E' is obtained when the $\sin \omega t = 1$
 $\therefore \omega t \text{ or } \theta = 90^\circ$

$$E_{\max} = NBA \omega \quad \text{--- (2)}$$

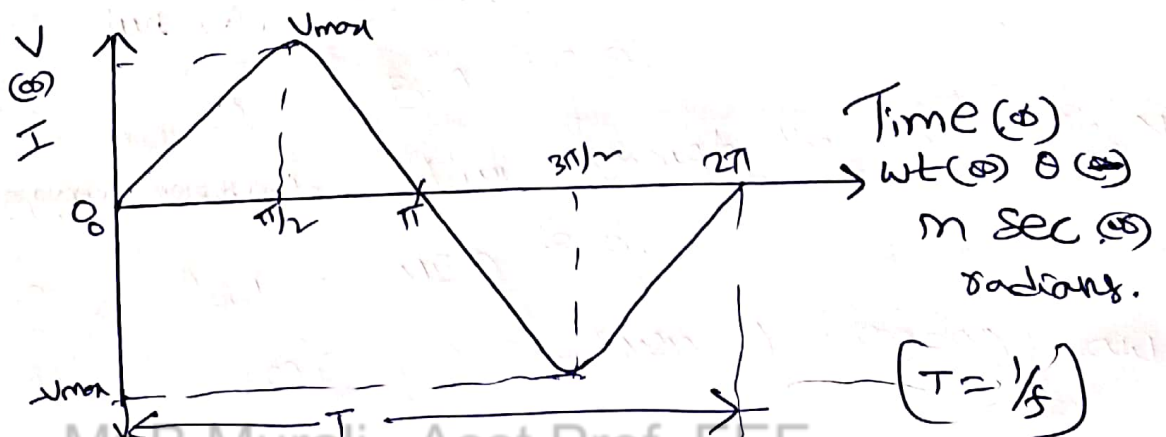
Now equation (2) is substitute in equation (1)

then $E = E_{\max} \sin(\omega t)$ (or) $E = E_m \sin \theta$

This equation shows that the instantaneous voltage (E) produced by an AC generator varies sinusoidally with time, from a maximum value of $+V_{\max}$ to a minimum value of $-V_{\max}$.

Alternating Quantity is any quantity which is varying with respect to time is called as an alternating quantity.

Wave form is The shape of the curve drawn between voltage (or) current [on-Y-axis] and time [on-X-axis] is known as "wave form".



cycle - One complete set of all positive and negative values of an alternating quantity [voltage or current] is known as cycle. The above figure shows the one cycle of alternating current.

A cycle can also be defined in terms of angular measure i.e. one cycle corresponds to 360° electrical or 2π radians.

Time period - The time taken by an alternating quantity to complete one full cycle is called time period. It is denoted by letter "T" in second.

Frequency - The no. of cycles completed by an alternating quantity in one second is called "frequency". It is denoted by the letter "f" and is measured in "Hertz" (Hz).

In India almost of all electrical appliances are operated at 50 Hz. In case of North America it is 60 Hz and in Russia it is 40 Hz.

Instantaneous Value - The value of alternating quantity (v or i) at any instant of time is called "instantaneous value".

maximum or peak value - The maximum value attained by an alternating quantity either in positive or negative direction is called amplitude or peak value of an alternating quantity.

Root-mean-square [R.M.S] value:-

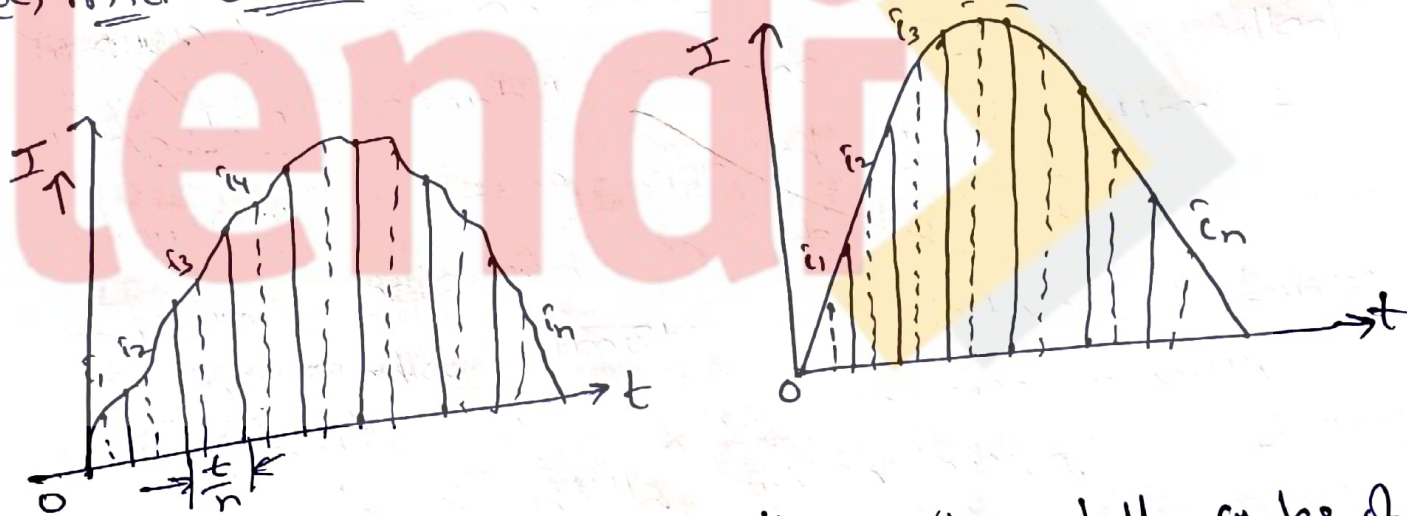
"The steady (D-C) current which when flowing through a given circuit for a given time produces the "same amount of Heat" as produced by an alternating current when flowing through the same circuit for the same time. It is also called as effective or virtual value."

R.M.S value of an alternating quantity can be determined by two methods namely

(a) mid ordinate method.

(b) Analytical method.

(a) mid ordinate method:-



The above figure shows the positive half-cycles of both symmetrical sinusoidal and non-sinusoidal alternating currents. Divide the time base into "n" - equal intervals of time each of duration " $\frac{t}{n}$ " seconds. Let the average values of instantaneous currents during these intervals be $i_1, i_2, i_3, \dots, i_n$ respectively.

We know the Heat " H " = $\frac{I^2 R t}{J}$

$$[\because J = 4200 \text{ kcal}]$$

$$H = \frac{I^2 R t}{4200}$$

$$\therefore H = 0.24 I^2 R t \text{ cal.}$$

$$\text{Heat produced in 1st interval} = 0.24 i_1^2 R \frac{t}{n} \text{ cal}$$

$$2^{\text{nd}} \text{ interval} = 0.24 i_2^2 R \frac{t}{n} \text{ cal}$$

$$\vdots$$
$$n^{\text{th}} \text{ interval} = 0.24 i_n^2 R \frac{t}{n} \text{ cal.}$$

$\therefore$ The total Heat produced in " t " second

$$= 0.24 R t \left[\frac{i_1^2 + i_2^2 + \dots + i_n^2}{n} \right]$$

Now, suppose that a direct current of value " I " produced the same heat through the same resistance during the same time " t ".

$$\text{Heat produced, } H = 0.24 I^2 R t \text{ cal.}$$

By definition, the two amounts of heat produced should be equal.

$$\therefore 0.24 I^2 R t = 0.24 R t \left[\frac{i_1^2 + i_2^2 + \dots + i_n^2}{n} \right]$$

$$I^2 = \left[\frac{i_1^2 + i_2^2 + \dots + i_n^2}{n} \right]$$

$$\therefore I_{\text{rms}} = \sqrt{\frac{i_1^2 + i_2^2 + \dots + i_n^2}{n}}$$

(b) Analytical method: The standard form of sinusoidal alternating current is $i = I_m \sin \omega t$ (or)

$$e = I_m \sin \theta.$$

The mean of the squares of the instantaneous values of current over one complete cycle is

$$\begin{aligned}
 I_{rms}^2 &= \int_0^{2\pi} \frac{i^2}{(2\pi-0)} d\theta \\
 &= \int_0^{2\pi} \frac{I_m^2 \sin^2 \theta}{2\pi} d\theta \quad \left[\cos 2\theta = 1 - 2\sin^2 \theta \right] \\
 &= \frac{I_m^2}{2\pi} \int_0^{2\pi} \left(\frac{1 - \cos 2\theta}{2} \right) d\theta \\
 &= \frac{I_m^2}{2\pi} \cdot \frac{1}{2} \left[\theta \right]_0^{2\pi} - \left(\frac{\sin 2\theta}{2} \right) \Big|_0^{2\pi} \\
 &= \frac{I_m^2}{4\pi} \left[(2\pi - 0) - \left(\frac{\sin 2(2\pi)}{2} - \frac{\sin 2(0)}{2} \right) \right]
 \end{aligned}$$

$$\begin{aligned}
 I_{rms} &= \sqrt{\frac{I_m^2}{4\pi} \cdot 2\pi} = \frac{I_{max}}{\sqrt{2}} = 0.707 I_{max}.
 \end{aligned}$$

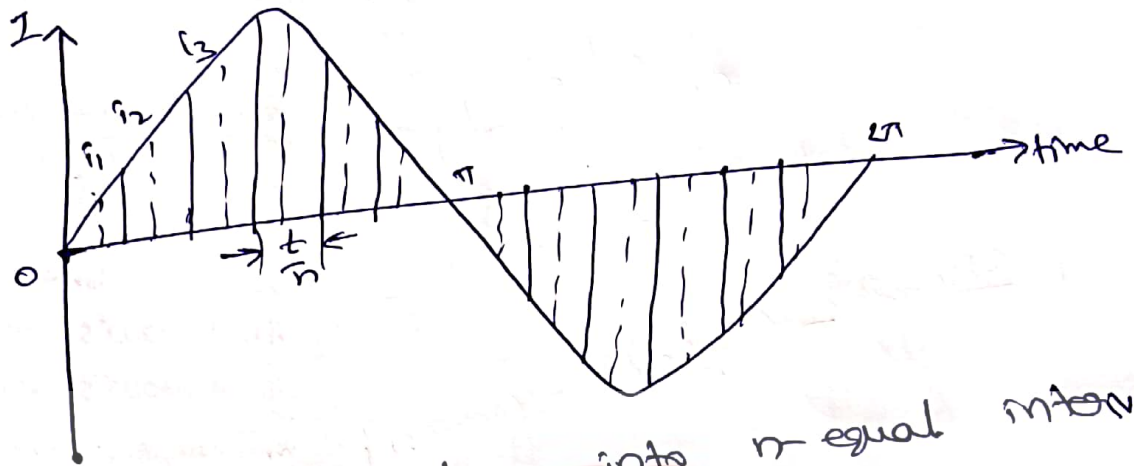
$$I_{r.m.s} = \frac{I_{max}}{\sqrt{2}}$$

Average value: "The steady (D-C) current which when flow through a given circuit for a given time produces the "same amount of charge" as produced by an alternating current when flowing through the same circuit for the same time."

In case of symmetrical alternating quantities [i.e one cycle whose two-half

cycle are exactly similar whether the waveform are sinusoidal or non-sinusoidal, the average value over a complete cycle is zero.

(a) mfd ordinate method:-



Divide the time base into n equal intervals of time each of duration " $\frac{t}{n}$ " seconds. Let the average values of instantaneous currents during these intervals be $i_1, i_2, \dots, i_n$ respectively.

∴ The average value of the alternating current is given by

$$I_{avg} = \frac{i_1 + i_2 + \dots + i_n}{n}$$

(b) Analytical method:-

The standard form of a sinusoidal alternating current is $i = I_{max} \sin \theta$ (eq)

$I_{max} \sin \theta$

The average value of alternating quantity over a half cycle

$$I_{av} = \int_0^{\pi} \frac{i}{\pi - 0} d\theta$$

$$= \int_0^{\pi} \frac{I_{max} \sin \theta}{\pi} d\theta$$

$$= \frac{I_{max}}{\pi} \int_0^{\pi} \sin \theta d\theta$$

$$= \frac{I_{max}}{\pi} [-\cos \theta]_0^{\pi}$$

$$= \frac{I_{max}}{\pi} [-\cos \pi + \cos 0]$$

$$= \frac{I_{max}}{\pi} [-(-1) + 1]$$

$$\therefore I_{avg} = \frac{2 I_{max}}{\pi}$$

$$= 0.637 I_{max}$$

$$\text{Similarly } V_{avg} = \frac{2 V_{max}}{\pi} = 0.637 V_{max}$$

Form factor's "The ratio of R.m.s value to average value".

$$\text{Form Factor } (k_f) = \frac{\text{R.m.s value}}{\text{Average value}}$$

eg: For sinusoidal voltage (or) current wave form

$$\text{Form factor} = \frac{0.707 I_{max}}{0.637 I_{max}} = 1.11$$

Peak factor's (or) Crest factor

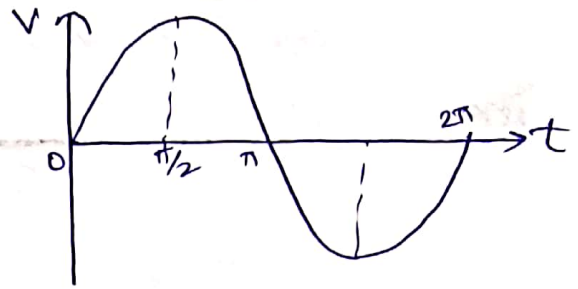
"The ratio of maximum value to R.m.s value"

$$\text{Peak factor } (k_p) = \frac{\text{maximum value}}{\text{R.m.s value}}$$

eg: For sine wave, $k_p = \frac{I_{max}}{0.707 I_{max}} = 1.414$

PHASE phase of an alternating quantity depends upon the instant from which the time is measured.

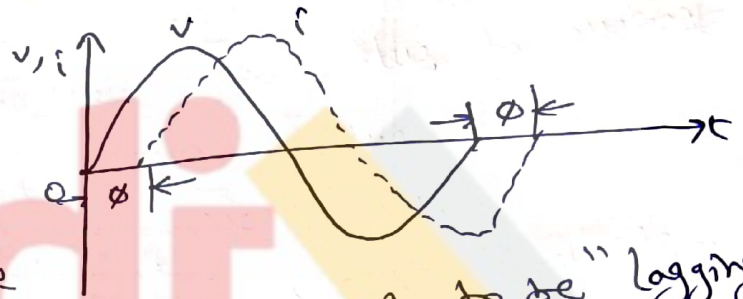
From figure time is measured from the instant of the voltage is zero.



Phase Difference's

Two alternating quantities of the same frequency and differ in the fraction of the time period is called the "phase difference". Here " ϕ " is called phase difference and is measured in "degrees" or "Radian's".

The alternating quantity which passes through zero position earlier is said to be "leading" and while the other said to be "lagging".



condition for finding the phase angle between two alternating sinusoidal quantities:-

→ Both the alternating quantities must be have the Same frequency otherwise it is not possible to find phase angle.

eg: Let
$$\begin{aligned} v_1(t) &= V_m \sin \omega t \\ v_2(t) &= V_m \cos \omega t \end{aligned}$$
 } The phase angle between $v_1(t)$ & $v_2(t)$ cannot be determined.

→ Both the quantities must be either sinusoidally varying or cosinusoidally varying.

→ Both the quantities must be expressed with positive amplitude.

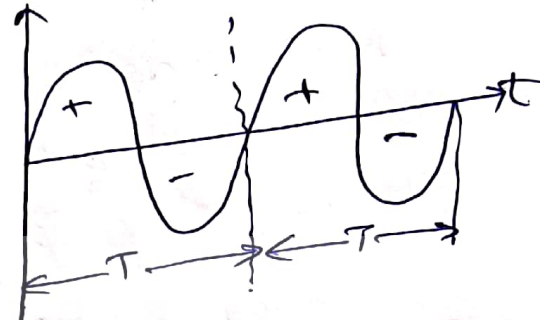
→ Both the quantities need not have the same Amplitude.

wave forms are two types

① periodic wave form ② Non-periodic wave form.

① periodic wave form → periodic wave form is one which repeats after a fixed period. These are again two types.

(i) Symmetrical wave form → If the negative half is same as the positive half then it is called Symmetrical wave form.

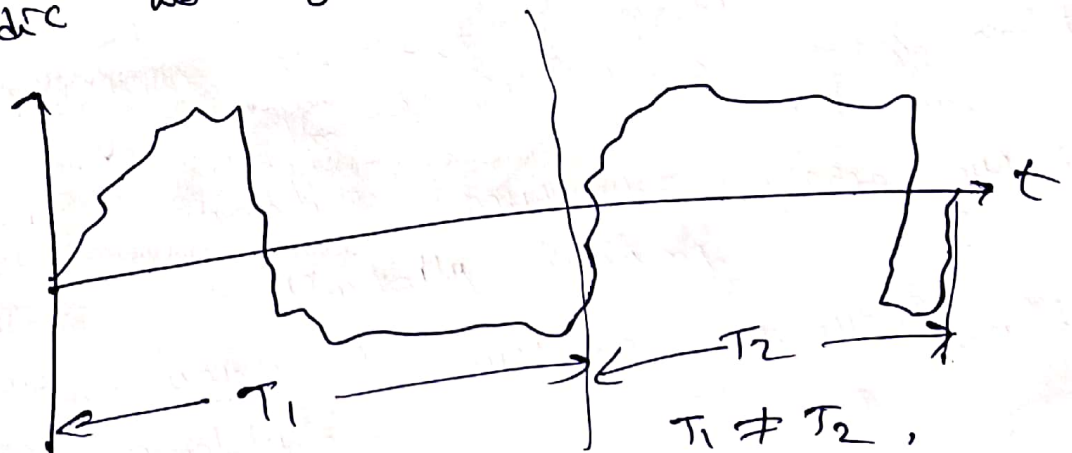


(ii) Unsymmetrical wave form → If the negative half is different from positive half then it is called unsymmetrical wave form.



② Non periodic wave form →

If the wave form is does not have specific period then it is called non-periodic wave form



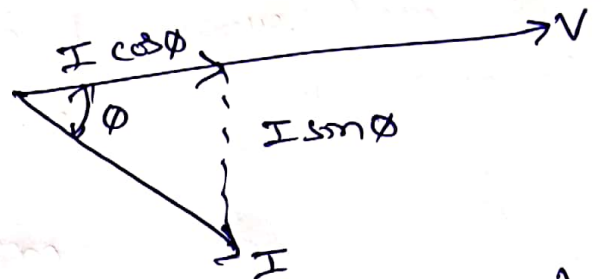
Power is the rate of energy conversion.

(i) Active power (or) Real power (P):

It is the product of rms voltage and the in phase component of rms current.

$$\therefore P = VI \cos \phi \text{ watts.}$$

Units are watts (or) KW



(ii) Reactive power (Q)

It is the product of rms voltage and the quadrature component of rms current.

$$\therefore Q = VI \sin \phi \text{ VAR. (or) KVAR.}$$

Reactive power is the power which is responsible for production of flux " ϕ ".

(iii) Apparent power (S)

The product of R-m-s voltage and rms current is known as Apparent power (S).
It is known as Volt amperes. (VA or KVA).

$$\therefore S = VI$$

Power Triangle

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

$$S = P + jQ$$

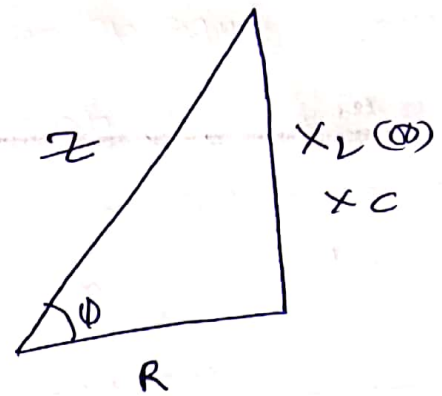


Impedance Triangle

$$Z = \sqrt{R^2 + X_L^2} \quad (\omega)$$

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

$$Z = R + jX$$



Power Factor

 It is defined as

→ The cosine of the phase angle between voltage and current.

→ The Ratio of Real power to apparent power.

$$\therefore P.F., (\cos \phi) = \frac{P}{S}$$

→ The Ratio of Resistance to Impedance

$$\therefore P.F., (\cos \phi) = \frac{R}{Z}$$

* The value of Power factor can never be more than "Unity".

Resistance (R): which material to opposes the flow of current. [units are Ω]

Inductive Reactance (X_L): It opposes the sudden change of current, then $X_L = 2\pi fL$; $Z = jX_L$

Capacitive Reactance (X_C): It opposes the sudden change of voltage, then $X_C = 1/2\pi fC$; $Z = -jX_C$.

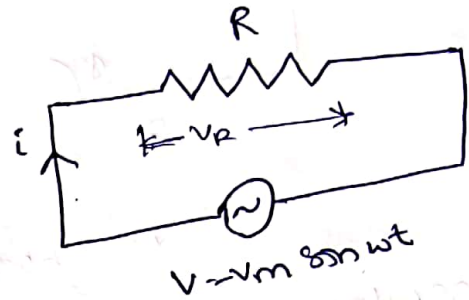
Impedance (Z): It is ratio of voltage to current in A-c circuit.

$$Z = \frac{V}{I} \text{ } \Omega$$

Voltage and current relationship with phase drag

→ Sam in R circuit (a) Resistance is
Connected across an A-C Source

Consider a pure resistor (R)
 Connected across an A-C
 voltage source $V = V_m \sin \omega t$



The current flowing through the "Resistor"

$$i = \frac{V}{R} = \frac{V_m \sin \omega t}{R} \quad \text{--- (1)}$$

when $\sin \omega t = 1$ [the value of i is maximum]

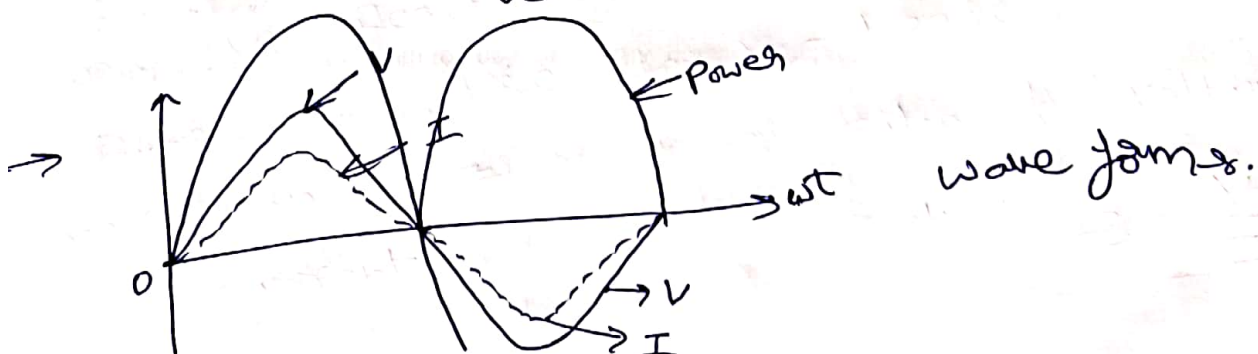
$$\therefore i = \frac{V_m}{R} (1) = \frac{V_m}{R} \Rightarrow \quad \text{--- (2)}$$

$$\therefore I_{\max} = \frac{V_{\max}}{R}$$

From (1) & (2) $i = I_{\max} \sin \omega t$ --- (3)

→ From $V = V_m \sin \omega t$ and $I = I_m \sin \omega t$ is
 observed that the applied voltage and the
 current flowing through the resistance are
 "In phase" with each other.

→ Vector diagram. or phasor diagram.



→ The phase difference " ϕ " = 0.

→ Power factor, $\cos \phi = 1$ (unity).

→ Impedance $Z = \frac{V}{I} = \frac{V_m}{I_m/R} = R$.

→ Average power, $P = V_m \sin \omega t \cdot I_m \sin \omega t$

$$= V_m I_m \sin^2 \omega t$$

$$= V_m I_m \frac{(1 - \cos 2\omega t)}{2}$$

$$= \frac{V_m I_m}{2} - \frac{V_m I_m \cos 2\omega t}{2}$$

For whole cycle $\frac{V_m I_m \cos 2\omega t}{2}$ equal to zero.

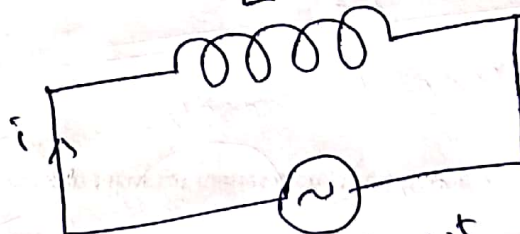
$$\therefore \text{So, } P = \frac{V_m I_m}{2} = \frac{V_m}{\sqrt{2}} \cdot \frac{I_m}{\sqrt{2}}$$

$$P = V_{rms} \cdot I_{rms}$$

$$\boxed{P = VI}$$

Voltage and current relationship with phase diagram
in inductor "L" circuit (a) Behaviour of a
pure inductor in an A-c circuit

Let us consider a pure inductance (L) is
connected across an A-c voltage source.



$$V = V_m \sin \omega t$$

The instantaneous value of A-c voltage is
given by $V = V_m \sin \omega t$ ——— (1)

We know that when ever an AC voltage is applied across a pure inductance coil causes a back emf is produced due to the self inductance of the coil.

$$V = L \frac{di}{dt} \quad \text{--- (2)}$$

$$\therefore di = \frac{V}{L} dt = \frac{V_m \sin \omega t}{L} dt$$

Integrating the above equation on both sides.

$$\int di = \int \frac{V_m}{L} \sin \omega t dt$$

$$i = \frac{V_m}{L} \left(\frac{-\cos \omega t}{\omega} \right) = -\frac{V_m}{\omega L} \cos \omega t$$

$$i = \frac{V_m}{\omega L} \sin \left(\omega t - \frac{\pi}{2} \right) \quad \text{--- (3)}$$

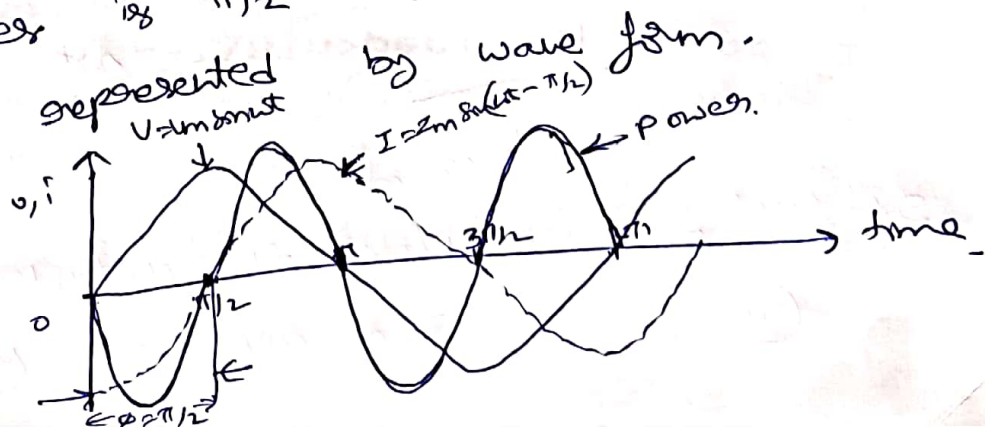
maximum value attained by the current at $\sin \left(\omega t - \frac{\pi}{2} \right) = 1$

$$\text{So, } I_{\max} = \frac{V_m}{\omega L} \quad \text{--- (4)}$$

Substitute the equation (4) in equation (3)

$$I = I_m \sin \left(\omega t - \frac{\pi}{2} \right) \quad \text{--- (5)}$$

From equation (1) & (5) it is observed that the current lags behind the applied voltage by an angle $\pi/2$ and it is represented by vector form. The phase difference between the two quantities is $\pi/2$ with voltage leading and it is represented by wave form.



Power Product of voltage and current at that instant.

$\therefore$ instantaneous power, $P = v \cdot i$

$$= V_m \sin \omega t \cdot I_m \sin(\omega t - \frac{\pi}{2})$$

$$= V_m I_m \sin \omega t \sin(\omega t - \frac{\pi}{2})$$

$$= V_m I_m \frac{2}{2} \sin \omega t (-\cos \omega t)$$

$$= -\frac{V_m I_m}{2} \sin 2\omega t$$

$$= -\frac{V_m I_m}{2} \sin 2\omega t$$

$$P = -\frac{V_m I_m}{2} \int_0^{2\pi} \sin 2\omega t \, dt$$

$\therefore$ The power for whole cycle, $P = 0$ watts.

The above wave form during the first 90° of cycle, the voltage is positive and current is negative. The power supplied negative and during the next 90° of cycle the voltage and current are positive. Hence the resultant power over half cycle is zero. Similarly during the next cycle the power becomes zero i.e., the power consumed in a pure inductance is zero.

$\rightarrow$ The current flowing through the pure inductance is 90° lagging with the voltage phase.

$\rightarrow$ phase difference, $\phi = 90^\circ$ lagging

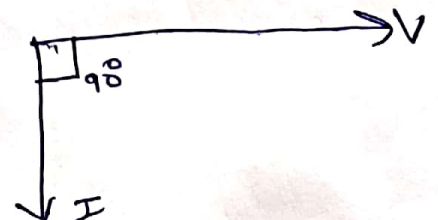
$\rightarrow$ power factor, $\cos \phi = 0$ lag

$\rightarrow$ power consumed, $P = 0$ watts.

$\rightarrow$ inductive reactance, $X_L = 2\pi fL$

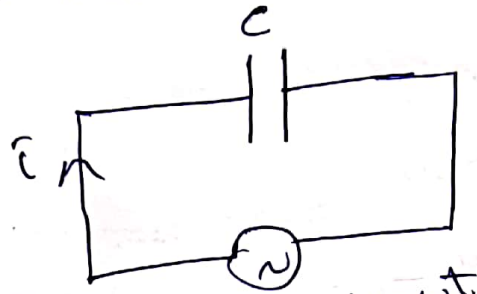
$\rightarrow$ impedance (Z) = jX_L

$\rightarrow$ vector diagram $\Rightarrow$



Capacitor is connected across an A-c source

Let us consider a pure capacitance (C) is connected across an A-c voltage source.



$$V = V_m \sin \omega t$$

Let the instantaneous value of A-c voltage is given by $V = V_m \sin \omega t$ ——— ①

we know that when ever an alternating voltage is applied across a pure capacitance causes the capacitor is charged from in one direction and then in the opposite direction.

Let q be the charge on plates at the given instantaneous $\therefore q = CV = C V_m \sin \omega t$ ——— ②

we have $i = \frac{dq}{dt}$

(The current is nothing but rate of flow of charge)

$$i = \frac{d}{dt}(q) \text{ ——— ③}$$

from equation ② & ③

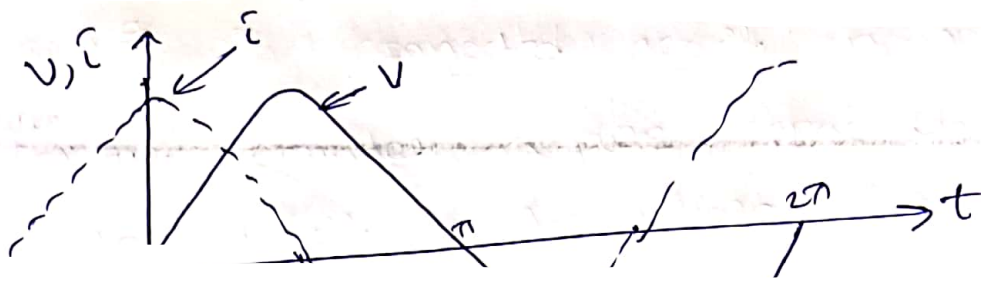
$$i = \frac{d}{dt}(C V_m \sin \omega t)$$

$$i = C V_m \cos \omega t \cdot \omega$$

$$= \omega C V_m \cos \omega t$$

$$i = \frac{V_m}{1/\omega C} \cos \omega t$$

$$i = \frac{V_m}{1/\omega C} \sin\left(\omega t + \frac{\pi}{2}\right) \text{ ——— ④}$$



From the equations ① & ③ it is observed that the current leads the applied voltage by an angle $\frac{\pi}{2}$ and it is represented by vector form.

Power product of voltage and current at that instant.

Instantaneous power, $P = V i$

$$P = V_m \sin \omega t \cdot I_m \sin \left(\omega t + \frac{\pi}{2} \right)$$

$$P = V_m I_m \sin \omega t \cos \omega t$$

$$P = \frac{V_m I_m}{2} \sin 2\omega t$$

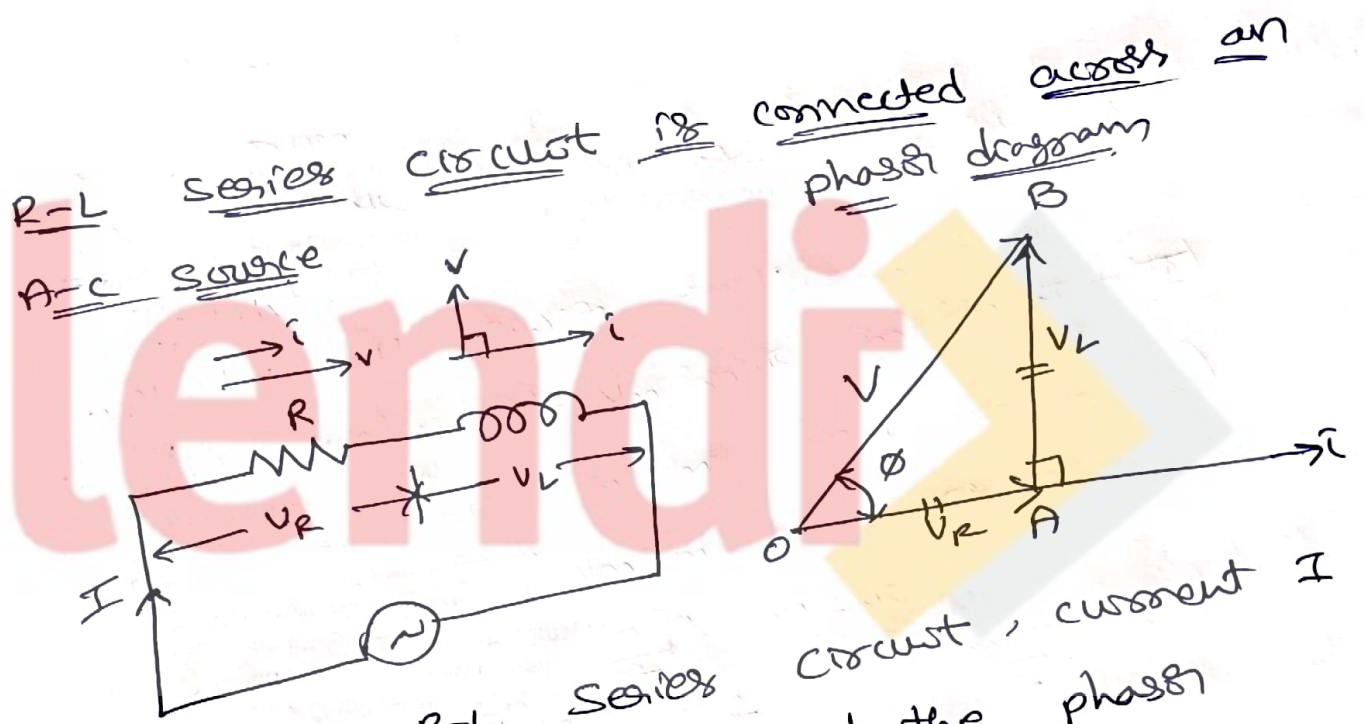
$$\therefore \text{power for the whole cycle} = \int_0^{2\pi} \frac{V_m I_m}{2} \sin 2\omega t \, dt$$

$$\therefore P_{\text{max}} = \frac{V_m I_m}{2} = 0 \text{ watt,}$$

Vector diagram



- The current flowing through the pure capacitance is 90° leading with the voltage phase.
- phase difference, $\phi = 90^\circ$ leading.
- power factor, $\cos \phi = 0$ leading.
- power consumed, $P = 0$ watts.
- Capacitive reactance, $X_C = \frac{1}{2\pi fC}$
- impedance, $Z = -jX_C$



In this R-L series circuit, current I is taken as reference phasor and the phasor diagram is drawn.

The applied voltage " V " is the phasor sum of " V_R " and " V_L ".

Sum of voltage drops of " V_R " and " V_L ".

From the vector diagram " OB " = $\sqrt{OA^2 + AB^2}$

$$V = \sqrt{V_R^2 + V_L^2}$$

$$V = \sqrt{(IR)^2 + (IX_L)^2}$$

$$V = I \sqrt{R^2 + X_L^2}$$

$$\therefore I = \frac{V}{\sqrt{R^2 + X_L^2}}$$

Here $Z = \sqrt{R^2 + X_L^2}$ (Impedance)

$$\therefore I = \frac{V}{Z} \Rightarrow V = IZ$$

→ phase angle (ϕ) :- From the vector diagram the current I lag behind the applied voltage V by an angle " ϕ "

$$\therefore \tan \phi = \frac{V_L}{V_R} = \frac{IX_L}{I \cdot R} = \frac{X_L}{R}$$

$$\therefore \phi = \tan^{-1} \left[\frac{X_L}{R} \right]$$

→ Power in R-L circuit

$$P = VI = V_m \sin \omega t \cdot I_m \sin (\omega t - \phi)$$

$$= \frac{1}{2} V_m I_m [2 \sin \omega t \cdot \sin (\omega t - \phi)]$$

[We know that $2 \sin A \sin B = \cos(A-B) - \cos(A+B)$]

$$P = \frac{V_m I_m}{2} [\cos \phi - \cos (2\omega t - \phi)]$$

$$P = \frac{V_m I_m}{2} \cos \phi - \frac{V_m I_m}{2} \cos (2\omega t - \phi)$$

Since average value of pulsating component $\frac{1}{2} V_m I_m \cos (2\omega t - \phi)$ over a complete cycle is zero.

$$\therefore P = \frac{1}{2} V_m I_m \cos \phi$$

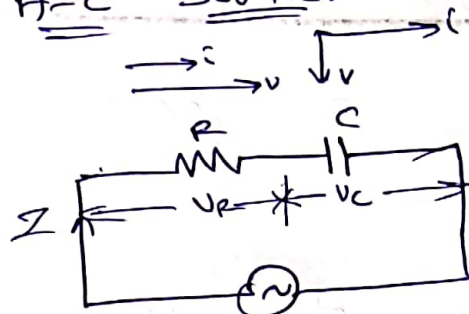
$$= \frac{V_m}{\sqrt{2}} \cdot \frac{I_m}{\sqrt{2}} \cos \phi$$

$$\therefore P = VI \cos \phi$$

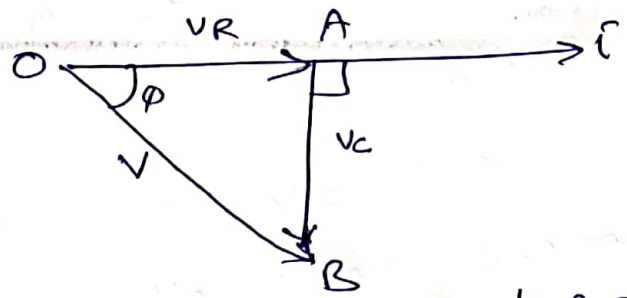
Average Power, $P = VI \cos \phi$

where V & I are the rms values of voltage and current.

R-C circuit is connected across an A-C Source



$V = V_m \sin \omega t$
circuit diagram



Vector (or) phasor diagram.

From the vector diagram, $OB = \sqrt{OA^2 + AB^2}$

$$V = \sqrt{V_R^2 + V_C^2}$$

$$V = I \sqrt{R^2 + X_C^2}$$

$$\therefore I = \frac{V}{\sqrt{R^2 + X_C^2}} = \frac{V}{Z}$$

Here, impedance $Z = \sqrt{R^2 + X_C^2}$

→ phase angle (φ): From the vector diagram, the current 'I' leads at an angle φ w.r.t to applied voltage 'V'.

$$\therefore \tan \phi = \frac{V_C}{V_R} = \frac{I X_C}{I R} = \frac{X_C}{R}$$

$$\phi = \tan^{-1} \left[\frac{X_C}{R} \right] \text{ leading.}$$

→ power factor, $(\cos \phi) = \frac{R}{Z}$ (or)

$$\cos \phi = \cos \left[\tan^{-1} \left(\frac{X_C}{R} \right) \right] \text{ leading.}$$

→ power in R-C series circuit:

$$P = VI = V_m \sin \omega t \cdot I_m \sin (\omega t + \phi)$$

$$= \frac{1}{2} V_m I_m [2 \sin \omega t \sin (\omega t + \phi)]$$

$$= \frac{V_m I_m}{2} [\cos \omega t - \cos (2\omega t + \phi)]$$

Since the average value of pulsating component $\frac{1}{2} V_m I_m \cos \phi$ over a complete cycle is zero.

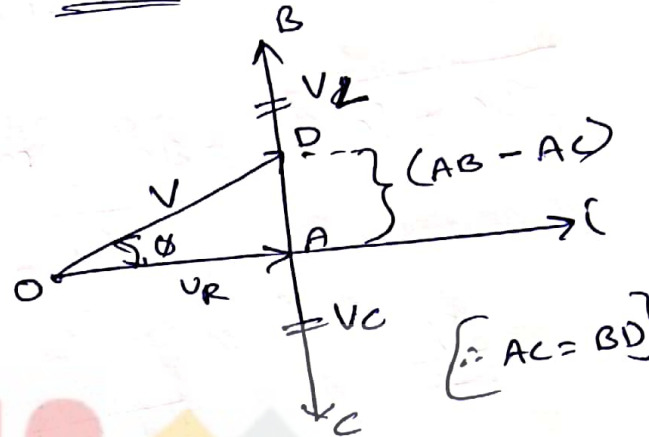
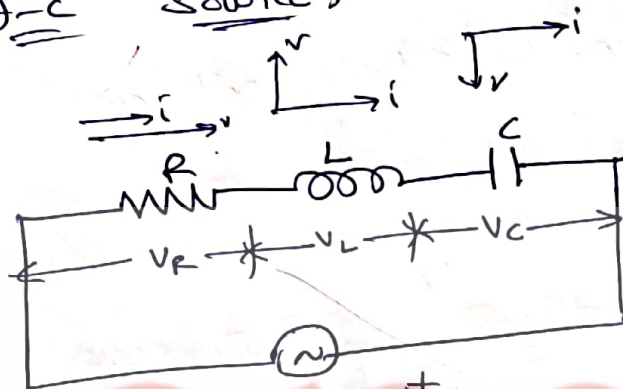
$$\therefore P = \frac{1}{2} V_m I_m \cos \phi = \frac{V_m}{\sqrt{2}} \cdot \frac{I_m}{\sqrt{2}} \cos \phi$$

$$P = VI \cos \phi.$$

$\therefore$ Average power, $P = VI \cos \phi$.

R-L-C series circuit is connected across an

A-C source



$V = V_m \sin \omega t$.
From the vector diagram, the voltage drops across inductor (V_L) and capacitor (V_C) are 180° out of phase with each other.

Assume that $V_L > V_C$

$$\begin{aligned} \text{The net reactance drop} &= AB - BD \quad \text{or} \\ &= AB - AC \\ &= AD. \end{aligned}$$

From voltage triangle

$$OD^2 = OA^2 + AD^2$$

$$V^2 = V_R^2 + (V_L - V_C)^2$$

$$V^2 = IR^2 + (Z_L - XC)^2$$

$$V = I \sqrt{R^2 + (X_L - X_C)^2}$$

$$\therefore I = \frac{V}{Z}$$

$$\therefore Z = \sqrt{R^2 + (X_L - X_C)^2}$$

Power factor, $\cos \phi = \frac{R}{Z}$

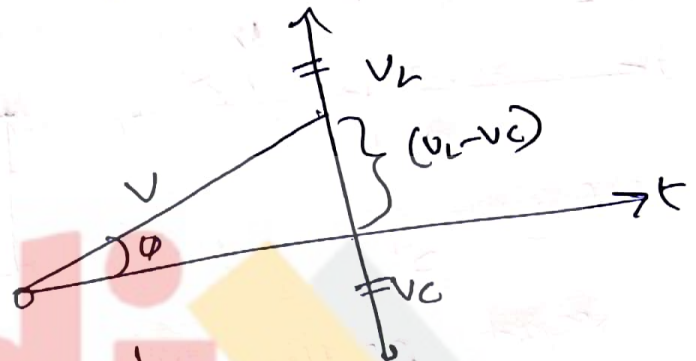
power = power consumed, $P = VI \cos \phi$ watt.

Three cases in R-L-C series circuit:

Case 1: when $X_L > X_C$ and $X_L - X_C$ is positive.
In this condition the circuit behaves like more inductive. The current I lags behind the applied voltage V by an angle ' ϕ '.

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

$$\therefore Z = \sqrt{R^2 + (X_L - X_C)^2}$$

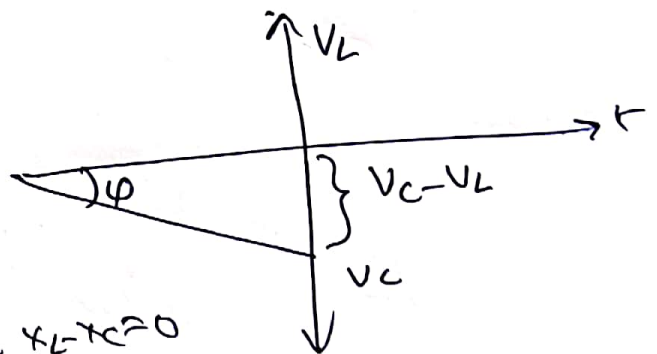


Case (ii) when $X_C > X_L$ and $X_L - X_C$ is negative.

In this condition, the circuit behaves like more capacitive. The current I leads the applied voltage V by an angle ' ϕ '.

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

$$\therefore Z = \sqrt{R^2 + (X_C - X_L)^2}$$



Case (iii), when $X_L = X_C$ and $X_L - X_C = 0$
[behaves like pure resistive]

$$\therefore \phi = 0^\circ, Z = \sqrt{R^2 + (X_L - X_C)^2}$$

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

$$\boxed{Z = R}$$

