

7. Alternating Current

Module 2: AC Circuits with Frequency Dependent Components

This module is designed to help you to:

- explain the concept of phase in Alternating Currents (AC) and voltages;
- illustrate AC and voltage representation using rotating vectors-phasors;
- derive the equations for voltage and current in a purely inductive circuit along with the phasor diagram;
- describe working of a series LR circuit and discuss its applications;
- derive the equations for voltage and current in a purely capacitive circuit along with the phasor diagram;
- derive equations to show that in a series CR circuit, the resultant voltage lags the current by an angle between 0° to 90° .

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7.2.1 Introduction

Electrical and electronic devices such as generators, motors, energy storage devices, display devices, mobile phones, computers, etc. extensively use resistors, inductors and capacitors for a wide variety of applications. Since the commonly available electrical supply is essentially AC, it is important to understand the behavior of resistors, inductors and capacitors in AC circuits for ensuring their proper usage. An AC current or voltage is represented by a periodic function having equal positive and negative half cycle in a complete period, therefore it is important to define the phase of the AC current and voltage i.e., when does the periodic cycle representing alternating circuit(AC) current and voltage start from zero on the frequency-time axis. AC current and voltage may possess zero, positive or negative phase difference. This phase difference plays an important role in superposition of AC currents and voltages which is exploited in providing nearly constant power, higher output and efficiency for two phase, three phase and poly-phase systems. This phase difference plays a crucial role in understanding the effect of resistance, inductance and capacitance on the voltage and current of an AC circuit since the AC voltage has zero, positive and negative phase difference with respect to AC current for these three components respectively. This helps in using the resistor, inductor and capacitor either individually or in combination for a variety of applications.

7.2.2 Phase difference

While studying the topic on waves, you might have learnt that when a sinusoidal waveform is represented graphically with respect to time along x-axis it has a positive and negative maximum value at $\frac{\pi}{2}$ and $\frac{3\pi}{2}$ respectively and zero value at $0, \pi$ and 2π along the x-axis. However, some sine waves may be shifted to the right or left of 0 by some value compared to another sine wave as all sine waveforms do not pass through the x-axis at the same time. Such waves are said to be shifted from a certain reference point along the x-axis. This angular shift is termed as the phase difference between the two sinusoidal waveforms and is measured in terms of angle ϕ in radians.

Phase difference between two Sinusoidal waveforms

Let us consider equations of two sinusoidal waveforms having the same frequency ω .

$$y_1(t) = y_{m_1} \sin(\omega t), \quad y_2(t) = y_{m_2} \sin(\omega t + \phi)$$

where y_{m_1} and $y_{m_2} \rightarrow$ Amplitudes of the two waveforms

$\omega \rightarrow$ angular frequency of the waveform in radians/ sec

$\phi \rightarrow$ Phase between the two waveforms in radians

(i) Zero phase difference

Two waves of same frequency will be said to be in the same phase (i.e. having zero phase difference) when the corresponding maxima and minima of the two waves occur simultaneously (i.e. at the same time). Their amplitudes may or may not be the same.

For this case $\phi=0$ and equations of two waves will become

$$y_1(t) = y_{m_1} \sin \omega t, \quad y_2(t) = y_{m_2} \sin \omega t$$

The two waves in same phase (with zero phase difference) are shown in the Fig.7.2.1

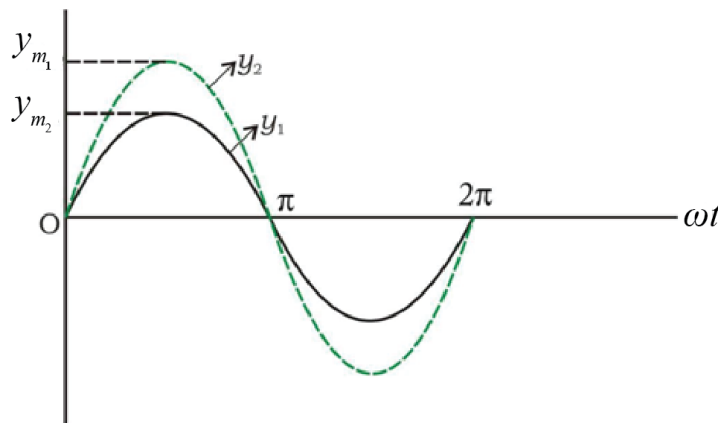


Fig. 7.2.1 Two waves in the same phase (with zero phase difference)

(ii) Positive phase difference

Two waves of the same frequency will be said to be having a phase difference when the corresponding maxima and minima of the two waves occur at different times. If the second wave attains its maxima earlier than the first, it is said to have a positive phase difference with respect to the first. We say $\phi > 0$.

The equations of two waves will become

$$y_1(t) = y_{m_1} \sin \omega t \quad (7.2.1(a))$$

$$y_2(t) = y_{m_2} \sin(\omega t + \phi) \quad (7.2.1(b))$$

When we plot waveforms, it appears as the second wave has shifted towards the left, i.e. the second wave has reached to its maxima before the first.

In this case, we can say that the second wave is leading the first wave by an angle ϕ or we can also say that the first wave is lagging behind the second wave by an angle ϕ (Fig. 7.2.2).

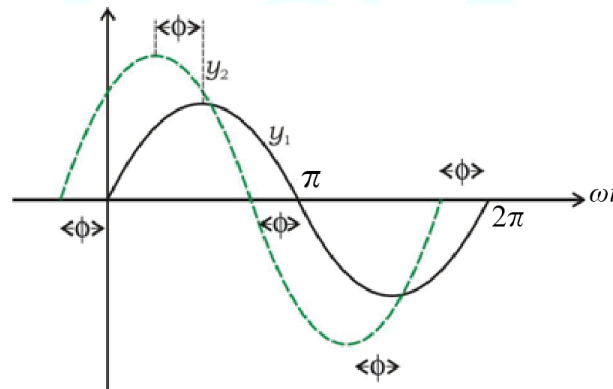


Fig. 7.2.2 Positive phase difference

(iii) Negative phase difference

When the second wave is having negative phase difference with respect to the first wave then for this case $\phi < 0$ and equations of two waves will become

$$y_1(t) = y_{m_1} \sin \omega t \quad (7.2.2(a))$$

$$y_2(t) = y_{m_2} \sin(\omega t - \phi) \quad (7.2.2(b))$$

When we plot waveforms, it appears as the second wave has shifted towards the right, i.e. the second wave has reached to its maxima after the first.

In this case, we can say that the second wave is lagging behind the first wave by an angle ϕ or we can also say that the first wave is leading the second wave by an angle ϕ (Fig.7.2.3).

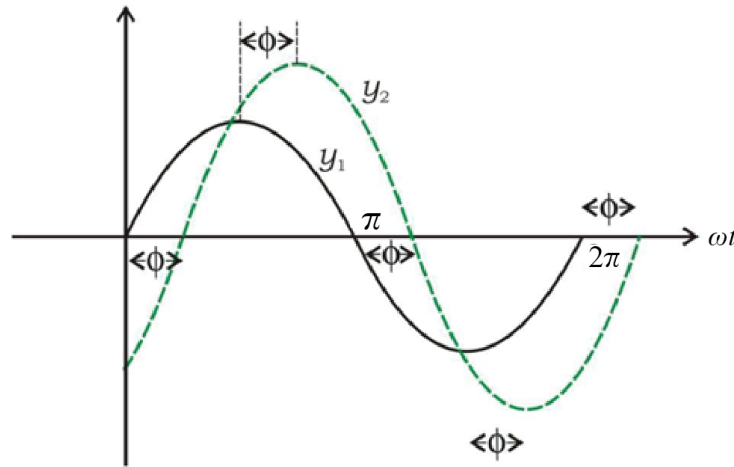


Fig. 7.2.3 Negative phase difference

Graph of current and voltage waveforms having phase difference of $\frac{\pi}{2}$

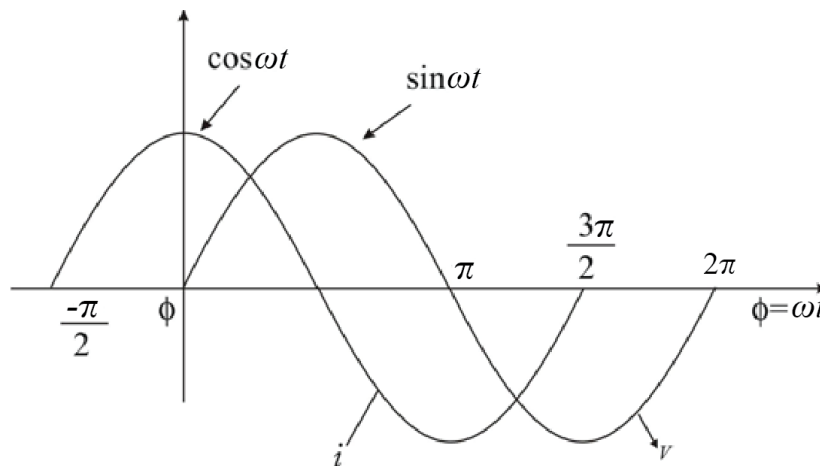


Fig.7.2.4 Graph of current and voltage waveforms having phase difference of $\pi/2$.

In this case (Fig.7.2.4) we have taken two sinusoidal waveforms representing alternating current and voltage having $\pi/2$ phase difference.

Here the voltage waveform starts at zero along the x-axis, the current waveform is negative in value and crosses the x-axis after $\phi = 90^\circ$ or $\pi/2$. Therefore we can say that the current is leading the voltage by an angle $\frac{\pi}{2}$ or voltage is lagging behind the current by an angle $\pi/2$.

By comparing these graphs with the graphs for sine function and cosine function we can say that a graph for cosine function is equivalent to a graph of sine function that has been shifted in the negative direction by an angle $\phi = \pi/2$.

7.2.3 Phasors

A phasor is simply a rotating vector rotating with constant angular velocity whose length represents the magnitude (peak value) of any physical quantity and its angular position represents the direction (phase) of that physical quantity. Tail of this vector is fixed at the origin. Anticlockwise rotation of its head is considered as positive whereas clockwise rotation is considered as negative. We can use this phasor diagram to visualize the relationship between current and voltages of an ac circuit.

Let us see by an activity how a phasor diagram can be related to a physical quantity whose magnitude and direction change sinusoidally.

An activity for phasor

The actual shape of a sinusoidal waveform can be obtained with the help of a phasor by using the method given below.

Refer to Fig 7.2.5

1. Draw a circle of radius equal to the peak value of a sinusoidal wave.
2. Divide the circumference into equal even numbers of parts (e.g. 12 parts).
3. Draw a horizontal line through the centre of the circle.
4. Mark a portion of this line as PQ.
5. Divide this segment PQ equally in the same number of parts as the circumference and draw a vertical axis at P.
6. Now the division 1 - 2, 2 - 3, ... will represent the same intervals of time or angles as the arcs 1 - 2, 2 - 3 respectively.
7. When the radius vector OA starts rotating in the anticlockwise direction with constant angular speed, then the horizontal projection of this radius vector on the vertical axis to the right will also start moving.
8. When the tip of this rotating vector OA touches each of these fixed positions (0,1,2,...) erect an ordinate at corresponding points on PQ equal to the projection of the radius vector OA on the vertical axis.
9. Now draw a smooth curve through the ends of these ordinates.

10. The curve obtained here is a sinusoidal curve.

The rotating vector used here is termed phasor.

Note: For drawing cosine waves, the only difference is that it will have its peak value at time $t = 0$. We can make a vertical projection of the rotating vector OA to construct the phasor for the cosine wave.

(In this correction, you may recall from your study on 'oscillation', that if particle executes uniform circular motion, then the foot of the perpendicular on any diameter executes SHM)

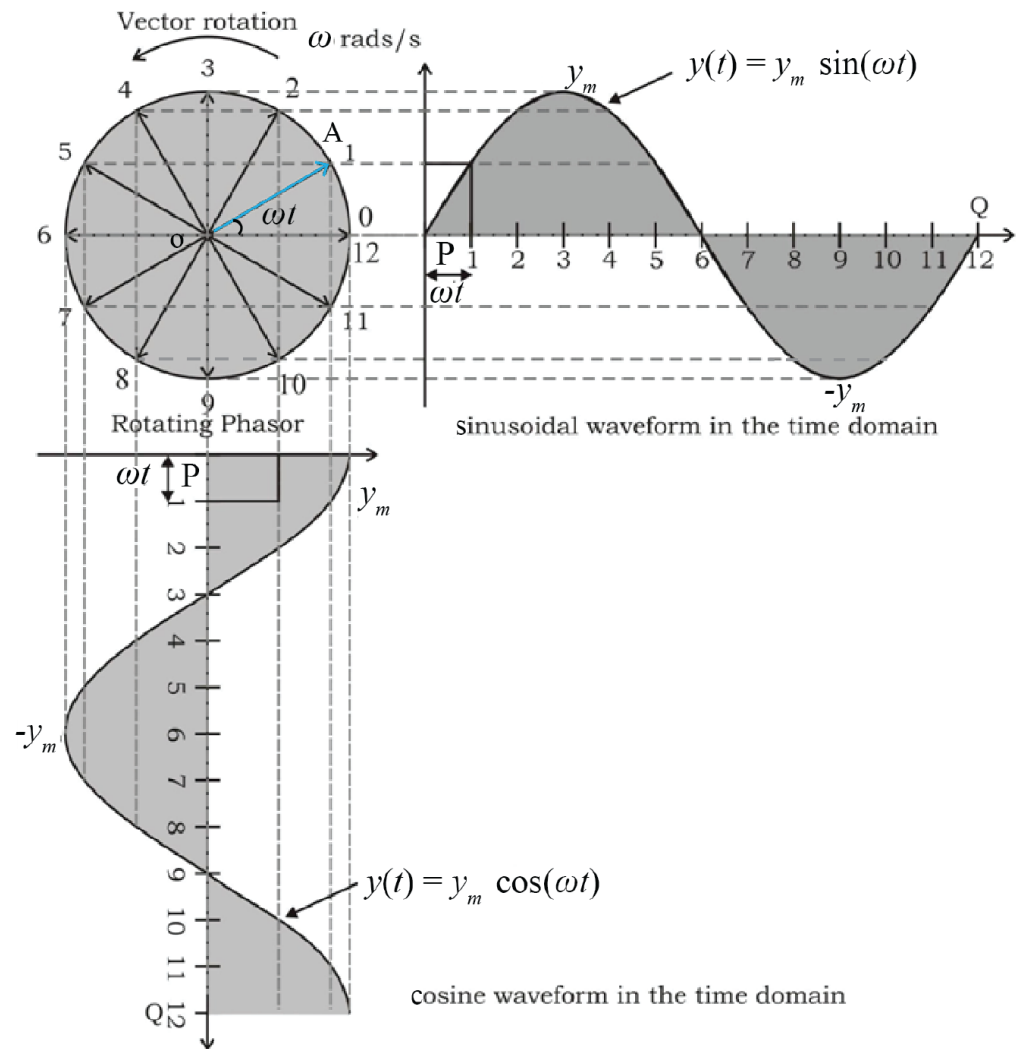


Fig. 7.2.5 Shape of sinusoidal and cosine waveforms obtained with the help of a phasor

***Counter clockwise direction has been adopted as the positive direction of rotation.**

After performing this activity, we will get an idea of how we can use phasors in place of sinusoidal waveforms.

In case of AC circuits we generally use phasor diagrams for simplifying or for avoiding complex mathematical treatments. Two or more physical quantities can be simultaneously shown in a phasor diagram by using different vectors for different quantities. In this way, we can also find the resultant of two different waveforms easily. Lead and lag between different quantities can also be easily visualized. In case of AC circuits, current in different elements and voltage across those elements do not necessarily remain in the same phase. Therefore we utilize phasor diagram solutions to get an idea about the lead or lag between different quantities.

Let us take few equations like

$$V_1(t) = V_{m1} \sin(\omega t) \quad (7.2.3(a))$$

$$I_2(t) = I_{m2} \sin(\omega t + \phi) \quad (7.2.3(b))$$

In this case we can say that current is lagging the voltage by an angle ϕ . Let us take a particular value of $\phi = 30^\circ$. Then the phasor diagram to depict this situation will be as given in Fig.7.2.6.

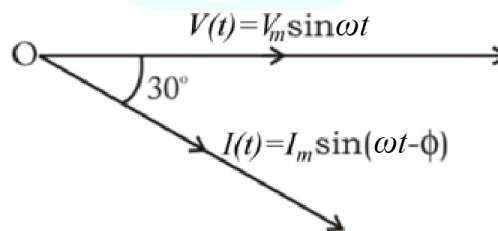


Fig.7.2.6 phasor diagram

We can treat one of the phasors as reference and on the basis of that phasor we can comment on the other phasor. If we consider current phasor as reference phasor, we can say voltage phasor is leading the current phasor by an angle ϕ (because we have adopted a convention that counter clockwise direction will be positive direction of rotation).

Now we will see how the use of phasors can simplify the understanding of AC circuits.

7.2.4 Alternating current through a pure inductor

Fig.7.2.7 shows an AC source connected to an inductor: usually, inductors have appreciable resistance in their windings, but we shall assume that this inductor has negligible resistance.

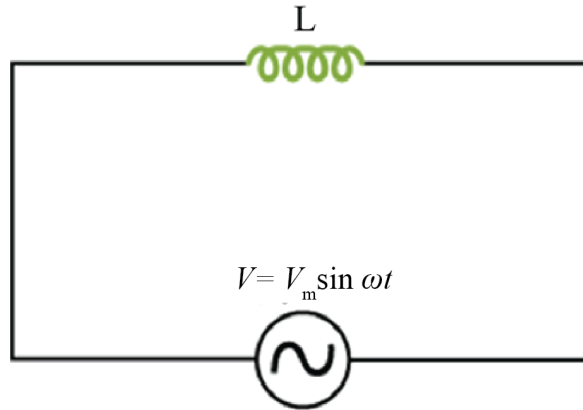


Fig.7.2.7 An AC source connected to an inductor

$$\text{Let, } I(t) = I_m \sin \omega t$$

From Kirchhoff's second law, we have

$$V(t) + V_L = 0 \quad (7.2.4)$$

$$\therefore V(t) + \left(-L \frac{di}{dt}\right) = 0, \quad \text{[i and } I(t) \text{ are one and the same]}$$

$$\therefore V(t) = L \frac{di}{dt}$$

$$\therefore V(t) = L \frac{di}{dt} (I_m \sin \omega t)$$

$$\therefore V(t) = \omega L I_m \cos \omega t = \omega L I_m \sin \left(\omega t + \frac{\pi}{2} \right) \quad (7.2.5)$$

$$\therefore V(t) = V_m \sin \left(\omega t + \frac{\pi}{2} \right)$$

So, we see that in the case of a purely inductive AC circuit, voltage leads the current by an angle 90° . The equations for current and voltage can be written as below

$$I(t) = I_m \sin \omega t \quad (7.2.6(a))$$

$$V(t) = V_m \sin \left(\omega t + \frac{\pi}{2} \right) \quad (7.2.6(b))$$

This situation can be shown in terms of waveform and phasor diagrams in Fig. 7.2.8

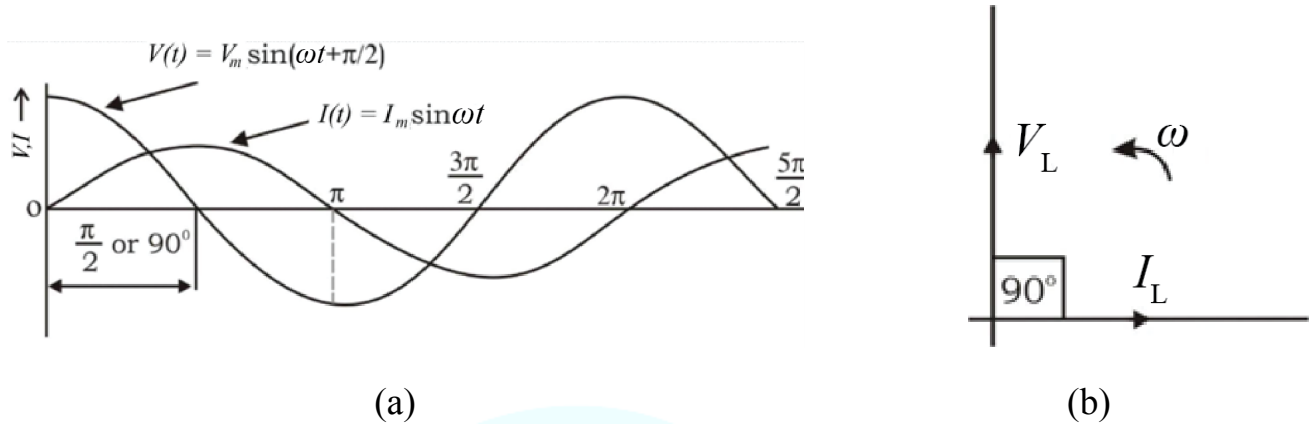


Fig. 7.2.8 Alternating current through pure inductor

In the case of an AC circuit containing a pure inductor, the opposition to the flow of current depends not only upon the inductance of the coil but also on the frequency of the applied alternating voltage.

Just as the opposition offered by a resistor to the flow of electric current is called resistance, the opposition offered by an inductor to the flow of alternating current is called inductive reactance. Inductive reactance is expressed in ohms. From Eq.(7.2.5), we see that it is equal to ωL .

If an alternating current of frequency ν is passed through an inductor of inductance L , its inductive reactance will be given as

$$X_L = \omega L = 2\pi\nu L \quad (\omega = 2\pi\nu) \quad (7.2.7(a))$$

$$I = \frac{V}{X_L} \quad (7.2.7(b))$$

From above equations, it appears that

when $\nu = 0$, $X_L = 0$ and $I = \infty$

But as $\nu \rightarrow 0$, $X \rightarrow 0$ and $I \rightarrow$ very large

not infinite, because none of the inductors are purely inductive, although its inductive reactance becomes zero but it always has some resistance due to the resistance of the wire of which the coil is made. Therefore we can visualize a practical inductor as an inductor and resistor in series.

For an ideal inductor, inductive reactance becomes zero at $\nu = 0$, and the inductor behaves as a short circuit.

The variation of inductive reactance with frequency is shown in the graph below (Fig.7.2.9):

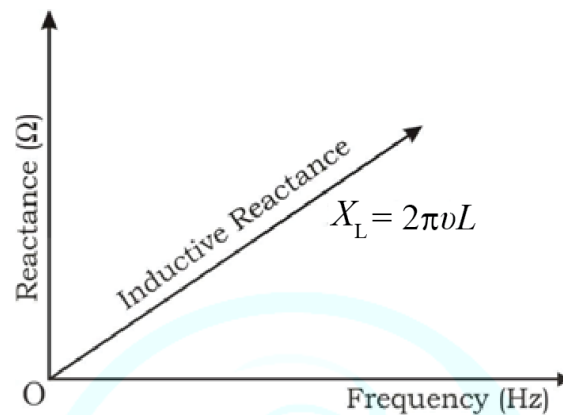


Fig.7.2.9 Variation of inductive reactance with frequency



Let Us Reflect

Q.7.2.1 A coil of inductance 200 mH and zero resistance is connected across a 100 V, 50 Hz supply. Calculate the inductive reactance of the coil and the current flowing through it.



Answers

A.7.2.1

Inductive Reactance

$$X_L = 2\pi\nu L = 2 \times \pi \times 50 \times 0.20 = 62.8 \Omega$$

$$I = \frac{V}{X_L} = \frac{100}{62.5} = 1.59 \text{ A}$$

$$\text{Current } I = V/X_L = 100/62.8 = 1.59 \text{ A}$$

Now, we will analyze the effect of adding a resistor in series with the inductor, on the phase difference between effective current and voltage in the circuit.

7.2.5 Alternating current through LR series circuit

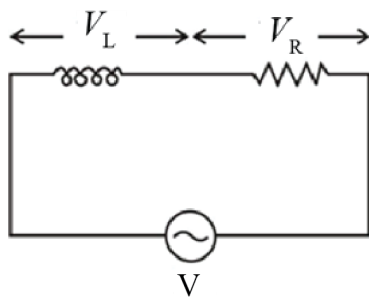
If we want to use phasor diagram for *LR* series circuit, we should keep in mind the following :

- Current and voltage remains in same phase in pure resistor
- Voltage leads the current by 90° in a pure inductor.

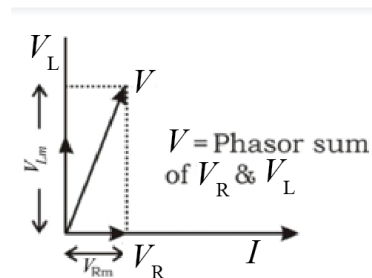
Since in series circuits, current in all the elements remains same, therefore we can take current phasor as reference.

Let the current in this circuit be given by $i(t) = i_m \sin(\omega t)$ and let I be the phasor representing it. Further, let V_L , V_R and V represent phasors for the voltage across inductor, resistor and the source (Fig.7.2.10(a) respectively.

Draw the voltage phasor due to resistor along the current phasor (because in pure resistor, current and voltage remains in same phase) and draw the voltage phasor due to inductor leading the current phasor by 90° (because in pure inductor voltage leads the current by 90°)



(a)



(b)

Fig. 7.2.10 Alternating current through LR series circuit

The length of these phasors or the amplitude of V_L , V_R are

$$V_{Rm} = I_R R, V_{Lm} = I_{Lm} X_L$$

$$V_R = I R, V_L = I X_L \quad (\because I_R = I_{LM} = I)$$

The resultant voltage is given by parallelogram law for vector addition as shown in Fig. 7.2.10(b).

$$\text{We have } V_m^2 = V_{Rm}^2 + V_{Lm}^2$$

$$= (I_m R)^2 + (I_m X_L)^2$$

$$= I_m^2 (R^2 + X_L^2)$$

$$\text{or } I_m = \frac{V_m}{\sqrt{R^2 + X_L^2}} \quad (7.2.8)$$

By analogy to the resistance in a circuit, we introduce the term impedance Z in an LR series circuit:

$$I_m = \frac{V_m}{Z} \text{ where } Z = \sqrt{R^2 + X_L^2} \quad (7.2.9)$$

$$\tan \phi = \frac{v_{Lm}}{v_{Rm}} = \frac{I_m X_L}{I_m R}$$

$$\tan \phi = \frac{X_L}{R}, \quad (7.2.10)$$

Equation for voltage will be

$$v = v_m \sin(\omega t + \phi) \quad (7.2.11)$$

Hence voltage leads current by an angle ϕ between 0° to 90° .

The value of ϕ depends on the magnitudes of resistance and inductance.

Important note: It should be remembered that the voltages, although scalars are vectorially represented by phasors. They are added using the laws of vector addition.

7.2.6 Alternating current through a pure capacitor

If a DC voltage is applied across a capacitor, a current flows for a very short time until the capacitor gets charged. Then the capacitor blocks the direct current in the circuit. If AC voltage is applied across a capacitor, the polarity across the capacitor plates continuously changes. Therefore the capacitor charges and discharges continuously with the applied AC voltage and in this way an alternating current keeps flowing through the circuit.

Fig.7.2.11 shows an ac source ε generating ac voltage $V = V_m \sin \omega t$ connected to a capacitor only, a purely capacitive ac circuit

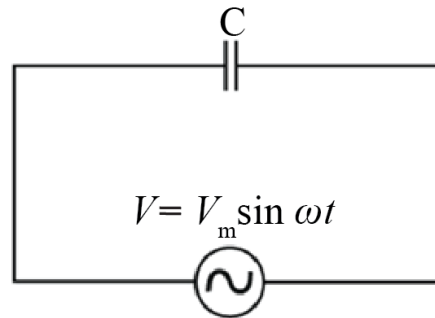


Fig.7.2.11 AC source connected to a capacitor

$$\text{Let } I(t) = I_m \sin \omega t$$

$$\therefore \frac{dq}{dt} = I_m \sin \omega t$$

$$\therefore q = I_m \int \sin \omega t \, dt$$

$$\therefore q = -\frac{I_m}{\omega} \cos \omega t \quad (7.2.12)$$

$$\begin{aligned} V(t) &= \frac{q}{c} = -\frac{I_m}{\omega c} \cos \omega t \quad (7.2.13) \\ &= \frac{I_m}{\omega c} (-\cos \omega t) \end{aligned}$$

$$\therefore V(t) = \frac{I_m}{\omega C} \sin\left(\omega t - \frac{\pi}{2}\right) \quad (7.2.14)$$

$$\therefore V(t) = V_m \sin\left(\omega t - \frac{\pi}{2}\right) \quad (7.2.15)$$

We have seen that the current leads the voltage by 90° (or voltage lags the current by 90°) in a purely capacitive circuit (Fig. 7.2.12).

The equations for current and voltage can be written as

$$I = I_m \sin \omega t \quad (7.2.16(a))$$

$$V(t) = V_m \sin\left(\omega t - \frac{\pi}{2}\right) \quad (7.2.16(b))$$

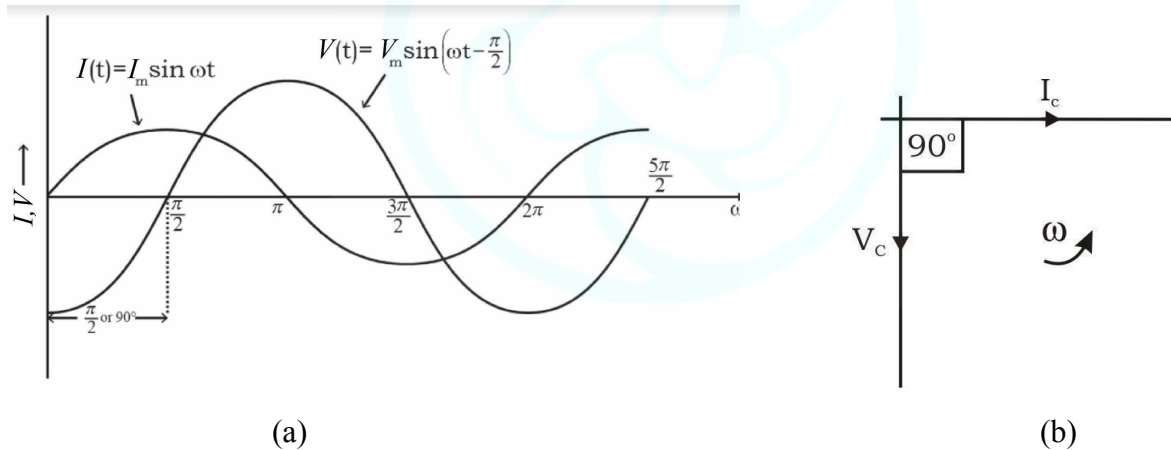


Fig. 7.2.12 Alternating current through capacitor

In the case of an AC circuit containing a pure capacitor, the opposition to the flow of current not only depends upon the capacitance of the capacitor but also on the frequency of the applied alternating voltage.

The opposition offered by a capacitor to the flow of alternating current is called capacitive reactance.

Capacitive reactance is expressed in ohms. From Eq(7.2.14), it is equal to $\frac{1}{\omega C}$.

If an alternating voltage of frequency ν is applied across a capacitor of capacitance C , its capacitive reactance will be given as

$$X_C = \frac{1}{\omega C} = \frac{1}{2\pi\nu C} \quad (\omega = 2\pi\nu) \quad (7.2.17)$$

From above equations, it appears that when

$$\nu = 0, X_C = \infty \text{ and } I = 0$$

But as $\nu \rightarrow \infty$, $X_C \rightarrow 0$ and current becomes very large (not infinite, because there will always be some resistance of connecting wires).

For an ideal capacitor, capacitive reactance becomes infinite at zero frequency (DC). Hence the capacitor behaves as an open circuit.



Let Us Reflect

Q.7.2.2 Calculate the capacitive reactance of a 200 nF capacitor at a frequency of 50 Hz and 10 MHz.

Q.7.2.3 At what frequency would a 2.0 μF capacitor have a reactance of 100 Ω ?

Q.7.2.4 What will be the value of capacitance of a capacitor in farads which has a capacitive reactance of 100 Ω when connected to a 50 Hz supply?



Answers

A.7.2.2

For $\nu = 50 \text{ Hz}$,

$$X_C = \frac{1}{2\pi\nu C} = \frac{1}{2 \times \pi \times 50 \times 200 \times 10^{-9}} = 15923.57 \Omega = 15.92 \text{ k}\Omega$$

For $\nu = 10 \text{ MHz}$

$$X_C = \frac{1}{2 \times \pi \times 10 \times 10^6 \times 200 \times 10^{-9}} = 0.08 \Omega$$

Therefore, it can be seen from above that as the frequency applied to a 200 nF capacitor increases from 50 Hz to 10MHz, its reactance decreases from approximately 15.92 k Ω to just 0.08 Ω . For any given value of capacitance, the reactance of a capacitor can be plotted against the frequency as shown below(Fig.7.2.13).

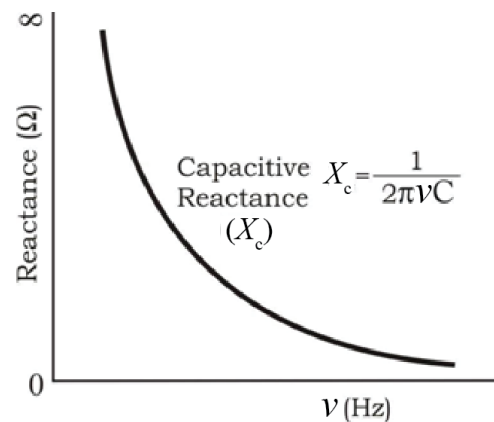


Fig. 7.2.13 *Reactance vs Frequency Curve*

A.7.2.3

$$C = 2.0 \mu\text{F}$$

$$X_C = \frac{1}{\omega C} = 100 \Omega$$

$$\omega = \frac{1}{200 \times 10^{-6} \times 100} = 5000 \text{ rad/s}$$

$$v = \frac{\omega}{2\pi} = \frac{5000}{2\pi} = 795.8 \text{ Hz}$$

A.7.2.4

$$X_C = \frac{1}{2\pi v C}$$

$$C = \frac{1}{2\pi v X_C} = \frac{1}{2 \times \pi \times 100 \times 50 \times 100} = 31.85 \mu\text{F}$$

So the required value = $31.85 \times 10^{-6} \text{F}$

We can see from the above examples that a capacitor when connected to a variable frequency AC supply, acts like a “frequency controlled variable resistor”. At very low frequencies, such as 50 Hz our 200 nF capacitor has a high capacitive reactance value of approximately 15.92 k Ω (giving the effect of an open circuit).

At very high frequencies such as 10 MHz, the capacitor has a low capacitive reactance value of just 0.08 ohms (giving the effect of a short circuit). At zero frequency or steady state DC, the capacitor has infinite reactance, behaves as an “open circuit” between the plates and blocks the flow of current through it.

We can summarize the behavior of the inductor and capacitor as shown in Fig. 7.2.13

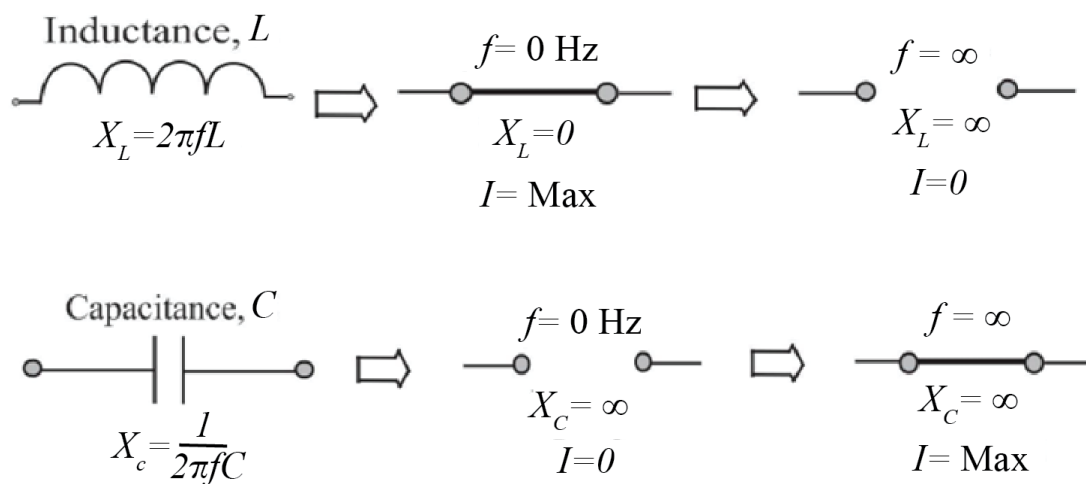


Fig. 7.2.13 Schematic diagram of behavior of inductor and capacitor

7.2.7 Alternating current through CR series circuit

If we want to get phasor diagram solution for CR series circuit, we should keep in mind the following :

- Current and voltage remain in the same phase in a purely resistive circuit.
- Voltage lags behind the current by 90° in pure capacitive circuits.

Since in series circuit current in all the elements remains same, we can take current phasor as reference.

Let the current in this circuit is given by $i(t) = i_m \sin(\omega t)$ and let I be the phasor representing it. Further let V_C , V_R and V represent phasors for the voltage across capacitor, resistor and the source respectively.

Now, draw the voltage phasor due to resistor along the current phasor (because in pure resistor, current and voltage remain in same phase) and draw the voltage phasor due to capacitor lagging the current phasor by 90° (because in pure capacitor, voltage lags behind the current by 90°) (Fig. 7.2.14)

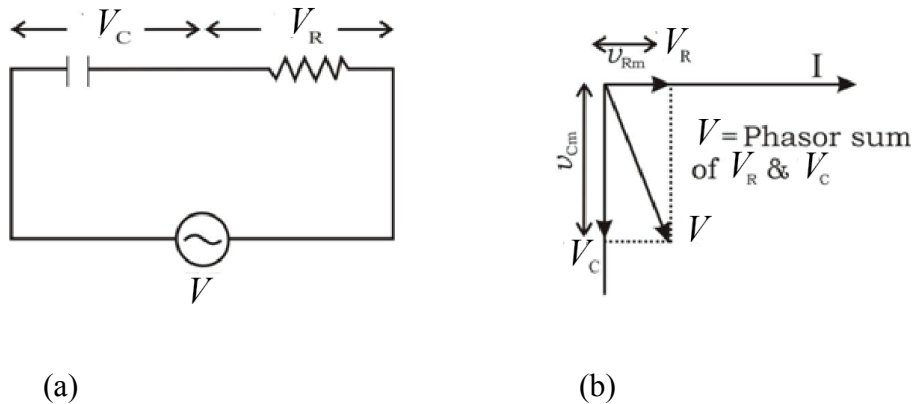


Fig. 7.2.14 Alternating current through CR series circuit

The length of these phasors or the amplitude of V_C , V_R are

$$V_{Rm} = I_m R, \quad V_{Cm} = I_m X_C$$

Using parallelogram law for vector addition, we get

$$V_m^2 = V_{Rm}^2 + V_{Cm}^2$$

$$= I_m^2 (R^2 + X_C^2)$$

$$\text{or } I_m = \frac{V_m}{\sqrt{R^2 + X_C^2}} \quad (7.2.18)$$

By analogy to the resistance in a circuit, we introduce the term impedance Z in a CR series circuit:

Using the right triangle

$$\tan \phi = \frac{V_{cm}}{V_{Rm}} = \frac{I_m X_C}{I_m R}$$

$$\phi = \tan^{-1}\left(\frac{X_C}{R}\right) \quad (7.2.19)$$

Equation for voltage will be

$$V = V \sin(\omega t + \phi) \quad (7.2.20)$$

i.e. voltage lags the current by an angle ϕ , as ϕ is a negative angle (See Fig.7.2.13).

We see that in a series CR circuit, the resultant voltage lags the current by an angle between 0° to 90° .

7.2.8 Summary

In order to show the phase relationship between voltage and current in an AC circuit, we use the notion of phasors. Analysis of an ac circuit is facilitated by the use of a phasor diagram. A phasor is a vector that rotates about the origin with angular speed ω .

- An AC voltage $V = V_m \sin \omega t$ applied to a pure inductor L , drives a current to the inductor,

$I = I_m \sin (\omega t + \frac{\pi}{2})$ where $I_m = V_m / X_L$. $X_L = \omega L$ is called inductive reactance. The current in the inductor lags behind the voltage by $\pi/2$. The average power supplied to an inductor over one complete cycle is zero.

- In LR circuit, current $I_m = \frac{V_m}{Z}$ where $Z = \sqrt{R^2 + X_L^2}$

$$\tan \phi = \frac{v_{Lm}}{v_{Rm}} = \frac{I_m X_L}{I_m R} = \frac{X_L}{R},$$

Equation for voltage will be $V = V_m \sin(\omega t + \phi)$.

Hence voltage leads current by an angle ϕ between 0° to 90° .

- An AC voltage $V = V_m \sin \omega t$ applied to a pure capacitor C, drives a current in the capacitor

$I = I_m \sin (\omega t + \frac{\pi}{2})$, where $i_m = v_m / X_C$. $X_C = 1/\omega C$ is called capacitive reactance. The current through the capacitor is $\pi/2$ ahead of the applied voltage. As in the case of an inductor, the average power supplied to a capacitor over one complete cycle is zero.

- In a purely inductive or capacitive circuit, $\cos \phi = 0$, and no power is dissipated even though a current is flowing in the circuit. In such cases, the current is referred to as **wattless current**.
- In an AC circuit, while adding voltages across different elements, one should take care of their phases properly. For example, if V_R and V_C are voltages across R and C , respectively in an RC circuit, then the total voltage across RC combination is

$$V_{RC} = \sqrt{V_R^2 + V_C^2} \text{ and not } V_R + V_C \text{ since } V_C \text{ is } \pi/2 \text{ out of phase w.r.t. } V_R.$$

- The phase relationship between current and voltage in an ac circuit can be shown conveniently by representing voltage and current by rotating vectors called *phasors*. A phasor is a vector that rotates about the origin in an anticlockwise direction with angular speed ω . The length of a phasor represents the amplitude or peak value of the quantity (voltage or current) represented by the phasor. The analysis of an ac circuit is facilitated by the use of a phasor diagram.

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