AC CIRCUITS

10

OBJECTIVES

After completing this Chapter, you will be able to:

- *Explain what the impedance triangle for an ac circuit is.*
- *Define 'resistance', 'reactance' and 'complex impedance' with reference to an ac circuit.*
- *Draw phasor diagrams for a series and a parallel ac circuit containing R, L and C.*
- *Define 'complex power', 'apparent power', 'average power' and 'reactive power', in an ac circuit, and state their units.*

10.1 SERIES *RL* CIRCUIT

Figure 10.1*a* shows a series *RL* circuit. We know that a practical inductor possesses inductance and resistance effectively in series. Therefore, the following analysis of R and L in series is equivalent to the analysis of a circuit containing a practical inductor.

Our aim is to find its steady-state response (i.e., the current I) for the given applied ac voltage V. Note that the reference polarity of V is shown by means of an arrow. Let V_R and V_L be the voltage drops across resistance R and inductance L, respectively. Unlike dc circuits, here we cannot obtain the total voltage V just by adding the magnitudes of the voltages across the resistor and inductor. That is, to write

$$V = V_R + V_L \qquad \text{is } \textbf{\textit{wrong}}.$$

This does not mean that KVL is not applicable here. KVL is a basic law and is applicable to all circuits whether dc or ac. In an ac circuit, the voltages and currents are phasors. So, the two voltages must be added by treating them as ***phasors***,

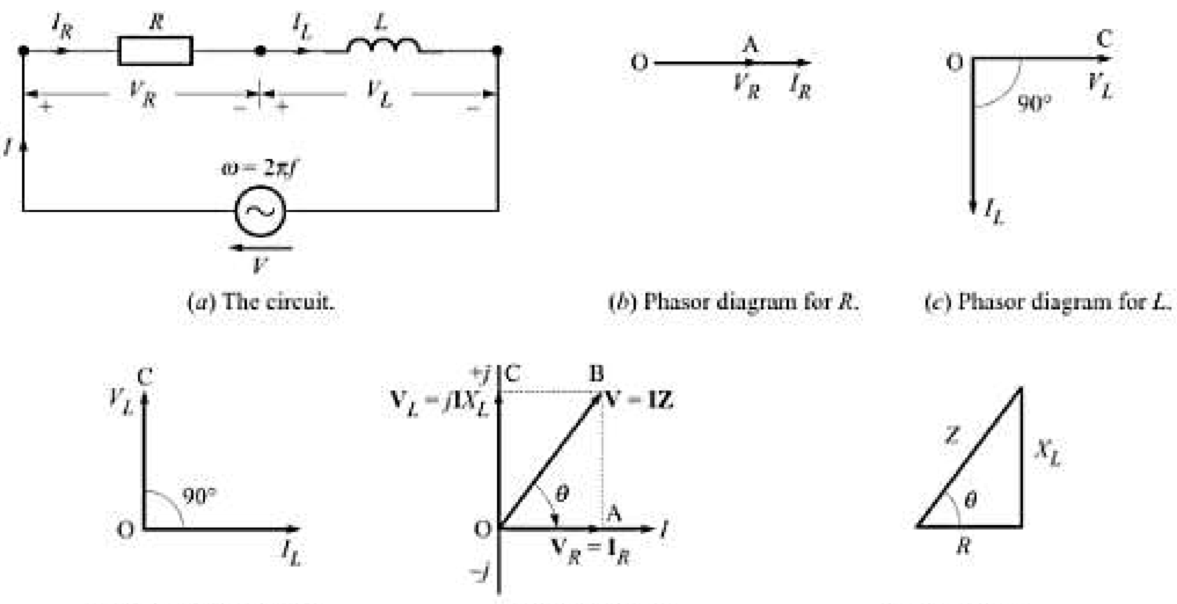
$$\mathbf{V} = \mathbf{V}_R + \mathbf{V}_L \tag{10.1}$$

How to Draw a Phasor Diagram

We shall now explain the procedure of drawing the phasor diagram for an ac circuit. As an example, we take the series *RL* circuit of Fig. 10.1*a*.

Step 1 Mark the source voltage V, showing its polarity, either by an arrow or by using + and – signs. Mark the source current I showing its direction by an arrow. As a convention, the current I must leave the positive terminal of the source.

Step 2 Mark 'the voltage across' and 'the current through' each individual component of the circuit, following



(*a*) The circuit. (*b*) Phasor diagram for *R*. (*c*) Phasor diagram for *L*.

(*d*) Phasor diagram for *L*, rotated by +90°. (*e*) The complete phasor diagram. (*f*) Impedance triangle.

Fig. 10.1 *Series RL circuit.*

the passive sign convention (i.e., the current must enter the plus-marked terminal of the component). We have marked V_R and I_R for the resistance R, and V_L and I_L for the inductance L.

Step 3 Draw the phasor diagrams for individual components.

(*i*) ***For resistance*** R: The current is in phase with the voltage. Draw the voltage phasor V_R along the reference direction (i.e., along $+x$ direction). Draw the current phasor I_R also along the reference direction (see Fig. 10.1*b*).

(*ii*) ***For inductance*** L: The current lags the voltage by 90°. Draw the voltage phasor V_L along the reference direction. Draw the current phasor I_L 90° lagging, as shown in Fig. 10.1*c*.

Step 4 To get complete phasor diagram, superimpose all the individual phasor diagrams, by recognizing the ***common phasor*** among them. For this, you may have to rotate some phasor diagrams.

Here, we find that the common phasor is the current $I = I_R = I_L$. In Fig. 10.1*b*, the current phasor $I_R = I$ is already along the reference direction. But, in Fig. 10.1*c*, the current phasor $I_L = I$ is not along the reference direction. To align the two current phasors, we rotate the phasor diagram of Fig. 10.1*c* by 90° counter-clockwise (Fig. 10.1*d*). We can now superimpose Fig. 10.1*d* and Fig. 10.1*b*, to get the complete phasor diagram of the circuit, as shown in Fig. 10.1*e*.

Step 5 Find the phasor addition (same as vector additon) of V_R and V_L, by drawing the parallelogram OABC (here, it is a rectangle).

The resultant of this addition is given by the diagonal OB. The phasor OB must be equal to supply voltage V, as per KVL. From Fig. 10.1*e*, it becomes clear the current phasor I lags the supply voltage V by an angle BOA = θ.

Step 6 Once the phasor diagram is drawn, we can take the help of complex algebra to make calculations. Imagine that the phasor diagram is drawn in the complex plane. That is, mark the reference direction (+x-axis) as the positive real axis and the y-axis as the imaginary axis. We can then write

$$\mathbf{I} = I\angle 0°; \quad \mathbf{V}_R = \mathbf{I}R \quad \text{and} \quad \mathbf{V}_L = j\mathbf{I}X_L = \mathbf{I}jX_L = \mathbf{I}j\omega L$$

Therefore, Eq. 10.1 can be rewritten as

$$\mathbf{V} = \mathbf{V}_R + \mathbf{V}_L = \mathbf{I}R + \mathbf{I}j\omega L = \mathbf{I}(R + j\omega L) \tag{10.2}$$

Complex Impedance

In general, for an ac circuit, the ratio of the voltage phasor to the current phasor is a complex quantity, called ***complex impedance*** (represented by symbol **Z**). Its real part is called ***resistance*** and its imaginary part is called ***reactance***. Thus,

$$\textit{Complex impedance} = (\text{resistance}) + j(\text{reactance}) \quad \text{or} \quad \mathbf{Z} = R + jX \tag{10.3}$$

For the series RL circuit, from Eq. 10.2, we have

$$\mathbf{Z} = \frac{\mathbf{V}}{\mathbf{I}} = R + j\omega L = Z\angle\theta \tag{10.4}$$

where,

$$Z = \sqrt{R^2 + (\omega L)^2} \quad \text{and} \quad \theta = \tan^{-1}\frac{\omega L}{R} \tag{10.5}$$

From the phasor diagram of Fig. 10.1*e*, we can separate the voltage triangle OAB. If each side of this triangle is divided by I, the result is the ***impedance triangle***, shown in Fig. 10.1*f*. **Note** that an inductive circuit has an impedance triangle in the first quadrant of complex plane.

Voltage Phasor as Reference Often, we are given the source voltage and then we are required to find resulting current in a circuit. This can be done by taking the voltage as reference, and then writing the current as

$$\mathbf{I} = \frac{\mathbf{V}}{\mathbf{Z}} = \frac{V\angle 0°}{Z\angle\theta} = \frac{V}{Z}\angle -\theta \tag{10.6}$$

This shows that the current lags the applied voltage by an angle θ, given by Eq. 10.5. For a given ac voltage $v = V_m \sin \omega t$ volts, the equation of the resulting current is

$$i = \frac{V_m}{\sqrt{R^2 + (\omega L)^2}} \sin\{\omega t - \tan^{-1}(\omega L)/R\} \text{ amperes} \tag{10.7}$$

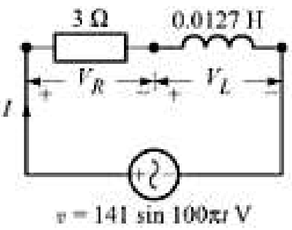
EXAMPLE 10.1

For the series RL circuit shown in Fig. 10.2*a*,

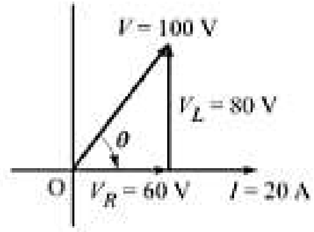
(*a*) Calculate the rms value of the steady state current and the relative phase angle.
(*b*) Write the expression for the instantaneous current.
(*c*) Find the average power dissipated in the circuit.
(*d*) Determine the power factor.
(*e*) Draw the phasor diagram.

Solution

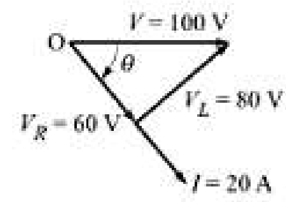
(*a*) Since the phase angle of the applied voltage is given as 0°. In the complex form, the applied voltage can be written as



(*a*) The circuit.



(*b*) Phasor diagram.



(*c*) Phasor diagram redrawn.

Fig. 10.2 *A series RL circuit.*

$$\mathbf{V} = V\angle 0° = \frac{V_m}{\sqrt{2}}\angle 0° = \frac{141}{\sqrt{2}}\angle 0° = 100\angle 0° = 100 + j0 \text{ volts}$$

The impedance, $\mathbf{Z} = R + j\omega L = 3 + j100\pi \times 0.0127 = 3 + j4 = 5\angle 53.1°$ ohms

$$\therefore \quad \text{Current, } \mathbf{I} = \frac{\mathbf{V}}{\mathbf{Z}} = \frac{100\angle 0°}{5\angle 53.1°} = \mathbf{20\angle{-53.1°}\ A}$$

Thus, the rms value of the steady state current is 20 A, and the phase angle is 53.1° lagging.

(*b*) The expression for the instantaneous current can be written as

$$i = 20\sqrt{2}\sin(100\pi t - 53.1°) = \mathbf{28.28\sin(100\pi t - 53.1°)\ A}$$

(*c*) Average power, $P = VI\cos\theta = 100 \times 20 \times \cos 53.1° =$ **1200 W**

Or, $$P = I^2R = (20)^2 3 = \mathbf{1200\ W}$$

(*d*) $pf = \cos\theta = \cos 53.1° =$ **0.6 lagging**. Alternatively,

$$pf = \frac{\text{Average power}}{\text{Apparent power}} = \frac{P}{VI} = \frac{1200}{100 \times 20} = \mathbf{0.6\ lagging}$$

(*e*) Taking the current as reference, the phasor diagram is drawn in Fig. 10.2*b*, where

$$I = 20\text{ A};\quad V_R = IR = 20 \times 3 = 60\text{ V};\quad V_L = IX_L = 20 \times 4 = 80\text{ V} \quad \text{and} \quad V = 100\text{ V}$$

The same phasor diagram is redrawn in Fig. 10.2*c*, by rotating it clockwise by an angle 53.1°, so that the applied voltage becomes the reference phasor.

10.2 SERIES *RC* CIRCUIT

For the series *RC* circuit of Fig. 10.3*a*, we can apply KVL and get

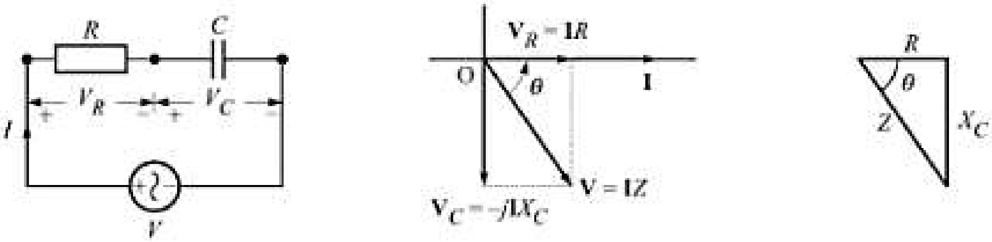
$$\mathbf{V} = \mathbf{V}_R + \mathbf{V}_C = \mathbf{I}R - j\mathbf{I}X_C = \mathbf{I}(R - jX_C) = \mathbf{I}\left(R - j\frac{1}{\omega C}\right) = \mathbf{IZ} \tag{10.8}$$

where **Z** is the ***complex impedance*** for the series *RC* circuit. Since the voltage across a capacitor lags the current by 90°, we have put in the above equation,

$$\mathbf{V}_C = -j\mathbf{I}X_C = \mathbf{I}(-jX_C)$$

Also, note that $-j$ is associated with X_C (whereas $+j$ is associated with X_L).

Phasor Diagram Since the current is common to both the resistor and the capacitor, we take current phasor **I** as reference. For the resistance, the voltage $\mathbf{V}_R$ is drawn in phase with the current **I**; but for the capacitance, the voltage $\mathbf{V}_C$ is drawn *lagging* the current **I** by 90°. The complete phasor diagram for series *RC* circuit is drawn in Fig. 10.3*b*. Here, the supply voltage **V** is the phasor sum of $\mathbf{V}_R$ and $\mathbf{V}_C$. From this phasor



(*a*) The circuit. (*b*) Phasor diagram. (*c*) Impedance triangle.

Fig. 10.3 *Series RC circuit.*

diagram, we can obtain the impedance triangle of Fig. 10.3*c*. **Note** that a capacitive circuit has an impedance triangle in fourth quadrant.

For an impedance triangle to be in either the second or third quadrant, a circuit must have a negative resistance. This may occur if a circuit contains dependent sources.

10.3 COMPLEX POWER

We have seen that, if the terminal voltage is $\mathbf{V} = V\angle\theta$ and the current is $\mathbf{I} = I\angle\phi$ in an ac circuit, the average power absorbed by it is given as

$$P = VI\cos(\theta - \phi) \tag{10.9}$$

By using Euler's formula, the above equation can be written as

$$P = VI\,\mathrm{Re}[e^{j(\theta-\phi)}] = \mathrm{Re}[(Ve^{j\theta})\,(Ie^{-j\phi})] \tag{10.10}$$

The first factor $Ve^{j\theta}$ is simply the voltage phasor. The second term $Ie^{-j\phi}$ is seen to be the complex conjugate $\mathbf{I}^*$ of the current phasor $\mathbf{I} = Ie^{j\phi}$. Hence, Eq. 10.10 can be written as

$$P = \mathrm{Re}[\mathbf{VI}^*] \tag{10.11}$$

We now define the ***complex power*** (represented by symbol **S**) as

$$\mathbf{S} = P + jQ = \mathbf{VI}^* = VIe^{j(\theta-\phi)} \tag{10.12}$$

It is seen that the magnitude VI of **S** is the ***apparent power*** and the angle $(\theta - \phi)$ of **S** is the *pf* angle. The real part P of **S** is the ***average (real*** or ***actual) power*** absorbed by the circuit. The imaginary part Q of **S** is given the name ***reactive power***. From Eq. 10.12, the reactive power is given as

$$Q = VI\sin(\theta - \phi) \tag{10.13}$$

It is obvious that the dimensions of Q should be the same as that of P. However, to avoid confusion, the units of Q are taken as 'volt ampere reactive' (abbreviated as VAR). To summarize,

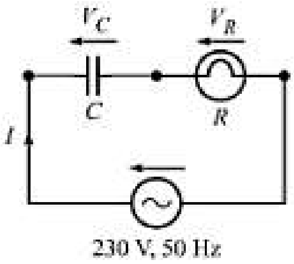
Name	*Symbol*	*Value*	*Units*
1. Apparent power	S	VI	volt amperes (VA)
2. Average power	P	$VI\cos(\theta - \phi)$	watts (W)
3. Reactive power	Q	$VI\sin(\theta - \phi)$	volt ampere reactive (VAR)

EXAMPLE 10.2

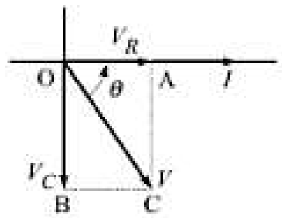
A metal-filament lamp, rated at 750 W, 100 V, is to be used on a 230-V, 50-Hz supply, by connecting a capacitor of suitable value in series. Determine (*a*) the capacitance required, (*b*) the phase angle, (*c*) the power factor, (*d*) the apparent power, and (*e*) the reactive power.

Solution The circuit is given in Fig. 10.4*a*, and the phasor diagram is shown in Fig. 10.4*b*. The voltage phasor V_R is in phase with the current I. The voltage phasor V_C lags the current I by 90°. The rated current of the lamp is

$$I = \frac{P}{V_R} = \frac{750}{100} = 7.5\ \text{A}$$



(*a*) The circuit.



(*b*) Phasor diagram.

Fig. 10.4 *Using a capacitor to light a lower-voltage-rating lamp on ac mains.*

(*a*) From ΔOAC in Fig. 10.4*b*, we can determine the voltage across the capacitor,

$$V_C = \sqrt{V^2 - V_R^2} = \sqrt{(230)^2 - (100)^2} = 207\ \text{V}$$

Now, $$X_C = \frac{V_C}{I} = \frac{207}{7.5} = 27.6\ \Omega \Rightarrow \frac{1}{2\pi f C} = 27.6.$$

∴ $$C = \frac{1}{2\pi \times 50 \times 27.6} = 115 \times 10^{-6}\ \text{F} = \mathbf{115\ \mu F}$$

(*b*) Phase angle, $\phi = \cos^{-1}\frac{V_R}{V} = \cos^{-1}\frac{100}{230} = \mathbf{64°12'}$

(*c*) Power factor, $pf = \cos\phi = (100/230) =$ **0.435 leading**

(*d*) Apparent power $= VI = 230 \times 7.5 =$ **1725 VA**

(*e*) Reactive power $= VI\sin\phi = 230 \times 7.5 \times \sin 64°12' =$ **1553 VAR**

EXAMPLE 10.3

A current of 0.9 A flows through a series combination of a resistor of 120 Ω and a capacitor of reactance 250 Ω. Find the impedance, power factor, supply voltage, voltage across resistor, voltage across capacitor, apparent power, active power and reactive power.

Solution Taking current as the reference phasor, $\mathbf{I} = 0.9\angle 0°$ A.

Impedance,	$\mathbf{Z} = 120 - j250 = \mathbf{277.3\angle{-64.4°}\ \Omega}$
Power factor,	$pf = \cos\theta = \cos(-64.4°) =$ **0.432 leading**
Supply voltage,	$\mathbf{V} = \mathbf{IZ} = (0.9\angle 0°)(277.3\angle{-64.4°}) = \mathbf{249.6\angle{-64.4°}\ V}$
Voltage across resistor,	$V_R = IR = (0.9\angle 0°) \times 120 = \mathbf{108\angle 0°\ V}$
Voltage across capacitor,	$V_C = IX_C = (0.9\angle 0°)(250\angle{-90°}) = \mathbf{225\angle{-90°}\ V}$
Apparent power,	$P_{app} = VI = 249.6 \times 0.9 =$ **224.6 VA**
Actual power,	$P_a = VI\cos\theta = 249.6 \times 0.9 \times \cos 64.4° =$ **97.06 W**
Reactive power,	$P_r = VI\sin\theta = 249.6 \times 0.9 \times \sin 64.4° =$ **202.58 VAR**

Since the imaginary part of the impedance is negative, the circuit is **capacitive**.

Power factor, $pf = \cos(-74.93°) =$ **0.26 leading**

Active power, $P_a = VI\cos\theta = 200 \times 10.77 \times 0.26 =$ **560 W**

Reactive power, $P_r = VI\sin\theta = 200 \times 10.77 \times 0.966 =$ **2079.9 VAR**

EXAMPLE 10.5

When a two-element series circuit is connected across an ac source of frequency 50 Hz, it offers an impedance $\mathbf{Z} = (10 + j10)\ \Omega$. Determine the values of the two elements.

Solution The nature of the impedance indicates that the circuit is inductive.

$$\mathbf{Z} = R + jX_L = (10 + j10)\ \Omega$$

$$\therefore \qquad R = \mathbf{10\ \Omega} \quad \text{and} \quad X_L = 10\ \Omega \ \Rightarrow\ L = \frac{X_L}{2\pi f} = \frac{10}{2\pi \times 50} = 0.0318\ \text{H} = \mathbf{31.8\ mH}$$

EXAMPLE 10.6

When a two-element parallel circuit is connected across an ac source of frequency 50 Hz, it offers an impedance $\mathbf{Z} = (10 - j10)\ \Omega$. Determine the values of the two elements.

Solution The nature of the impedance indicates that the circuit is capacitive. Since the circuit has two elements connected in parallel, we find the admittance of the circuit.

$$\mathbf{Y} = (G + jB) = \frac{1}{\mathbf{Z}} = \frac{1}{10 - j10} = \frac{1}{14.14\angle -45°} = 0.0707\angle 45°\ \text{S} = (0.05 + j0.05)\ \text{S}$$

$$\therefore \qquad G = 0.05\ \text{S} \ \Rightarrow\ R = \frac{1}{G} = \frac{1}{0.05} = \mathbf{20\ \Omega} \quad \text{and} \quad B = 0.05\ \text{S} \ \Rightarrow\ C = \frac{B}{\omega} = \frac{0.05}{2\pi f} = \mathbf{159\ \mu F}$$

10.6 SERIES *RLC* CIRCUIT

Figure 10.7*a* shows a series *RLC* circuit. Writing KVL equation, we get applied voltage as

$$\mathbf{V} = \mathbf{V}_R + \mathbf{V}_L + \mathbf{V}_C = \mathbf{I}R + \mathbf{I}(jX_L) + \mathbf{I}(-jX_C) = \mathbf{I}[R + j(X_L - X_C)] = \mathbf{IZ} \qquad (10.22)$$

where, $\mathbf{Z}$ is the complex impedance of the given circuit. We can write

$$\mathbf{Z} = R + j(X_L - X_C) = R + j\left(\omega L - \frac{1}{\omega C}\right)$$

or

$$\mathbf{Z} = \sqrt{R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2}\ \angle \tan^{-1}\frac{\omega L - (1/\omega C)}{R} \qquad (10.23)$$

or

$$Z = |\mathbf{Z}| = \sqrt{R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2} \quad \text{and} \quad \theta = \tan^{-1}\frac{\omega L - (1/\omega C)}{R} \qquad (10.24)$$

Usually, we take the applied voltage as the reference phasor, i.e., $\mathbf{V} = V\angle 0°$. In such case the resulting current $\mathbf{I}$ is given as

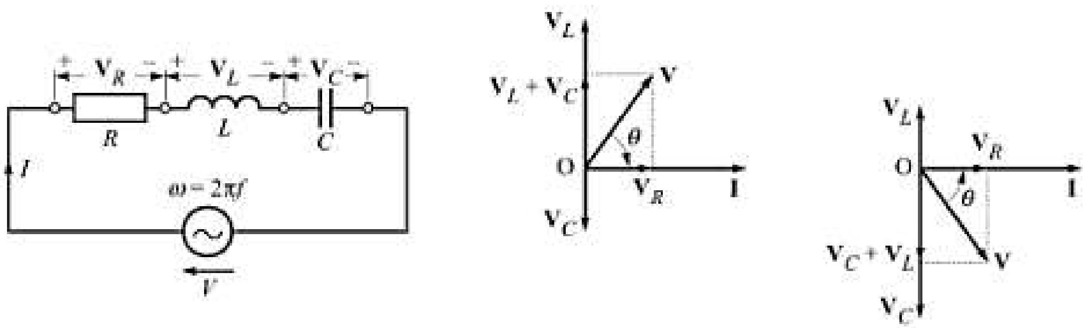
$$\mathbf{I} = I\angle\phi = \frac{\mathbf{V}}{\mathbf{Z}} = \frac{V\angle 0°}{\sqrt{R^2 + (\omega L - 1/\omega C)^2}}\ \angle -\tan^{-1}\frac{\omega L - (1/\omega C)}{R} \qquad (10.25)$$

In a series *RLC* circuit, one cannot definitely say whether the current lags or leads the applied voltage. It depends upon the relative values of the terms ωL and $1/\omega C$. There can be following three possibilities:

(1) *When* $\omega L > 1/\omega C$ The phase angle ϕ of the current phasor is negative (see Eq. 10.25). The current lags the voltage. The circuit behaves as an ***inductive circuit***.

(2) *When* $\omega L < 1/\omega C$ The phase angle ϕ of the current phasor is positive (see Eq. 10.25). The current leads the voltage. The circuit behaves as a ***capacitive circuit***.

(3) *When* $\omega L = 1/\omega C$ The phase angle $\phi = 0$. The current is in phase with voltage. The circuit behaves as a ***purely resistive circuit***. This is a special case, and is called ***resonance***. We shall talk about this phenomenon a little later.



(*a*) The circuit. (*b*) Phasor diagram (when $\omega L > 1/\omega C$). (*c*) Phasor diagram (when $\omega L < 1/\omega C$).

Fig. 10.7 *Series RLC circuit.*

Phasor Diagram Since it is a series circuit, we take current **I** as the reference phasor. The voltage $\mathbf{V}_R$ across resistor R will be in phase with the current **I**. The voltage $\mathbf{V}_L$ across inductor L leads the current **I** by 90°. The voltage $\mathbf{V}_C$ across capacitor C lags the current **I** by 90°. For $\omega L > 1/\omega C$, the phasor diagram is as shown in Fig. 10.7*b*. For the case, $\omega L < 1/\omega C$, the phasor diagram is as shown in Fig. 10.7*c*. Since the phasors $\mathbf{V}_L$ and $\mathbf{V}_C$ are along in opposite directions, we first find the phasor sum $\mathbf{V}_L + \mathbf{V}_C$. We then add to it the phasor $\mathbf{V}_R$, as shown in the figure.

EXAMPLE 10.7

For the circuit shown in Fig. 10.8*a*, calculate (*a*) the impedance, (*b*) the current, (*c*) the phase angle, (*d*) the voltage across each element, (*e*) the power factor, (*f*) the apparent power, and (*g*) the average power. Also, draw the phasor diagram for the circuit.

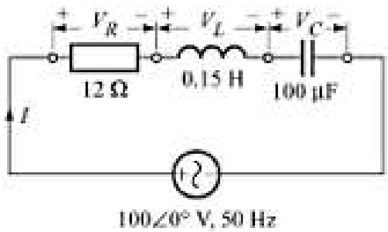
Solution $X_L = \omega L = 2\pi f L = 100\pi \times 0.15 = 47.1\ \Omega$; $X_C = 1/\omega C = 1/(100\pi \times 100 \times 10^{-6}) = 31.8\ \Omega$

(*a*) The impedance, $\mathbf{Z} = R + j(X_L - X_C) = 12 + j(47.1 - 31.8) = \mathbf{(12 + j15.3)}\ \Omega$

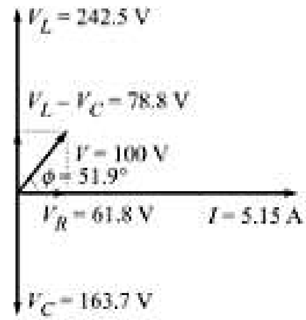
$$= \sqrt{12^2 + 15.3^2}\ \angle \tan^{-1}(15.3/12) = \mathbf{19.4\angle 51.9°}\ \Omega$$

(*b*) The current, $\mathbf{I} = \dfrac{\mathbf{V}}{\mathbf{Z}} = \dfrac{100\angle 0°}{19.4\angle 51.9°} = \mathbf{5.15\angle -51.9°\ A}$

(*c*) The phase angle, $\phi = \mathbf{-51.9°}$



(*a*) The circuit.



(*b*) Phasor diagram.

Fig. 10.8 *Series RLC circuit.*

(*d*) The voltage, $V_R = IR = 5.15 \times 12 = \mathbf{61.8\ V}$; $V_L = IX_L = 5.15 \times 47.1 = \mathbf{242.5\ V}$;
$V_C = IX_C = 5.15 \times 31.8 = \mathbf{163.7\ V}$

(*e*) The power factor, $pf = \cos 51.9° = \mathbf{0.617\ lagging}$

(*f*) The apparent power $P_{app} = VI = 100 \times 5.15 = \mathbf{515\ VA}$

(*g*) The average power $P_{avg} = VI \cos 51.9° = \mathbf{317.75\ W}$

The phasor diagram is given in Fig. 10.8*b*.

10.7 PARALLEL *RLC* CIRCUIT

Figure 10.9*a* shows a parallel *RLC* circuit. Writing KCL equation, we get total current **I** supplied by the applied voltage as

$$\mathbf{I} = \mathbf{I}_R + \mathbf{I}_L + \mathbf{I}_C = \frac{\mathbf{V}}{R} + \frac{\mathbf{V}}{jX_L} + \frac{\mathbf{V}}{-jX_C} = \mathbf{V}G + \mathbf{V}(-jY_L) + \mathbf{V}(jY_C)$$

or
$$\mathbf{I} = \mathbf{V}[G + j(Y_C - Y_L)] = \mathbf{VY} \tag{10.26}$$

where, **Y** is the complex admittance of the given circuit. Obviously,

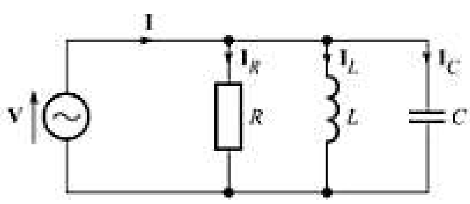
$$G = \frac{1}{R};\ Y_L = \frac{1}{X_L} = \frac{1}{\omega L} \qquad \text{and} \qquad Y_C = \frac{1}{X_C} = \frac{\omega C}{1} = \omega C$$

Note that $+j$ is associated with Y_C (and not with X_L) and $-j$ with Y_L. The complex admittance of the circuit can be written as

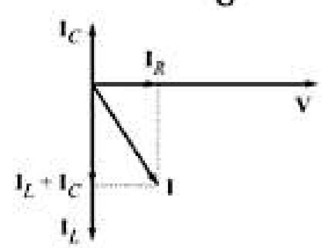
$$\mathbf{Y} = G + j(Y_C - Y_L) = \sqrt{G^2 + (Y_C - Y_L)^2}\ \angle \tan^{-1}\frac{Y_C - Y_L}{G}$$

Take the applied voltage as the reference phasor, i.e., $\mathbf{V} = V\angle 0°$, the resulting current **I** can be written as

$$\mathbf{I} = I\angle\phi = \mathbf{VY} = (V\angle 0°)\left(\sqrt{G^2 + (Y_C - Y_L)^2}\right)\angle \tan^{-1}\frac{Y_C - Y_L}{G}$$



(*a*) The circuit.



(*b*) Phasor diagram.

Fig. 10.9 *Parallel RLC circuit.*