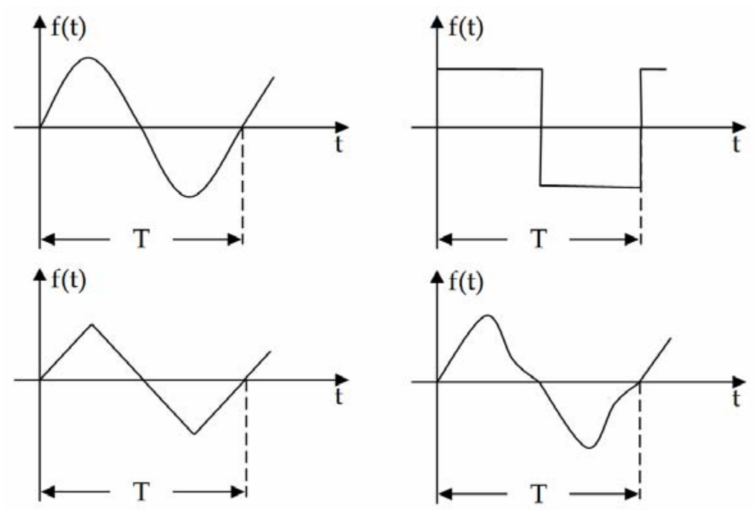
A SINUSOIDAL STEADY STATE ANALYSIS OF ELECTRIC CIRCUITS

INTRODUCTION

The steady state behavior of an electric circuit with sinusoidal excitations is very important in power industry, because the power supply to the consumers is a sinusoidal quantity. The behavior of the loads for these excitations will be useful in fixing proper measuring instruments at the consumer ends which may be used for collection of the tariff based on the consumption. Even in the various laboratories a number of sinusoidal generators with different frequencies can be used to predict the type of the circuit and its performance.

ALTERNATING QUANTITY

The name implies that a wave form goes through a series of different values both positive and negative in a period of time after which it continuously repeats the same wave form in a cyclic manner as shown in fig..



These are called the periodic waveforms and any non-sinusoidal wave form voltage (or) current can be represented by Fourier series in trigonometric form as

$$f(t) = A_0 + A_1 \sin(\omega t + \theta_1) + A_2 \sin(\omega t + \theta_2) + ...$$

If the wave form is representing in a current then

$$i(t) = I_0 + I_1 \sin(\omega t + \theta_1) + I_2 \sin(\omega t + \theta_2) + ...$$

Where i(t) is an instantaneous quantity of the periodic current in time 't'. I_0, I_1, I_2 ... are positive nonzero constants. ω is the radian frequency of the periodic wave.

"An alternating current (or) voltage is a periodic current (or) voltage, the mean value (or) average value of which over a period is zero".

PERIOD

The 'Period' of an alternating current (or) voltage is the smallest value of time which separates the recurring values of the alternating quantity. The period of time which separates these recurring values is shown as 'T' in the above fig.'s.

CYCLE

One complete set of positive and negative values of an alternating quantity is called a 'Cycle'. One complete cycle is then to extend over 360° (or) 2π radians.

FREQUENCY

'Frequency' is the number of cycles per second over a periodic wave. If 'P' is the number of poles, 'N' is the number of revolutions per minute of a generator then the frequency of the supply is $f = \frac{PN}{120}$ cycles/sec (or) simply Hertz's (Symbol Hz). The relation between time period and frequency is $f = \frac{1}{T}$, where 'T' is the time period in seconds.

The angular frequency, $\omega = 2\pi f = \frac{2\pi}{T}$ Rad / Sec.

PHASE

A fractional part of a period through which time (or) the associated time in degrees (or) radians that specifies the position of a periodic wave relative to a reference is called 'Phase'. The phase angle is a very important parameter for properly locating different alternating quantities with respect to one another. For example if the voltage waveform $v(t) = V_m \sin \omega t$ and current $i(t) = I_m \sin(\omega t + \theta^0)$ then the plot of the two waveforms is as shown in fig.(a).

Consider the plot of the two periodic waves it is observed that i(t) is zero at point A, where as $v(t)$ is zero after some time at the point B. Then the angular difference 'θ^0' is called phase angle difference. In this case the current wave is ahead of the voltage wave. Hence this phase angle is leading as per the current is concerned with respect to voltage. Now, the two alternating quantities $v(t) = V_m \sin\omega t$ and $i(t) = I_m \sin(\omega t - \theta^0)$ are plotted is as shown in fig.(b). The angular difference 'θ^0' is called phase angle difference. In this case the voltage wave is ahead of the current wave. Hence this phase angle is lagging as per the current is concerned with respect to voltage.

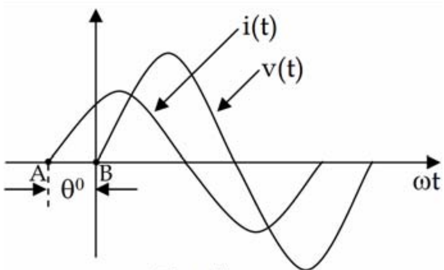


Fig.(a)

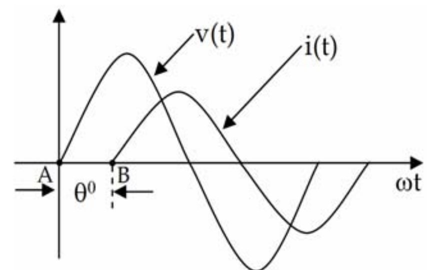
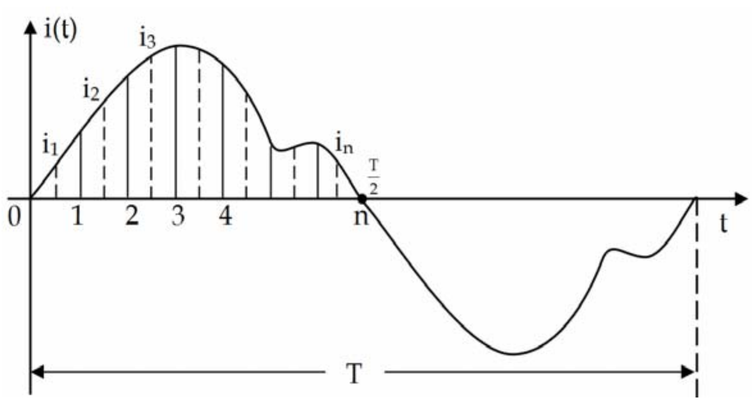


Fig.(b)

AVERAGE (OR) MEAN VALUE OF AN ALTERNATING QUANTITY

Sometimes it is necessary to determine the average (or) mean value of an alternating voltage (or) a current in an A.C circuit. Any shape of the wave can be measured with the help of an Oscilloscope. Let us assume that the current waveform as shown in fig.. The determination of average value of this waveform is explained below. Divide the base line into 'n' equal parts. Let the mid-ordinates measured be i_1, i_2… i_n.



Then the average value is $I_{avg} = \dfrac{i_1 + i_2 + \dots\dots + i_n}{n}$

If the waveform of a current i(t) can be expressed by a simple mathematical expression then the average value is given by

$$I_{av} = \frac{1}{(T/2)} \int_0^{T/2} i(t)\,dt = \frac{2}{T} \int_0^{T/2} i(t)\,dt$$, where 'T' is the time period of the given wave

ROOT MEAN SQUARE (OR) EFFECTIVE VALUE OF AN ALTERNATING QUANTITY

If a steady state alternating current is flowing through a resistance for certain time, a certain amount of heat is produced. Now suppose that same direct current is supplied through the same resistance for the same amount of time and assume that the same amount of heat is produced. This value of steady state current which has caused the same heat is called as Root Mean Square value (or) Effective value of the alternating quantity. Assume that the current shown in fig., is flowing through a resistance 'R'Ω. Let the current at different intervals are i_1, i_2, …, i_n then the average heating effect is given by

$$I^2 R = \frac{i_1^2 R + i_2^2 R + \dots\dots + i_n^2 R}{n}$$

Where 'n' is the number of mid-ordinates for the first half cycle and 'I' is the RMS value of the current wave

$$\therefore\ I = \sqrt{\frac{i_1^2 + i_2^2 + \dots\dots + i_n^2}{n}}$$ [Root Mean Square or RMS value of the current wave]

If the current is represented by a mathematical expression then

$$I^2_{rms} = \frac{1}{T} \int_0^T i(t)^2\,dt \Rightarrow I_{rms} = \sqrt{\frac{1}{T} \int_0^T i(t)^2\,dt}$$

FORM FACTOR

It is the ratio of RMS value to the Average value of a periodic wave.

$$\text{Form factor} = \frac{\text{RMS value}}{\text{Average value}}$$

CREST FACTOR (OR) PEAK FACTOR

It is the ratio of the Maximum (or) Peak value to the RMS value of the periodic wave.

$$\text{Peak (or) crest factor} = \frac{\text{Maximum value}}{\text{RMS value}}$$

THE AVERAGE AND EFFECTIVE VALUES OF A SINUSOIDALLY VARYING CURRENT WAVE

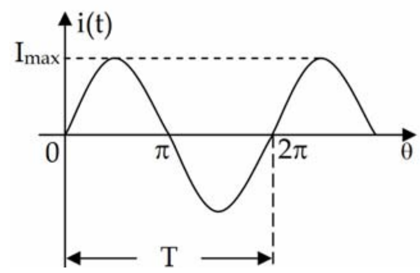


Fig.: Sinusoidally varying current wave

Let $i(t) = I_{max} \sin\theta$, since the wave is symmetric along the horizontal axis the average value is found by taking half of the wave into consideration, otherwise the average of the two half cycles is zero.

$$I_{avg} = \frac{1}{\pi}\int_0^{\pi} I_{max} \sin\theta \, d\theta = \frac{I_{max}}{\pi}\left[-\cos\theta\right]_0^{\pi} = \frac{2 I_{max}}{\pi} = 0.637 \; I_{max}$$

$$\therefore \; I_{avg} = 0.637 \; I_{max}$$

The RMS value of the sine wave is given by

$$I_{rms}^2 = \frac{1}{2\pi}\int_0^{2\pi} I_m^2 \sin^2\theta \, d\theta = \frac{I_{max}^2}{2\pi}\int_0^{2\pi}\frac{(1-\cos 2\theta)}{2} d\theta = \frac{I_{max}^2}{2\pi}\left[\frac{\theta}{2} - \frac{\sin 2\theta}{4}\right]_0^{2\pi} = \frac{I_{max}^2}{2}$$

$$\therefore \; I_{rms} = \frac{I_{max}}{\sqrt{2}} = 0.707 \; I_{max}$$

Form factor of the sinusoidally varying current = $\frac{I_{rms}}{I_{av}} = \frac{0.707 \; I_{max}}{0.637 \, I_{max}} = 1.11$

Crest (or) peak factor of the sinusoidally varying current = $\frac{I_{max}}{I_{rms}} = \frac{I_{max}}{0.707 \; I_{max}} = 1.414$

PHASOR NOTATION

The Phasor is a complex number that carries the amplitude and phase angle information of a sinusoidal function. The phasor notation relates the exponential function to the trigonometric function. The of a complex number is written in rectangular form as $a = x + jy$, where x is the real part and y is the imaginary part and j is by definition $\sqrt{-1}$, i.e., a rotation of vector by 90º in counter clock wise direction and j² means rotation of vector by 180º in counter clock wise direction. A complex number can be written in a exponential form as $a = c e^{j\theta}$, where c is the magnitude, θ is the angle and e is the base of the natural logarithm and $j = \sqrt{-1}$, the polar form frequently used is $a = c\angle\theta^o$. The transition form, the polar form to rectangular form is

$$a = c e^{j\theta} = c\angle\theta^o = c\,(\cos\theta \pm j\sin\theta) = x \pm jy$$

$$\therefore \; (x + jy) = \left(\sqrt{x^2 + y^2}\right) \times e^{j\theta} = c\, e^{j\theta}, \text{ where } \operatorname{Tan}\theta = \frac{y}{x}.$$

Let the voltage phasor in polar form is $v = V_m e^{j\theta}$, then in rectangular form of this phasor is $v = V_m \cos\theta + j\, V_m \sin\theta$.

CONCEPT OF IMPEDANCE AND ADMITTANCE

The impedance of the circuit is defined as the total opposition of the circuit to the alternating current through it. It is the vector sum of resistance (R) and reactance (X) (Inductive (or) Capacitive) as shown in impedance triangle fig.'s(a) & (b). Their unit is ohms.

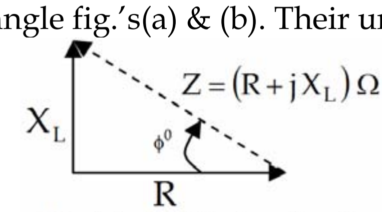


Fig.(a) : RL Series circuit

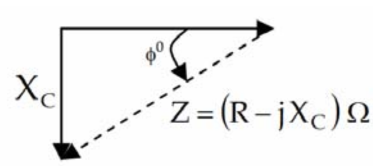


Fig.(b) : RC Series circuit

$$\therefore \; \text{Impedance}, \overline{Z} = (R \pm jX)\,\Omega = z\angle \pm \phi^0 \;\; \Omega$$

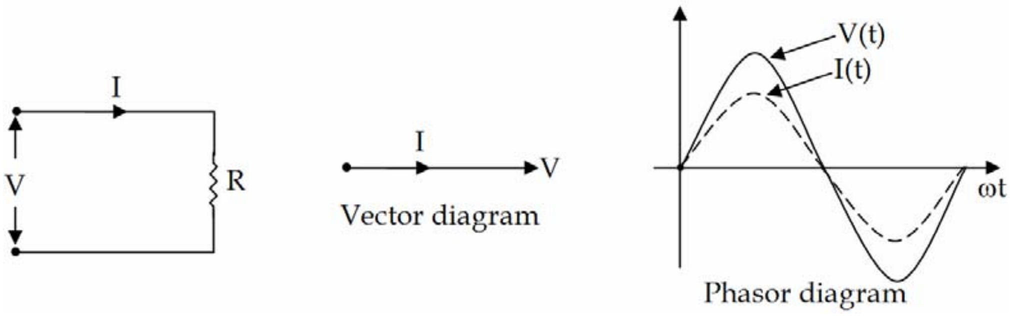
Where $z = \sqrt{R^2 + X^2}$ and $\operatorname{Tan}\phi = \frac{X}{R}$, also $X = X_L - X_C \rightarrow$ Inductive (or) $X = X_C - X_L \rightarrow$ Capacitive

Admittance is defined as the ability of the circuit carry alternating currents through it. It is the reciprocal of impedance and its units is Mho's (or) Semien's. It is the vector sum of conductance (G) and susceptance (B).

$$\therefore \; \text{Admittance}, \overline{Y} = \frac{1}{\overline{Z}} = \frac{1}{(R \pm jX)} = (G \mp jB) \text{ Mhos}$$

THE V – I RELATIONSHIP FOR A RESISTOR

Let $I = I_m \sin \omega t$ is the current flowing through then the voltage across the resistor by ohms law is given by $V = R I_m \sin \omega t = V_m \sin \omega t$, where $V_m = R I_m$ then the voltage and current are in phase because the phase difference is zero.

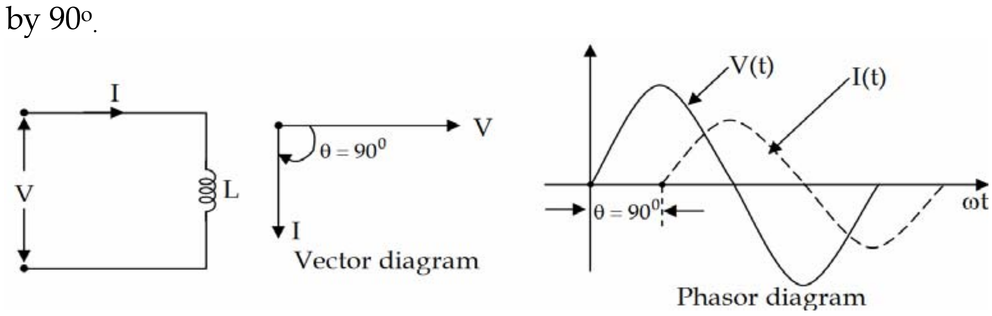


THE V – I RELATIONSHIP FOR AN INDUCTOR

Let the current flowing through an Inductor is $I = I_m \sin \omega t$, then the voltage across the inductor is given by

$$V = L\frac{dI}{dt} = L\frac{d}{dt}(I_m \sin \omega t) = L\,\omega\, I_m \cos \omega t = X_L\, I_m \sin(\omega t + 90^o) \text{ (or) } V = jX_L I$$

Where $X_L = L\omega$ called inductive reactance and its units is Ohm's. Therefore the voltage across the inductor leads the current through the inductor by 90^o as shown in vector diagram (or) the current lags the voltage by 90^o.

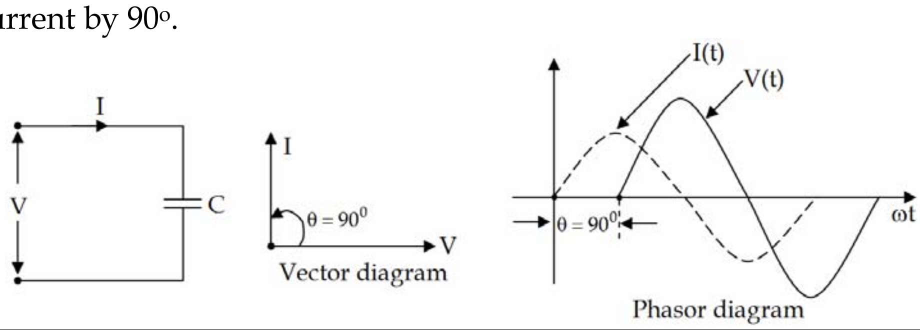


THE V – I RELATIONSHIP FOR A CAPACITOR

Let the current flowing through the capacitor is $I = I_m \sin \omega t$, and then the voltage across the capacitor is given by

$$V = \frac{1}{c}\int I\, dt = V = \frac{1}{c}\int I_m \sin \omega t\, dt = -\frac{I_m}{c\omega}\sin(\omega t - 90^o) = X_C\, I_m \sin(\omega t - 90^o) \text{ (or) } V = -jX_C I$$

Where $X_C = \frac{1}{c\omega}$ is called capacitive reactance. In this case the current leads the voltage by 90^o (or) the voltage lags the current by 90^o.



S.No.	Circuit	Impedance		Power factor angle	Power factor	Remarks
		Polar form	Rectangular form			
1.	Pure Resistor	$R\angle 0^0\ \Omega$	$(R + j0)\Omega$	0^0	1	Unity power factor
2.	Pure Inductor	$X_L\angle 90^0\ \Omega$	$(0 + jX_L)\Omega$	90^0	0	Zero power factor
3.	Pure Capacitor	$X_C\angle -90^0\ \Omega$	$(0 - jX_C)\Omega$	-90^0	0	Zero power factor

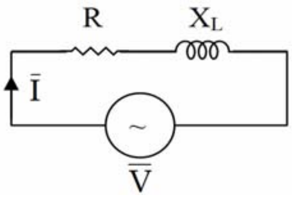
ANALYSIS OF SINGLE PHASE AC SERIES CIRCUITS

RL series circuit:

Let the circuit contains of resistance 'R' in series with an inductance 'L' as shown in fig.. The current flowing through it is '$\bar{I}$' Amps. The voltage drop across the resistor and the current through it are in phase. Where as the voltage drop across the inductor is leading by 90^0 with respect to the current, then the impedance of the given circuit is,

$$\overline{Z} = (R + jX_L)\Omega = z\angle\phi^0 \quad \Omega, \text{ where } z = \sqrt{R^2 + X_L{}^2} \text{ and } \operatorname{Tan}\phi = \frac{X_L}{R}$$

If $\overline{V}$ is the voltage applied, then $\bar{I} = \frac{\overline{V}}{\overline{Z}} = \frac{V\angle 0^0}{z\angle\phi^0} = \frac{V}{z}\angle -\phi^0$, where V is taken as reference. The corresponding vector diagram and impedance diagram for this circuit is as shown in fig.'s(a) & (b).



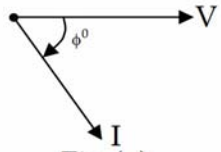


Fig.(a)

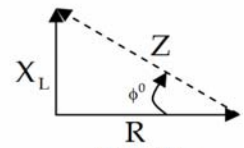


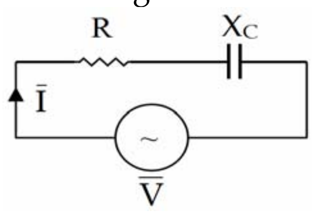
Fig.(b)

RC Series circuit:

Let the circuit contains resistance 'R' in series with the capacitor 'C' as shown in fig.. The current flowing through it is '$\bar{I}$' Amps. The voltage drop across the resistor and the current through it are in phase. Where as the voltage drop across the capacitor is lagging the current through it by 90^0, then the impedance of the given circuit is,

$$\bar{Z} = (R - jX_C) = z\angle -\phi^0, \text{ where } z = \sqrt{R^2 + X_C^2} \text{ and } \operatorname{Tan}\phi = \frac{X_C}{R}$$

If $\bar{V}$ is the voltage applied, then $\bar{I} = \frac{\bar{V}}{\bar{Z}} = \frac{V\angle 0^0}{z\angle -\phi^0} = \frac{V}{z}\angle \phi^0$, where V is taken as reference. The corresponding vector diagram and impedance diagram for this circuit is as shown in fig.'s(a) & (b).



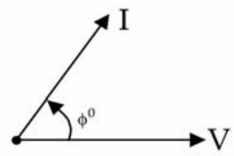


Fig.(a)

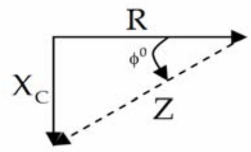


Fig.(b)

RLC Series circuit:

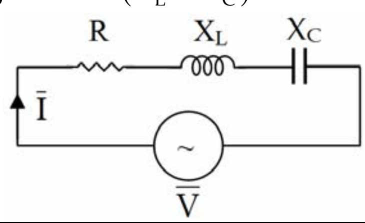
A Series RLC circuit supplied with a sinusoidal voltage source is shown in fig.. Let the current flowing through the circuit is '$\bar{I}$' Amps. The total impedance of the circuit if $X_L > X_C$ is

$$\bar{Z} = R + j(X_L - X_C) = z\angle\phi^0$$

Taking $\bar{V}$ as a reference quantity, the current $\bar{I}$ is given by

$$\bar{I} = \frac{\bar{V}}{\bar{Z}} = \frac{V\angle 0^0}{z\angle\phi^0} = \frac{V}{z}\angle -\phi^0 \quad \text{Where } z = \sqrt{R^2 + (X_L - X_C)^2} \text{ and } \operatorname{Tan}\phi = \frac{(X_L - X_C)}{R}$$

The vector diagram for $(X_L - X_C) > 0$ is shown in fig.(a) and $(X_L - X_C) < 0$ is shown in fig.(b).



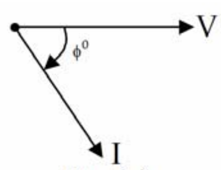


Fig.(a)

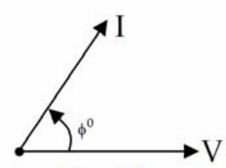
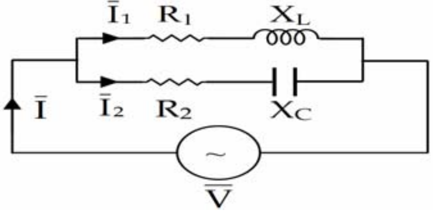


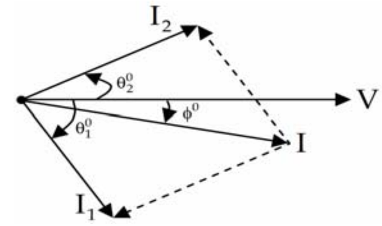
Fig.(b)

S.No.	Circuit	Impedance		Power factor angle	Power factor	Remarks
		Polar form	Rectangular form			
1.	RL Series	$z\angle\phi^0\ \Omega$	$(R + jX_L)\Omega$	$0^0 < \phi^0 < 90^0$	$\cos\phi^0$	Lagging current
2.	RC Series	$z\angle -\phi^0\ \Omega$	$(R - jX_C)\Omega$	$0^0 > \phi^0 > 90^0$	$\cos\phi^0$	Leading current
3.	RLC Series	$z\angle \pm\phi^0\ \Omega$	$(R \pm jX)\Omega$ $+ \rightarrow X = X_L - X_C$ $- \rightarrow X = X_C - X_L$	$+ \rightarrow 0^0 < \phi^0 < 90^0$ $- \rightarrow 0^0 > \phi^0 > 90^0$	$\cos\phi^0$	$X_L > X_C \rightarrow$ Lagging current $X_L < X_C \rightarrow$ Leading current $X_L = X_C \rightarrow$ Unity

ANALYSIS OF SINGLE PHASE AC PARALLEL CIRCUITS

Assume that the single phase AC parallel circuit having two branches in parallel is as shown in fig.. Let the first branch impedance is $\bar{Z}_1 = (R_1 + jX_L)\Omega$ and second branch impedance is $\bar{Z}_2 = (R_2 - jX_C)\Omega$.





Taking $\bar{V}$ as reference vector and corresponding currents in each branch is,

$$\bar{I}_1 = \frac{\bar{V}}{\bar{Z}_1} = \frac{V\angle 0^0}{z_1\angle\theta_1^0} = \frac{V_1}{z_1}\angle -\theta_1^0 = (I_{x_1} - j\,I_{y_1}) \quad \& \quad \bar{I}_2 = \frac{\bar{V}}{\bar{Z}_2} = \frac{V\angle 0^0}{z_2\angle -\theta_2^0} = \frac{V}{z_2}\angle\theta_2^0 = (I_{x_2} + jI_{y_2})$$

$\therefore$ the total current, $\bar{I} = \bar{I}_1 + \bar{I}_2 = (I_{x_1} - j\,I_{y_1}) + (I_{x_2} + jI_{y_2})$

$$= (I_{x_1} + I_{x_2}) + j(-I_{y_1} + I_{y_2})$$

$$\text{Tan}\,\phi = \frac{(I_{y_2} - I_{y_1})}{(I_{x_1} + I_{x_2})}$$

Where I_{x_1} , I_{x_2} & I_{y_1} , I_{y_2} are the real & imaginary parts of branch currents $\bar{I}_1$ and $\bar{I}_2$ respectively. The vector diagram is as shown in fig. for a lagging current. Otherwise the vector diagram has to be modified accordingly.

Another solution: An alternative method may be by replacing the parallel network by its equivalent impedance $\bar{Z}_{eq}$, and its value is

$$\bar{Z}_{eq} = \frac{\bar{Z}_1 \bar{Z}_2}{\bar{Z}_1 + \bar{Z}_2} = z_{eq} \angle\phi^0 \text{ , then } \bar{I} = \frac{\bar{V}}{\bar{Z}_{eq}} = \frac{V\angle 0^0}{z_{eq}\angle\phi^0} = \frac{V}{z_{eq}}\angle -\phi^0$$

, then by using current division method the branch currents are

$$\bar{I}_1 = \frac{\bar{I} \times \bar{Z}_2}{\bar{Z}_1 + \bar{Z}_2} \text{ and } \bar{I}_2 = \frac{\bar{I} \times \bar{Z}_1}{\bar{Z}_1 + \bar{Z}_2}$$

SOLUTION OF SINGLE PHASE PARALLEL CIRCUITS BY THE ADMITTANCE METHOD

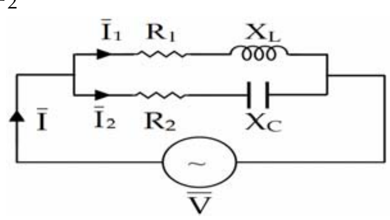
Let the parallel network is as shown in fig.. Taking the applied voltage as reference we have, admittance of the inductive branch is

$$\bar{Y}_1 = \frac{1}{\bar{Z}_1} = \frac{1}{R_1 + jX_L} = \frac{1}{R_1 + jX_L} \times \left(\frac{R_1 - jX_L}{R_1 + jX_L}\right) = \frac{R_1 - jX_L}{(R_1^2 + X_L^2)}$$

Similarly, admittance of the capacitive branch is

$$\bar{Y}_2 = \frac{1}{\bar{Z}_2} = \frac{1}{R_2 - jX_C} = \frac{1}{R_2 - jX_C} \times \left(\frac{R_2 + jX_C}{R_2 - jX_C}\right) = \frac{R_2 + jX_C}{(R_2^2 + X_C^2)}$$

$\therefore$ The total admittance is $\bar{Y} = \bar{Y}_1 + \bar{Y}_2$

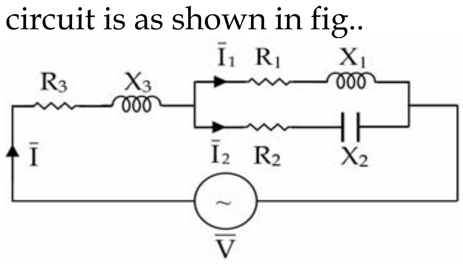


The current supplied by the source is

$$\bar{I} = \bar{Y}\,\bar{V}, \bar{I}_1 = \bar{Y}_1\,\bar{V} \text{ \& } \bar{I}_2 = \bar{Y}_2\,\bar{V}\text{, then } \bar{Y} = G + jB \text{ and Tan}\phi = \frac{B}{G}$$

ANALYSIS OF SINGLE PHASE SERIES PARALLEL CIRCUIT

Let the single phase series parallel circuit is as shown in fig..

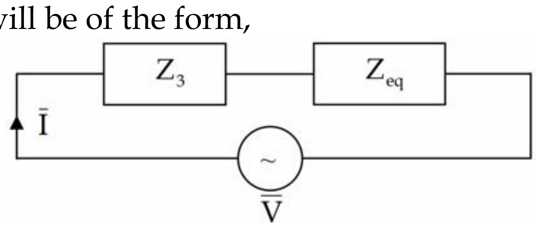


Taking $\bar{V}$ as a reference vector, the various impedances are

$\bar{Z}_1 = (R_1 + jX_1) = z_1 \angle\theta_1^0$, $\bar{Z}_2 = (R_2 - jX_2) = z_2 \angle -\theta_2^0$ & $\bar{Z}_3 = (R_3 + jX_3) = z_3 \angle\theta_3^0$

The equivalent impedance of the parallel branch is $\bar{Z}_{eq} = \dfrac{\bar{Z}_1 \times \bar{Z}_2}{\bar{Z}_1 + \bar{Z}_2}$

Now the series parallel circuit will be of the form,



$\therefore$ the total current, $\bar{I} = \dfrac{\bar{V}}{\bar{Z}_{eq} + \bar{Z}_3} = I\angle\theta^0$ and by using current division method the branch currents are $\bar{I}_1 = \dfrac{\bar{I} \times \bar{Z}_2}{\bar{Z}_1 + \bar{Z}_2} = I_1\angle\theta_1^0$ and $\bar{I}_2 = \dfrac{\bar{I} \times \bar{Z}_1}{\bar{Z}_1 + \bar{Z}_2} = I_2\angle\theta_2^0$

A GENERAL EXPRESSION FOR POWER IN A NETWORK EXCITED BY SINUSOIDAL QUANTITY

It is seen that a sinusoidal voltage at a given frequency gives rise to a sinusoidal current at the same frequency but at different phase angle. Let the applied voltage is $v(t) = V_m \sin\omega t$ and the current in the circuit is $i(t)=I_m \sin(\omega t+\phi^0)$. If ϕ^0 is a positive then the current is a leading current with respect to applied voltage and if ϕ^0 is a negative then the current is a lagging current with respect to applied voltage.

The instantaneous power is

$$p(t)=v(t)\times i(t)=(V_m \sin\omega t)\times(I_m \sin(\omega t+\phi))$$

The average power over a cycle is

$$p_{avg}=\frac{\omega}{2\pi}\int_0^{\frac{2\pi}{\omega}} V_m\, I_m \sin\omega t\ \sin(\omega t+\phi)\,dt=\frac{V_m\, I_m\ \omega}{2\pi}\int_0^{\frac{2\pi}{\omega}}[\cos\phi-\cos(2\omega t+\phi)]dt$$

$$p_{avg}=\frac{V_m I_m}{2}\cos\phi=\left(\frac{V_m}{\sqrt{2}}\right)\left(\frac{I_m}{\sqrt{2}}\right)\cos\phi=V_{rms}\ I_{rms}\ \cos\phi \quad \text{watts}$$

The power consumed in a DC circuit is equal to $P_{DC}=VI$ watts, where as in single phase AC circuit the average power, $P_{avg}=V_{rms}\,I_{rms}\cos\phi$ watts.

The product of $V_{rms}\ I_{rms}$ is volt amperes and is called the Apparent power. The Active (or) True (or) Real power consumed is $V_{rms}\ I_{rms}\ \cos\phi$ in Watts. Also the Reactive (or) False power is $V_{rms}\ I_{rms}\ \sin\phi$ in VAR's.

POWER FACTOR

The ratio of real power to the apparent power is called the power factor. Mathematically,

$$\text{Power factor}=\frac{V_{rms}\ I_{rms}\ \cos\phi}{V_{rms}\ I_{rms}}=\cos\phi$$

Where ϕ is the phase angle, difference between the voltage and current. If the current is lagging with the voltage then the power factor is lagging power factor. If the current is leading with the voltage then the power factor of the circuit is leading power factor.

COMPLEX POWER

Real and Reactive power:

Let the voltage applied to a circuit is $\overline{V}=V\angle\theta^0$ and the current $\overline{I}=I\angle\phi^0$. Assume that $\theta^0>\phi^0$ then the expression for complex power is given by

$$S=P+jQ=\overline{V}\ \overline{I}^*=VI\angle\theta^0-\phi^0 \quad \text{Volts}-\text{Amperes}$$

The active power, P = Real part of $\overline{V}\ \overline{I}^*=VI\cos(\theta^0-\phi^0)$ Watts.

The reactive power, Q = Imaginary part of $\overline{V}\,\overline{I}^*=VI\sin(\theta^0-\phi^0)$ VAR's.

The power triangle of a complex power for inductive and capacitive in series with resistance are shown in fig.'s(a) & (b).

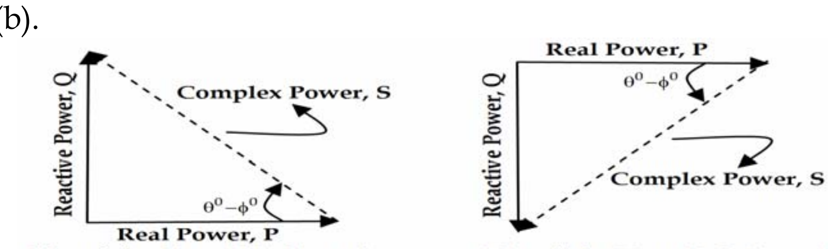


Fig.(a) : For RL Load   Fig.(b) : For RC Load

Power in a pure resistive network:

Let V and I be the voltage and current of a pure resistance network. It is shown that the phase angle difference between V and I is zero, then

Power factor = $\cos\phi=\cos 0=1\rightarrow$ unity is the maximum value.

Active power, P = $VI\cos\phi=VI$ watts

Reactive power, Q = $VI\sin\phi=VI\sin 0=0$ VAR's

Power in a pure inductive network:

It is shown that in the case of pure inductive network the current is lagging the voltage by 90°.

Power factor = cos90° = 0 $\rightarrow$ lagging

Active power, P = $VI\cos 90^\circ=0$ watts

Reactive power, Q = $VI\sin 90^\circ=VI$ VAR's

Power in a pure capacitor network:

It is shown that the current of a pure capacitor leads the voltage across it by 90°

Power factor = cos90° = 0 $\rightarrow$ leading

Active power, P = V I cos90° = 0 watts

Reactive power, Q = $VI\sin 90^\circ=VI$ VAR's