Course Title: Basic Electrical and Electronics Engineering

Paper Code: 22310

Chapter 2: A.C. Circuits (10 Hours)

Total Marks: 12

Course Outcomes:

a. Use principles of electric and magnetic circuits to solve engineering problems.
b. Determine voltage and current in A.C. circuits.
c. Connect transformers and electric motors for specific requirements.
d. Identify electronic components in electric circuits.
e. Use relevant electronic components safely.
f. Use relevant electric/electronic protective devices safely.

Contents:

2.1 Cycle, Frequency, Periodic time, Amplitude, Angular velocity, RMS value, Average value, Form Factor, Peak Factor, impedance, phase angle, and power factor.

2.2 Mathematical and phasor representation of alternating emf and current; Voltage and Current relationship in Star and Delta connections.

2.3 A.C. in resistors, inductors and capacitors; A.C. in R-L series, R-C series, R-L-C series and parallel circuits; Power in A. C. Circuits, power triangle

DEFINITIONS:

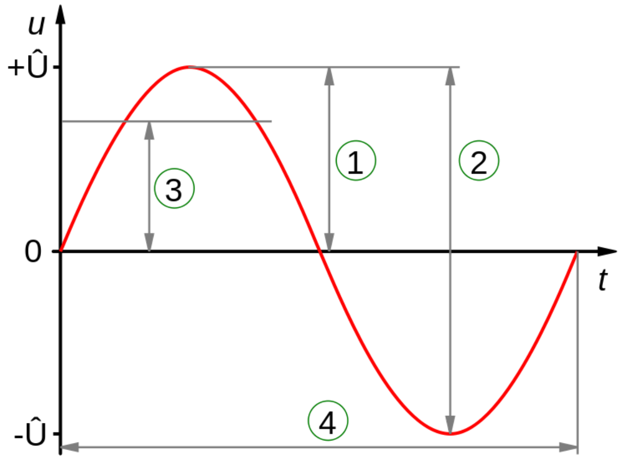
Cycle: One complete wave of alternating current or voltage is called cycle.

Frequency: frequency is the number of cycles per second in an ac sine wave. Frequency is the rate at which current changes direction per second. It is measured in hertz (Hz), an international unit of measure where 1 hertz is equal to 1 cycle per second.

Periodic time: The time required to produce one complete cycle of a waveform.

Amplitude: The amplitude of a periodic variable is a measure of its change over a single period (such as time or spatial period). There are various definitions of amplitude.

1. **Peak-to-peak amplitude**
   Peak-to-peak amplitude is the change between peak (highest amplitude value) and trough (lowest amplitude value, which can be negative).
2. **Peak amplitude**
   In audio system measurements, telecommunications and other areas where the measurand is a signal that swings above and below the reference value but is not sinusoidal, peak amplitude is often used. If the reference is zero, this is the maximum absolute value of the signal
3. **Semi-amplitude**
   Semi-amplitude means 1/2(Half) of the peak-to-peak amplitude.Some scientists use amplitude or peak amplitude to mean semi-amplitude.
4. **Root mean square amplitude**
   Root mean square (RMS) amplitude is used especially in electrical engineering: the RMS is defined as the square root of the mean over time of the square of the vertical distance of the graph from the rest state; i.e. the RMS of the AC waveform (with no DC component).



A sinusoidal curve Peak amplitude (1), Peak-to-peak amplitude (2), Root mean square amplitude (3), Wave period (not an amplitude)(4).

Angular velocity:

- In physics, angular velocity refers to how fast an object rotates or revolves relative to another point, i.e. how fast the angular position or orientation of an object changes with time.
- There are two types of angular velocity: orbital angular velocity and spin angular velocity.
- **Spin angular velocity** refers to how fast a rigid body rotates with respect to its centre of rotation.
- **Orbital angular velocity** refers to how fast a rigid body's centre of rotation revolves around a fixed origin, i.e. the time rate of change of its angular position relative to the origin.
- In general, angular velocity is measured in angle per unit time, e.g. radians per second. The SI unit of angular velocity is expressed as radians/sec with the radian having a dimensionless value of unity, thus the SI units of angular velocity are listed as 1/sec. Angular velocity is usually represented by the symbol omega (ω, sometimes Ω). By convention, **positive angular velocity indicates counter-clockwise rotation, while negative is clockwise.**

Average value: The average of all the instantaneous values of an alternating voltage and currents over one complete cycle is called Average Value.

If we consider symmetrical waves like sinusoidal current or voltage waveform, the positive half cycle will be exactly equal to negative half cycle. Therefore, the average value over a complete cycle will be zero. The work is done by both, positive and negative cycle and hence the average value is determined without considering the signs.

So the only positive half cycle is considered to determine the average value of alternating quantities of sinusoidal waves.

$$V_{AVE} = \frac{2V_P}{\pi} = 0.637V_p$$

- *The main differences between an RMS Voltage and an Average Voltage, is that the mean value of a periodic wave is the average of all the instantaneous areas taken under the curve over a given period of the waveform, and in the case of a sinusoidal quantity, this period is taken as one-half of the cycle of the wave. For convenience the positive half cycle is generally used.*

- *The effective value or root-mean-square (RMS) value of the waveform is the effective heating value of the wave compared to a steady DC value and is the square root of the mean of the squares of the instantaneous values taken over one complete cycle.*

- *For a pure sinusoidal waveform ONLY, both the average voltage and the RMS voltage (or currents) can be easily calculated as:*

  Average value = 0.637 × maximum or peak value, Vpk

  RMS value = 0.707 × maximum or peak value, Vpk

Form Factor: In electronics or electrical the form factor of an alternating current waveform (signal) is the ratio of the RMS (root mean square) value to the average value (mathematical mean of absolute values of all points on the waveform). It identifies the ratio of the direct current of equal power relative to the given alternating current.

Peak Factor: Peak Factor is defined as the ratio of maximum value to the R.M.S value of an alternating quantity. The alternating quantities can be voltage or current. The maximum value is the peak value or the crest value or the amplitude of the voltage or current.

Mathematically it is expressed as

$$\text{Peak Factor} = \frac{I_m}{I_{r.m.s}} \text{ or } \frac{E_m}{E_{r.m.s}}$$

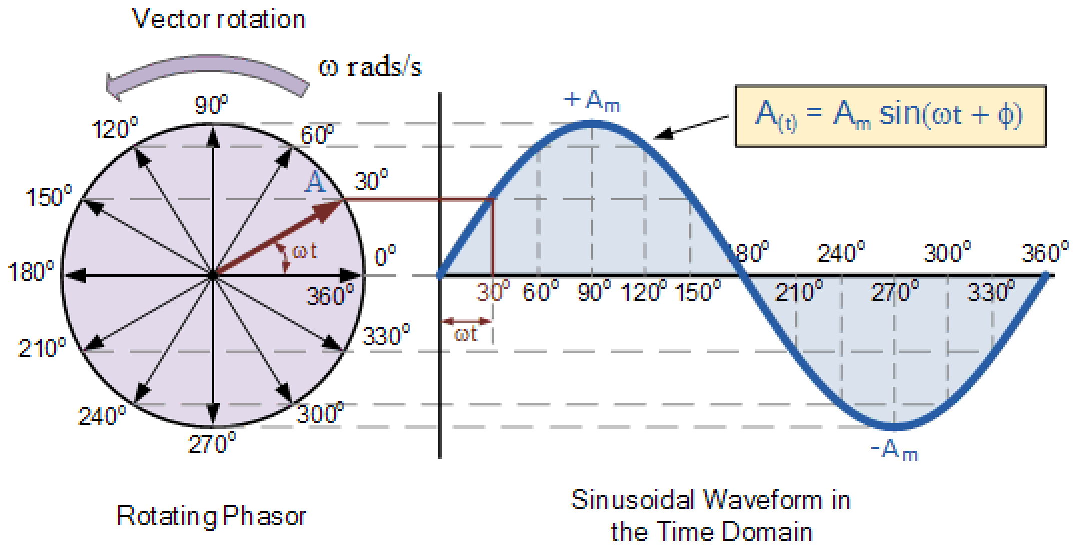
impedance: Impedance (Z), in electrical devices, refers to the amount of opposition faced by direct or alternating current when it passes through a conductor component, circuit or system. Impedance is null when current and voltage are constant and thus its value is never zero or null in the case of alternating current.

phase angle: In the context of phasors, phase angle refers to the angular component of the complex number representation of the function. The notation $A\angle\theta,$ for a vector with magnitude (or amplitude) A and phase angle θ, is called angle notation.

power factor:

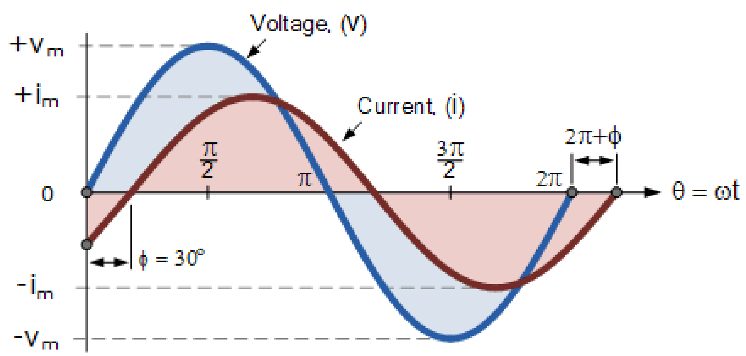
- In electrical engineering, the power factor of an AC electrical power system is defined as the ratio of the real power absorbed by the load to the apparent power flowing in the circuit, and is a dimensionless number in the closed interval of −1 to 1.
- A power factor of less than one indicates the voltage and current are not in phase, reducing the instantaneous product of the two. Real power is the instantaneous product of voltage and current and represents the capacity of the electricity for performing work.
- Apparent power is the average product of current and voltage. Due to energy stored in the load and returned to the source, or due to a non-linear load that distorts the wave shape of the current drawn from the source, the apparent power may be greater than the real power.
- A negative power factor occurs when the device (which is normally the load) generates power, which then flows back towards the source.

Mathematical and phasor representation of alternating emf and current



As the single vector rotates in an anti-clockwise direction, its tip at point A will rotate one complete revolution of 360o or 2π representing one complete cycle. If the length of its moving tip is transferred at different angular intervals in time to a graph as shown above, a sinusoidal waveform would be drawn starting at the left with zero time. Each position along the horizontal axis indicates the time that has elapsed since zero time, t = 0. When the vector is horizontal the tip of the vector represents the angles at 0degree, 180degree and at 360degree

Phase Difference of a Sinusoidal Waveform



The generalised mathematical expression to define these two sinusoidal quantities will be written as:

$$v_{(t)} = V_m \sin(\omega t)$$

$$i_{(t)} = I_m \sin(\omega t - \phi)$$

The current, i is lagging the voltage, v by angle Φ and in our example above this is 30o. So the difference between the two phasors representing the two sinusoidal quantities is angle Φ and the resulting phasor diagram will be.

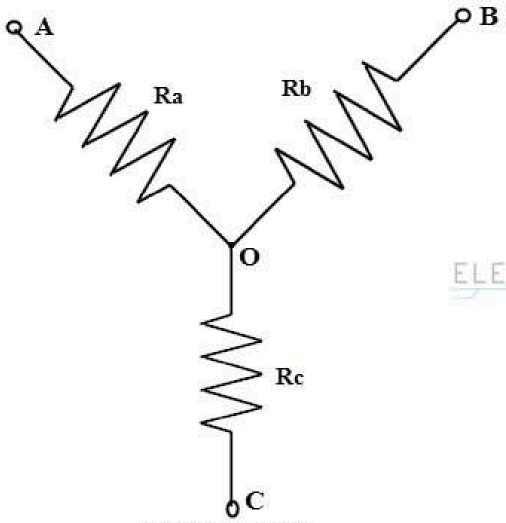
Phasor Diagram of a Sinusoidal Waveform

- The phasor diagram is drawn corresponding to time zero (t = 0) on the horizontal axis. The lengths of the phasors are proportional to the values of the voltage, (V) and the current, (I) at the instant in time that the phasor diagram is drawn. The current phasor lags the voltage phasor by the angle, Φ, as the two phasors rotate in an anticlockwise direction as stated earlier, therefore the angle, Φ is also measured in the same anticlockwise direction.
- If however, the waveforms are frozen at time, t = 30o, the corresponding phasor diagram would look like the one shown on the right. Once again the current phasor lags behind the voltage phasor as the two waveforms are of the same frequency.
- However, as the current waveform is now crossing the horizontal zero axis line at this instant in time we can use the current phasor as our new reference and correctly say that the voltage phasor is "leading" the current phasor by angle, Φ. Either way, one phasor is designated as the reference phasor and all the other phasors will be either leading or lagging with respect to this reference.

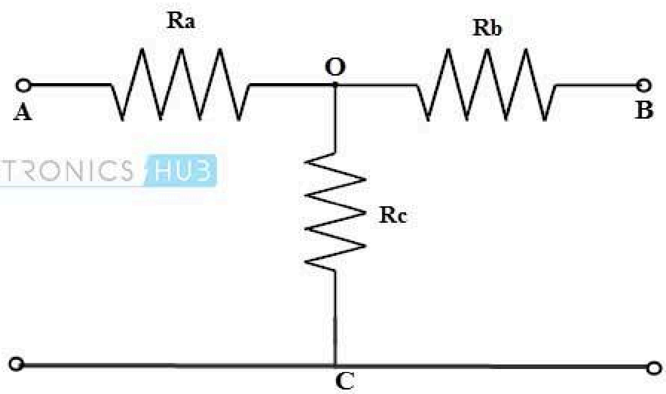
Voltage and Current relationship in Star and Delta connections.

- Star and Delta Connections are the two types of connections in a 3 – phase circuits. A Star Connection is a 4 – wire system and a Delta Connection is a 3 – wire system. A single phase system consists of just two conductors (wires): one is called the phase, through which the current flows and the other is called neutral, which acts as a return path to complete the circuit.

- In a three – phase system, we have a minimum of three conductors or wires carrying AC voltages. It is more economical to transmit power using a 3 – phase power supply when compared to a single phase power supply as a three – phase supply can transmit three times the power with three conductors when compared to a two – conductor single – phase power supply.
- In star connection, components are connected in such a way that one end of all the resistors or components are connected to a common point. By the arrangement of three resistors , this star network looks like an alphabet Y hence , this network is also called as Wye or Y network. The equivalent of this star connection can be redrawn as T network (as a four terminal network) as shown in the below figure. Most of the electrical circuits constitute this T form network.

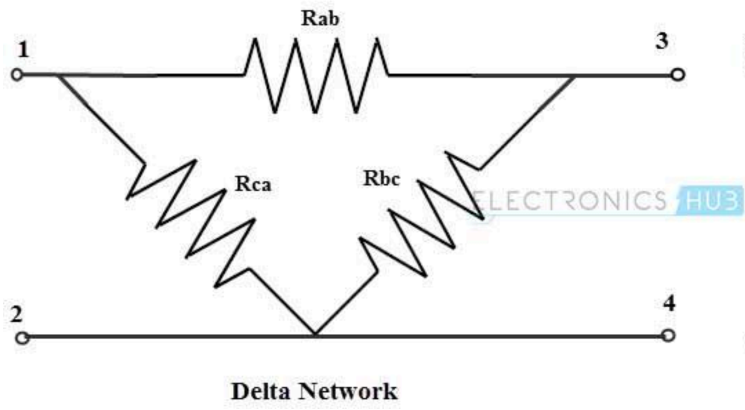


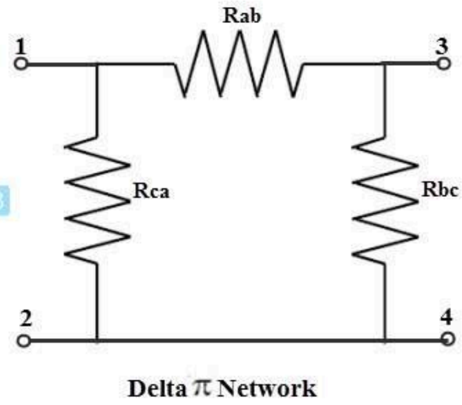
Star Network



Star-T Network

- In a delta connection, end point of each component or coil is connected to the start point of another component or coil. It is a series connection of three components that are connected to form a triangle. The name indicates that connection look like an alphabet delta (Δ). The equivalent delta network can be redrawn , to look like a symbol Pi (or four terminal network) as shown in figure. So this network can also be referred as Pi network.





For Conversion: https://www.electronicshub.org/star-delta-transformations/

https://www.electrical4u.com/delta-star-transformation-star-delta-transformation/

Relation Between voltage and current:

Y-connected (Star) loads (also sources) have line voltages greater than phase voltages, and line currents equal to phase currents. If the Y-connected load is balanced, the line voltage will be equal to the phase voltage times the square root of 3.

In case of Δ-connected (Delta) loads, line voltage and line current are equal. If the Δ-connected load is balanced, the line current will be equal to the phase current times the square root of 3.

i.e.

For Star connected loads,

$\mathbf{E}_{\text{line}} = \sqrt{3}\mathbf{E}_{\text{phase}}$

$\mathbf{I}_{\text{line}} = \mathbf{I}_{\text{phase}}$

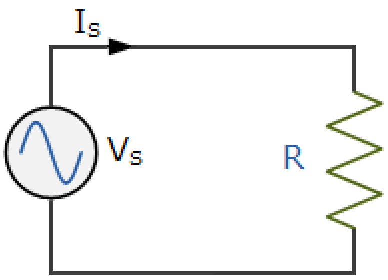
For delta connected loads,

$\mathbf{E}_{\text{line}} = \mathbf{E}_{\text{phase}}$

$\mathbf{I}_{\text{line}} = \sqrt{3}\mathbf{I}_{\text{phase}}$

Resistors in AC Circuits:

Resistors regulate, impede or set the flow of current through a particular path or impose a voltage reduction in an electrical circuit as a result of this current flow. Resistors have a form of impedance which is simply termed resistance, (R) with the resistive value of a resistor being measured in Ohms, Ω. Resistors can be of either a fixed value or a variable value (potentiometers).



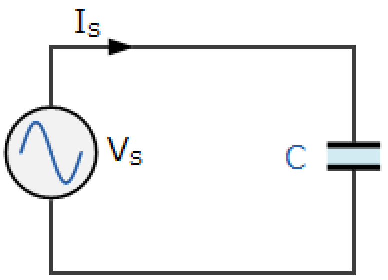
$$Z = \frac{V_R}{I_R} = R$$

$$Z = \angle 0^{\circ} = R + j0$$

$$I_S = \frac{V_S}{R}$$

Purely Capacitive Circuit

The capacitor is a component which has the ability or "capacity" to store energy in the form of an electrical charge like a small battery. The capacitance value of a capacitor is measured in Farads, F. At DC a capacitor has infinite (open-circuit) impedance, (XC) while at very high frequencies a capacitor has zero impedance (short-circuit).



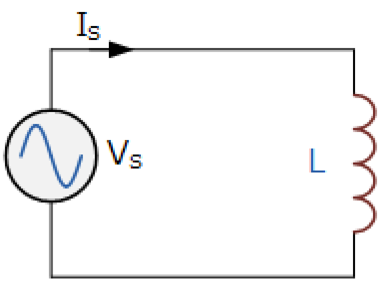
$$X_C = \frac{V_C}{I_C} = \frac{1}{2\pi f C}$$

$$Z = \angle{-90^{\circ}} = 0 - jX_C$$

$$I_S = \frac{V_S}{X_C}$$

Purely Inductive Circuit

An inductor is a coil of wire that induces a magnetic field within itself or within a central core as a direct result of current passing through the coil. The inductance value of an inductor is measured in Henries, H. At DC an inductor has zero impedance (short-circuit), while at high frequencies an inductor has infinite (open-circuit) impedance, (XL).

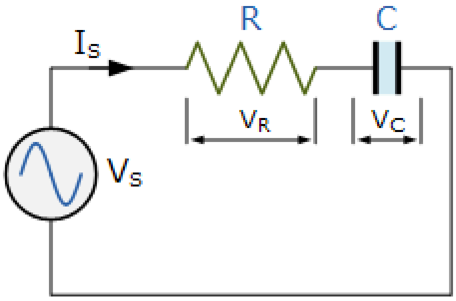


$$X_L = \frac{V_L}{I_L} = 2\pi f L$$

$$Z = \angle{+90^{\circ}} = 0 + jX_L$$

$$I_S = \frac{V_S}{X_L}$$

Series RC Circuit



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

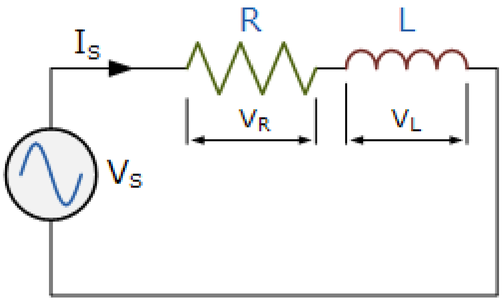
$$Z = \angle{-\phi} = R - jX_C$$

$$\phi_{(-90\rightarrow 0)} = \tan^{-1}\left(-\frac{X_C}{R}\right)$$

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

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

Series RL Circuit



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

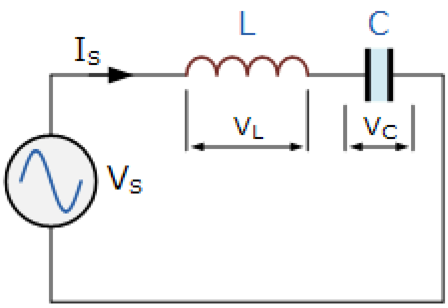
$$Z = \angle{+\phi} = R + jX_L$$

$$\phi_{(0\rightarrow 90)} = \tan^{-1}\left(\frac{X_L}{R}\right)$$

$$I_S = \frac{V_S}{Z} = \frac{V_S}{\sqrt{R^2 + X_L^2}}$$

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

Series LC Circuit



$$Z = \sqrt{X_L^2 - X_C^2}$$

$$\therefore Z = X_L - X_C \text{ or } X_C - X_L$$

$$Z = \angle\phi + j = 0 + (jX_L - jX_C)$$

$$f_R = \frac{1}{2\pi\sqrt{LC}}$$

at f_R $X_L = X_C$ and $V_L = V_C$

$$I_S = I_L = I_C$$

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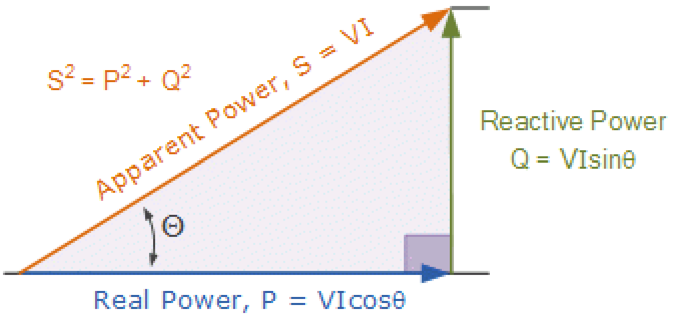
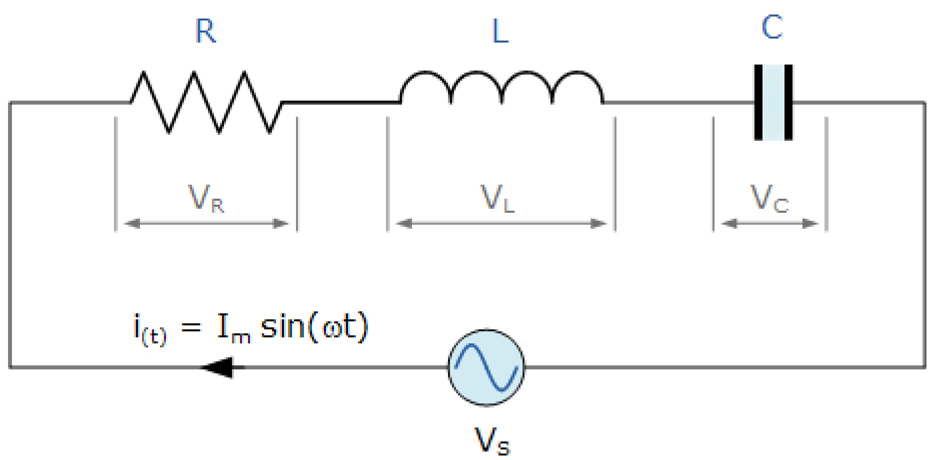
Power Triangle:

Electrical power consumed in an AC circuit can be represented by the three sides of a right angled triangle, known commonly as a power triangle



SERIES RLC CIRCUIT :

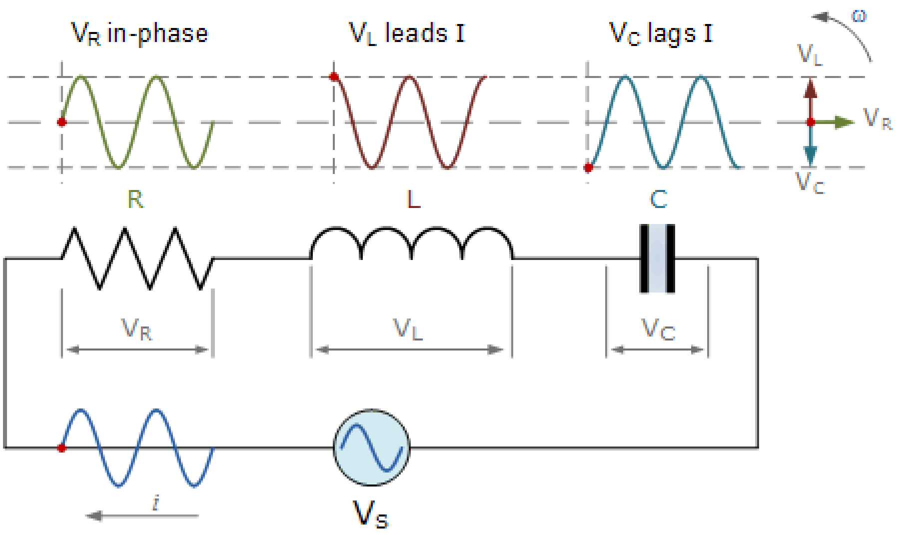


The series RLC circuit above has a single loop with the instantaneous current flowing through the loop being the same for each circuit element. Since the inductive and capacitive reactance's XL and XC are a function of the supply frequency, the sinusoidal response of a series RLC circuit will therefore vary with frequency, *ƒ*. Then the individual voltage drops across each circuit element of R, L and C element will be "out-of-phase" with each other as defined by: **i(t) = Imax sin(ωt)**

- The instantaneous voltage across a pure resistor, VR is "in-phase" with current
- The instantaneous voltage across a pure inductor, VL "leads" the current by 90 Degree
- The instantaneous voltage across a pure capacitor, VC "lags" the current by 90 Degree

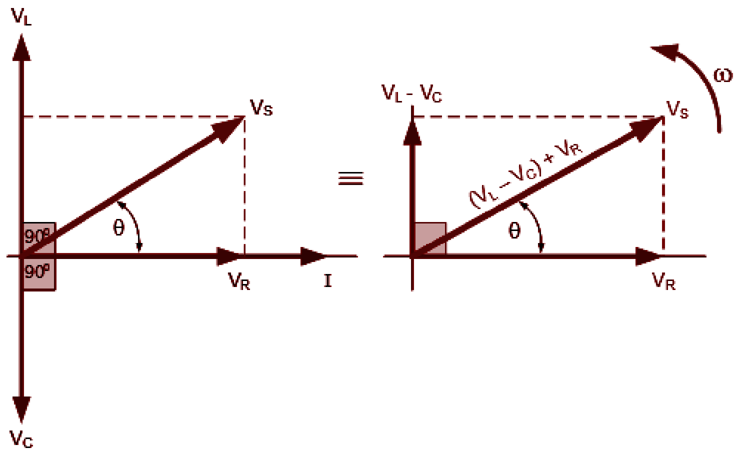
Therefore, VL and VC are 180 Degree "out-of-phase" and in opposition to each other.

For the series RLC circuit above, this can be shown as:



Phasor Diagram for a Series RLC Circuit

We can see from the phasor diagram on the right hand side above that the voltage vectors produce a rectangular triangle, comprising of hypotenuse VS, horizontal axis VR and vertical axis VL – VC Hopefully you will notice then, that this forms our old favourite the Voltage Triangle and we can therefore use Pythagoras's theorem on this voltage triangle to mathematically obtain the value of VS as shown.



Voltage Triangle for a Series RLC Circuit

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

$$V_S = \sqrt{V_R^2 + (V_L - V_C)^2}$$

Please note that when using the above equation, the final reactive voltage must always be positive in value, that is the smallest voltage must always be taken away from the largest voltage we can not have a negative voltage added to VR so it is correct to have VL – VC or VC – VL. The smallest value from the largest otherwise the calculation of VS will be incorrect.

We know from above that the current has the same amplitude and phase in all the components of a series RLC circuit. Then the voltage across each component can also be described mathematically according to the current flowing through, and the voltage across each element as.

$$V_R = iR\sin(\omega t + 0^0) = i.R$$

$$V_L = iX_L\sin(\omega t + 90^0) = i.j\omega L$$

$$V_C = iX_C\sin(\omega t - 90^0) = i.\frac{1}{j\omega C}$$

By substituting these values into the Pythagoras equation above for the voltage triangle will give us:

$$V_R = I.R \qquad V_L = I.X_L \qquad V_C = I.X_C$$

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

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

$$\therefore V_S = I \times Z \qquad \text{where: } Z = \sqrt{R^2 + (X_L - X_C)^2}$$

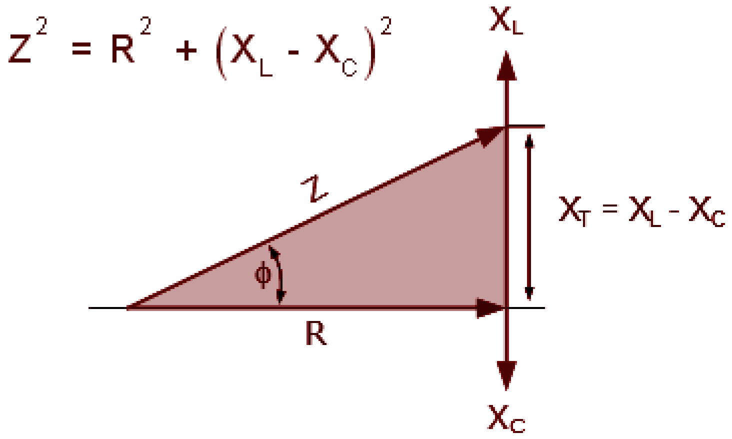
So we can see that the amplitude of the source voltage is proportional to the amplitude of the current flowing through the circuit. This proportionality constant is called the Impedance of the circuit which ultimately depends upon the resistance and the inductive and capacitive reactance’s.

Then in the series RLC circuit above, it can be seen that the opposition to current flow is made up of three components, XL, XC and R with the reactance, XT of any series RLC circuit being defined as: XT = XL – XC or XT = XC – XL whichever is greater. Thus the total impedance of the circuit being thought of as the voltage source required to drive a current through it.

The Impedance of a Series RLC Circuit

As the three vector voltages are out-of-phase with each other, XL, XC and R must also be "out-of-phase" with each other with the relationship between R, XL and XC being the vector sum of these three components. This will give us the RLC circuits overall impedance, Z. These circuit impedance's can be drawn and represented by an Impedance Triangle as shown below.

The Impedance Triangle for a Series RLC Circuit



The impedance Z of a series RLC circuit depends upon the angular frequency, ω as do XLand XC If the capacitive reactance is greater than the inductive reactance, XC > XL then the overall circuit reactance is capacitive giving a leading phase angle.

Likewise, if the inductive reactance is greater than the capacitive reactance, XL > XC then the overall circuit reactance is inductive giving the series circuit a lagging phase angle. If the two reactance's are the same and XL = XC then the angular frequency at which this occurs is called the resonant frequency and produces the effect of resonance which we will look at in more detail in another tutorial.

Then the magnitude of the current depends upon the frequency applied to the series RLC circuit. When impedance, Z is at its maximum, the current is a minimum and likewise, when Z is at its minimum, the current is at maximum. So the above equation for impedance can be re-written as:

$$\text{Impedance, } Z = \sqrt{R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2}$$

The phase angle, θ between the source voltage, VS and the current, i is the same as for the angle between Z and R in the impedance triangle. This phase angle may be positive or negative in value depending on whether the source voltage leads or lags the circuit current and can be calculated mathematically from the ohmic values of the impedance triangle as:

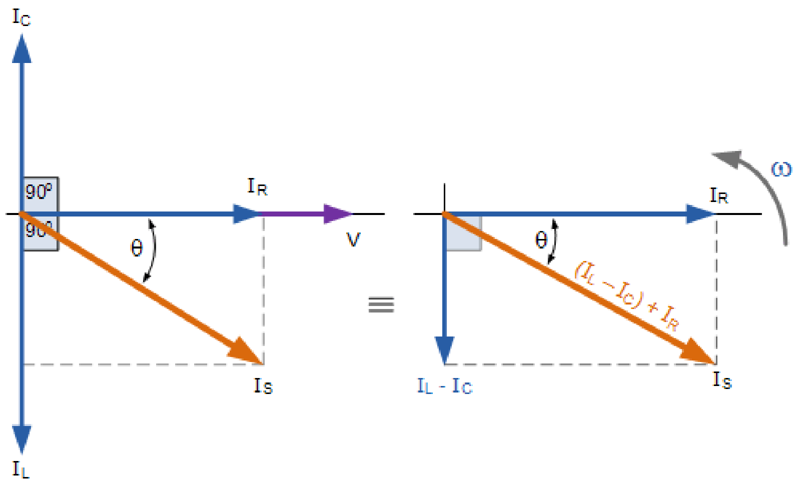
$$\cos\phi = \frac{R}{Z} \qquad \sin\phi = \frac{X_L - X_C}{Z} \qquad \tan\phi = \frac{X_L - X_C}{R}$$

<u>Parallel RLC Circuit:</u>

In the above parallel RLC circuit, we can see that the supply voltage, VS is common to all three components whilst the supply current IS consists of three parts. The current flowing through the resistor, IR, the current flowing through the inductor, IL and the current through the capacitor, IC.

But the current flowing through each branch and therefore each component will be different to each other and to the supply current, IS. The total current drawn from the supply will not be the mathematical sum of the three individual branch currents but their vector sum.

<u>Phasor Diagram for a Parallel RLC Circuit</u>



$$I_S^2 = I_R^2 + (I_L - I_C)^2$$

$$I_S = \sqrt{I_R^2 + (I_L - I_C)^2}$$

$$\therefore \; I_S = \sqrt{\left(\frac{V}{R}\right)^2 + \left(\frac{V}{X_L} - \frac{V}{X_C}\right)^2} = \frac{V}{Z}$$

$$\text{where:} \quad I_R = \frac{V}{R}, \quad I_L = \frac{V}{X_L}, \quad I_C = \frac{V}{X_C}$$

Impedance of a Parallel RLC Circuit

$$R = \frac{V}{I_R} \qquad X_L = \frac{V}{I_L} \qquad X_C = \frac{V}{I_C}$$

$$Z = \frac{1}{\sqrt{\left(\frac{1}{R}\right)^2 + \left(\frac{1}{X_L} - \frac{1}{X_C}\right)^2}}$$

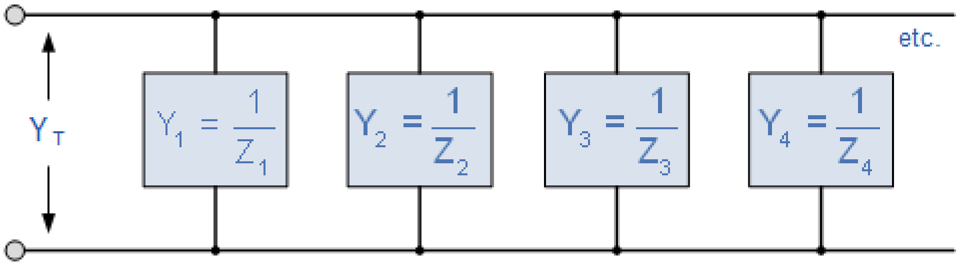
$$\therefore \frac{1}{Z} = \sqrt{\left(\frac{1}{R}\right)^2 + \left(\frac{1}{X_L} - \frac{1}{X_C}\right)^2}$$

You will notice that the final equation for a parallel RLC circuit produces complex impedance for each parallel branch as each element becomes the reciprocal of impedance, (1/Z) with the reciprocal of impedance being called Admittance.

In parallel AC circuits it is more convenient to use admittance, symbol (Y) to solve complex branch impedance especially when two or more parallel branch impedance are involved (helps with the math). The total admittance of the circuit can simply be found by the addition of the parallel admittances. Then the total impedance, ZT of the circuit will therefore be 1/YT Siemens as shown.

Admittance of a Parallel RLC Circuit

$$\frac{1}{Z_T} = Y_T = Y_1 + Y_2 + Y_3 + Y_4 + \text{......etc}$$



The new unit for admittance is the Siemens, abbreviated as S, (old unit mho's ℧, ohm's in reverse). Admittances are added together in parallel branches, whereas impedance's are added together in series branches. But if we can have a reciprocal of impedance, we can also have a reciprocal of resistance and reactance as impedance consists of two components, R and X. Then the reciprocal of resistance is called Conductance and the reciprocal of reactance is called Susceptance.

Conductance, Admittance and Susceptance

The units used for conductance, admittance and susceptance are all the same namely Siemens (S), which can also be thought of as the reciprocal of Ohms or ohm-1, but the symbol used for each element is different and in a pure component this is given as:

Admittance (Y) :

Admittance is the reciprocal of impedance, Z and is given the symbol Y. In AC circuits admittance is defined as the ease at which a circuit composed of resistances and reactances allows current to flow when a voltage is applied taking into account the phase difference between the voltage and the current.

The admittance of a parallel circuit is the ratio of phasor current to phasor voltage with the angle of the admittance being the negative to that of impedance.

$$Y = \frac{1}{Z} \; [S]$$

Conductance (G) :

Conductance is the reciprocal of resistance, R and is given the symbol G. Conductance is defined as the ease at which a resistor (or a set of resistors) allows current to flow when a voltage, either AC or DC is applied.

$$G = \frac{1}{R} \; [S]$$

Susceptance (B) :

Susceptance is the reciprocal of of a pure reactance, X and is given the symbol B. In AC circuits susceptance is defined as the ease at which a reactance (or a set of reactances) allows an alternating current to flow when a voltage of a given frequency is applied.

Susceptance has the opposite sign to reactance so Capacitive susceptance BC is positive, (+ve) in value while Inductive susceptance BL is negative, (-ve) in value.

$$B_L = \frac{1}{X_L} \; [S]$$

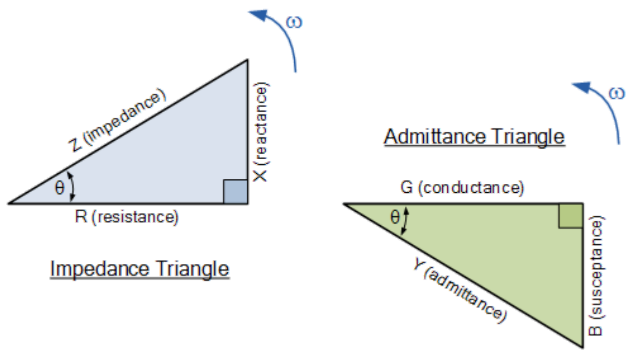
$$B_C = \frac{1}{X_C} \; [S]$$

We can therefore define inductive and capacitive susceptance as being:

$$B_L = B\angle -90^0 = 0 - jB \quad \text{and} \quad B_C = B\angle +90^0 = 0 + jB$$

In AC series circuits the opposition to current flow is impedance, Z which has two components, resistance R and reactance, X and from these two components we can construct an impedance triangle. Similarly, in a parallel RLC circuit, admittance, Y also has two components, conductance, G and susceptance, B. This makes it possible to construct an admittance triangle that has a horizontal conductance axis, G and a vertical susceptance axis, jB as shown.

Admittance Triangle for a Parallel RLC Circuit



Now that we have an admittance triangle, we can use Pythagoras to calculate the magnitudes of all three sides as well as the phase angle as shown.

from Pythagoras

$$Y = \sqrt{G^2 + \left(B_L - B_C\right)^2}$$

$$\text{where:} \quad Y = \frac{1}{Z} \qquad G = \frac{1}{R}$$

$$B_L = \frac{1}{\omega L} \qquad B_C = \omega C$$

Then we can define both the admittance of the circuit and the impedance with respect to admittance as:

$$\text{Admittance:} \quad Y = \sqrt{\left(\frac{1}{R}\right)^2 + \left(\frac{1}{(\omega L)} - (\omega C)\right)^2}$$

$$\text{Impedance:} \quad Z = \frac{1}{Y} = \frac{1}{\sqrt{\left(\frac{1}{R}\right)^2 + \left(\frac{1}{(\omega L)} - (\omega C)\right)^2}}$$

Giving us a power factor angle of:

$$\cos\phi = \frac{G}{Y} \qquad \phi = \cos^{-1}\left(\frac{G}{Y}\right)$$

or

$$\tan\phi = \frac{B}{G} \qquad \phi = \tan^{-1}\left(\frac{B}{G}\right)$$

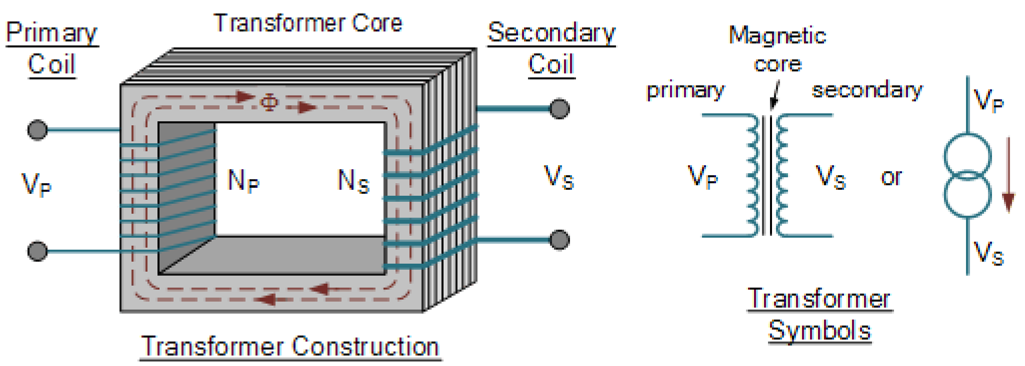
As the admittance, Y of a parallel RLC circuit is a complex quantity, the admittance corresponding to the general form of impedance $Z = R + jX$ for series circuits will be written as $Y = G - jB$ for parallel circuits where the real part G is the conductance and the imaginary part jB is the susceptance. In polar form this will be given as:

$$Y = G + jB = \sqrt{G^2 + B^2} \angle \tan^{-1}\frac{B}{G}$$

Transformers:

The Voltage Transformer can be thought of as an electrical component rather than an electronic component. A transformer is basically very simple static (or stationary) electro-magnetic passive electrical device that works on the principle of Faraday's law of induction by converting electrical energy from one value to another.
The transformer does this by linking together two or more electrical circuits using a common oscillating magnetic circuit which is produced by the transformer itself. A transformer operates on the principals of "electromagnetic induction", in the form of Mutual Induction.

Transformer Construction (single-phase):



Where:

VP - is the Primary Voltage

VS - is the Secondary Voltage

NP - is the Number of Primary Windings

NS - is the Number of Secondary Windings

Φ (phi) - is the Flux Linkage

Notice that the two coil windings are not electrically connected but are only linked magnetically. A single-phase transformer can operate to either increase or decrease the voltage applied to the primary winding. When a transformer is used to "increase" the voltage on its secondary winding with respect to the primary, it is called a Step-up transformer. When it is used to "decrease" the voltage on the secondary winding with respect to the primary it is called a Step-down transformer.

However, a third condition exists in which a transformer produces the same voltage on its secondary as is applied to its primary winding. In other words, its output is identical with respect to voltage, current and power transferred. This type of transformer is called an "Impedance Transformer" and is mainly used for impedance matching or the isolation of adjoining electrical circuits.

The difference in voltage between the primary and the secondary windings is achieved by changing the number of coil turns in the primary winding (NP) compared to the number of coil turns on the secondary winding (NS).

As the transformer is basically a linear device, a ratio now exists between the number of turns of the primary coil divided by the number of turns of the secondary coil. This ratio, called the ratio of transformation, more commonly known as a transformers “turns ratio”, (TR). This turns ratio value dictates the operation of the transformer and the corresponding voltage available on the secondary winding.

It is necessary to know the ratio of the number of turns of wire on the primary winding compared to the secondary winding. The turns ratio, which has no units, compares the two windings in order and is written with a colon, such as 3:1 (3-to-1). This means in this example, that if there are 3 volts on the primary winding there will be 1 volt on the secondary winding, 3 volts-to-1 volt. Then we can see that if the ratio between the number of turns changes the resulting voltages must also change by the same ratio, and this is true.

Transformers are all about “ratios”. The ratio of the primary to the secondary, the ratio of the input to the output, and the turns ratio of any given transformer will be the same as its voltage ratio. In other words for a transformer: “turns ratio = voltage ratio”. The actual number of turns of wire on any winding is generally not important, just the turns ratio and this relationship is given as:

A Transformers Turns Ratio:

$$\frac{N_P}{N_S} = \frac{V_P}{V_S} = n = \text{Turns Ratio}$$

Assuming an ideal transformer and the phase angles: $\Phi P \equiv \Phi S$

Note that the order of the numbers when expressing a transformer turns ratio value is very important as the turns ratio 3:1 expresses a very different transformer relationship and output voltage than one in which the turns ratio is given as: 1:3.