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Introduction to AC Circuits

Meet Soni
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Content

Introduction to AC Circuit

- An AC (Alternating Current) circuit is an electrical circuit powered by an alternating source, where the current changes its direction and magnitude periodically. Unlike DC circuits, AC circuits include reactance due to capacitors and inductors, which affect current flow.

- **Key characteristics of AC circuits:**
  - Voltage and current vary sinusoidally.
  - Includes resistance (R), inductance (L), and capacitance (C).
  - Frequency and phase angle are essential parameters.

Significance of AC Supply

- Alternating Current (AC) is the standard form of electricity delivered to homes and industries.
- **Highlighting Points:**
  - Efficient Long-Distance Transmission
  - Transformers Can Easily Step Up or Down Voltage
  - Widely Available and Cost-Effective
  - Suitable for Motors, Appliances, and Lighting
- **Note**: AC supply is preferred over DC for power distribution due to its ability to be transformed and transmitted over long distances with minimal losses.

Sinusoidal Voltages and Currents

- In AC systems, sinusoidal waveforms are most commonly used because of their smooth, repetitive nature and ease of analysis.
- A sinusoidal voltage or current can be described using amplitude, frequency, angular frequency, and phase angle.
- Standard form:
  - Voltage: $v(t) = Vm \sin(\omega t + \phi)$
  - Current: $i(t) = Im \sin(\omega t + \theta)$
- Where:
  - Vm, Im : Maximum (peak) values
  - ω: Angular frequency = $2\pi f$
  - ϕ, θ: Phase angles in radians
  - f: Frequency in Hz
  - t: Time in seconds

Mathematical Representation

- Sinusoidal voltage and current waveforms follow a predictable mathematical pattern:

Highlighting Points:

- Instantaneous value: Value of voltage or current at any instant.
- Peak value: Maximum amplitude of waveform.
- RMS value: $Vrms = Vm/\sqrt{2}$, $Irms = Im/\sqrt{2}$
- Time period (T): $T = 1/f$
- These parameters help in analyzing real-time behavior of AC signals in electrical circuits.

Graphical Representation

- The sine wave is a graphical representation of alternating current and voltage.

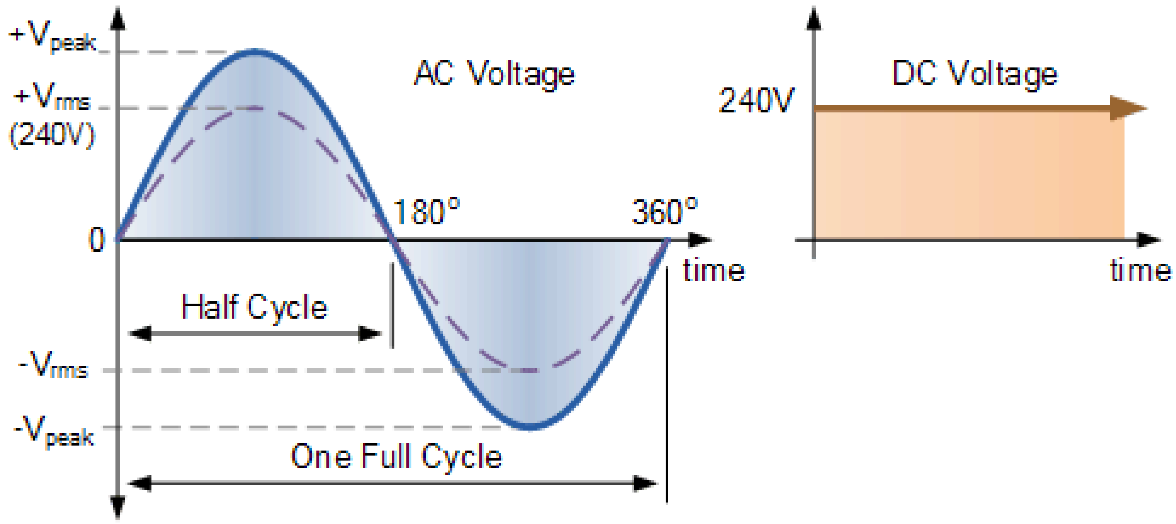

Figure 1: Standard sinusoidal waveform of voltage

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Sinusoidal Quantities and Phasor Representation

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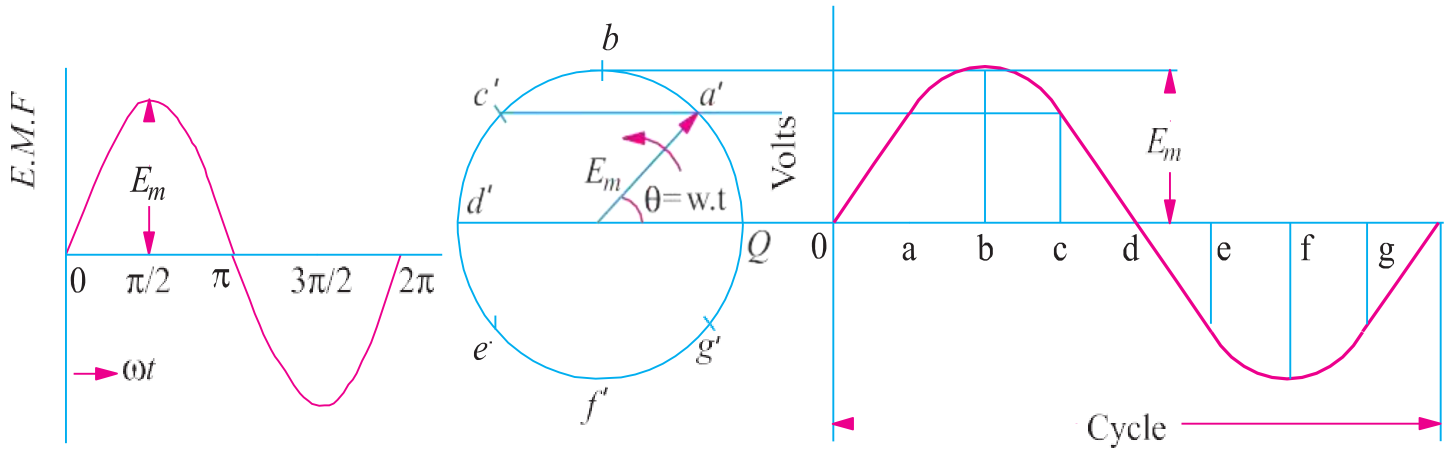
Instantaneous Value

- The instantaneous value of a sinusoidal quantity refers to its magnitude at a particular instant of time.
- Mathematical expression: $v(t) = V m \sin(\omega t + \phi)$



Peak (Maximum) Value

- The peak value is the maximum value (positive or negative) reached by a waveform during one cycle.

- Highlighting Points:
  - Denoted by: Vm or Im
  - Represents the amplitude of the wave
  - Occurs once every half cycle

Average Value

- The average value of a pure sinusoidal wave over a full cycle is zero.

- However, for practical calculations, average value is taken over one-half cycle.
- Average Value Formula:

$$Vavg = 2Vm/\pi$$

$$Iavg = 2Im/\pi$$

R.M.S. Value

- R.M.S. (Root Mean Square) value represents the effective or equivalent DC value of an AC quantity.
- Formula:

$$Vrms = Vm/\sqrt{2}$$

$$Irms = Im/\sqrt{2}$$

- Highlighting Points:
- Used in power calculations
- Most commonly used value in AC analysis

Frequency, Cycle, and Period

- Cycle : One complete set of positive and negative values of alternating quantity is known as cycle

- Time Period: The time taken by an alternating quantity to complete one cycle is called its time period T. For example, a 50-Hz alternating current has a time period of 1/50 second.

- Frequency : The number of cycles/second is called the frequency of the alternating quantity. Its unit is hertz (Hz).

Peak Factor and Form Factor

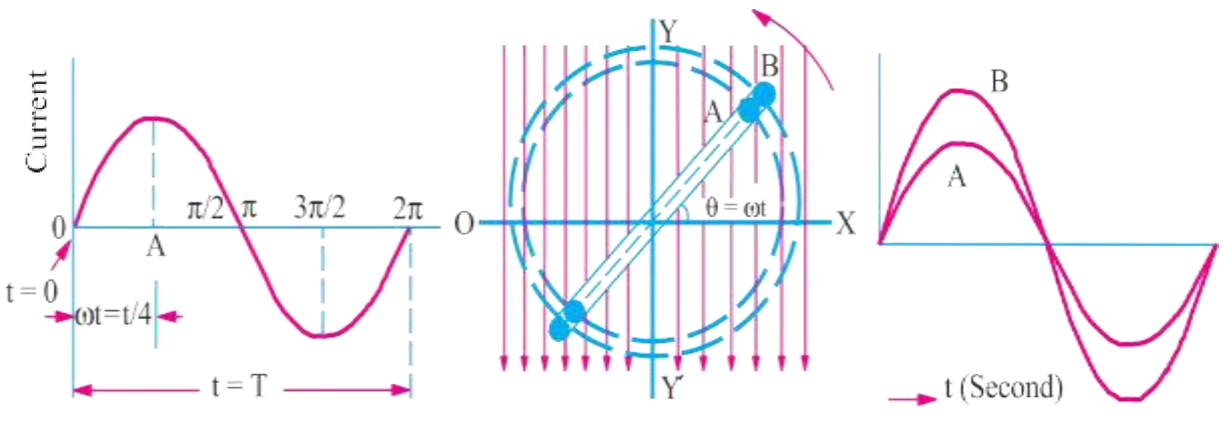
- Peak Factor = Peak Value/RMS Value
  $= Vm/Vrms \approx 1.414$

- Form Factor = RMS Value/Average Value
  $= Vrms/Vavg \approx 1.11$

- Highlighting Points:
  - Used in waveform comparison
  - Standard values for pure sine wave

Phase Difference

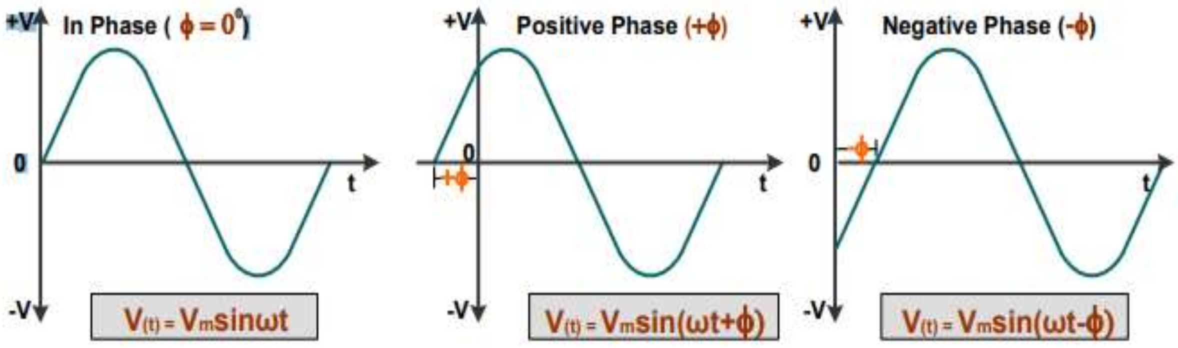
- Phase difference is the angular displacement between two sinusoidal waveforms of the same frequency.



(a)
(b)

Phase Difference

- Leading phase difference: A quantity which attains its zero or positive maximum value before the compared to the other quantity.
- Lagging phase difference: A quantity which attains its zero or positive maximum value after the other quantity.
- In-Phase: Voltage and current reach maxima/minima at the same time



Phasor Representation

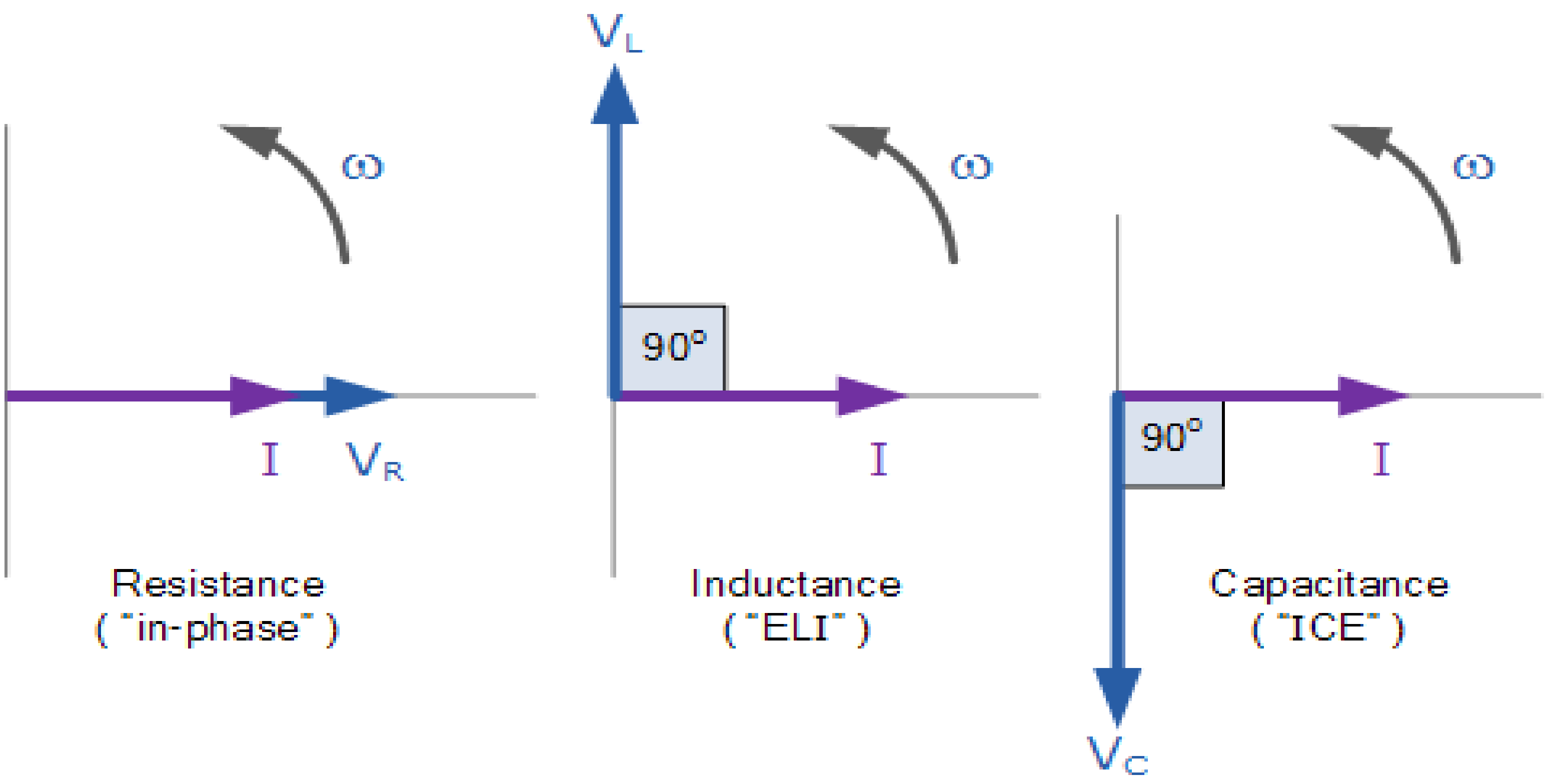
- A phasor is a rotating vector representing a sinusoidal function with constant amplitude and frequency.

- Used to simplify the analysis of sinusoidal waveforms in AC circuits.

- Phasor Notation:
  - $V = Vm\angle\phi$
  - $I = Im\angle\theta$

- Highlighting Points:
  - Easier to apply Ohm's Law and KVL/KCL in AC
  - Visualizes phase relationships clearly

Phasor Representation



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Rectangular and Polar Representation of Phasors, Examples Based on Theory

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Introduction to Phasor Representation

- A phasor is a complex number representing a sinusoidal function of time in the frequency domain. It simplifies analysis of AC circuits by converting differential equations into algebraic equations.

- Highlighting Points:
  - Phasors contain both magnitude and phase angle
  - Used in steady-state sinusoidal analysis

Rectangular Form of Phasor

- In Rectangular form, a phasor is expressed as:

$$A = x + jy$$

Where:

x: Real part (horizontal axis)

y: Imaginary part (vertical axis)

$j = \sqrt{-1}$

- Highlighting Points:
  - Useful in phasor addition/subtraction
  - Represents phasors on the complex plane

Polar Form of Phasor

- In Polar form, a phasor is represented as:$A = |A| \angle \theta$

- Where:
  - $|A|$: Magnitude of the phasor
  - θ: Phase angle (degrees or radians)

- Highlighting Points:
  - Preferred for phasor multiplication/division
  - Provides clear view of phase relationship

Conversion: Rectangular to Polar

To convert $A=x+jy$ to polar form:

- Magnitude: $|A|=\sqrt{x2+y2}$
- Angle: $\theta=\tan-1(y/x)$

Highlighting Points:

- Make sure to adjust angle according to quadrant

Conversion: Polar to Rectangular

To convert $A=|A|\angle\theta$ to rectangular form:

- Real part: $x=|A|\cos(\theta)$
- Imaginary part: $y=|A|\sin(\theta)$

Highlighting Points:

- Angle must be in radians if using a calculator
- Helps in using phasors in matrix or loop equations

Example 1 – Conversion of a Phasor

Given: A=6+j8

- Magnitude: $|A|=\sqrt{36+64}$
  =10
- Angle: $\theta=\tan^{-1}(8/6)$
  =53.13∘
- Polar Form: A=10∠53.13∘A
  =10∠53.13 ∘

Highlighting Points:

- Accurate angle is important in power factor analysis

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Analysis with phasor diagram of Purely Resistive Load

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Content

Introduction to AC and Resistive Load

- Alternating Current (AC) is a type of electrical current that varies sinusoidally with time.

- AC voltage:

$$V(t) = Vm \times \sin(\omega t)$$

Where,
Vm = peak voltage, ω = angular frequency

- A resistive load is an electrical component that resists the flow of current and converts electrical energy into heat.
- Common examples of resistive loads: incandescent bulbs, electric heaters, resistors.

Characteristics of Purely Resistive Load

- In a purely resistive circuit, the load contains only resistance (R); no inductance (L) or capacitance (C).

- The voltage and current are in the same phase.

- There is no phase difference (θ = 0°) between voltage and current.

- Power is completely dissipated as heat in the resistor.

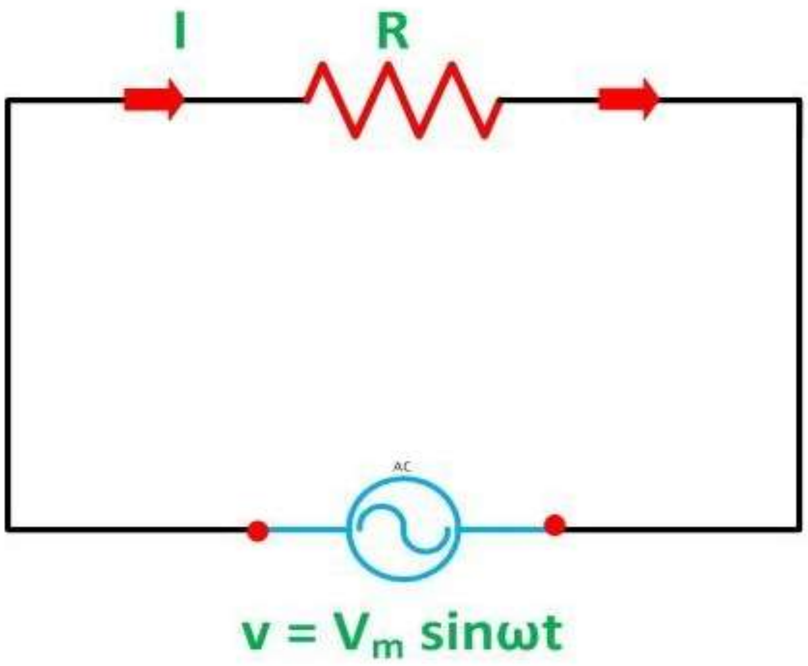

Figure 2.1 Purely Resistive Circuit

Voltage and Current Relationship

- Ohm's Law applies: $V = I \times R$

- If

$$V(t) = Vm \times \sin(\omega t),$$

Then Current:

$$i(t) = Im \times \sin(\omega t)$$

where,

$$Im = Vm / R$$

- Both voltage and current have identical waveforms and peak at the same time.

- No time lag or lead between voltage and current.

Phasor Representation

- Phasors are rotating vectors used to represent sinusoidal quantities.

- For a purely resistive load:
- Voltage phasor (V) and current phasor (I) lie on the same axis.

- Phase angle θ = 0°

- No angular separation between phasors.

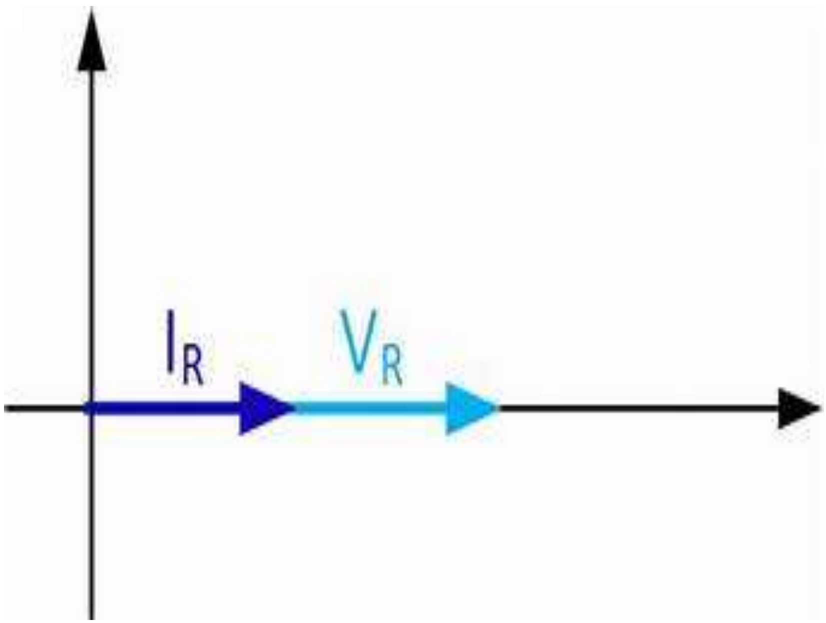

Figure 2.2 Phasor Diagram

Waveforms of Voltage and Current

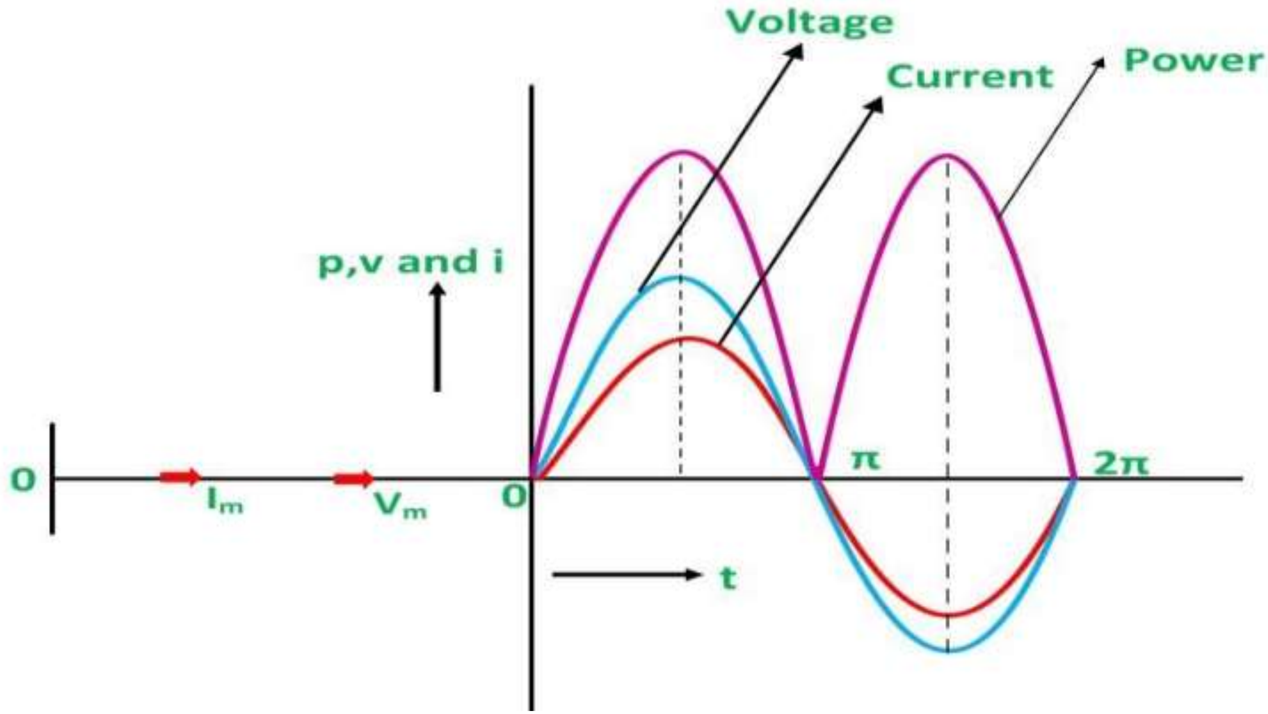

Figure 2.2 Waveform Diagram

- Both waveforms are sinusoidal and superimpose in time.
- Peak values of current and voltage occur simultaneously.

Power in Pure Resistive Load

•**Instantaneous Power**:

$$p(t) = v(t) \times i(t) = Vm \times Im \times \sin^2(\omega t)$$

•Since $\sin^2(\omega t)$ is always positive, power is always positive.

•**Average Power (P)** over one cycle:

$$P = (Vm \times Im) / 2 = Vrms \times Irms$$

•Power is continuously consumed in the resistor and converted to heat.

Key Formulas:

$$V(t) = Vm \times \sin(\omega t)$$

$$I(t) = Im \times \sin(\omega t)$$

$$P(t) = Vm \times Im \times \sin^2(\omega t)$$

$$Pavg = (Vm \times Im)/2 = Vrms \times Irms$$

Summary

- In a purely resistive AC circuit, voltage and current are in phase ($\theta = 0°$).
- No reactive components → no energy is stored or returned.
- Phasors of V and I align, indicating phase alignment.
- Power is always positive, indicating real power consumption.
- Useful for understanding basic power dissipation in AC resistive loads.

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Analysis with phasor diagram of Purely Inductive Load

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Introduction to Inductance and AC Circuits

- An inductor opposes changes in current and stores energy in a magnetic field.

- In AC circuits, the current continuously changes direction, and inductors exhibit inductive reactance (XL).

- The inductive reactance is given by: $XL = 2\pi fL$, where f = frequency, L = inductance in henry (H)

- A pure inductive load has only inductance, no resistance or capacitance.

Characteristics of Purely Inductive Load

- In a purely inductive circuit, current lags voltage by 90° (π/2 radians).

- The energy is alternately stored and released by the inductor; no real power is consumed.

- The circuit absorbs and returns power to the source each cycle.

- The average power consumed over a full cycle is zero.

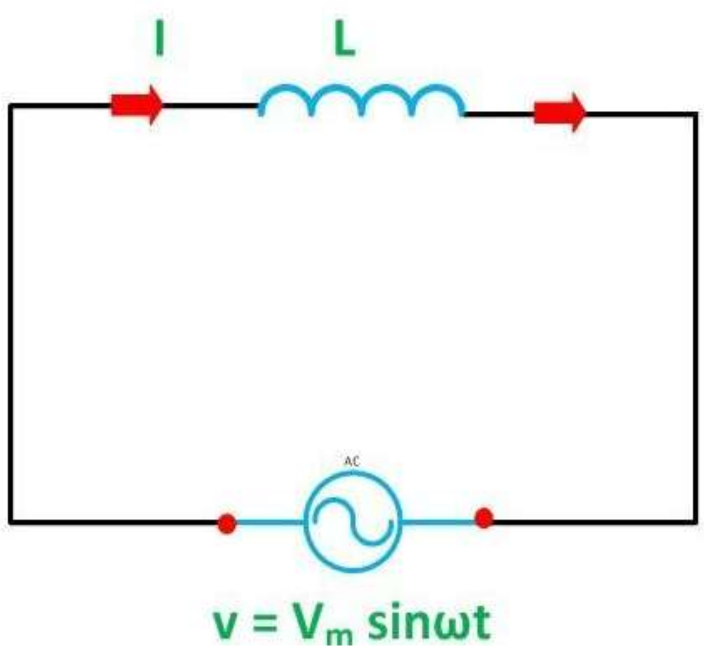

Figure 2.1 Purely Inductive Circuit

Voltage and Current Relationship

- Applied voltage:

$$v(t) = Vm \times \sin(\omega t)$$

- Current through pure inductor:

$$\mathbf{i(t) = Im \times \sin(\omega t - 90°) = Im \times (-\cos(\omega t))}$$

- Current lags the voltage by 90° due to inductive nature.

- Peak of current occurs **after** the peak of voltage.

Key Formula:

$$Im = Vm / XL,$$

where $XL = 2\pi fL$

Phasor Representation

In phasor form:

- Voltage phasor **leads** the current phasor by 90°

- Alternatively, **current lags** the voltage phasor by 90°

- This 90° phase shift represents purely inductive behavior.

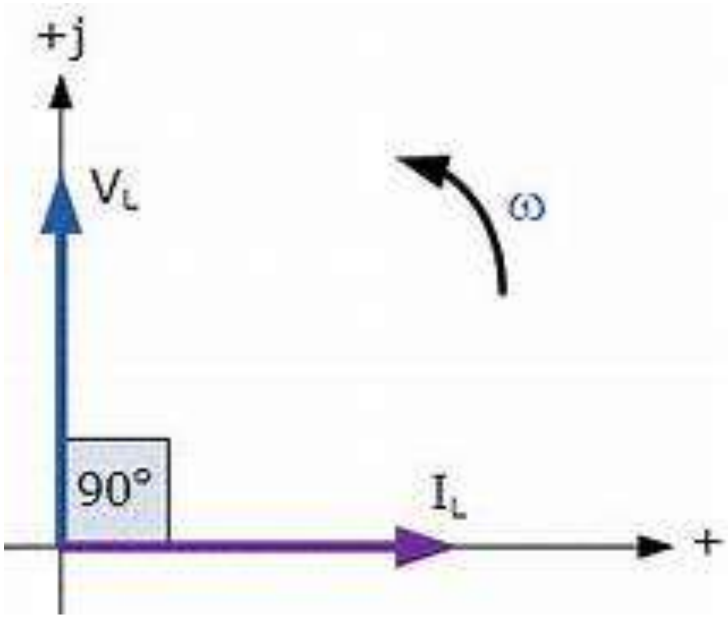

Figure 2.2 Phasor Diagram

Waveforms of Voltage and Current

- Voltage waveform: sinusoidal

- Current waveform: sinusoidal and lags voltage by 90°

- Zero crossing of current occurs after zero crossing of voltage.

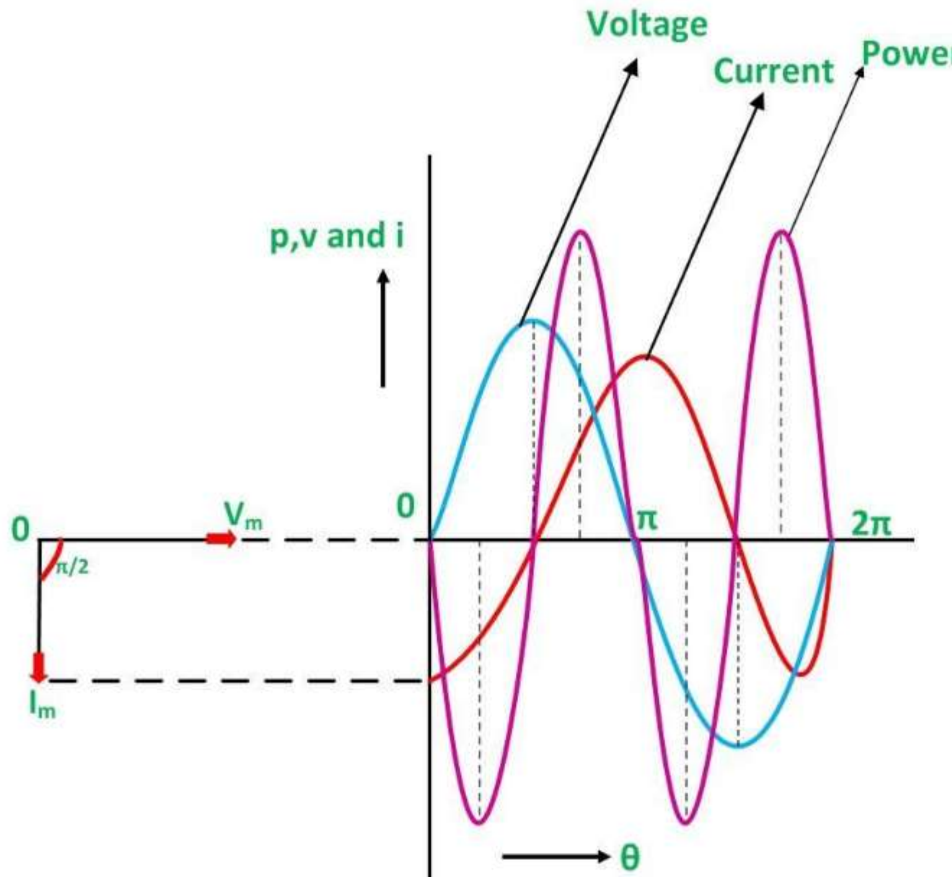

Figure 2.2 Waveform Diagram

Power in Pure Inductive Load

- **Instantaneous Power**:

$$p(t) = v(t) \times i(t) = Vm \times Im \times \sin(\omega t) \times \sin(\omega t - 90°)$$
$$p(t) = Vm \times Im \times \sin(\omega t) \times (-\cos(\omega t))$$
$$p(t) = -Vm \times Im \times \sin(\omega t) \times \cos(\omega t)$$

- This results in alternating positive and negative power.
- Average Power (P) = 0 (No net power consumed)

Important Observation:

- Power oscillates between source and inductor.
- Energy is stored and returned, not dissipated.

Summary

- In a purely inductive AC circuit, current lags voltage by 90°.
- Inductor stores energy in its magnetic field and returns it back.
- Phasor diagram shows 90° lag of current behind voltage.
- No real power is consumed; average power is zero.
- Circuit is reactive, and power oscillates within the system.

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Analysis with phasor diagram of Purely Capacitive Load

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Content

Introduction to Capacitance and AC Circuits

•A capacitor stores electrical energy in the form of an electric field between its plates.

•In an AC circuit, capacitors exhibit capacitive reactance (XC) which opposes current flow.

•Capacitive reactance is given by: $XC = 1 / (2\pi fC)$
where, f = frequency, C = capacitance in farads (F)

•A purely capacitive circuit contains only capacitance, with no resistance or inductance.

Characteristics of Purely Capacitive Load

- In a purely capacitive AC circuit, current leads voltage by 90° ($\pi/2$ radians).

- The capacitor charges and discharges every half-cycle.

- No real power is consumed; energy is stored and then returned.

- The average power over a full cycle is zero.

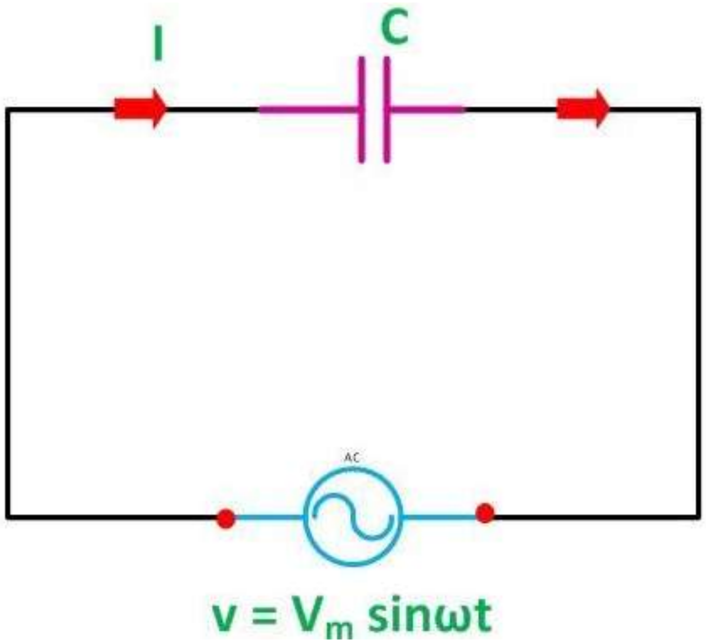

Figure 2.1 Purely Capacitive Circuit

Voltage and Current Relationship

- Applied voltage:

$$v(t) = Vm \times \sin(\omega t)$$

- Current through pure capacitor:

$$i(t) = Im \times \sin(\omega t + 90°) = Im \times \cos(\omega t)$$

- Current leads voltage by 90° in time domain.

- Peak current occurs before the peak voltage.

Key Formula:

$$Im = Vm / XC, \text{ where } XC = 1 / (2\pi fC)$$

Phasor Representation

In phasor form:

•Current phasor leads voltage phasor by 90°

•This lead represents capacitive nature of the load

•Voltage lags behind current in purely capacitive circuit

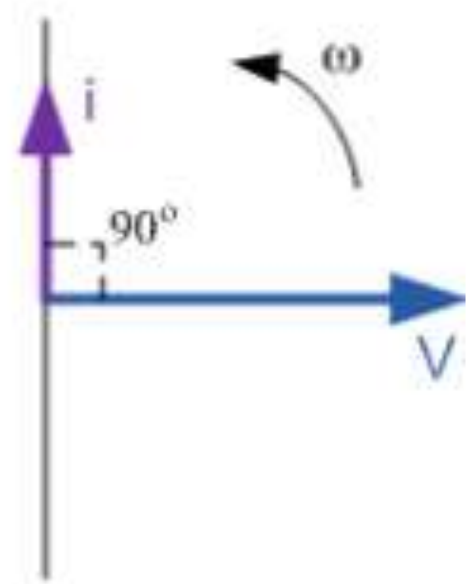

Figure 2.2 Phasor Diagram

Waveforms of Voltage and Current

- Voltage waveform is sinusoidal.
- Current waveform is sinusoidal and leads the voltage by 90°.
- Zero crossing of current occurs before that of voltage.

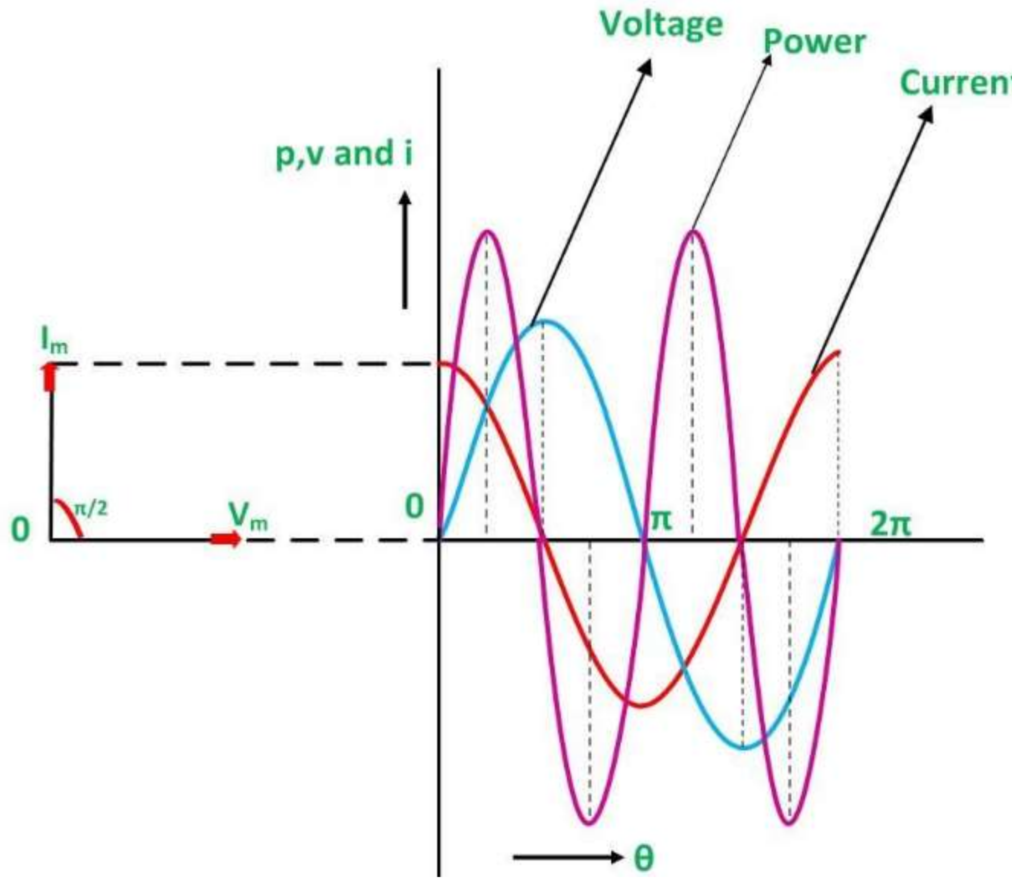

Figure 2.2 Waveform Diagram

Power in Pure Capacitive Load

- **Instantaneous Power**:

$$p(t) = v(t) \times i(t) = Vm \times Im \times \sin(\omega t) \times \sin(\omega t + 90°)$$
$$p(t) = Vm \times Im \times \sin(\omega t) \times \cos(\omega t)$$
$$p(t) = Vm \times Im \times 0.5 \times \sin(2\omega t)$$

- Power alternates between positive and negative values.
- Average Power (P) = 0 over one full cycle.

Key Insight:

- Energy is not dissipated but is stored and returned to the source cyclically.

Summary

- In a purely capacitive circuit, current leads voltage by 90°.
- The capacitor stores and returns energy every cycle.
- Phasor diagram shows current ahead of voltage.
- No real power is consumed; only reactive power is present.
- Capacitors offer capacitive reactance (XC) which decreases with frequency.

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Analysis with phasor diagram of RL Series Load

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Introduction to RL Series Circuit

- An RL series circuit contains a resistor (R) and an inductor (L) connected in series.

- When supplied with an AC source, both elements influence the total behavior:

1. Resistor causes voltage drop in phase with current.
2. Inductor causes voltage drop leading the current by 90°.

- The total current is common through both R and L.

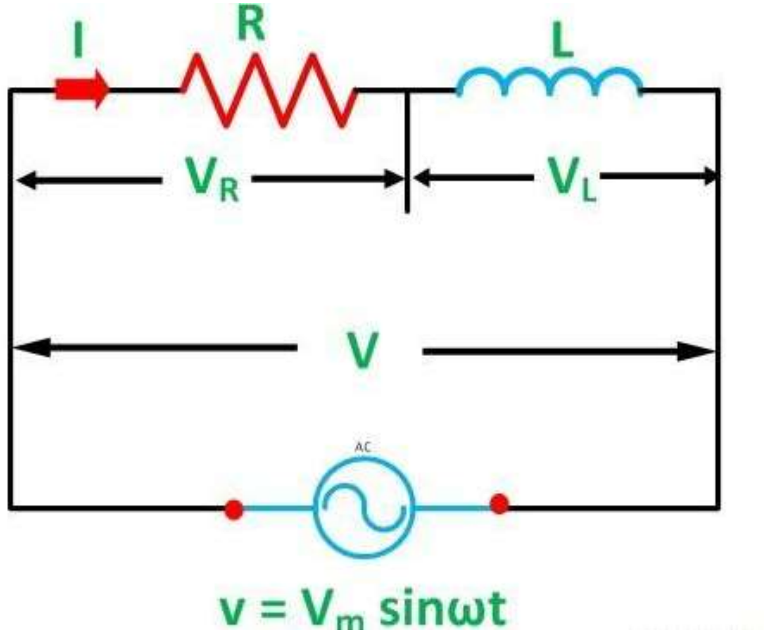

Figure 2.1 RL Series Circuit

Impedance in RL Circuit

- The total opposition offered to AC is called impedance (Z).
- Impedance in an RL circuit is given by:

$$Z = \sqrt{(R^2 + XL^2)}$$

Where, $XL = 2\pi fL$

- The circuit behaves partly resistive and partly inductive.

Key Formula:

$$I = V / Z,$$

- Where,

V = applied voltage,

Z = total impedance

Voltage and Current Relationship

•Current in the RL circuit lags the applied voltage by a phase angle ϕ.

•The phase angle is determined by the relative values of R and XL.

$$tan(\varphi) = XL / R$$

Current Equation:

$$i(t) = Im \times sin(\omega t - \varphi)$$
$$Im = Vm / Z$$

Phasor Representation

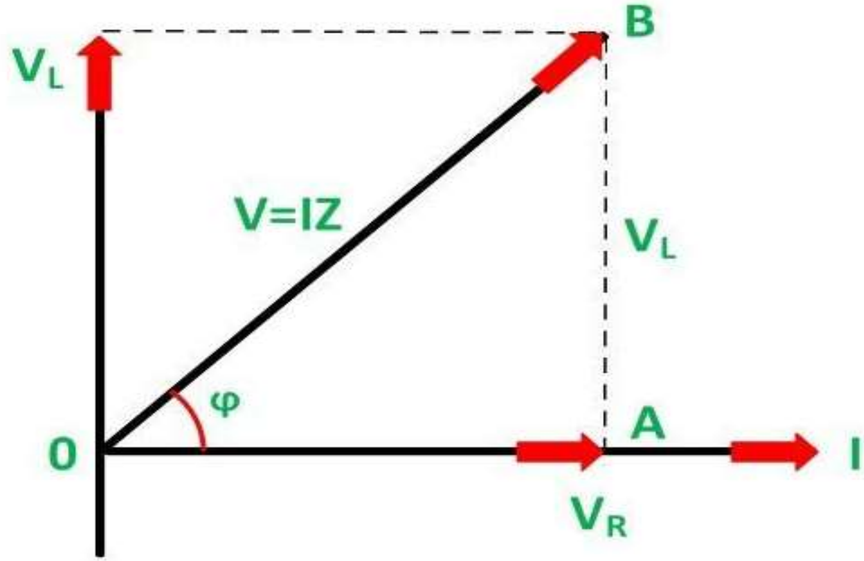

Figure 2.2 Phasor Diagram

- The voltage drop across R (VR) is in phase with the current.
- The voltage drop across L (VL) leads the current by 90°.
- The total applied voltage (V) is the phasor sum of VR and VL.

Waveforms of Voltage and Current

- The current waveform lags behind the voltage waveform by angle ϕ.

- Waveforms are sinusoidal but not in phase.

- The degree of lag depends on the R to L ratio.

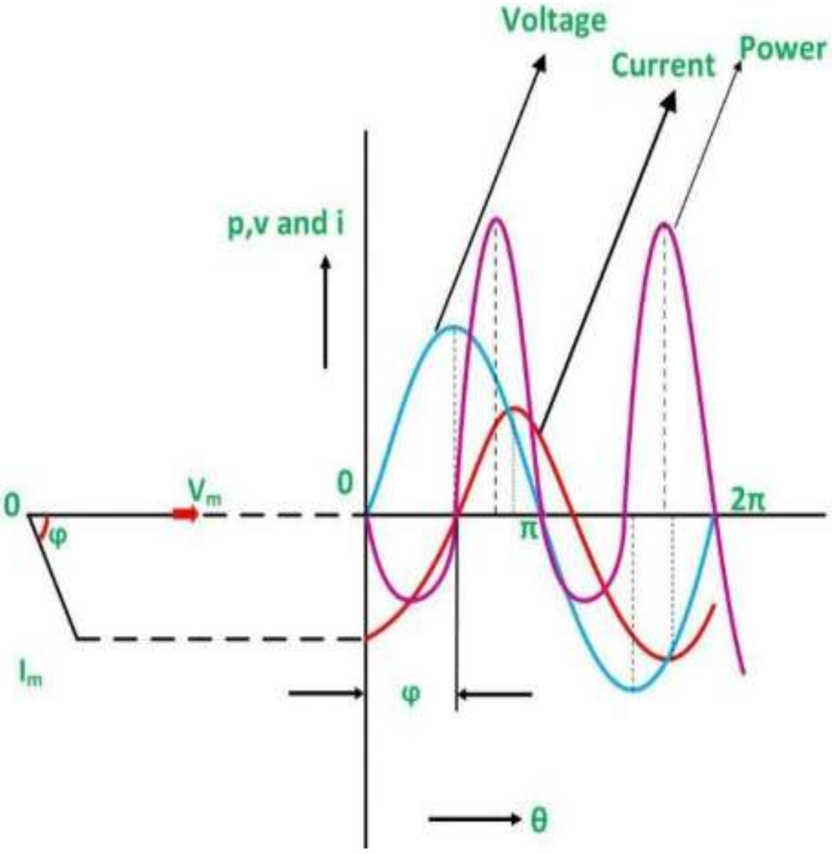

Figure 2.2 Waveform Diagram

Power in RL Circuit

- **Instantaneous Power:**

$$p(t) = v(t) \times i(t)$$

- **True (Active) Power:**

$$P = VI \times \cos(\varphi) \text{ (Measured in watts)}$$

- **Reactive Power (Q):**

$$Q = VI \times \sin(\varphi) \text{ (Measured in VAR)}$$

- **Apparent Power (S):**

$$S = VI \text{ (Measured in VA)}$$

Note:

- Only the resistive part consumes real power.
- Inductive part causes reactive power flow.

Power Factor and Phase Angle

•Power Factor (PF) = cos(ϕ)
It indicates the efficiency of power usage.

•ϕ is the phase angle between applied voltage and current.

•If XL increases (i.e., more inductive), PF decreases.

Good to Know:
•A low PF implies high reactive power, causing inefficiency.
•Ideal PF = 1 (purely resistive)

Summary

- RL series circuit contains both resistance and inductance.
- Impedance (Z) is the vector sum of R and XL.
- Current lags voltage by an angle ϕ.
- Power factor depends on R to XL ratio.
- Only resistive element consumes real power.
- Phasor diagram and waveforms help in visualizing the phase relationship.

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Analysis with phasor diagram of RC Series Load

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Content

Introduction to RC Series Circuit

- An RC series circuit contains a resistor (R) and a capacitor (C) connected in series.

- When connected to an AC source:

1. Resistor causes voltage drop in phase with current.
2. Capacitor causes voltage drop that lags the current by 90°.

- The total current flows through both R and C.

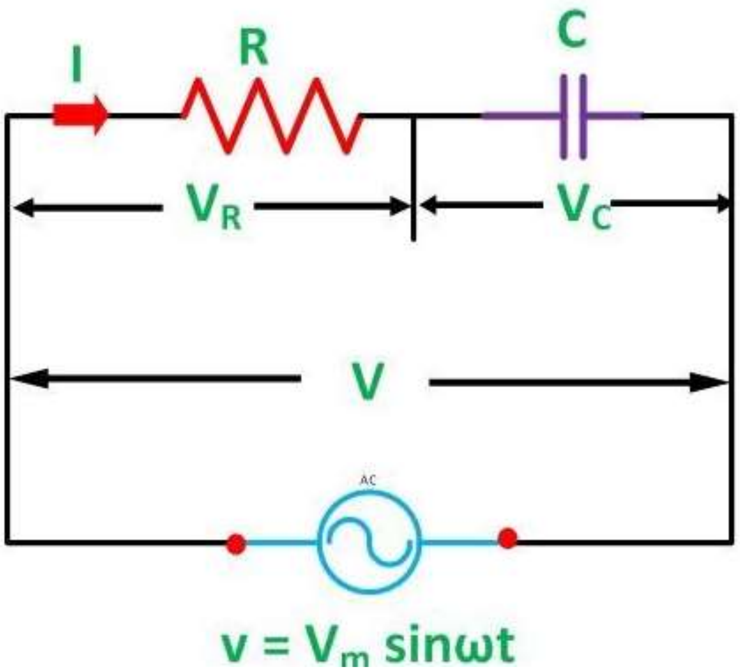

Figure 2.1 RC Series Circuit

Impedance in RC Circuit

•The total opposition in an RC circuit is the impedance (Z).

•Impedance is calculated using:

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

Where, XC = 1 / (2πfC)

•Capacitive reactance decreases with increasing frequency.

Key Formula:

$$I = V / Z$$

Voltage and Current Relationship

•The current leads the applied voltage by a phase angle ϕ.

•The phase angle depends on the relative values of R and XC.

$$tan(\varphi) = -XC / R$$

Current Equation:

$$I(t) = Im \times sin(\omega t + \varphi)$$
$$Im = Vm / Z$$

Phasor Representation

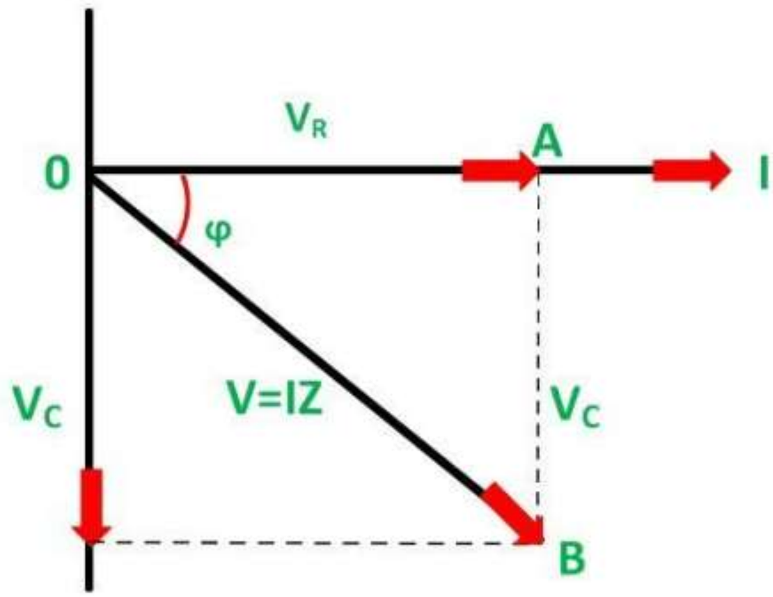

Figure 2.2 Phasor Diagram

- Voltage across resistor (VR) is in phase with current.
- Voltage across capacitor (VC) lags the current by 90°.
- Total voltage is the phasor sum of VR and VC.

Waveforms of Voltage and Current

- Voltage and current are sinusoidal but not in phase.
- Current leads voltage by phase angle ϕ.
- The lead depends on the ratio of R and XC.

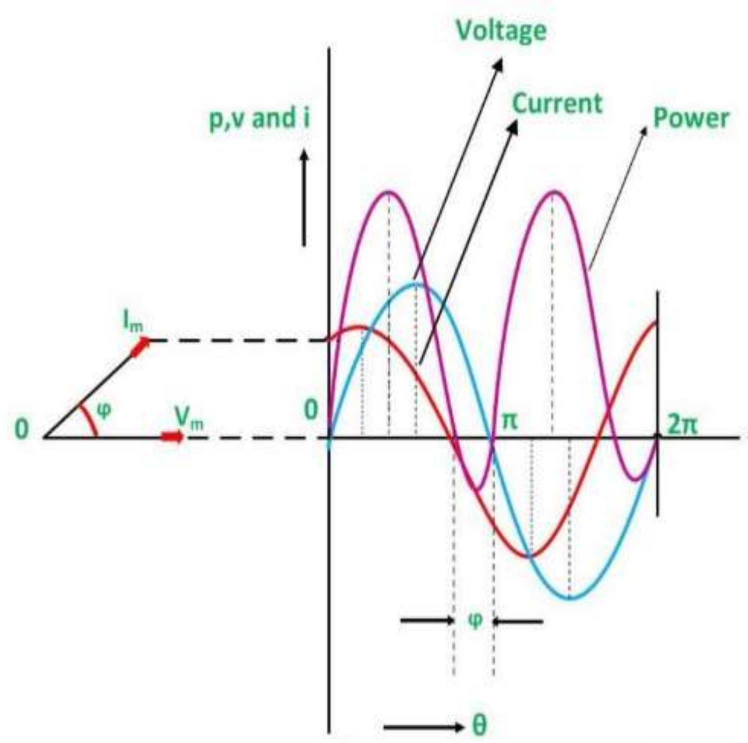

Figure 2.2 Waveform Diagram

Power in RC Circuit

- **Instantaneous Power:**

$$p(t) = v(t) \times i(t)$$

- **True (Active) Power:**

$$P = VI \times \cos(\varphi) \text{ (Measured in watts)}$$

- **Reactive Power (Q):**

$$Q = VI \times \sin(\varphi) \text{ (Measured in VAR)}$$

- **Apparent Power (S):**

$$S = VI \text{ (Measured in VA)}$$

Note:

- Only the resistive part consumes real power.
- Capacitor only causes energy storage and return.

Power Factor and Phase Angle

- Power Factor (PF) = cos(ϕ)

Measures the efficiency of power usage.

- In an RC circuit, ϕ is negative, indicating leading current.

- High XC → High phase angle → Low PF

Important:

- A high-power factor means better energy efficiency.

Summary

- RC series circuit consists of a resistor and a capacitor in series.
- Impedance is calculated using vector addition of R and XC.
- Current leads voltage by angle ϕ.
- Only resistor consumes real power; capacitor causes reactive power.
- Power factor depends on R and XC.
- Phasor diagrams and waveforms clarify phase relationships.

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Information and Communication Technology

Analysis with phasor diagram of RLC Series Load

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Content

Introduction to RLC Series Circuit

- An RLC series circuit contains a resistor (R), inductor (L), and capacitor (C) connected in series.

- It combines the effects of resistance, inductance, and capacitance.

- The behavior of the circuit depends on the relative values of L and C.

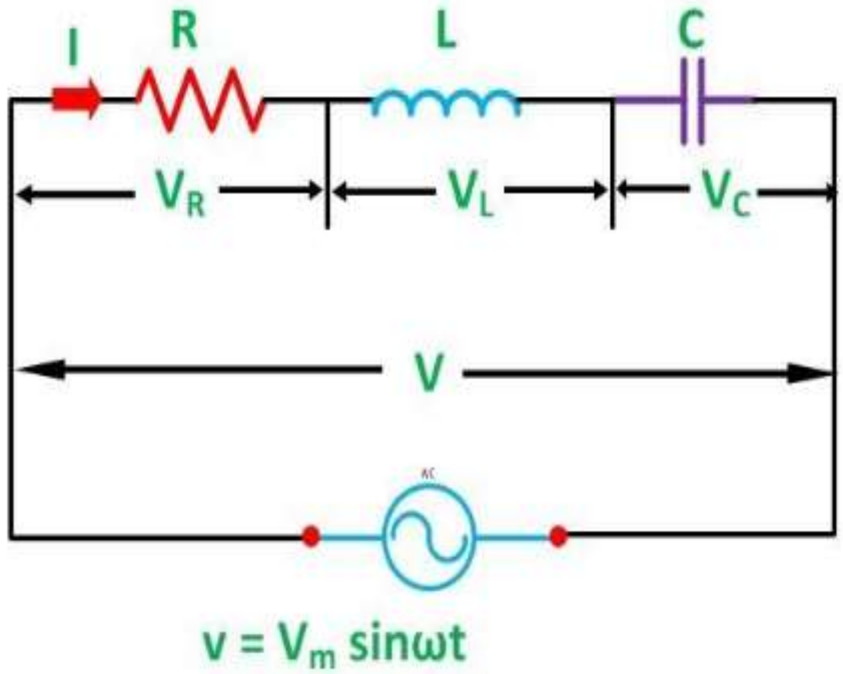

Figure 2.1 RLC Series Circuit

Impedance in RLC Circuit

•Total impedance (Z) is given by:

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

where:

XL = 2πfL and XC = 1 / (2πfC)

•Net reactance (X = XL − XC) can be:

- Positive → Inductive circuit
- Negative → Capacitive circuit
- Zero → Resonant circuit

Current Magnitude:

$$I = V / Z$$

Voltage and Current Relationship

•Depending on net reactance, current either lags, leads, or is in phase with voltage.

$$\tan(\varphi) = (X_L - X_C) / R$$

Current Equation:

$$i(t) = I_m \times \sin(\omega t \pm \varphi)$$

(Sign depends on inductive or capacitive nature)

Phasor Representation

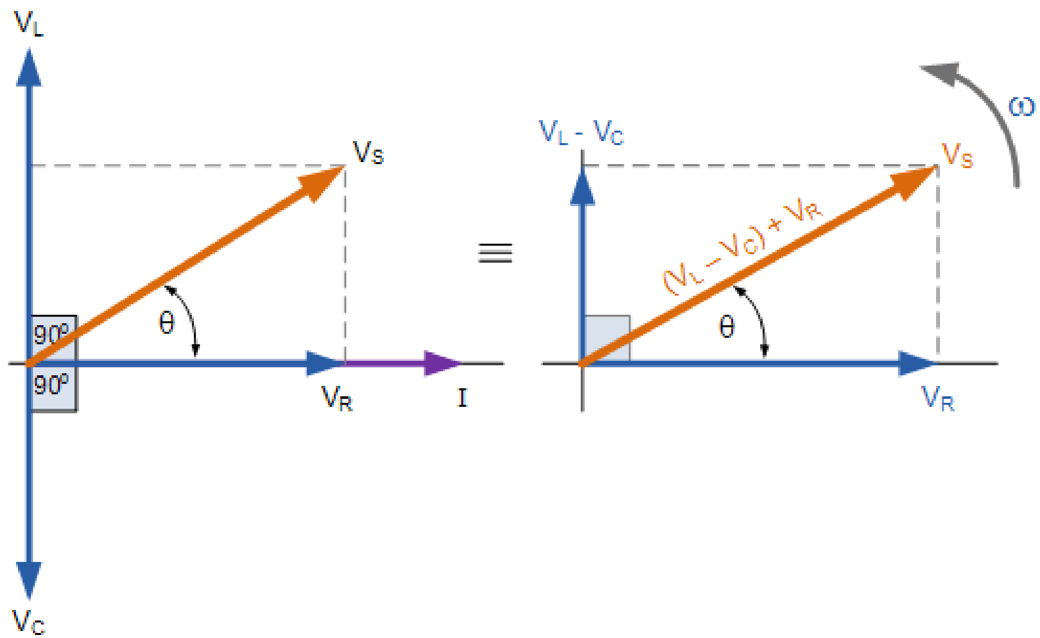

Figure 2.2 Phasor Diagram

- VR is in phase with current.
- VL leads the current by 90°.
- VC lags the current by 90°.
- Net reactive voltage = VL – VC

Waveforms of Voltage and Current

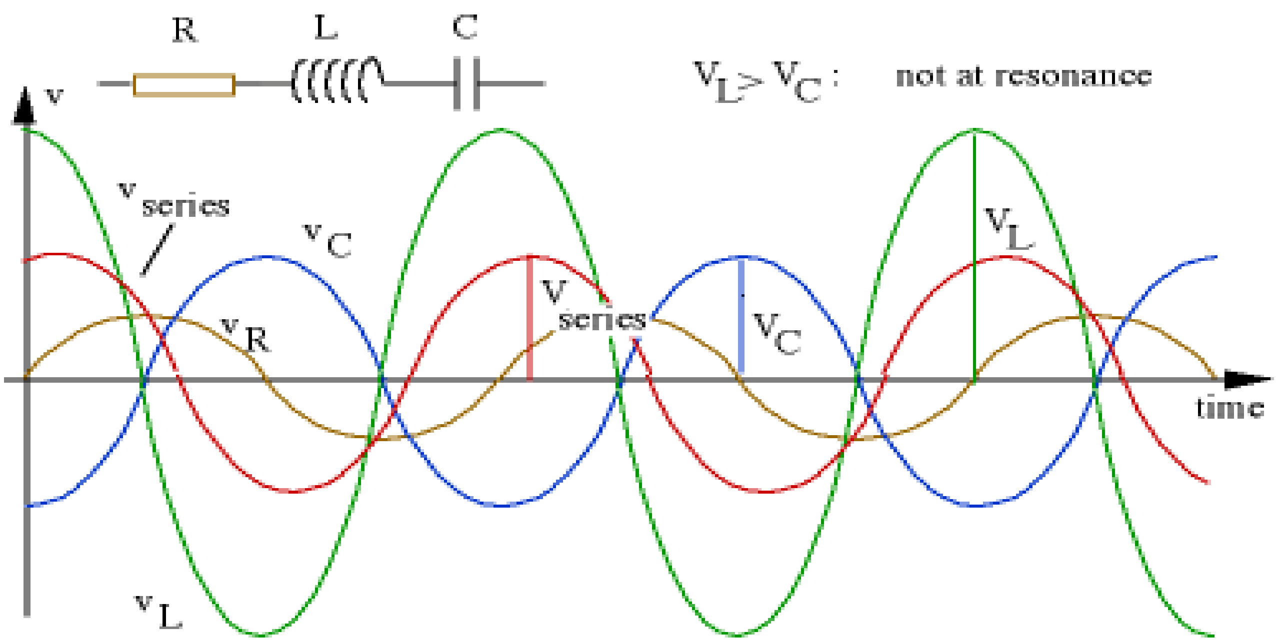

Figure 2.2 Waveform Diagram

- Current waveform varies in phase with applied voltage depending on net reactance.
- At resonance, current is in phase with voltage (purely resistive behavior).

Power in RLC Series Circuit

- **Instantaneous Power:**

$$p(t) = v(t) \times i(t)$$

- **True (Active) Power:**

$$P = VI \times \cos(\varphi) \text{ (Measured in watts)}$$

- **Reactive Power (Q):**

$$Q = VI \times \sin(\varphi) \text{ (Measured in VAR)}$$

- **Apparent Power (S):**

$$S = VI \text{ (Measured in VA)}$$

Note:

- Power is dissipated only by the resistor.
- Inductor and capacitor store and release energy without dissipation.

Resonance in RLC Circuit

•Resonance occurs when XL = XC, making net reactance zero.

•At resonance:

- Z = R (minimum)
- Current is maximum
- Power factor = 1

•Resonant Frequency (fr):

$$fr = 1 / (2\pi\sqrt{(LC)})$$

Important:

•Resonance improves circuit efficiency and is useful in tuning applications.

Power Factor and Phase Angle

- Power Factor (PF) = cos(ϕ)

- ϕ depends on (XL – XC) / R

- PF = 1 at resonance

- Inductive circuit → PF lagging
- Capacitive circuit → PF leading

Key Insight:

- Better power factor means better energy utilization and reduced losses.

Summary

- RLC circuit combines R, L, and C in series.
- Total impedance depends on R and net reactance (XL − XC).
- Current can lead, lag, or be in phase with voltage.
- Resonance occurs when XL = XC, resulting in maximum current and unity power factor.
- Real power is consumed only by R; L and C exchange reactive power.
- Applications include filters, oscillators, and tuning circuits.

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Analysis with phasor diagram of RL Parallel Load

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Content

Introduction to RL Parallel Circuit

- An RL parallel circuit has a resistor (R) and inductor (L) connected in parallel across an AC voltage source.
- The voltage across both branches is the same.
- The total current is the phasor sum of current through R and current through L.

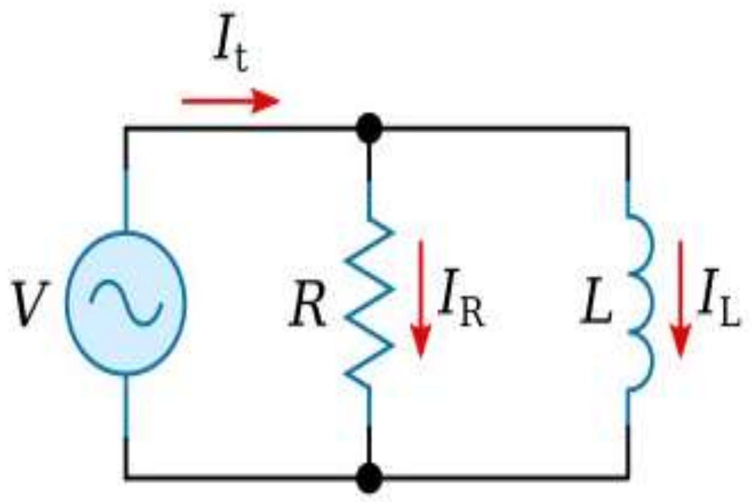

Figure 2.1 RL parallel Circuit

Behavior of RL Branches in Parallel

- Resistive branch current (IR) is in phase with voltage.

- Inductive branch current (IL) lags behind voltage by 90°.

- The resulting current is neither in phase nor 90° lagging, but has a phase angle ϕ.

Current Distribution and Impedance

•Total current (IT) is calculated using phasor addition:

$$IT = \sqrt{(IR^2 + IL^2)}$$

•Branch currents:

$$IR = V / R$$

$$IL = V / XL, \text{ where } XL = 2\pi fL$$

•The total impedance (Z) is not just a scalar sum.

Admittance (Y) is used for easier analysis:

$$Y = \sqrt{(G^2 + BL^2)},$$

Where,

G = 1 / R (conductance),

BL = 1 / XL (susceptive part)

Phasor Representation

- Voltage (V) is taken as reference (horizontal axis).
- IR is in phase with V (horizontal phasor).
- IL lags behind V by 90° (vertical downward phasor).
- IT is the phasor sum of IR and IL.

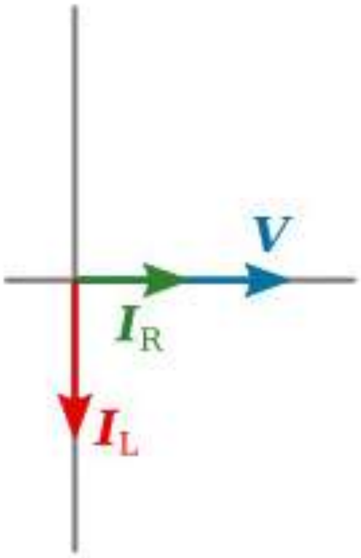

Figure 2.2 Phasor Diagram

Waveforms of Voltage and Current

- Voltage remains common and sinusoidal across both branches.
- IR follows voltage waveform.
- IL lags voltage waveform by 90°.

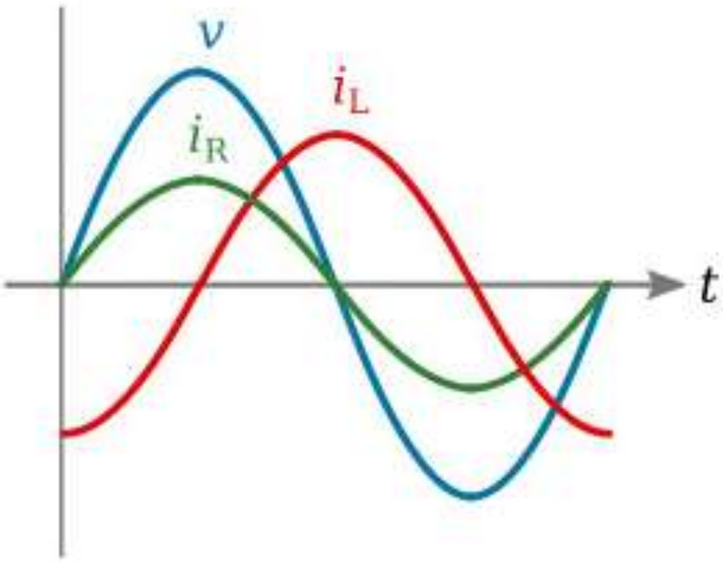

Figure 2.2 Waveform Diagram

Power in RL Parallel Circuit

- **Instantaneous Power:**

$$p(t) = v(t) \times i(t)$$

- **Real Power (P)** is consumed only in resistive branch:

$$P = V \times IR = V^2 / R$$

- **Reactive Power (Q)** is associated with the inductor:

$$Q = V \times IL = V^2 / XL$$

- **Apparent Power (S):**

$$S = V \times IT$$

Power Factor and Phase Angle

- Power Factor (PF) = cos(ϕ), where ϕ is the angle between total current and voltage.

- ϕ is positive (lagging) due to inductive effect.

- Higher XL → higher phase lag → lower PF

- Improving PF can reduce losses and increase efficiency.

Summary

- RL parallel circuit shares common voltage, but branch currents differ in phase.
- IR is in phase with V; IL lags behind by 90°.
- Total current is phasor sum of IR and IL.
- Only resistor consumes real power.
- Power factor is lagging due to inductance.
- Useful in analyzing filter circuits, tuning applications, and AC analysis.

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Analysis with phasor diagram of RC Parallel Load

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Content

Introduction to RC Parallel Circuit

- An RC parallel circuit has a resistor (R) and capacitor (C) connected in parallel across an AC supply.

- The voltage is common to both branches.

- The total current is the phasor sum of currents in R and C branches.

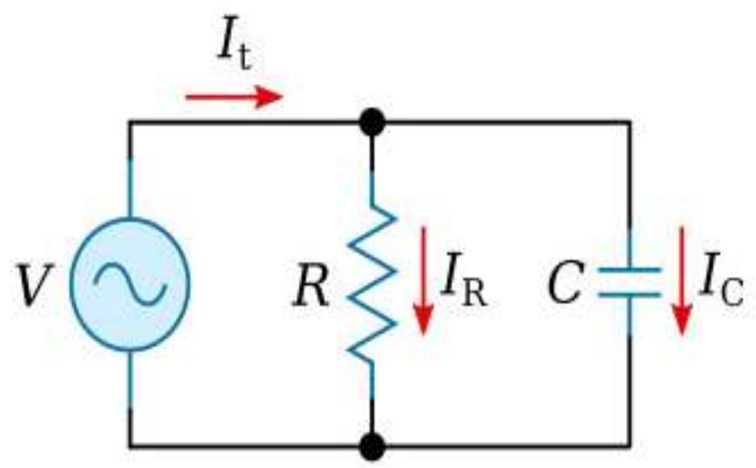

Figure 2.1 RC parallel Circuit

Behavior of RC Branches in Parallel

- IR (Resistor current) is in phase with the voltage.
- IC (Capacitor current) leads the voltage by 90°.
- The resultant current leads the voltage by an angle ϕ depending on relative magnitudes of IR and IC.

Current Distribution and Impedance

- Branch currents:

$$I_R = V / R$$

$$I_C = V / X_C, \text{ where } X_C = 1 / (2\pi f C)$$

- Total current (I_T) is the phasor sum:

$$I_T = \sqrt{I_R^2 + I_C^2}$$

Admittance (Y):

$$Y = \sqrt{G^2 + B_C^2}$$

where:

G = 1 / R (conductance),

$B_C = 2\pi fC$ (capacitive susceptance)

Phasor Representation

- Voltage is the reference phasor (horizontal).
- IR is in phase with V (horizontal).
- IC leads V by 90° (vertical upward).
- IT is the phasor resultant of IR and IC.

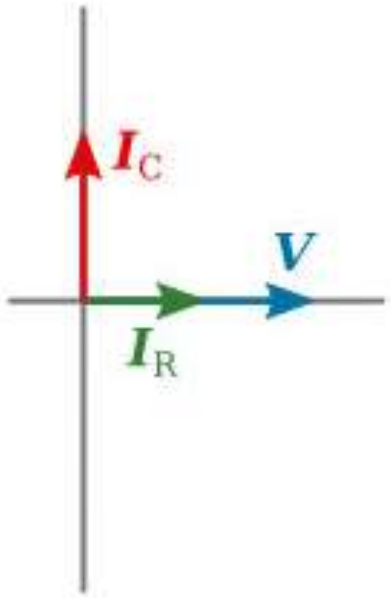

Figure 2.2 Phasor Diagram

Waveforms of Voltage and Current

- Voltage across both branches remains sinusoidal and common.
- IR is in phase with voltage.
- IC leads voltage by 90°.

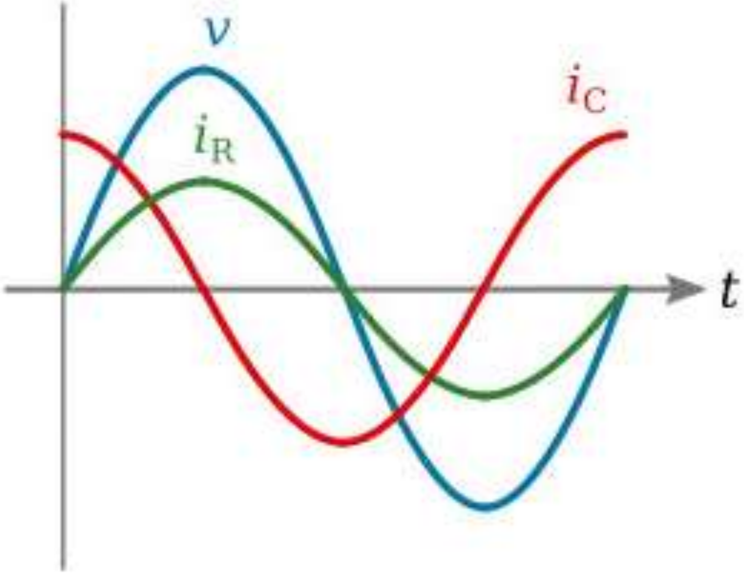

Figure 2.2 Waveform Diagram

Power in RL Parallel Circuit

- **Instantaneous Power:**

$$p(t) = v(t) \times i(t)$$

- **Real Power (P)** is consumed only in resistive branch:

$$P = V \times IR = V^2 / R$$

- **Reactive Power (Q)** is associated with the inductor:

$$Q = V \times IC = V^2 / XC$$

- **Apparent Power (S):**

$$S = V \times IT$$

Power Factor and Phase Angle

- Power Factor (PF) = cos(ϕ)
- ϕ is the phase angle between total current and voltage.
- PF is leading due to capacitive current.
- High capacitance or frequency → higher IC → greater lead → lower PF

Summary

- RC parallel circuit consists of R and C in parallel across an AC source.
- Voltage remains common, but currents differ in phase.
- IR is in phase; IC leads by 90°.
- Total current leads voltage → leading power factor.
- Power is dissipated only in resistor, not in capacitor.
- Widely used in filtering, signal shaping, and tuning.

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Analysis with phasor diagram of RLC Parallel Load

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Introduction to RLC Parallel Circuit

- An RLC parallel circuit has a resistor (R), inductor (L), and capacitor (C) connected in parallel across an AC voltage source.

- All components share the same voltage.

- The total current is the phasor sum of IR, IL, and IC.

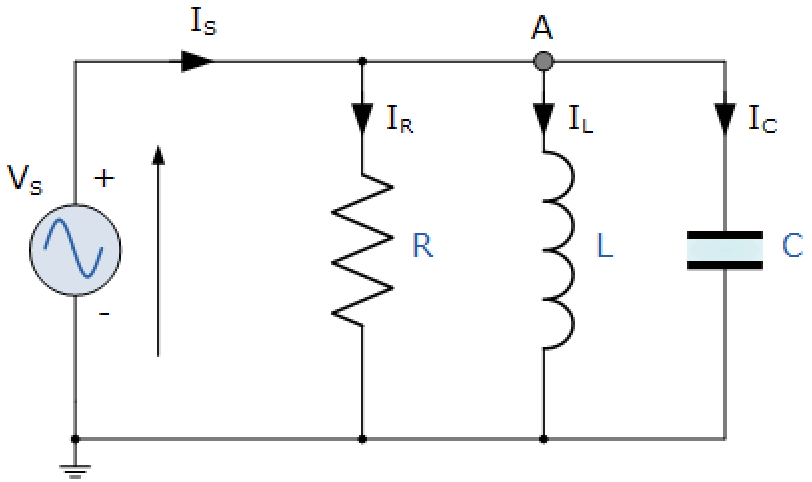

Figure 2.1 RLC parallel Circuit

Nature of Components and Current Flow

- I_R is in phase with voltage.
- I_L lags voltage by 90°.
- I_C leads voltage by 90°.
- Net reactive current: $I_X = I_C - I_L$
- Total current $I_T = I_R + I_X$ (phasor sum)

Branch Currents and Admittance

- Individual branch currents:

$$IR = V / R$$

$$IL = V / XL, \text{ where } XL = 2\pi fL$$

$$IC = V / XC, \text{ where } XC = 1 / (2\pi fC)$$

- Use Admittance (Y) for calculation:

$$Y = \sqrt{G^2 + (BC - BL)^2}$$

where:

$G = 1 / R$

$BC = 2\pi fC$,

$BL = 1 / (2\pi fL)$

Phasor Representation

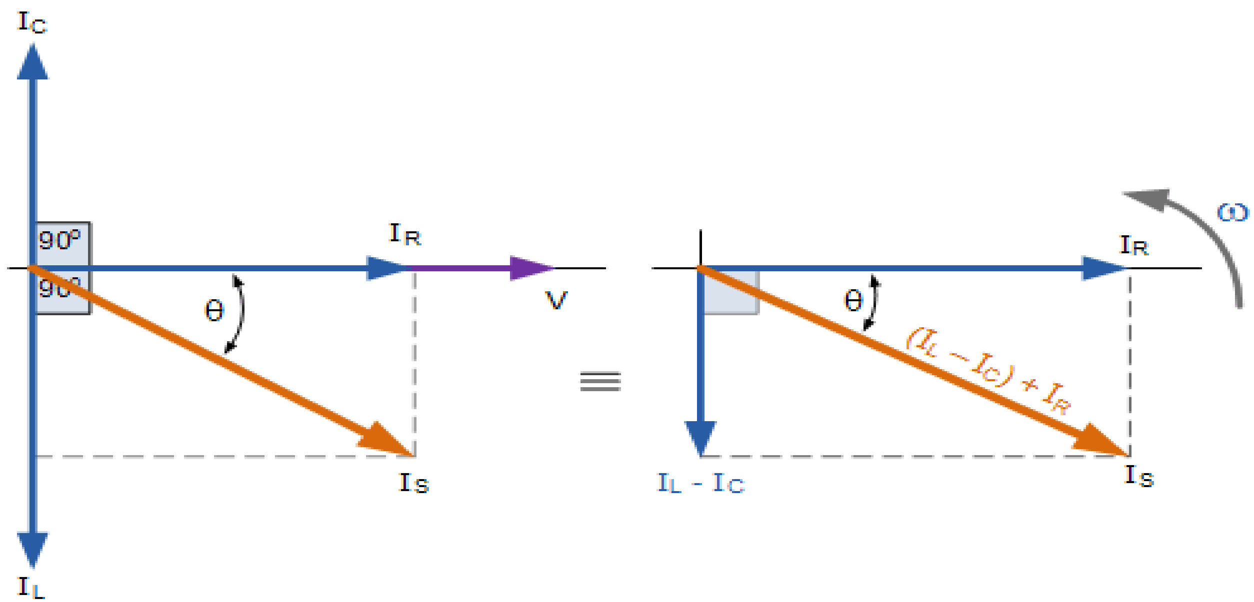

Figure 2.2 Phasor Diagram

- V is taken as reference phasor.
- IR is in phase with V (horizontal).
- IL lags V by 90° (downward).
- IC leads V by 90° (upward).
- Net reactive current = IC - IL
- IT is resultant phasor of IR and IX.

Resonance in RLC Parallel Circuit

- Resonance occurs when inductive reactance = capacitive reactance
i.e., XL = XC

- At resonance:

$$I_C = I_L \rightarrow I_X = 0, \text{ so } I_T = I_R$$

- Power factor becomes unity (purely resistive).

- Minimum line current at resonance.

Voltage and Current Waveforms

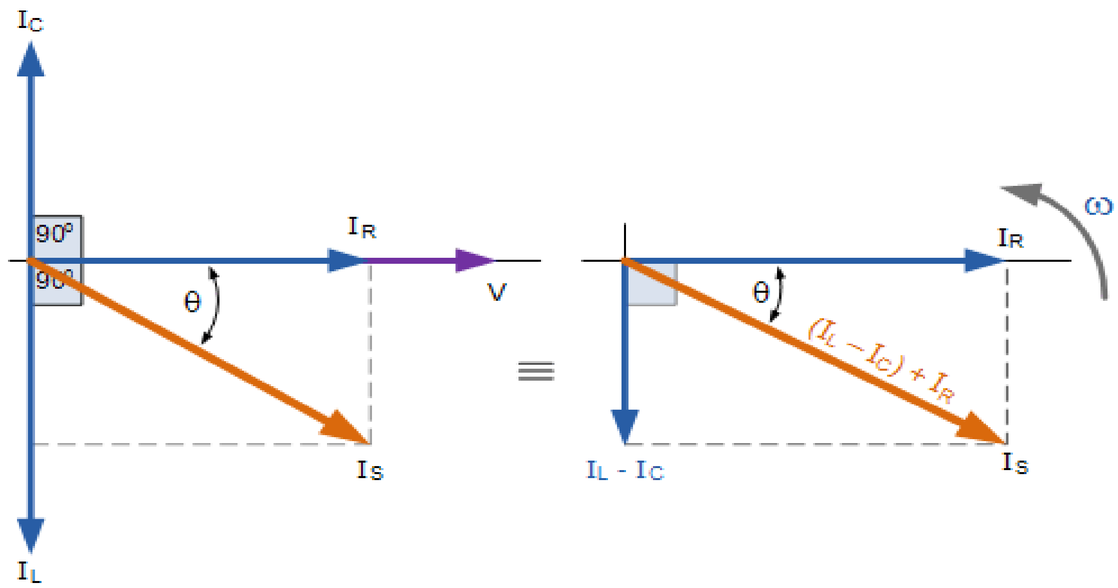

Figure 2.3 Waveform Diagram

- Voltage remains sinusoidal and same across all elements.
- IR follows V(t), IL lags V(t) by 90°, IC leads V(t) by 90°.

Power and Power Factor

- **Real Power (P):**

$$P = V^2 / R$$

- **Reactive Power (Q):**

$$Q = V^2 \times (1 / XL - 1 / XC)$$

- **Apparent Power (S):**

$$S = V \times IT$$

- **Power Factor (PF):**

$$PF = \cos(\varphi)$$

- Leading, lagging, or unity based on net reactance.

Summary

- RLC parallel circuit has R, L, and C in parallel with AC source.
- All components share common voltage, but branch currents differ in phase.
- Total current is phasor sum of IR, IL, and IC.
- Resonance occurs when XL = XC, and current is minimized.
- Power factor depends on whether circuit is capacitive, inductive, or resistive.
- Useful in parallel resonance applications, filters, and tuned circuits.

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Concept of Impedance, Admittance, Conductance, and Susceptance

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Introduction

- These four terms are essential for analyzing AC circuits, especially involving complex quantities.
- Impedance (Z) and Admittance (Y) are vector quantities, while Conductance (G) and Susceptance (B) are scalar.
- They represent opposition or ease to current flow in AC systems.

Impedance (Z)

- Impedance is the total opposition to current in an AC circuit.

- It includes both resistance (R) and reactance (X):

$$Z = R + jX$$

- R: Resistive component
- X: Reactance (can be inductive or capacitive)
- j: Imaginary unit ($\sqrt{-1}$)

Magnitude:

$$|Z| = \sqrt{R^2 + X^2}$$

- Unit: Ohm (Ω)

Admittance (Y)

- Admittance is the reciprocal of impedance:

$$Y = 1 / Z$$

- It indicates how easily current can flow.

- Expressed as:

$$Y = G + jB$$

- G: Conductance
- B: Susceptance

Magnitude:

$$|Y| = \sqrt{(G^2 + B^2)}$$

- Unit: Siemens (S)

Conductance (G)

- Conductance is the real part of admittance.
- Represents the part of current that is in phase with voltage.

$$G = R / (R^2 + X^2)$$

- Unit: Siemens (S)
- In a purely resistive circuit:

$$G = 1 / R$$

Susceptance (B)

- Susceptance is the imaginary part of admittance.

- Represents the reactive component of current:

$$B = -X / (R^2 + X^2)$$

- Positive B → Capacitive
- Negative B → Inductive

In purely reactive circuits:

- For inductors: $B = -1 / X_L$
- For capacitors: $B = +1 / X_C$

Mathematical Relationships

$$Z = R + jX$$

$$Y = 1 / Z = G + jB$$

$$G = Re(Y), \quad B = Im(Y)$$

$$|Z| = 1 / |Y|$$

- Ohm's Law in AC form:

$$V = IZ$$
$$I = VY$$

Phasor Domain View

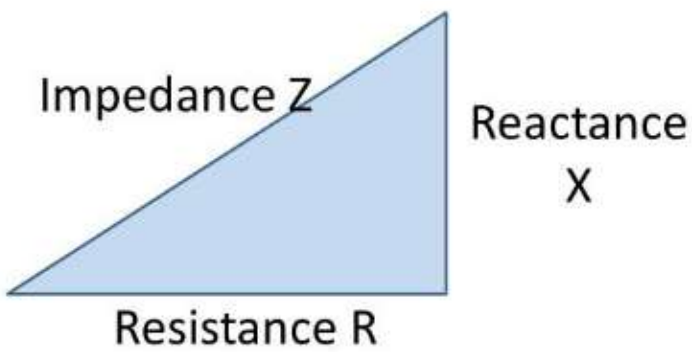

Figure 2.1 Impedance Triangle

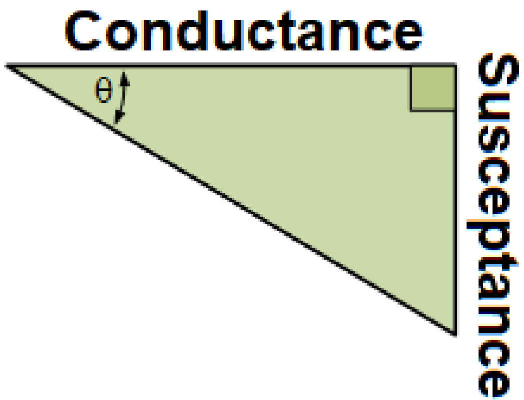

Figure 2.2 Admittance Triangle

Summary

- Impedance (Z): Opposition to AC, includes resistance and reactance.
- Admittance (Y): Ease of AC flow, reciprocal of Z.
- Conductance (G): Real part of admittance, represents resistive behavior.
- Susceptance (B): Imaginary part of admittance, represents reactive behavior.
- These terms are essential for solving and analyzing AC networks, especially in parallel circuits and phasor analysis.

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Concept of Active Power, Reactive Power, Apparent Power and Power Factor

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Content

Introduction

•In AC circuits, power is not just a product of voltage and current.

•Due to phase difference, different types of power are defined:

1. Active Power (P)
2. Reactive Power (Q)
3. Apparent Power (S)

•These quantities help understand how efficiently power is utilized.

Active Power (P)

•Also known as real or true power.

•Represents the actual power consumed by resistive components.

Formula:

$$P = V \times I \times \cos(\varphi)$$

•V: RMS Voltage
•I: RMS Current
•ϕ: Phase angle between V and I
•Unit: Watt (W)

•It performs useful work: lighting, heating, rotating machines.

Reactive Power (Q)

•Power that oscillates between source and reactive components (L and C).

•Does not perform any net work.

Formula:

$$Q = V \times I \times \sin(\varphi)$$

•Unit: VAR (Volt-Ampere Reactive)

•It supports the magnetic and electric fields in inductors and capacitors.

Apparent Power (S)

•The product of RMS voltage and current, regardless of phase angle.

Formula:

$$S = V \times I$$

•Unit: VA (Volt-Ampere)

•Represents the total power delivered to the circuit.

Relationship:

$$S^2 = P^2 + Q^2$$

Power Triangle

A right-angled triangle representing:

•Active power (P) – Base

•Reactive power (Q) – Height

•Apparent power (S) – Hypotenuse

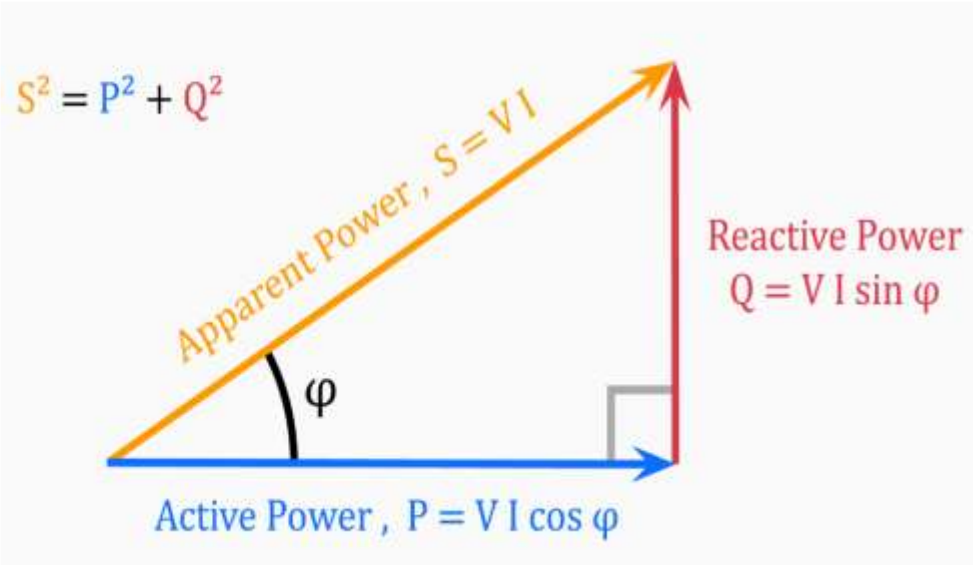

Figure 2.1 Power Triangle

Power Factor (PF)

•Indicates how effectively electrical power is converted into useful work.

Formula:

$$\text{Power Factor (PF)} = \cos(\varphi) = P / S$$

•PF ranges from 0 to 1
- PF = 1 → purely resistive (ideal)
- PF < 1 → reactive power is present

•Can be leading (capacitive) or lagging (inductive)

Significance of Power Factor

• Higher PF means better efficiency and reduced power losses.

• Low PF results in:

1. Increased current
2. Larger conductor sizes
3. Higher losses
4. Voltage drops

• Industries are penalized for low PF – hence power factor correction is common using capacitor banks or synchronous condensers.

Summary

- Active Power (P): Useful power consumed (W).
- Reactive Power (Q): Oscillating power (VAR).
- Apparent Power (S): Total supplied power (VA).
- Power Factor (PF): Efficiency ratio ($\cos(\phi)$).
- Power Triangle helps visualize the relationship among P, Q, and S.
- Efficient systems aim for high power factor to reduce losses and improve performance.

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Concept of three phase supply and phase sequence

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Introduction to Three-Phase System

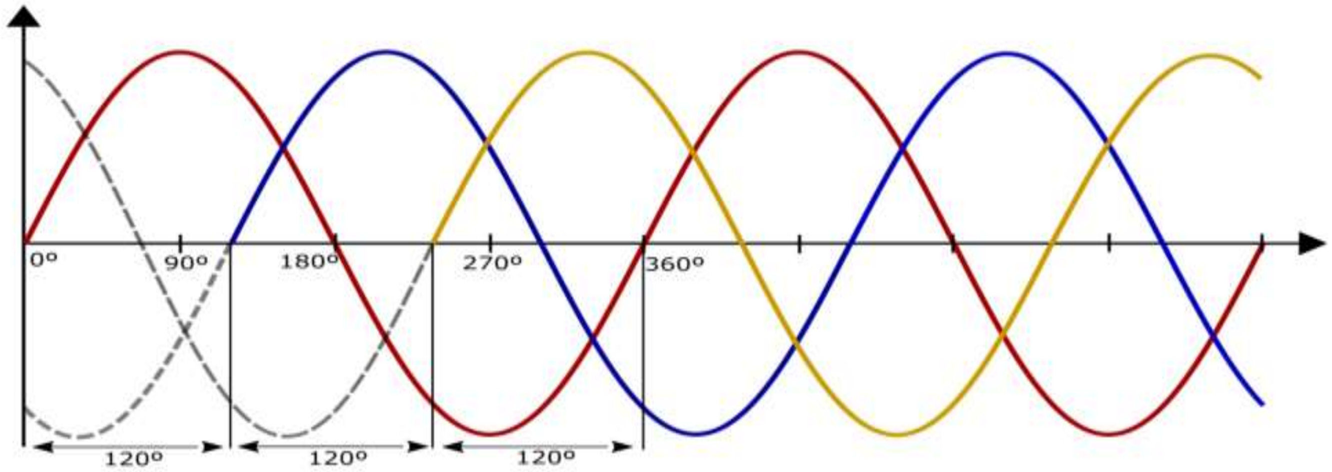


Figure 2.1 Three Phase AC supply waveform

- A three-phase system consists of three alternating voltages of the same frequency, 120° phase difference apart.
- Generated using a three-phase alternator with three windings 120° apart.
- Commonly used in industrial and power systems for efficient energy transfer.

Advantages of Three-Phase Supply

- More power delivered for the same current than single-phase.
- Constant power output – unlike pulsating power in single-phase.
- Requires less conductor material for transmission.
- Motors run more smoothly and efficiently.

Construction and Generation

- Generated by rotating a magnetic field inside a stator with three windings placed 120° apart.

- The output voltages are:
  - Balanced: Equal magnitude, 120° apart.
  - Unbalanced: Unequal magnitudes or angle deviations (not preferred).

- Voltage Equations (Balanced):

$$V_R(t) = Vm \times \sin(\omega t)$$

$$V_Y(t) = Vm \times \sin(\omega t - 120°)$$

$$V_B(t) = Vm \times \sin(\omega t - 240°)$$

Phase Sequence

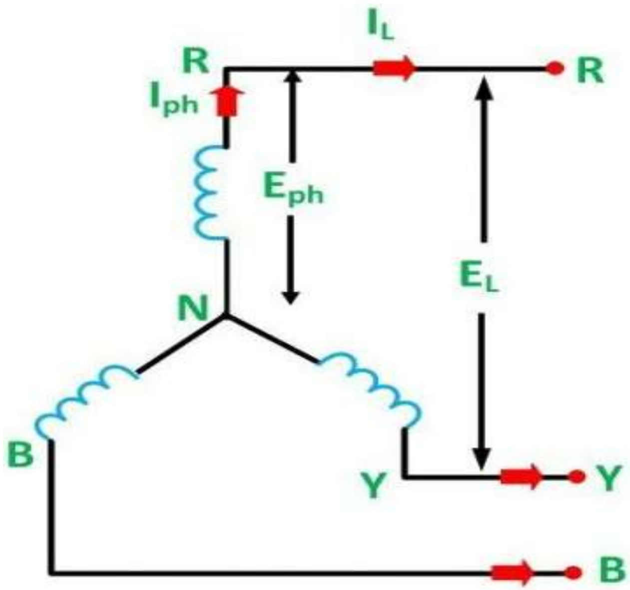
- Phase sequence refers to the order in which the voltages attain their maximum positive values.

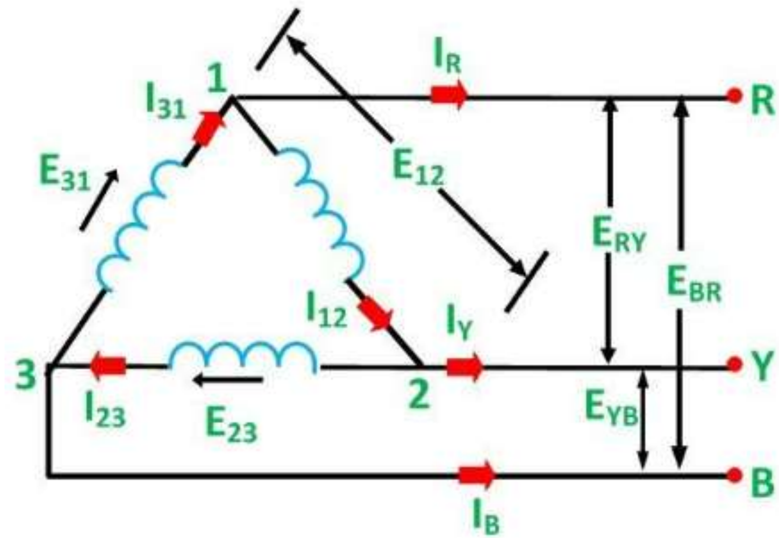
- In a standard system, it is either:

1. R → Y → B (Clockwise)
2. R → B → Y (Counterclockwise)

- Phase sequence is crucial in rotating machinery (e.g., motors) as it determines rotation direction.

Types of Connections





Star (Y) Connection:
•3 phase wires + 1 neutral
•Line voltage = √3 × Phase voltage

Delta (Δ) Connection:
•3 phase wires only
•Line voltage = Phase voltage

Significance of Phase Sequence

Incorrect phase sequence can:

- Reverse motor direction
- Damage sensitive equipment

Critical in:

- Synchronizing alternators
- Phase-sensitive devices
- Control circuits and automation

Applications

- Power distribution systems
- Three-phase motors and generators
- Heavy industrial loads
- HVAC systems
- Electric trains and escalators

Summary

•Three-phase supply uses 3 sinusoidal voltages 120° apart.

•Delivers more power efficiently and continuously.

•Phase sequence determines the direction of rotation in motors.

•Star and Delta are two main connection types.

•Understanding sequence is vital for system protection and synchronization.

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