NCERT NOTES

Class 12 Physics

Chapter 7: Alternating Current
Detailed NCERT Revision Notes

1 Alternating Current

1.1 Introduction

An **Alternating Current (AC)** is an electric current whose magnitude changes continuously with time, and whose direction reverses periodically.

- Unlike Direct Current (DC) (like the power supplied by a standard battery), which flows strictly in a single, unyielding direction, an Alternating Current repeatedly builds up from zero to a positive peak, falls back to zero, builds to an identical negative peak, and returns to zero over and over again.
- Because AC inherently follows a continuous wave-like pattern, it is most commonly represented by sinusoidal mathematical functions. The instantaneous value of alternating current at any exact moment in time t is universally given by:

Instantaneous AC Mathematical Formula

$$i = I_0 \sin(\omega t) \quad \text{or} \quad i = I_0 \cos(\omega t)$$

Where the equation parameters denote:

- **i** = The instantaneous current at any chosen time t.
- $\mathbf{I_0}$ = The peak current (the absolute maximum amplitude the current reaches during its cycle).
- $\omega = 2\pi f$ = The angular frequency of the alternating wave (measured in rad/s).

- **f** = The conventional frequency (how many cycles it completes in one second).
- **t** = The instantaneous time measured in seconds.

Important Parameters of AC

1. Time Period (T)
The exact time taken by the alternating current (or voltage) to complete one full sinusoidal cycle. It is the reciprocal of frequency.

$$T = \frac{1}{f}$$

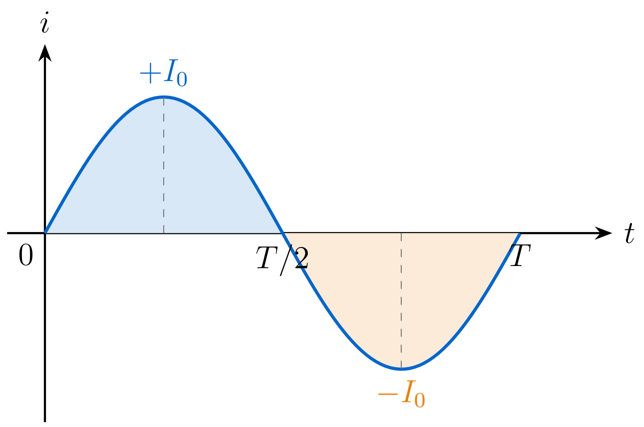
2. Frequency (f)
The number of complete cycles the alternating waveform executes in one second. The SI unit is **Hertz (Hz)**.

- *Real-World Fact:* The standard frequency of domestic AC supply in India is **50** Hz, meaning the current completes 50 full cycles every second (and reverses its direction exactly 100 times per second).

3. Angular Frequency (ω)
The rate at which the mathematical phase angle of the alternating wave changes with respect to time. It is expressed in **radians per second (rad/s)**.

$$\omega = 2\pi f = \frac{2\pi}{T}$$

1.2 Graph of Alternating Current



Observations

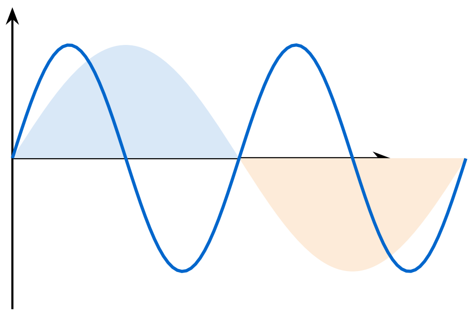
- Current is maximum at $\omega t = \frac{\pi}{2}$ (Positive peak)
- Current is zero at $\omega t = 0, \pi, 2\pi$
- Direction reverses after every half cycle (Negative peak)

1.3 AC vs DC Comparison

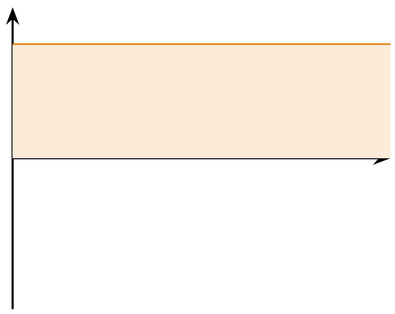
Alternating Current (AC)	Direct Current (DC)
Changes direction periodically	Flows in one direction only
Magnitude varies with time	Magnitude constant
Sinusoidal waveform	Straight line waveform
Produced by AC generator	Produced by cell or battery
Can be stepped up/down using transformer	Cannot be transformed directly

Graphical Comparison

AC



DC



1.4 Generation of AC

AC is generated using an Alternating Current Generator.

It works on the principle of electromagnetic induction.

When a coil rotates in a magnetic field, magnetic flux linked with it changes continuously.

Magnetic Flux & Induced EMF

$$\Phi = BA\cos(\omega t)$$

Using Faraday's law:

$$E = -N\frac{d\Phi}{dt} \implies E = NBA\omega\sin(\omega t)$$

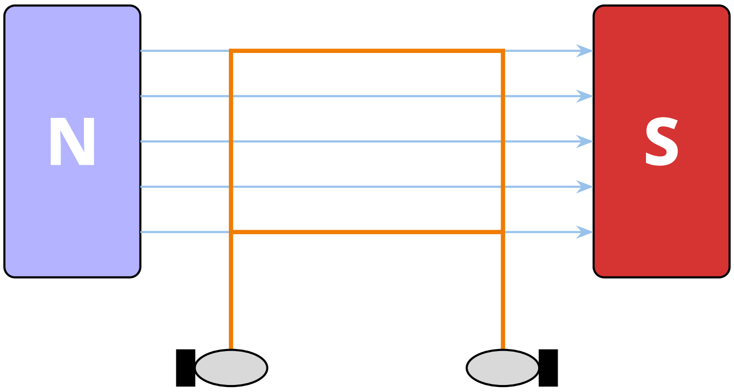
Thus alternating emf is produced.

1.5 Construction of AC Generator

Main components:

- Armature (rotating coil)
- Field magnet
- Slip rings

- Carbon brushes



AC Generator Diagram

1.6 Working of AC Generator

When coil rotates:

- Angle between magnetic field and area vector changes.
- Flux changes sinusoidally.
- EMF induced alternates in direction.

Maximum emf:

$$E_0 = NBA\omega$$

Instantaneous emf:

$$\boxed{E = E_0 \sin(\omega t)}$$

Exam Focus Points

- Define AC clearly.
- Write equation $i = I_0 \sin(\omega t)$.
- Draw sinusoidal graph.
- Mention frequency in India (50 Hz).
- Derive $E = NBA\omega \sin(\omega t)$.

2 Instantaneous Value of Alternating Current

2.1 Expression for Alternating Current

The instantaneous value of alternating current is the value of current at any particular instant of time.

For a sinusoidal alternating current:

Instantaneous Current

$$i = I_0 \sin(\omega t)$$

where:

- i = instantaneous current at time t
- I_0 = peak (maximum) current
- ω = angular frequency
- t = time

Angular frequency is related to frequency by:

$$\boxed{\omega = 2\pi f}$$

and

$$f = \frac{1}{T}$$

where:

- f = frequency (Hz)
- T = time period

Important Observations

- When $\omega t = 0$, $i = 0$
- When $\omega t = \frac{\pi}{2}$, $i = I_0$
- When $\omega t = \pi$, $i = 0$
- When $\omega t = \frac{3\pi}{2}$, $i = -I_0$

Thus, current changes direction every half cycle.

2.2 Instantaneous Voltage

Similarly, the instantaneous value of alternating voltage is:

Instantaneous Voltage

$$v = V_0 \sin(\omega t)$$

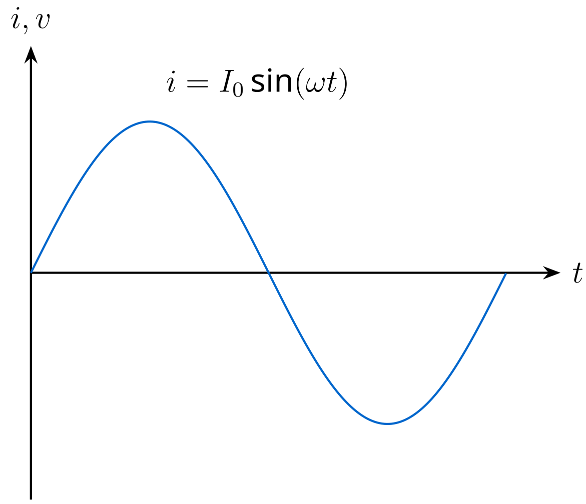
where:

- v = instantaneous voltage
- V_0 = peak voltage

In a purely resistive circuit:

$$v \text{ and } i \text{ are in phase}$$

2.3 Graphical Representation



2.4 Key Relationships

Summary Relationships

$$\omega = 2\pi f \qquad T = \frac{2\pi}{\omega} \qquad i_{\text{max}} = I_0 \qquad v_{\text{max}} = V_0$$

Important Exam Points

- Always write full equation $i = I_0 \sin(\omega t)$.
- Mention relation $\omega = 2\pi f$.
- Know values at $\omega t = 0, \frac{\pi}{2}, \pi$.
- Current reverses every half cycle.

3 Important AC Quantities

3.1 Time Period (T)

Time period is the time taken by alternating current to complete one full cycle.

$$\boxed{T = \frac{1}{f}}$$

Unit: second (s)

3.2 Frequency (f)

Frequency is the number of cycles completed per second.

$$f = \frac{1}{T}$$

Unit: Hertz (Hz)
In India:

$$f = 50 \text{ Hz}$$

3.3 Angular Frequency (ω)

Angular frequency is the rate of change of phase angle.

$$\boxed{\omega = 2\pi f}$$

Unit: rad/s

3.4 Peak Value (Maximum Value)

Peak value is the maximum value attained by current or voltage.

$$I_0 = \text{Maximum current} \qquad V_0 = \text{Maximum voltage}$$

At $\omega t = \frac{\pi}{2}$, $i = I_0$

3.5 Average Value

Average value of AC over one complete cycle is zero.
Therefore, average is taken over half cycle.
For current:

Average Value

$$I_{\text{avg}} = \frac{1}{\pi}\int_0^{\pi} I_0 \sin\theta \, d\theta \implies I_{\text{avg}} = \frac{2I_0}{\pi}$$

Similarly:

$$V_{\text{avg}} = \frac{2V_0}{\pi}$$

Numerically:

$$I_{\text{avg}} = 0.637 I_0$$

3.6 Root Mean Square (RMS) Value

RMS value is defined as:
Square root of the mean of squares of instantaneous values over one complete cycle.
For current:

RMS Value

$$I_{\text{rms}} = \sqrt{\frac{1}{T}\int_0^T i^2 dt} \implies I_{\text{rms}} = \frac{I_0}{\sqrt{2}}$$

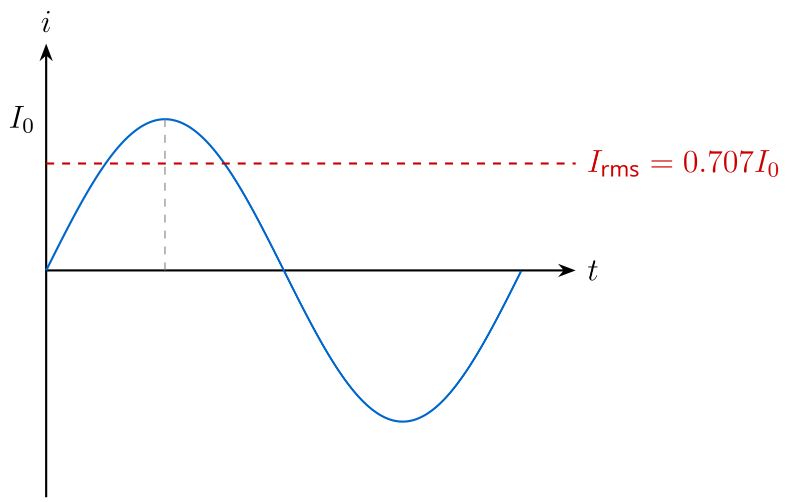
Similarly:

$$\boxed{V_{\text{rms}} = \frac{V_0}{\sqrt{2}}}$$

Numerically:

$$I_{\text{rms}} = 0.707 I_0$$

3.7 Graphical Understanding



3.8 Significance of RMS Value

Why we use RMS

RMS value represents the effective value of AC. It is defined as the value of DC current that produces the **same heating effect** as AC in a resistor.
Since heating effect depends on $P = I^2R$, RMS value is used in power calculations.

Example:
If domestic supply is 220 V:

$$V_{\text{rms}} = 220 \text{ V}$$

Peak voltage:

$$V_0 = \sqrt{2} \times 220 \approx 311 \text{ V}$$

Important Relations Summary

- $T = \frac{1}{f}$
- $\omega = 2\pi f$
- $I_{\text{avg}} = \frac{2I_0}{\pi} = 0.637 I_0$
- $I_{\text{rms}} = \frac{I_0}{\sqrt{2}} = 0.707 I_0$
- $V_{\text{rms}} = \frac{V_0}{\sqrt{2}}$

4 AC Circuit with Resistor Only

4.1 Voltage and Current Relation

Consider a pure resistive circuit connected to an AC source.
Using Ohm's law:

$$\boxed{v = iR}$$

If applied voltage is $v = V_0 \sin(\omega t)$, then current becomes:

$$i = \frac{v}{R} = \frac{V_0}{R} \sin(\omega t) \implies i = I_0 \sin(\omega t)$$

where $I_0 = \frac{V_0}{R}$. Thus current and voltage vary sinusoidally with same frequency.

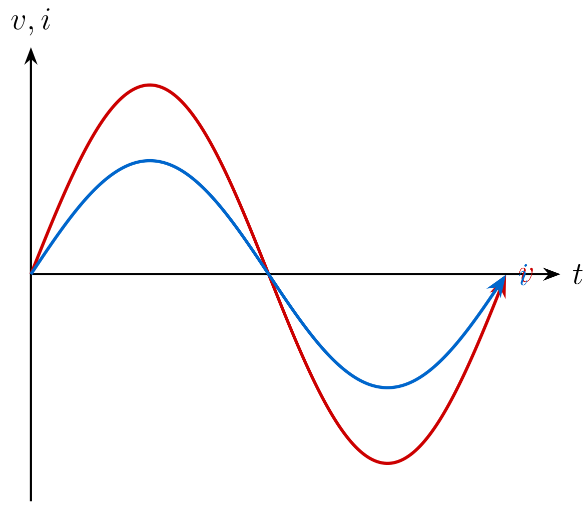
4.2 Phase Relationship

Phase: Pure Resistor

In a pure resistive circuit: **Voltage and current are IN PHASE** ($\phi = 0°$).

- Both reach maximum at same time.
- Both become zero at same time.

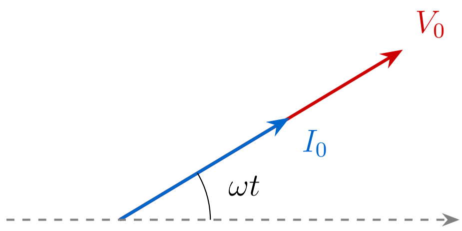
4.3 Graphical Representation



v and i in phase

4.4 Phasor Diagram

In phasor representation, voltage and current phasors lie along same direction.



Phasor Diagram (In Phase)

4.5 Power in Pure Resistive Circuit

Instantaneous power:

$$p = vi = V_0 \sin(\omega t) \cdot I_0 \sin(\omega t) = V_0 I_0 \sin^2(\omega t)$$

Average power over one cycle:

Average Power

$$P = \frac{V_0 I_0}{2} = V_{\text{rms}} I_{\text{rms}} = I_{\text{rms}}^2 R = \frac{V_{\text{rms}}^2}{R}$$

4.6 Important Points

- Phase angle $\phi = 0$

- Power factor = cos $\phi = 1$
- No reactive power
- Entire power is dissipated as heat

5 AC Circuit with Inductor Only

5.1 Inductive Reactance

In a purely inductive circuit, the inductor opposes the change in current. This opposition is called inductive reactance.

Inductive Reactance

$$X_L = \omega L = 2\pi f L \quad \text{(Unit: } \Omega)$$

Thus inductive reactance increases with frequency.

5.2 Voltage and Current Relation

For pure inductor, $v = L\frac{di}{dt}$
Assume $i = I_0 \sin(\omega t)$, then $\frac{di}{dt} = I_0\omega \cos(\omega t)$

$$v = LI_0\omega \cos(\omega t) = \omega L I_0 \sin\left(\omega t + \frac{\pi}{2}\right)$$

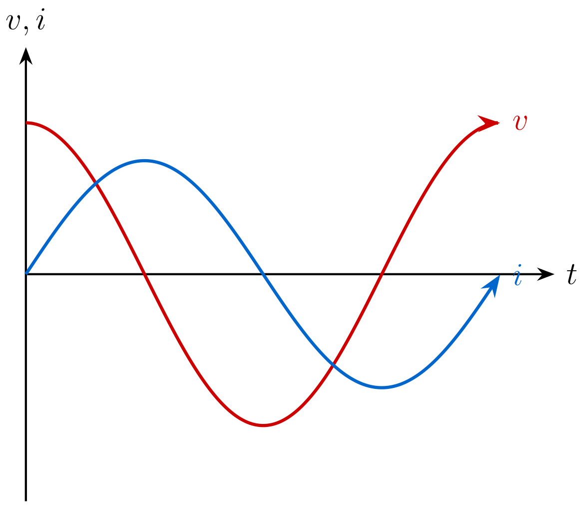
Peak voltage $V_0 = I_0 X_L$. Thus $\boxed{V = IX_L}$.

5.3 Phase Relationship

Phase: Pure Inductor

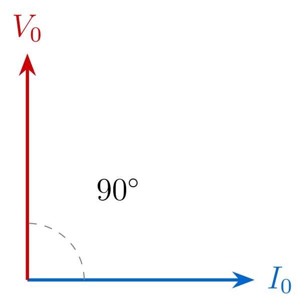
In a purely inductive circuit: **Current LAGS voltage by** 90° (or Voltage leads Current by 90°).

5.4 Graphical Representation



v leads i by $90°$

5.5 Phasor Diagram



Voltage Leads Current by $90°$

5.6 Power in Pure Inductive Circuit

Since voltage and current are $90°$ out of phase: $P_{\text{avg}} = V_{\text{rms}} I_{\text{rms}} \cos(90°) = 0$

Zero Power

No net power is consumed! Energy is stored in magnetic field during one half cycle and returned to source in the next half cycle.

6 AC Circuit with Capacitor Only

6.1 Capacitive Reactance

In a purely capacitive circuit, the capacitor opposes the change in voltage.

Capacitive Reactance

$$X_C = \frac{1}{\omega C} = \frac{1}{2\pi f C} \quad \text{(Unit: } \Omega\text{)}$$

As frequency increases, X_C decreases. Capacitor allows high-frequency currents easily.

6.2 Voltage and Current Relation

For capacitor: $i = C\frac{dv}{dt}$. Assume $v = V_0 \sin(\omega t)$.

$$i = CV_0\omega \cos(\omega t) = V_0\omega C \sin\left(\omega t + \frac{\pi}{2}\right)$$

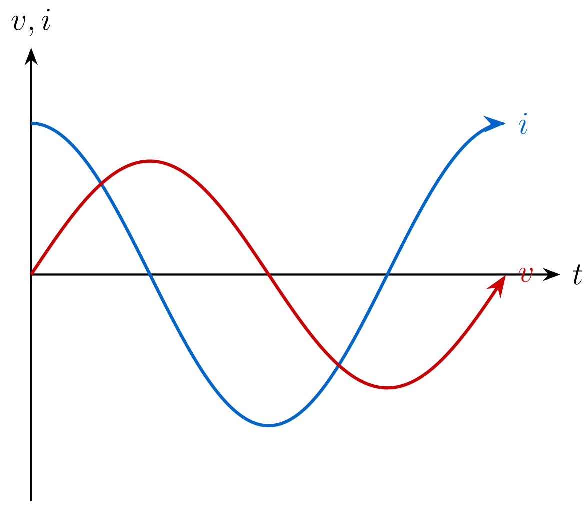
Peak current $I_0 = V_0\omega C = \frac{V_0}{X_C}$. Thus, $\boxed{V = IX_C}$.

6.3 Phase Relationship

Phase: Pure Capacitor

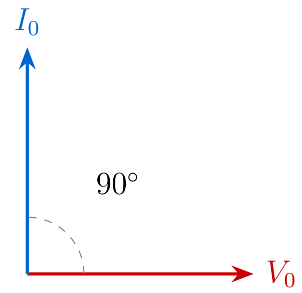
In a purely capacitive circuit: **Current LEADS voltage by** $90°$ (or Voltage lags Current by $90°$).

6.4 Graphical Representation



i leads v by $90°$

6.5 Phasor Diagram



Current Leads Voltage by $90°$

6.6 Power in Pure Capacitive Circuit

Average power over one cycle: $P_{\text{avg}} = V_{\text{rms}} I_{\text{rms}} \cos(-90°) = \boxed{0}$

Zero Power

Capacitor does not consume power. Energy is stored in the electric field during one half cycle and returned to the source in next half cycle.

7 LCR Series Circuit

7.1 AC Circuit Containing R, L and C (Series)

In an LCR series circuit, resistor (R), inductor (L) and capacitor (C) are connected in series. The same current flows through all elements, but the voltages across them have different phases.

7.2 Impedance (Z)

The total opposition to current is called impedance (Z), which is the vector sum of resistance and reactance.

Impedance

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

Applying Ohm's law for AC: $\boxed{I = \frac{V}{Z}}$.

7.3 Phase Angle

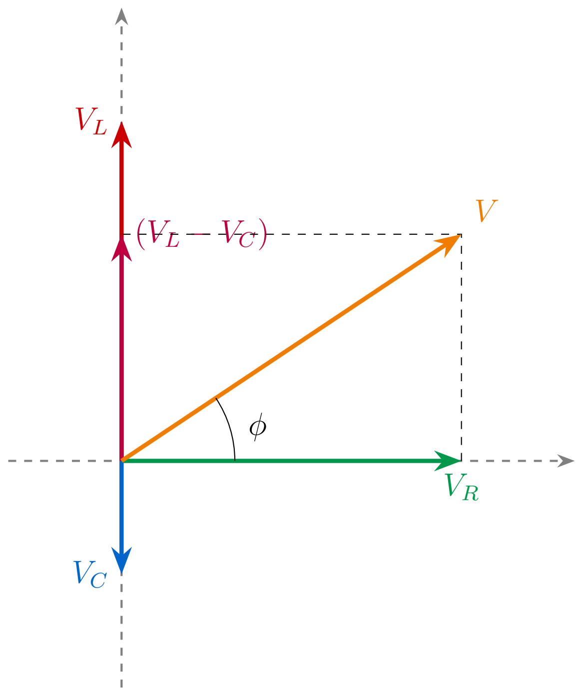
Voltage and current are not in phase in LCR circuit.

Phase Angle

$$\tan\phi = \frac{X_L - X_C}{R}$$

- $X_L > X_C \implies$ Inductive $\implies$ Current lags
- $X_C > X_L \implies$ Capacitive $\implies$ Current leads

7.4 Phasor Diagram



8 Resonance in LCR Series Circuit

8.1 Condition for Resonance

Resonance occurs when inductive reactance equals capacitive reactance: $\boxed{X_L = X_C}$. Thus net reactance $X = 0$, and impedance becomes minimum: $\boxed{Z = R}$.

8.2 Resonant Frequency

Resonant Frequency

$$\omega L = \frac{1}{\omega C} \implies \omega_0 = \frac{1}{\sqrt{LC}} \implies f_0 = \frac{1}{2\pi\sqrt{LC}}$$

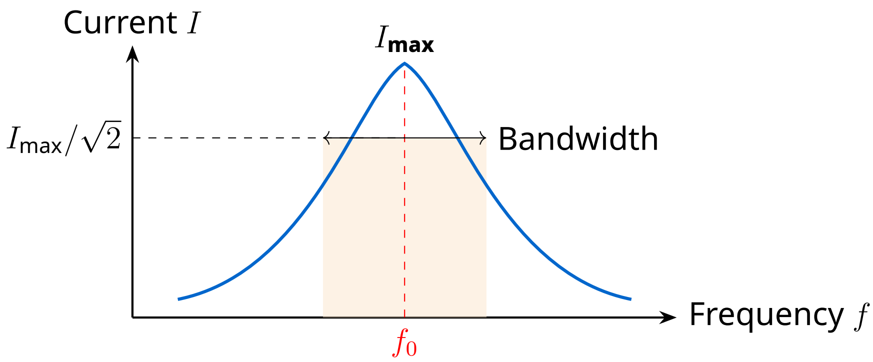
8.3 Characteristics at Resonance

At Resonance

- Impedance is minimum ($Z = R$).
- Current is maximum ($I = V/R$).
- Phase angle $\phi = 0$ (Voltage and Current are in phase).
- Power factor = 1.

Even though V_L and V_C can be very large, they cancel out exactly. This is called voltage magnification.

8.4 Graph of Current vs Frequency (Resonance Curve)



8.5 Quality Factor (Q) and Bandwidth

Quality factor measures sharpness of resonance.

Quality Factor

$$Q = \frac{\omega_0 L}{R} = \frac{1}{R}\sqrt{\frac{L}{C}} \qquad \text{Bandwidth} = f_2 - f_1 = \frac{f_0}{Q}$$

Higher Q means sharper resonance curve.

9 Power in AC Circuits

9.1 Instantaneous and Average Power

Instantaneous power $p = V_0 I_0 \sin(\omega t)\sin(\omega t + \phi)$. Average power over one complete cycle:

Average Power

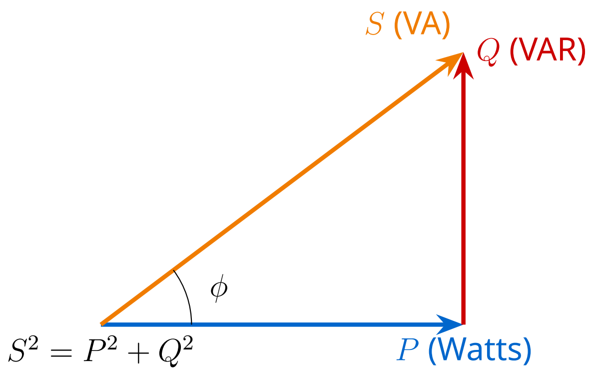
$$P_{avg} = V_{rms} I_{rms} \cos\phi$$

9.2 Power Factor and Types of Power

Power Components

- **Power Factor:** $\cos\phi = R/Z$.
- **Real (True) Power:** $P = V_{\text{rms}} I_{\text{rms}} \cos\phi \quad \text{(W)}$
- **Reactive Power:** $Q = V_{\text{rms}} I_{\text{rms}} \sin\phi \quad \text{(VAR)}$
- **Apparent Power:** $S = V_{\text{rms}} I_{\text{rms}} \quad \text{(VA)}$

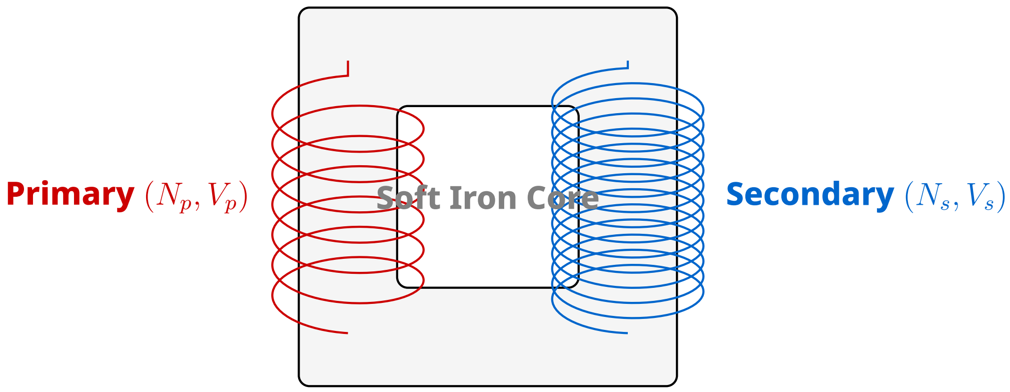
9.3 Power Triangle



10 Transformer

10.1 Principle and Construction

Transformer works on the principle of mutual induction. It transfers energy from primary to secondary without direct electrical contact.



10.2 Working and Turns Ratio

When AC voltage is applied to primary, magnetic flux changes continuously, inducing emf in secondary.

Transformer Ratio

$$\frac{V_s}{V_p} = \frac{N_s}{N_p} = \frac{I_p}{I_s}$$

- **Step-Up:** $N_s > N_p \implies V_s > V_p$
- **Step-Down:** $N_s < N_p \implies V_s < V_p$

10.3 Energy Losses in Transformer

4 Main Losses

1. **Copper Loss:** Heat in wires (I^2R). Fix: Use thick wires.
2. **Iron/Eddy Current Loss:** Swirling currents in core. Fix: Use laminated core.
3. **Hysteresis Loss:** Repeated magnetisation. Fix: Use soft iron.
4. **Flux Leakage:** Fix: Wind primary and secondary coils over each other.

11 Important Graphs in Alternating Current

Graphical representations concisely summarize the entire chapter. Recognizing these waveforms is crucial!

Summary of Key Graphs

- **Sinusoidal waveform** showing positive/negative alternating current.
- **Phase difference graphs** showing lead/lag rules for Pure R, L, C circuits.
- **Resonance curve** showcasing the current spike exactly at matching natural frequency.
- **Power Triangle** visually demonstrating the relation between real, reactive, and apparent power.

12 Important Derivations in Alternating Current

The backbone of AC mathematics relies on calculus and phasor vectors.

Key Steps in AC Derivations

- **RMS value:** Taking the root-mean-square integral of pure sine wave yields $I_0/\sqrt{2}$.
- **Average value:** Integrating over a half cycle yields $2I_0/\pi$.
- **Inductive Reactance (X_L):** Derived from $V = L\frac{di}{dt}$, bringing a $-$cos matching a $+$sin$(+90°)$.
- **Capacitive Reactance (X_C):** Derived from $I = C\frac{dv}{dt}$, bringing a $+$cos matching a $+$sin$(+90°)$.
- **Impedance (Z):** Pythagoras theorem applied to the 3-component LCR phasor diagram.
- **Resonant Frequency:** Set $X_L = X_C \implies \omega L = 1/(\omega C) \implies \omega^2 = 1/LC$.

13 Very Important Conceptual Micro-Topics

Below are the most frequently asked qualitative questions in NCERT exams:

Why RMS Value is Used in AC

Because AC voltage alternates polarity, taking the pure mathematical average over a full cycle yields strictly zero (0V). Consequently, saying "domestic supply is 0V" is useless. Instead, we equate its equivalent **heating effect** produced in a resistor ($P = I^2R$) to DC. This is why a 220V AC supply represents 220V RMS, giving an actual peak alternating voltage of $220\sqrt{2} = 311V$!

Why Inductor/Capacitor Consume No Average Power

For pure L or C, the phase shift $\phi = \pm 90°$. Average power is defined strictly as $P = VI\cos\phi$. Thus, $\cos(\pm 90°) = 0 \implies P = 0$. Physically, they borrow energy to build electric/magnetic fields, and then push that exact same energy completely back to the source alternatingly.

Why Resonance Increases Current

Current in an LCR circuit is limited by Impedance ($Z = \sqrt{R^2 + (X_L - X_C)^2}$). At resonance frequency, inductive and capacitive forces exactly cancel out magnetically/electrically. This zeroes out the parenthesis term, leaving $Z = \sqrt{R^2} = R$. This is the absolute mathematical minimum impedance possible, hence allowing maximal current to flow ($I_{max} = V/R$).

Why Power Factor Correction is Needed

If power factor ($\cos\phi$) is low, a larger current is required to deliver the same real power P. This causes large I^2R line transmission losses. Inserting parallel capacitors corrects the phase angle, reduces total current needed, and significantly improves efficiency.

Why Transformers Work Only on AC

A transformer fundamentally relies entirely on Faraday's Law of Electromagnetic Induction ($E = -N\frac{d\phi}{dt}$). For an electromotive force (voltage) to be induced on the secondary side, the magnetic flux ϕ must constantly change with time. If pure DC is used, ϕ is static, $d\phi/dt = 0$, and no secondary voltage will be created.