

CHAPTER 7.7 • AC CIRCUITS

Power Factor Made Simple

Understanding average power, wattless current, and resonance for NEET & JEE.

INSTANTANEOUS POWER



Voltage: $v = v_m \sin(\omega t)$

Current: $i = i_m \sin(\omega t + \varphi)$

Power: $p = vi$

Result expands into a time-dependent cosine term that fluctuates.

**AVERAGED
OVER A CYCLE →**

AVERAGE POWER (P)



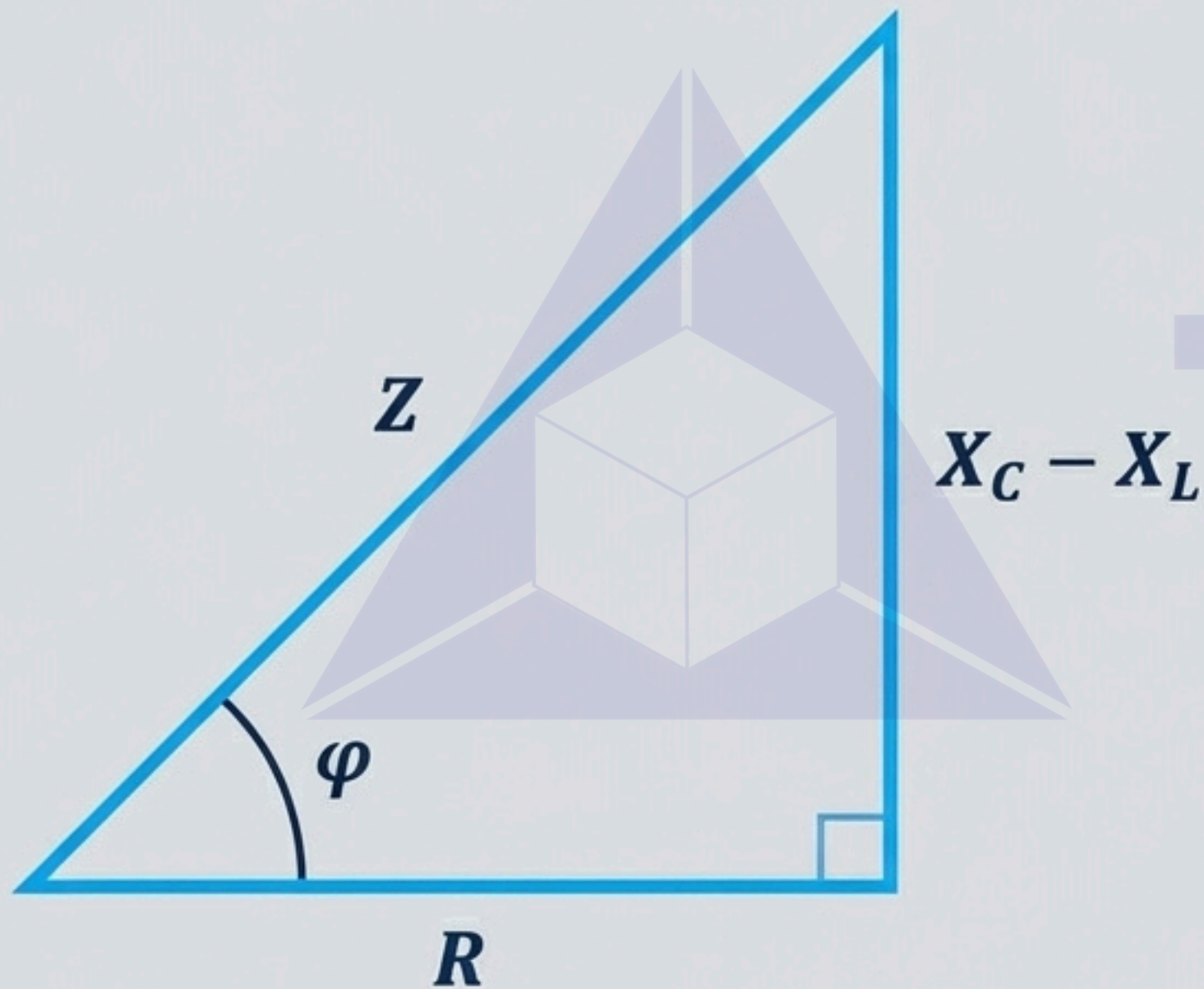
The time-dependent term averages to exactly zero over a full cycle.

We are left with the fundamental RMS relation:

$$P = VI \cos(\varphi)$$

Decoding the Power Factor ($\cos \varphi$)

The Power Factor scales the power based on the phase angle between voltage and current. It reveals how much of the circuit behaves like a pure resistor.



GEOMETRIC DEFINITION

From the impedance triangle:

$$\cos(\varphi) = \frac{R}{Z}$$

ALTERNATE FORMULA

Since $\mathbf{V} = \mathbf{IZ}$, we can rewrite average power as:

$$P = I^2 Z \cos(\varphi)$$



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$$E=mc^2$$



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How Power Behaves in Different Circuits

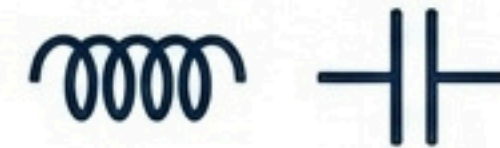
Pure Resistive



$$\varphi = 0 \rightarrow \cos(\varphi) = 1$$

Result: Maximum power dissipation ($P = VI$).

Pure Inductive / Capacitive



$$\varphi = \frac{\pi}{2} \rightarrow \cos(\varphi) = 0$$

Result: Zero average power dissipated.

Series LCR Circuit



$$\varphi = \tan^{-1} \left(\frac{X_C - X_L}{R} \right)$$

Result: Power is dissipated only in the resistor.

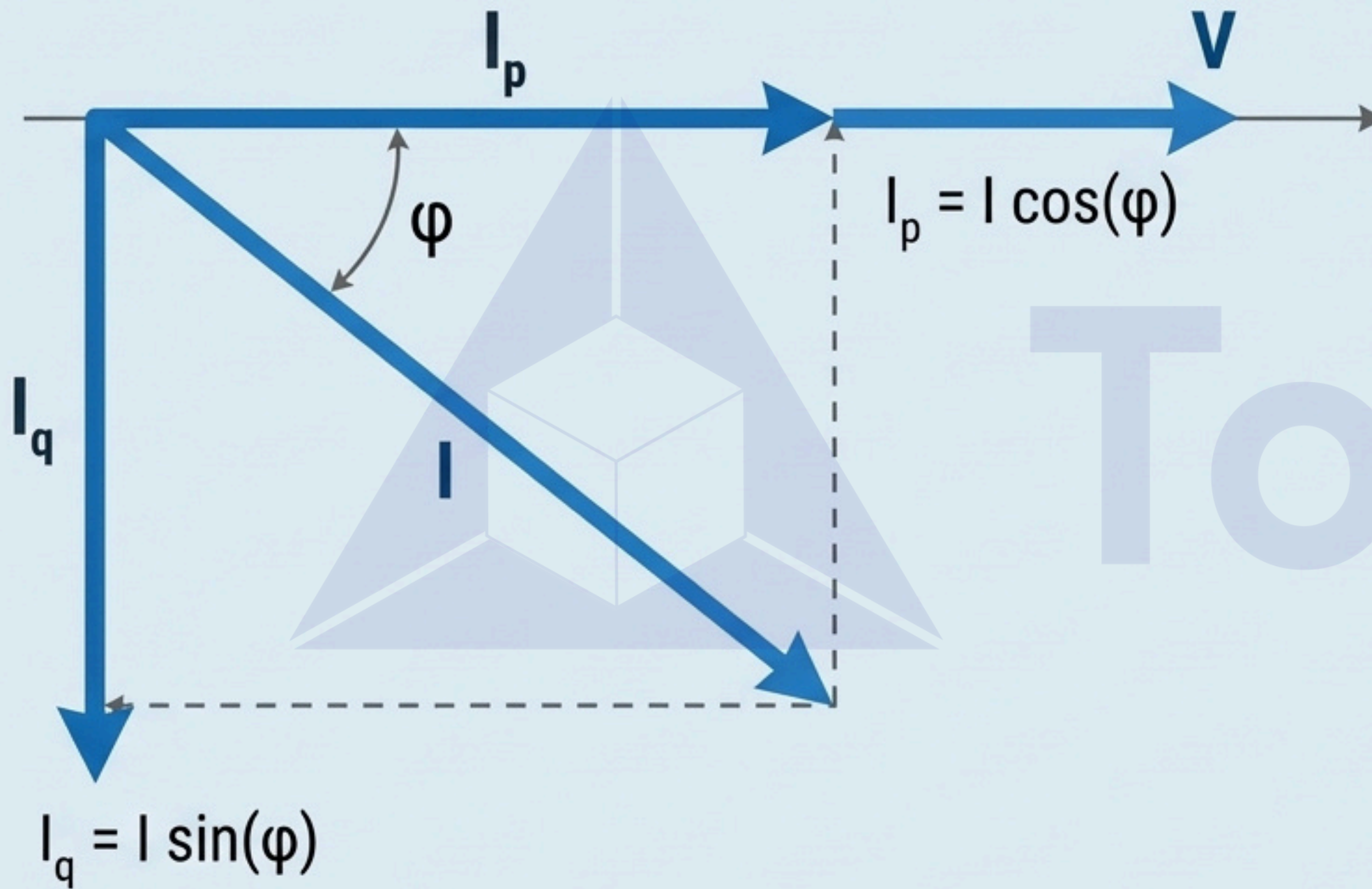
LCR at Resonance



$$X_C = X_L \rightarrow \varphi = 0 \rightarrow \cos(\varphi) = 1$$

Result: Maximum power dissipation ($P = I^2 R$).

Wattless Current: Flow Without Power



When current I lags or leads the voltage V by angle ϕ , it splits into two components:

I_p (Power Component): $I \cos(\phi)$

- In phase with voltage.
- Causes actual power loss and does the work.

I_q (Wattless Component): $I \sin(\phi)$

- Perpendicular to voltage (90° out of phase).
- Corresponds to zero average power loss.

Correcting the Power Factor

EXAM TIP: THE PROBLEM

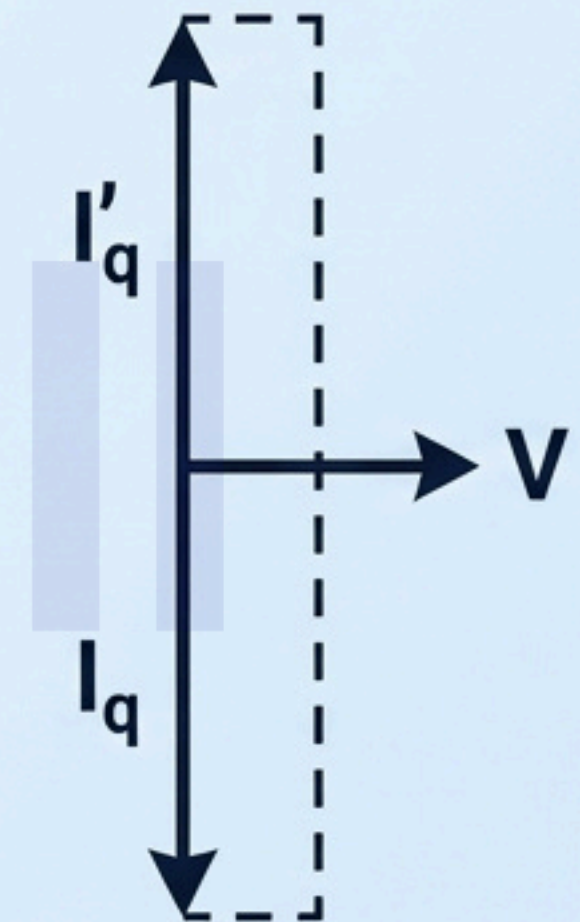
A low power factor ($\cos \phi$) requires a **much larger current** to supply the same power.

This leads to massive **I^2R energy waste** in transmission lines.

THE CAPACITOR FIX

1. Connect a **capacitor** of appropriate value in **parallel**.
2. It generates a **leading** wattless current (I'_q).
3. This perfectly **neutralizes** the lagging wattless current (I_q).

Result: The effective power factor improves and tends toward 1.



Key Takeaways

EXAM CHEAT SHEET

Average Power: $P = V I \cos(\phi)$ (where V, I are RMS values)

Power Factor: $\cos(\phi) = R / Z$

Wattless Current: The current component ($I \sin \phi$) perpendicular to voltage; dissipates zero average power.

Resonance Rule: At resonance ($X_C = X_L$), $\cos(\phi) = 1$ and power dissipation is maximum ($P = I^2 R$).

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