

Rms values, transformers and power lines

Physics grades 11-12 (A Level · IB · Class 11-12) · Lesson

Quick answer: An alternating current reverses direction regularly, and its rms value, $V_0/\sqrt{2}$ for a sine wave, gives the equivalent steady heating effect. A transformer uses electromagnetic induction to change the voltage in the ratio $V_s/V_p = N_s/N_p$. Transmitting power at high voltage reduces the current and so the I^2R loss in cables.

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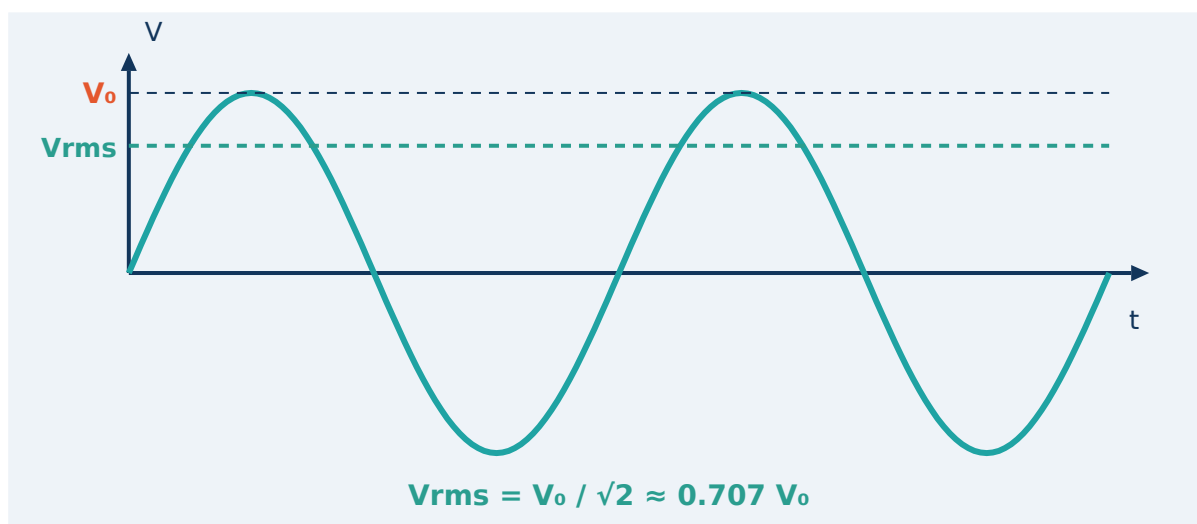
What is alternating current and what are rms values?

In direct current the charges drift one way. In alternating current (ac) they swing back and forth, and the voltage follows a sine wave. Mains electricity in the UK, India, Pakistan, Nigeria and Kenya alternates 50 times per second, while Texas and most of the Americas use 60 Hz.

A voltage that is positive half the time and negative half the time has an average of zero, so we use a more useful measure that tells us the heating effect.

Definition

The **root mean square (rms) value** of an alternating voltage or current is the value of the direct voltage or current that would deliver the same average power to a resistor. For a sine wave, $V_{\text{rms}} = V_0 / \sqrt{2}$ and $I_{\text{rms}} = I_0 / \sqrt{2}$, where V_0 and I_0 are the peak values.



The rms value is the steady dc voltage that would give the same average power in a resistor. For a sine wave it is 0.707 of the peak.

Formula

$$P = V_{\text{rms}} I_{\text{rms}} = I_{\text{rms}}^2 R = V_{\text{rms}}^2 / R$$

P = mean power (W), V_{rms} = rms voltage (V), I_{rms} = rms current (A), R = resistance (Ω). The frequency is $f = 1/T$, and $\omega = 2\pi f$.

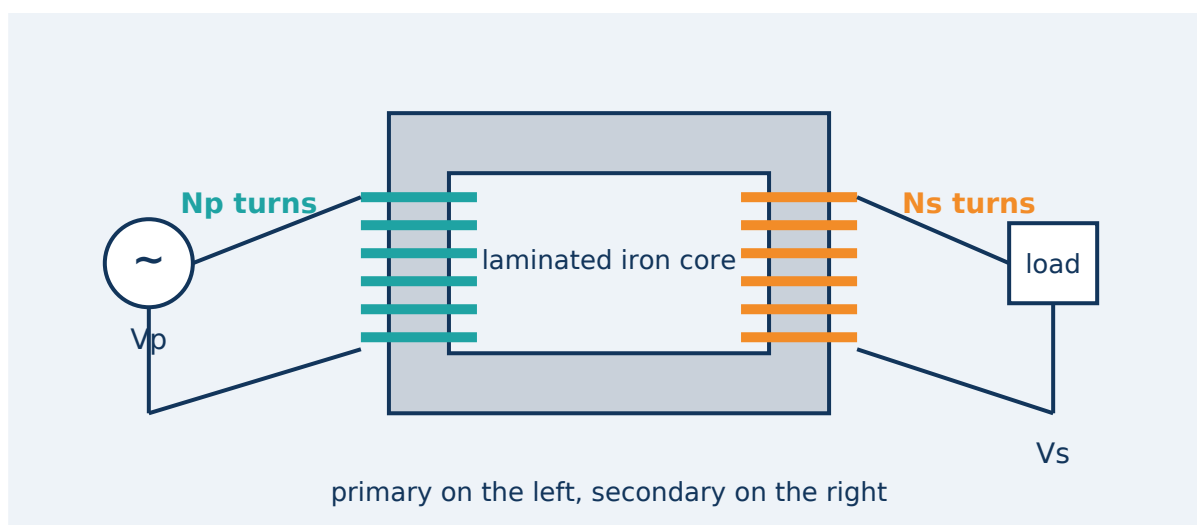
Worked example

A kettle is rated 2.3 kW on a 230 V rms supply. Calculate the peak voltage, the rms current and the resistance.

$$V_0 = \sqrt{2} \times 230 = \mathbf{325 \text{ V}}. \quad I_{\text{rms}} = P/V = 2300 / 230 = \mathbf{10 \text{ A}}. \quad R = V/I = 230 / 10 = \mathbf{23 \Omega}.$$

How does a transformer work?

A transformer has two coils wound on a shared soft iron core. The alternating primary current produces a changing flux in the core, and by Faraday's law this induces an alternating emf in the secondary coil. It only works with ac, because a steady flux induces nothing.



The alternating current in the primary creates a changing flux in the core. This induces an emf in the secondary.

Key law

$V_s / V_p = N_s / N_p$. For an ideal transformer there is no power loss, so $V_p I_p = V_s I_s$. More secondary turns gives a step-up transformer; fewer gives a step-down transformer.

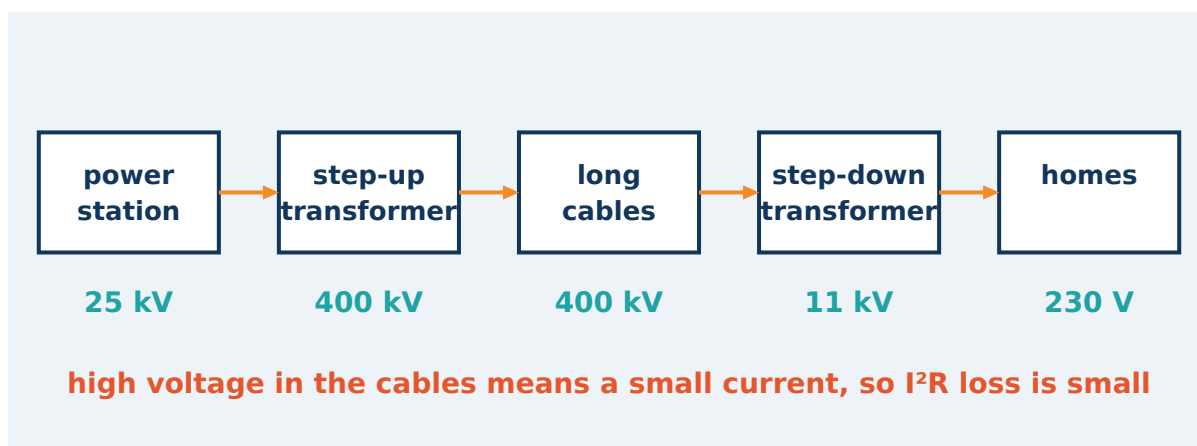
Worked example

A phone charger transformer has 920 primary turns and operates from 230 V. It needs a 12 V secondary. Calculate the secondary turns and, for a 30 W load, the primary current if the transformer is ideal.

$$N_s = N_p V_s / V_p = 920 \times 12 / 230 = \mathbf{48 \text{ turns}}. \quad I_p = P / V_p = 30 / 230 = \mathbf{0.13 \text{ A}}.$$

Why is electricity transmitted at high voltage?

The power lost as heat in a cable of resistance R is $I^2 R$. For a given power $P = VI$, raising the voltage lowers the current, so the loss falls with the square of the current. Transformers make this possible, because they change voltage cheaply and efficiently.



Power is sent at very high voltage so that the current, and therefore the heat loss in the cables, is small.

Worked example

A farm cooperative sends 20 kW through cables of total resistance 2.0Ω . Compare the loss at 400 V and at 8000 V.

At 400 V: $I = 20\,000 / 400 = 50 \text{ A}$, loss = $I^2R = 50^2 \times 2.0 = \mathbf{5000 \text{ W}}$ (25 %). At 8000 V: $I = 20\,000 / 8000 = 2.5 \text{ A}$, loss = $2.5^2 \times 2.0 = \mathbf{12.5 \text{ W}}$ (0.063 %).

What makes a real transformer lose energy?

Loss	Cause	Reduced by
Heating of coils	resistance of the wire	thick copper wire
Eddy currents	currents induced in the core	laminated iron core
Hysteresis	core magnetising and demagnetising	soft iron that magnetises easily
Flux leakage	not all flux links both coils	winding coils on top of each other

Common mistake

Students quote the peak voltage as “the mains voltage”. A mains supply of 230 V is an **rms** value, so its peak is 325 V.

Lina's tip

A step-up transformer raises the voltage but lowers the current by the same factor. You never get more power out than you put in, so always check $V_p \times I_p$ against $V_s \times I_s$.

Key points to remember

- $V_{\text{rms}} = V_0/\sqrt{2}$ and $I_{\text{rms}} = I_0/\sqrt{2}$ for a sine wave.
- Mean power $P = V_{\text{rms}} I_{\text{rms}} = I_{\text{rms}}^2 R$.
- Ideal transformer: $V_s/V_p = N_s/N_p$ and $V_p I_p = V_s I_s$.
- Power loss in cables: $P = I^2R$, so high voltage means low loss.
- Transformers need ac, laminated iron cores and thick copper windings.

Rms values, transformers and power lines: frequently asked questions

What does rms stand for and why is it used?

Rms means root mean square. It gives the steady value that would heat a resistor equally, so it lets us compare ac with dc in power calculations.

Why does a transformer not work on direct current?

A direct current gives a constant flux, so Faraday's law gives no induced emf in the secondary. Only a changing flux induces an emf.

Why does a step-up transformer not give more power?

Energy is conserved. Raising the voltage lowers the current by the same factor, so the output power cannot exceed the input power.

Why are transformer cores laminated?

The thin insulated sheets break up the paths of eddy currents in the iron, which reduces heating and wasted energy.

What is the peak voltage of 230 V mains?

The peak voltage is $\sqrt{2} \times 230 \text{ V}$, which is about 325 V. The 230 V figure is the rms value.