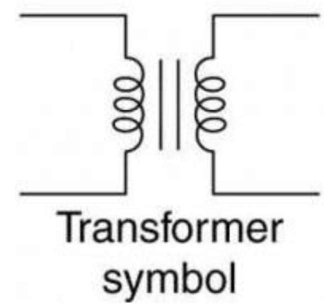
Lesson 8.4 - Transformers

Unit 8: Electromagnetic Induction

Transformers:



A **transformer** changes voltage in an **alternating current (AC)** circuit.

Step-up transformers **increase** voltage, while step-down transformers **decrease** voltage.

Common examples:	
Step-up	***Step-down***
Microwaves (120V->2-4 kV) *Neon Signs (120V -> 2-15kV)* *Engine Ignition Coil (12V->20-50kV)* *Tesla Coil (120V -> 50kV-1MV)*	*Phone chargers (120V->5-20V)* *Laptop Chargers (120V->19-20V)* *Distribution Transformers (25kV -> 120/240V)*

Transformers are very **efficient** because they have:

- no moving parts
- very little energy lost to friction

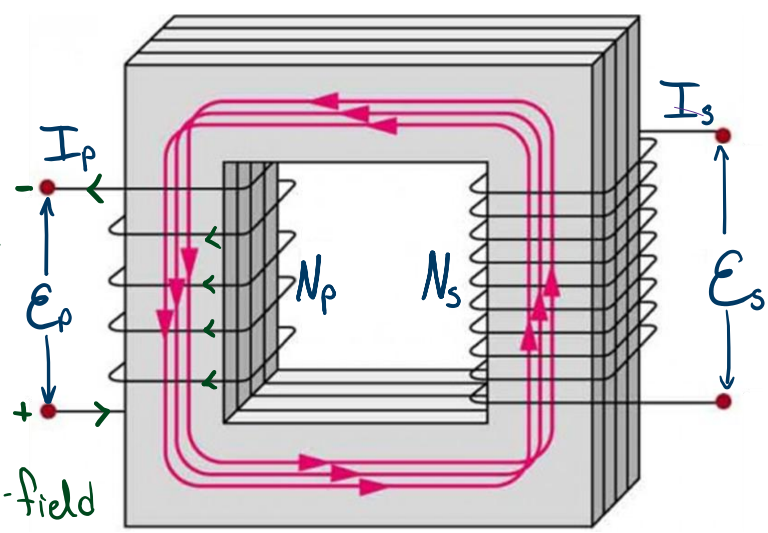
Important for transmitting electrical energy over long distances.

How a Transformer Works:

* $\Delta\Phi$ and Δt are same for both. $\therefore N_p > N_s \Rightarrow$ step-up transformer.

"$\mathcal{E}_p$"

AC Input voltage supplied to primary coil.



The flux through the secondary coil induces secondary voltage $\mathcal{E}_s$.

I_p produces a $\vec{B}$-field in the primary coil

Laminated iron core guides the flux to the secondary coil.

The Fundamental Transformer Equation:

Consider Faraday's Law:

* $\Delta\Phi$ and Δt are = for both.

$$\mathcal{E}_p = -N_p \frac{\Delta\Phi}{\Delta t} \qquad \mathcal{E}_s = -N_s \frac{\Delta\Phi}{\Delta t}$$

$$\frac{\mathcal{E}_s}{\mathcal{E}_p} = \frac{\cancel{+}N_s \cancel{\frac{\Delta\Phi}{\Delta t}}}{+N_p \cancel{\frac{\Delta\Phi}{\Delta t}}}$$

$$\frac{\mathcal{E}_s}{\mathcal{E}_p} = \frac{N_s}{N_p}$$

Consider Power:

* Transformers are very efficient (~99%)
⇒ Power output = Power Input.

$$P_p = P_s$$

$$I_p\mathcal{E}_p = I_s\mathcal{E}_s$$

$$\frac{\mathcal{E}_s}{\mathcal{E}_p} = \frac{I_p}{I_s}$$

$$\frac{\mathcal{E}_s}{\mathcal{E}_p} = \frac{N_s}{N_p} = \frac{I_p}{I_s}$$

Step-Up	Step Down
$\mathcal{E}_s > \mathcal{E}_p$	$\mathcal{E}_s < \mathcal{E}_p$
$N_s > N_p$	$N_s < N_p$
$I_s < I_p$	$I_s > I_p$

Example 1: A stepdown transformer converts 180 V ($\mathcal{E}_p$) to 80 V ($\mathcal{E}_s$). If the number of secondary windings is 120 (N_s):

a) find the number of primary windings:

$$\frac{\mathcal{E}_s}{\mathcal{E}_p} = \frac{N_s}{N_p} \qquad N_p = \frac{\mathcal{E}_p N_s}{\mathcal{E}_s} = \frac{(180V)(120)}{80V} = \boxed{270 \text{ turns.}}$$

b) If current in the primary coil is 30 A (I_p), find current in the secondary coil:

$$\frac{\mathcal{E}_s}{\mathcal{E}_p} = \frac{I_p}{I_s} \qquad I_s = \frac{\mathcal{E}_p I_p}{\mathcal{E}_s} = \frac{(180V)(30A)}{(80V)} = \boxed{67.5A}$$

Long Distance Transmission of Electricity:

- For a given power output, **increasing** one variable (I or V) will proportionally **decrease** the other.

- Transformers are essential for **long-distance** power transmission.
- Power loss in **transmission** wires is:

$$P = VI$$
$$P \propto V$$
$$P \propto I$$
$$V \propto \frac{1}{I}$$

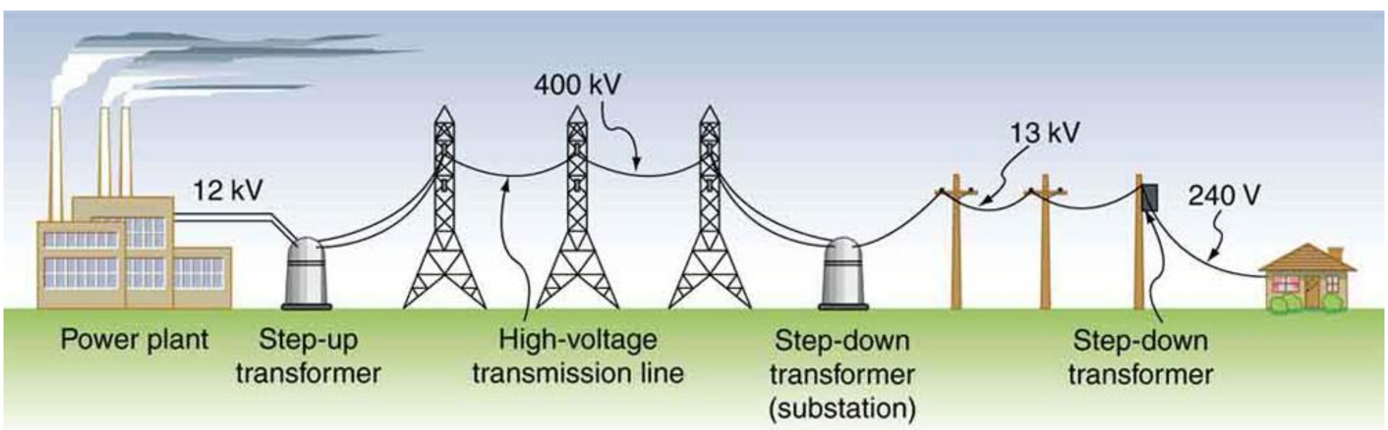
$$\boldsymbol{P_{loss} = I^2 R}$$

Resistance of Transmission Wires

Depends on:

- **material (usually aluminum)**
- **wire length**
- **cross-sectional area**

Resistance is difficult and expensive to change once power lines are built.



Example 2: Compare the power delivered over long-distance transmission when there is a) high-voltage, low current, and b) low-voltage, high current:

High-Voltage, Low Current

P = 1,000,000 W, R = 5 Ω

ε = 100,000 V, I = 10 A

$$P_{source} = IV$$
$$= (10A)(100{,}000V)$$
$$= 1{,}000{,}000\ W$$

← Same power at source →

$$P_{loss} = I^2R$$
$$= (10A)^2(5\Omega)$$
$$= 500W$$

$$P_{delivered} = P_{source} - P_{loss}$$
$$= 1000000W - 500W$$
$$= 999500W \quad (99.95\%)$$

Low-Voltage, High Current

P = 1,000,000 W, R = 5 Ω

ε = 1000 V, I = 1000 A

$$P_{source} = IV$$
$$= (1000A)(1000V)$$
$$= 1{,}000{,}000W$$

$$P_{loss} = I^2R$$
$$= (1000A)^2(5\Omega)$$
$$= 5000000W$$

$$P_{delivered} = P_{source} - P_{loss}$$
$$= 1000000 - 5000000$$
$$= 0W$$

No power delivered.