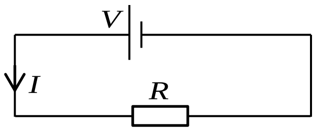
Electrical power generation & transmission

Voltage is the energy per unit charge lost when **charge** flows through an electrical component like a passive resistor. **Current** is the rate of flow of charge. Therefore the *product* of voltage and current is the total energy transferred per second. In other words, ***power***.



Power dissipated by a resistor in a single loop of a circuit is

$$P = VI$$

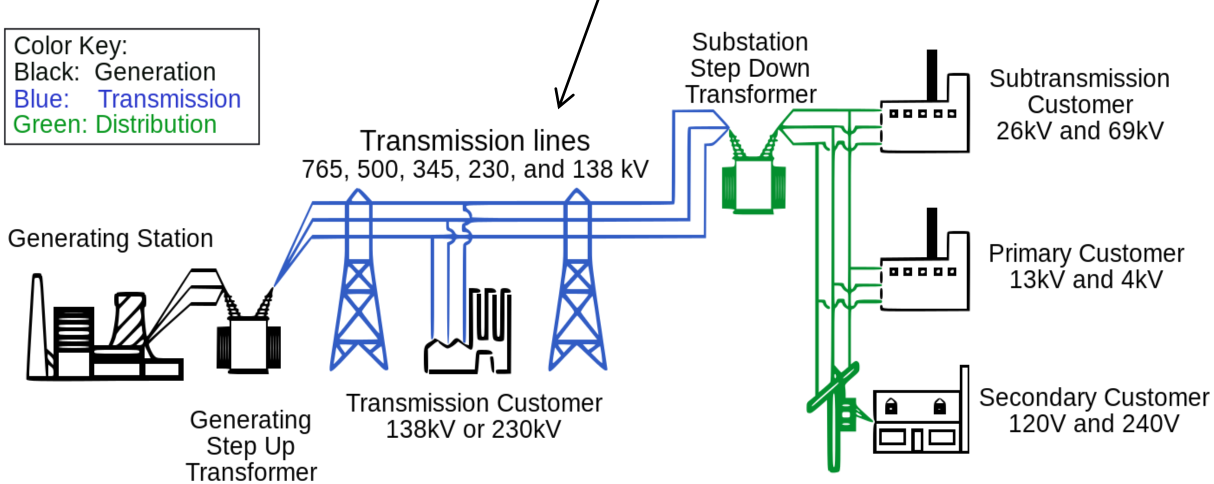
Using Ohm's law

$$V = IR$$

$$\therefore P = I^2 R$$

To reduce the losses in an electrical transmission system, one must *reduce the resistance* of the wires and, more importantly, *reduce the current.* For a given electrical power carried by the wire, $P = VI$ means we can *reduce* the current by **increasing V**. This explains why transmission lines are kept at **high voltage** but *low currents are drawn through them*.

"A 100 mile 765 kV line carrying 1000 MW of power can have losses of 1.1% to 0.5%" *



Calculating the radius of a power cable

$P = VI$ Power carried by 1000 MW, 765kV line

$$I = \frac{P}{V}$$

$$I = \frac{1000 \times 10^6}{765 \times 10^3} = 1307.2\text{A}$$ Current drawn

$$\text{P}_{loss} = 0.01 \times 1000 \times 10^6 = 10^7\,\text{W}$$ 1.1% loss

$$\text{P}_{loss} = I^2 R$$

$$\therefore R = \frac{\text{P}_{loss}}{I^2} = \frac{10^7}{1307.2^2} = 5.85\Omega$$ cable resistance

Power cables are typically made from *aluminium* which has resistivity

$$\rho = 2.8 \times 10^{-8}\,\Omega\text{m}$$

Assume cable is a cylinder and conduction happens throughout its volume uniformly

$$R = \frac{\rho l}{A}$$

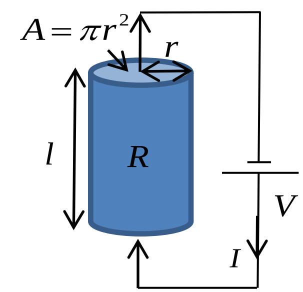
$$R = \frac{\rho l}{\pi r^2}$$

$$r = \sqrt{\frac{\rho l}{\pi R}}$$

$$r = \sqrt{\frac{2.8 \times 10^{-8} \times 160.93 \times 10^3}{\pi \times 5.85}}$$

$$r = 0.016\text{m}$$

$$r = 15.7\text{mm}$$



Note 'full depth uniform conduction' is an *approximation*. For *alternating current*, conduction only occurs in the surface, and the majority occurs within the 'skin depth' δ

This is because eddy currents induced in a conductor impede current flow in the interior, and reinforce it on the surface.

For most practical scenarios

$$\delta \approx 503 \times \sqrt{\frac{\rho}{\mu f}}$$

ρ is the resistivity of the conductor

μ is the relative permeability of the conductor (in other words how easily magnetisable is it. Aluminium, air, water are about unity. Nickel is about 100, Iron about 5,000)

f is the frequency of the alternating current.

So for an aluminium conductor carrying mains at 50Hz

$$\delta \approx 503 \times \sqrt{\frac{2.8 \times 10^{-8}}{1 \times 50}}$$

$$\delta \approx 11.9\text{mm}$$

https://en.wikipedia.org/wiki/Skin_effect

* http://en.wikipedia.org/wiki/Electric_power_transmission