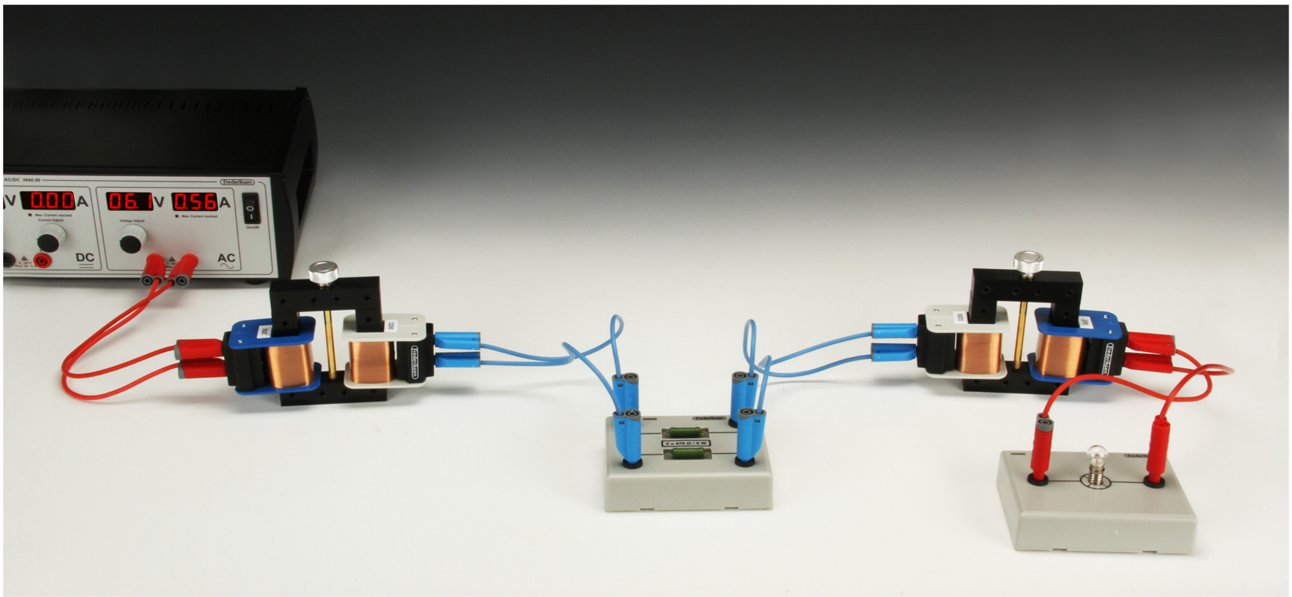
High voltage lines

Experiment number	136090-EN	*Topic*	Electricity, alternating current				
Version	2019-11-12 / HS	*Type*	Demo experiment	*Suggested for*	grade 9-12	*p.*	1/4



Objective

We investigate how the resistance of the wires affects the transmission of electrical energy at low and high voltage.

Principle

A small light bulb is connected to an AC power supply – first directly, then via two resistors that simulate long wires. Finally, two transformers are inserted so that the large resistors are in the "high voltage lines".

Equipment

AC power supply
6 V light bulb in socket
Two resistors on base

Two transformers, each consisting of:
UI Core
Coil, 200 turns
Coil, 3200 turns

Lab leads

Caution

This is a demonstration experiment.

With transformers it is easy to achieve voltages higher than what students are allowed to use.

Careful: Don’t touch parts of the setup that is connected to the 3200 winding coils.

Disconnect the circuit right at the power supply, before any changes in the setup.

Procedure

1) Direct connection

We will here assume that the "power plant" (the power supply) delivers just the voltage needed by the consumer. Vi also assume that there is only a short distance between power plant and consumer.

Connect the socket with the pygmy bulb directly to the AC output on the power supply. Adjust the voltage to 6 V (or a little bit higher).

Observe: The bulb lights up.

Direct (short) connection from power plant to consumer

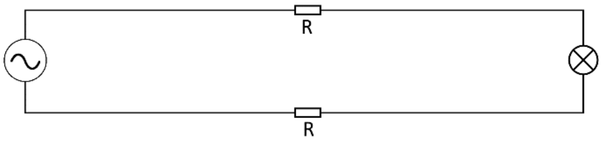
2) Long wires carrying low voltage

We don't change the voltage, but increases the distance to the consumer. We therefore need to send the current through some "long wires" – i.e. through the two resistors.

Disconnect the leads at the power supply.

Connect first the light bulb to the resistors, next the resistors to the power supply. (The voltage must be kept precisely the same as before.)

Observe: The bulb doesn't light up.



Long wires (large resistance)

3) High voltage lines

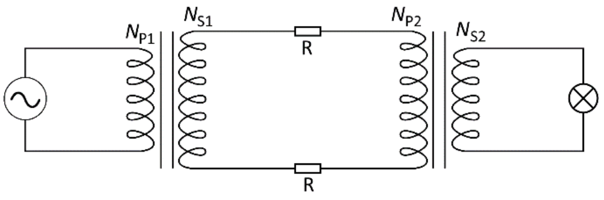
Now, we insert transformers close to the power plant and the consumer. This means that the long wires will transport high voltage – but the consumer gets the same voltage as before.

Disconnect the leads at the power supply.

Once again start at the light bulb and hook up the circuit as shown on p. 1 – notice that the 200 turns coils are connected to the power supply, resp. the light bulb, while the 3200 turns coils face "the long wires" (the resistors).

Finish with the connection to the power supply.

Observe: The bulb lights up.



Transformers inserted close to resp. power plant and consumer

Discussion

Draw attention to the fact that there is obviously some kind of connection through the resistors - otherwise the bulb would not light in position 3 - but that the same resistance prevents the bulb from lighting in position 2.

Further discussion of the observations can be made on the basis of the theory section on the next page.

Why not just bring the high voltage all the way to the consumer and save a transformer?

Theory

1) Ideal transformers, no resistance

If we assume the transformers are ideal, the ratio between primary and secondary voltages is equal to the ration between the number of windings:

$$\frac{U_\mathrm{S}}{U_\mathrm{P}} = \frac{N_\mathrm{S}}{N_\mathrm{P}}$$

(In practice, a small part of the magnetic field from the primary coil will not go through the secondary coil, resulting in a lower secondary voltage.)

An ideal transformer will simply transfer the power it receives to the load on the output:

$$P_\mathrm{S} = P_\mathrm{P}$$

Turning to primary and secondary currents, we have:

$$U_\mathrm{S} \cdot I_\mathrm{S} = U_\mathrm{P} \cdot I_\mathrm{P}$$

And thus

$$\frac{I_\mathrm{S}}{I_\mathrm{P}} = \frac{U_\mathrm{P}}{U_\mathrm{S}} = \frac{N_\mathrm{P}}{N_\mathrm{S}}$$

In short: If you transform the voltage *up*, the current will go *down*.

If two transformers that are connected after each other have reciprocal winding ratios – i.e. if

$$\frac{N_\mathrm{S1}}{N_\mathrm{P1}} = \frac{N_\mathrm{P2}}{N_\mathrm{S2}}$$

– then the voltage out of the last transformer will be the same as the voltage into the first:

$$U_{S2} = U_{P1}$$

(Still assuming that the transformers are ideal.)

2) Resistance in the wires

According to Joule's law, resistance in the wires will lead to loss of power:

$$P_\mathrm{LOSS} = R_\mathrm{W} \cdot I^2$$

Note that the loss is proportional to the current squared.
If a given electric power must be transferred through a wire with a given resistance, all else equal you will get a lower loss by transforming the voltage up. If you transform the voltage up by a factor of 16, the current will diminish by a factor of 16 – which makes the power loss 16^2 = 256 times less.

3) Numerical example

The transformers used in this experiment need to be easy to assemble and disassemble, which contributes to them being not as efficient as "real" transformers that are easier to optimize. We will still make the assumption that they are ideal – but keep in mind that the exact results below will not completely agree with the experiment.

Let us assume that the load (the bulb) draws a current of 50 mA, i.e. it receives the power

$$P = 6\ \mathrm{V} \cdot 0.05\ \mathrm{A} = 0.3\ \mathrm{W}$$

The total resistance in "the long wires" (the resistors in 429250) – is 2 · 470 Ω = 940 Ω.

If 50 mA must pass such a large resistor, the power loss will be

$$P_\mathrm{LOSS} = 940\ \Omega \cdot (0.05\ \mathrm{A})^2 = 2.35\ \mathrm{W}$$

– which is many times more than what the bulb consumes.
(This would moreover require that the voltage from the power supply was raised to more than 50 V!)

If we now insert transformers at the ends of "the long wires", the current drops to 50 mA/16 = 3.125 mA. The power loss will then be

$$P_\mathrm{LOSS} = 940\ \Omega \cdot (0.003125\ \mathrm{A})^2 = 0.0092\ \mathrm{W}$$

which represents only 3% of the transmitted power.

Teacher's notes

Concepts used

Voltage
Current
Resistance
Power

Mathematical skills

Fractions

About the equipment

Overhead power lines are normally made of aluminium, mechanically reinforced with steel. Typical voltages are between 10 kV and 500 kV.

A small high voltage line may have an electrical resistance of 0.4 Ω / km, but the current can be many hundreds of amps, so the voltage drop per kilometre is still noticeable despite the low resistance.

The resistances in 429250 are a bit higher than in one kilometre of high-voltage line, but conversely, the current in this experiment is many thousands times smaller. Therefore, to illustrate the difference in power loss at low and high voltages, the model is excellent.

(Most power lines carries alternating current which means that you in practice also need to take the inductance of the line into account.)

Sources

The photo on front page (lower right corner):
https://commons.wikimedia.org/wiki/File:2013-08-26_11_06_23_High-Voltage_power_lines_in_the_northwestern_portion_of_Mercer_County_Park_in_Lawrence,_New_Jersey.jpg

Detailed equipment list

Specifically for the experiment

429250	Resistors on base, 2 x 470 ohm 5W	
429000	Lamp holder E10, 4 connectors	
463000	U-I core	(2 pcs.)
462510	Coil 200 turns	(2 pcs.)
462540	Coil 3200 turns	(2 pcs.)

Standard equipment

364000	Power supply (or similar – must be able to supply 6 V AC)	
105721	Safety cable 50 cm, red	(4 pcs.)
105723	Safety cable 50 cm, blue	(4 pcs.)

Consumables

425025	Pygmy bulb 6 V 0,05 A (10 pcs. package. *One* bulb is used.)