# Keeping the lights on

## Taking it for granted

We take electricity for granted. We expect it to be available at all times in our homes, schools and workplaces. Any breakdown or *outage* can cause serious problems for individuals, communities and the economy. We may not realise that it takes a complex *generation*, *transmission* and *distribution* system to deliver the electricity that we need.

You may know that the electricity is delivered to your home by a *single phase* supply at a *nominal* 240 volts. However, the *generators* that produce the supply deliver a *three phase* supply which is then increased ('stepped up') to high voltages by *transformers*. This high voltage supply is carried across the country on *pylons*. The complete high voltage transmission system is called the *national grid*. Eventually, the high voltage is stepped down by transformers and connected to the lower voltage distribution system and made available to various users.

In this lesson we look at the characteristics of some of the materials that are used to construct the national grid.

## A little history

The first electricity distribution system was set up in a part of New York by Thomas Edison in 1882. His was a *direct current* (DC) system, which had some advantages. An *alternating current* (AC) distribution system was set up in Cerchi, Italy in 1886 and within a few years many other cities did the same.

## Power

Electricity suppliers do not charge for current or voltage; what they sell is electrical *energy*. The rate at which the energy is used is called *power*. The transmitted power is equal to the voltage multiplied by the current ($V \times I$). However the energy lost in transmission is proportional to the square of the current ( $I^2$). Clearly then, a higher voltage with a lower current will deliver power more efficiently. The big advantage of *AC* is that it can be easily stepped up (for transmission) and stepped down again (for local distribution).

## The conductors

*Metals* are generally good conductors of electricity, silver and copper being the best. Because silver is expensive, copper is commonly used for local distribution systems. For the longer transmission lines *aluminium* cables are more commonly used; for added *tensile strength* they are reinforced with *steel* and can be used for spans of more than a kilometre. Although the conductivity of aluminium is only about 63% of that of copper, it is much cheaper and lighter.

| Material | Conductivity & Resistivity | Resistivity (ρ) (W m) |
|---|---|---|
| Silver | Conductivity (□) ↑ | 1.59 $\times 10^{-8}$ |
| Copper | | 1.68 $\times 10^{-8}$ |
| Aluminum | | 2.65 $\times 10^{-8}$ |
| Iron | | 7.00E $\times 10^{-7}$ |
| … | | |
| … | | |
| Damp wood | | 1.00 $\times 10^{3}$ |
| Glass | | 1.00 $\times 10^{12}$ |
| Hard rubber | | 1.00 $\times 10^{13}$ |
| Porcelain | | 1.00 $\times 10^{13}$ |
| Air | ↓ Resistivity (□) | 1.30 $\times 10^{16}$ |

Conductivity (s) is expressed in siemens per metre ($S\ m^{-1}$) and resistivity (r) is the inverse and is expressed in ohm-metres (W m).

In *ACSR* cables (aluminium conductors steel reinforced cables) the steel is on the inside and is insulated from the aluminium conductors which are wrapped around it; the steel does not carry any current.

An aluminium conductor steel-reinforced cable (ACSR) cable, the steel strands are in the middle.

## Pylons

Electricity pylons (transmission towers) are commonly constructed from galvanised steel (i.e. it is coated with *zinc* to prevent it from rusting). Towers can be up to 100 m tall, and are normally assembled on site. They are constructed in a lattice form with beams and triangular sections called trusses which improve the structure's overall strength and stability.

Each structure must be designed for the loads it must carry. The weight of the conductor must be supported, as well as *dynamic loads* due to wind, ice accumulation and effects of vibration.

## Supporting the cable

Electrical *insulators* are materials that do not conduct electricity. If you have wired a plug you have seen the plastic insulation covering on the conductors. This insulation is there for safety reasons. It prevents *short circuits* between the individual wires and protects you from electric shock.

A 3-phase 110 kV transmission line carried on a steel pylon. The conductor carrying each phase is suspended from an insulator. The two conductors at the top of the pylon are connected to earth and act as lightning conductors.

However, the *transmission lines* high above the ground are not covered with material but are insulated by the surrounding air. Of course they must be insulated from the steel towers that support them and so they are suspended from special insulating supports.

These suspension insulators can be made from porcelain, glass, ceramic or polymer materials. They typically consist of a number of disc-shaped sections attached together. In general, the length of the insulator is related to the voltage. For example the insulators on a 220 kV line have twenty disc sections while those on a 110 kV line have nine, depending on the type of insulator used.

Like all metals, transmission cables expand with rising temperature and contract as the temperature falls. When cables are being installed allowance must be made for expansion due to *resistive heating* and variations in air temperature. The cables must also be far enough apart that they do not contact one another in stormy conditions and cause a short circuit or make contact with tall buildings or trees.

# Keeping the lights on

## Changing the voltage

The *transformer* is critical to the operation of the Grid. The AC current is sent through the *primary winding* and creates a varying *magnetic field* that creates (induces) a varying voltage in the *secondary winding*. This is the principle of *electromagnetic induction*.

A high voltage transformer

The voltage change is related to the ratio of the numbers of coils in both windings. The *magnetic flux* is concentrated in the transformer's core which is made of a material that is easily magnetised. Such materials have high *magnetic permeability*.

Steel is the material that is generally used in the core of Grid transformers. The winding conductors are usually made of copper. The current generates some heat and so these transformers are generally fitted with cooling fins.

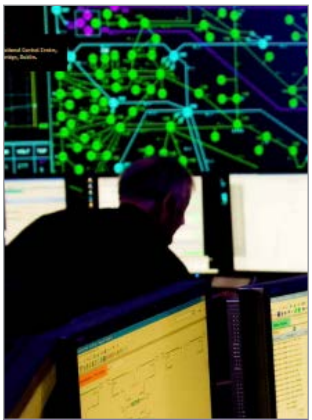
## Breaking the circuit

A *circuit breaker* is an *electro-mechanical* device that can interrupt the current by breaking the circuit. In other words it is a kind of *switch*. It operates automatically if the current is too high due to an *overload* or short circuit. In this sense, it is like a *fuse* but a fuse only operates once and then has to be replaced. A circuit breaker can be reset once the problem is cleared.

When the Grid current is interrupted an *electric arc* is formed. This arc generates a lot of heat and must be extinguished to prevent damage. There are various ways of doing this but a common way is to use non-flammable gases such as $CO_2$ (carbon dioxide) or $SF_6$ (*sulfur hexafluoride*) as the extinguishing agent.

## Who knows what's happening?

We have described some of the main components of the national Power Grid in this lesson. It will be obvious that with its many miles of line, switches and circuit breakers, the Grid requires close control.



The EirGrid Control Centre

Every power line on the national grid has a maximum power limit and is maintained below that level by EirGrid's National Control Centre (NCC). The NCC monitors all aspects of the system.

The NCC engineers must also match the supply with customer demand and ensure that the frequency is maintained at *50 Hz* all the time. The NCC allows us to take a safe, continuous, high quality supply of electricity for granted and 'keep the lights on'.

**EirGrid** is a state-owned company responsible for operating and developing the electricity transmission grid in Ireland for the benefit of electricity consumers. It is putting in place the grid infrastructure required to support competition in the supply of electricity, to assist economic growth and to meet Government targets for the generation of renewable energy.

EirGrid holds licences as independent electricity Transmission System Operator (TSO) and Market Operator (MO) in the wholesale trading system in Ireland, and is the owner of the System Operator Northern Ireland (SONI Ltd), the licensed TSO and market operator in Northern Ireland. As TSO, EirGrid is regulated by the Commission for Energy Regulation (CER).

**Grid25**

Grid25 is EirGrid's national development programme. Over the course of the programme, some €3.2 billion will be invested in a broad range of electricity transmission projects throughout the country. Current projects include the East West Interconnector, Meath-Cavan and Cavan-Tyrone lines.

**Consultation**

While conducting these projects, EirGrid engages with a wide range of stakeholders, including

- Landowners
- Local Communities and the General Public
- Business Organisations
- Statutory Bodies
- Public Representatives

You can find out more about the work of EirGrid at **www.eirgrid.com**

Find this and other lessons on **www.sta.ie**

## Syllabus References

**The relevant syllabus references are:**

**Leaving Certificate Physics**

- Electromagnetism
- Electromagnetic induction
- Alternating and direct current
- Transformers

**Leaving Certificate Technology**

- Structures and Mechanisms
- Energy, Electricity and Electronics

*Science and Technology in Action* is also widely used for project work in **Transition Year**.

## Learning Outcomes

**On completion of this lesson, students should be able to:**

- Distinguish between generation, transmission and distribution systems
- Explain the differences between alternating current and direct current.
- Explain why high voltages are used in power transmission
- Identify pylons and insulators in a transmission system and outline their function
- Describe the main types of conductor used in electrical power transmission and distribution
- Describe the function of the national grid.

## General Learning Points

**The following points can be used to enhance the lesson content and to inform discussion.**

- Electric power can also be transmitted by underground cables. However, this is generally only done in built up areas or in other special situations, as the cost of the insulated cable, excavation and reinstatement is higher than that of overhead systems.
- Unless they are superconducting, all materials offer some level of materials resistance to electric current and, therefore, produce heat.
- Overhead lines can oscillate under certain conditions, a phenomenon known as 'galloping' or 'dancing'. This adds to the forces placed on insulators and pylons as well as reducing the clearance between the conductors and other objects. One cause of this galloping is ice that forms an aerofoil shape when lodged on the conductors.

## Student Activities

1. What do the following equations mean:

   $V = I.R$ and $P = V.I$ ?

   At high currents a percentage of transmitted power is lost as heat from the conducting cables. Show that the power lost from a given electrical conductor is proportional to the square of the electric current passing through it.

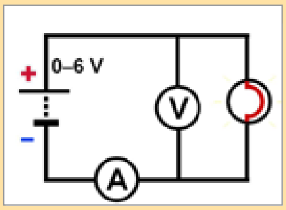
   What are the implications of this for the Grid?

2. For a fixed resistance $V = I.R$. However, the resistance of metals increases with temperature. Using a small flashlamp bulb (e.g. a 6 V, 60 mA bulb) and a variable power supply (0 V to about 6 V) investigate the current through the bulb at intervals of half a volt from 0 V to 6 V.

   Make a table of the results and in an extra column calculate the resistance at each voltage setting ( $R = V \div I$ ).

   What is the total percentage increase in the resistance over the range 0 V to 6 V?

   The lamp filament is made of tungsten. Assuming the temperature of the filament (at 6 V) is 2000 °C calculate the percentage increase in resistance of tungsten for each degree rise in temperature. (About 0.5% would be a typical value.)




## True/False Questions

| | | | |
|---|---|---|---|
| a) | The National Grid is a DC transmission system. | T | F |
| b) | The Grid carries three phase electricity. | T | F |
| c) | The high tension lines in the Grid are insulated by a plastic sheath. | T | F |
| d) | The high tension lines are suspended from the pylons by insulators. | T | F |
| e) | Insulators are made from materials with high conductance. | T | F |
| f) | A transformer operates on the principle of electromagnetic induction. | T | F |
| g) | The function of a circuit breaker is to change the voltage levels. | T | F |
| h) | The core of a transformer is made from materials with high magnetic permeability. | T | F |
| i) | In transmission, energy is lost as heat from the conductors. | T | F |
| j) | Eirgrid is responsible for setting the price of electricity. | T | F |
| k) | The resistance of a conductor is inversely proportional to its diameter. | T | F |

**Check your answers to these questions on www.sta.ie.**

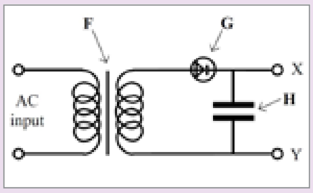
## Examination Questions

**Leaving Certificate Physics (HL) 2013, Q. 8**

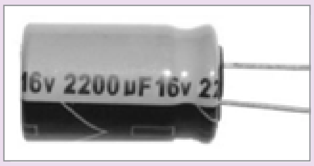
(a) The diagram shows a circuit used in a charger for a mobile phone.Name the parts labelled F, G and H. Describe the function of G in this circuit. Sketch graphs to show how voltage varies with time for

(i) the input voltage

(ii) the output voltage, VXY.




The photograph shows the device H used in the circuit. Use the data printed on the device to calculate the maximum energy that it can store.




(b) Electricity generating companies transmit electricity over large distances at high voltage. Explain why high voltage is used.

A 3 km length of aluminium wire is used to carry a current of 250 A. The wire has a circular cross-section of diameter 18 mm.

(i) Calculate the resistance of the aluminium wire.

(ii) Calculate how much electrical energy is converted to heat energy in the wire in ten minutes.
(resistivity of aluminium = $2.8 \times 10^{-8}\ \Omega$ m)

**Leaving Certificate Physics (HL) 2005, Q. 11b**

*Read the following passage and answer the accompanying questions.*

The scientist whose research would unite electricity and magnetism was Michael Faraday. He developed the first electric motor in 1821, showing that a current-carrying conductor could be made to revolve around a magnet. He went on to expand on Oersted's observation that an electric current produces a magnetic effect. Perhaps, Faraday thought, the opposite was also true: a moving magnetic field could generate an electric current. This was to be called electromagnetic induction. Soon he had created the first electric generator, and everyday life would never be the same again. His experiments with induced currents produced the transformer.

(Adapted from *Milestones of Science*; Curt Supple; 2000)

(i) List three factors that affect the force on a current-carrying conductor placed near a magnet.

(ii) What energy transformation takes place in an electric motor?

(iii) What is the function of a commutator in a dc motor?

(iv) Draw a sketch of the output voltage from an ac generator.

(v) How are the slip rings connected to an external circuit in an ac generator?

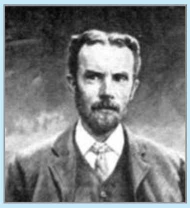
(vi) A transformer and an induction coil can both be used to change a small voltage into a larger voltage. What is the basic difference in the operation of these two devices?

## Did You Know?

- In 1888, Nikola Tesla delivered a lecture (A New System of Alternating Current Motors and Transformers) in which he described the generators and transformers needed for multi-phase alternating currents.
- Material such as germanium and silicon, that are neither good conductors nor good insulators, are called semiconductors. These are Group 4 elements in the Periodic Table. Certain composites of Group 3 & Group 5 elements are also semiconductors e.g gallium and arsenic form gallium arsenide (GaAs) which is used in some LEDs).
- The National Centre (NCC) uses advanced ICT systems to monitor and interact with the components of the National Grid. Grids that use advanced 'intelligent'technologies are known as 'Smart Grids'.

## Biographical Notes

**Oliver Heaviside (1850 –1925)**



Oliver Heaviside was an English engineer, physicist AND mathematician. He adapted complex numbers to the study of electrical circuits. He also invented many innovative mathematical techniques and coined the term 'magnetic permeability'. He was self taught and not highly ranked by scientists of his day. His contributions are now considered to be revolutionary.

**Joseph Henry (1797 – 1878)**

Joseph Henry was an American scientist. He discovered the electromagnetic phenomena of self inductance and also of mutual inductance independently of Michael Faraday, He developed the electromagnet and the electromagnetic relay, which were essential to the electrical telegraph.
The SI unit of inductance, the henry (H), is named after him.

## Revise The Terms

**Can you recall the meaning of the following terms? Revising terminology is a powerful aid to recall and retention.**

50 Hz, AC, ACSR, alternating current, aluminium, circuit breaker, direct current, distribution, dynamic loads, electric arc, electromagnetic induction, electro-mechanical, energy, fuse, generation, generators, insulators, magnetic field, magnetic flux, magnetic permeability, national grid, nominal, outage, overload, power, primary winding, pylons, resistive heating, secondary winding, short circuits, single phase, steel, sulfur hexafluoride, switch, tensile strength, three phase, transformer, transmission, transmission lines, zinc.

**Check the Glossary of terms for this lesson on www.sta.ie**