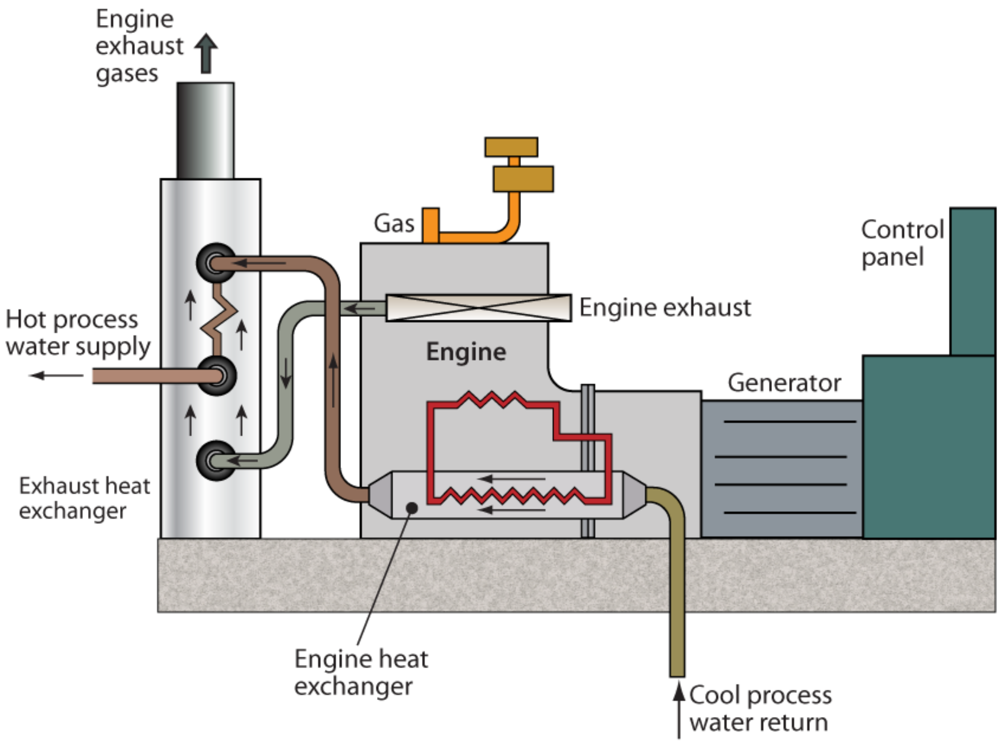
Level 3 Diploma
in
Installing Electrotechnical Systems & Equipment

C&G 2357

Unit 309-6 Understand electrical supply and distribution systems



B&B Training Associates Ltd
Learning Materials for the Electrical Industry

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Aims and objectives

By the end of this study book you will have had:

- Describe how electricity is generated and transmitted for domestic, commercial and industrial use.
- Specify the features and characteristics of the generation and transmission system.
- Explain how electricity is generated from other sources, including:
  - Batteries and cells.
  - Solar power.
  - Wind.
  - Wave.
  - Micro hydro.
  - Combined heat and power.
- Describe the main characteristics of:
  - Single phase supplies.
  - Three phase supplies.
  - Earth fault loop paths.
  - Star and delta connections.
- Describe the operating principles, applications and limitations of transformers.
- State the different types of transformers that are used in supply and distribution networks.
- Determine by calculation and measurement:
  - Primary and secondary voltages.
  - Primary and secondary currents.
  - kVA rating of transformers.

1: Sources of electricity

In this session the student will:

- Understand that electricity is produced from a variety of sources

In this session we will consider the varied sources of electricity available in the U.K.

Electricity is a relatively new source of energy. It was in 1831 that Michael Faraday discovered how to convert mechanical energy into electrical energy. The first practical application was in powering a lighthouse in 1856. It was not, until the 1880s that commercial production of electrical power took place. Because of its relative scarcity electricity was also quite expensive. At the turn of the 20^{th} century, major industries became aware of the benefits of electrical power.

Energy is an important requirement for our modern day living. From running our microwaves to fuelling our vehicles, our daily survival depends upon energy. Energy comes in various forms. The most convenient of all of them is electrical energy.

Electricity is the power that drives the world, from televisions and refrigerators to vehicles and computers, everything runs on power. Most power is provided in the form of electricity that is generated in different types of power plants.

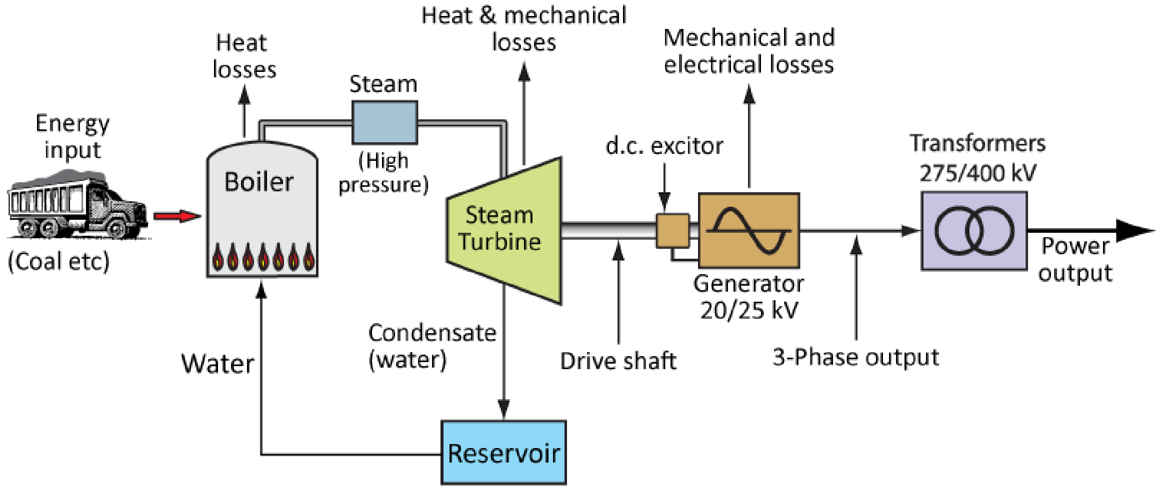
Within the United Kingdom (UK) electrical power has generally been produced from fossil fuels which include coal, oil and natural gas. Fossil fuels were formed millions of years ago when dead plants and animal remains got buried under layers of soil and under pressure and temperature, got converted into their present form.

A major problem of using fossil fuels to generate electricity is that burning them gives out a lot of toxic gases that pollute the environment and contribute to global warming. They are also mainly non-renewable and are running out fast.

Steam generation

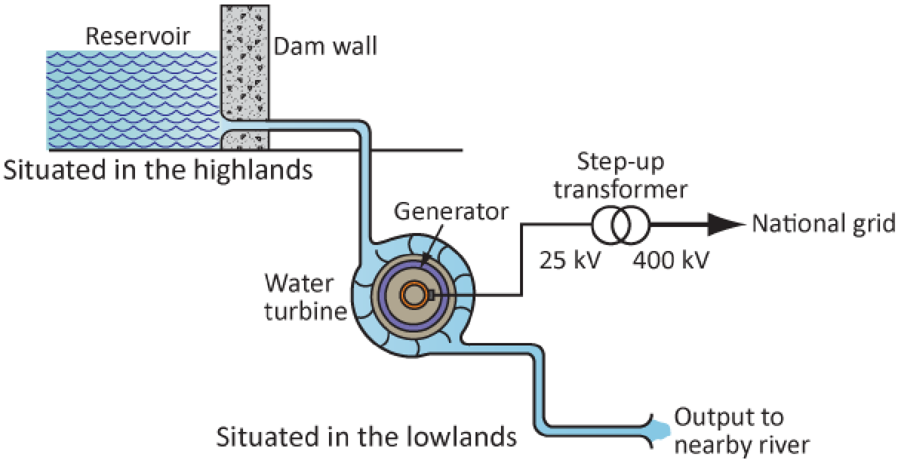
Coal, oil and nuclear energy all heat up water until it is high-pressure steam. This steam is then used to drive turbines, which in turn drive the generators that produce the electricity. Turbines are the mechanical means of converting steam into rotational energy; generators are the means of converting rotational energy into electrical energy.

A block diagram would be a useful way of showing this.



Water power

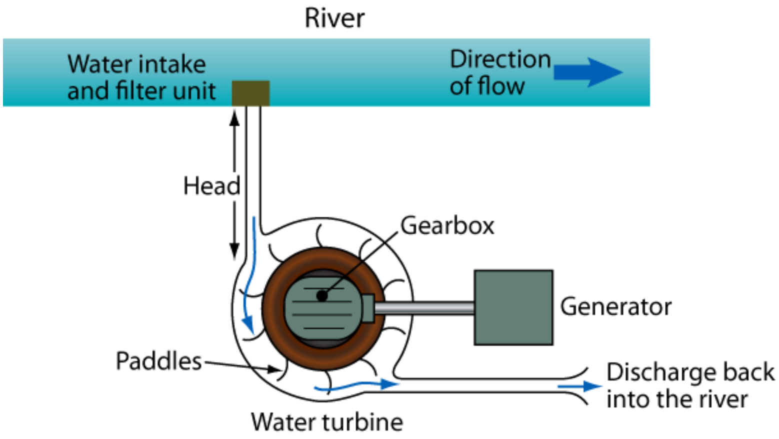
Large **hydroelectric** power plants make use of those areas of the country that have a high rainfall. They are placed either by the side of rivers or within dams. The water is fed through turbines that turn generators that again produce the electricity.
A diagram should help.



In this type of hydroelectric station, the water passes through the turbines that turn at 3000 rpm (revolutions per minute or 50 times a second). The water then passes out into a local river.

The drawback to this is that they are dependent on the constant flow of water.

Micro-hydro generation



Micro-hydro generation operates on the same principle just at lower scales. A river or stream is still required as is a head of water; that is the water must be capable of flowing through a turbine blade to get it to rotate.

The small-scale use of hydroelectric power generation makes it suitable in a limited number of areas and is not widely used.

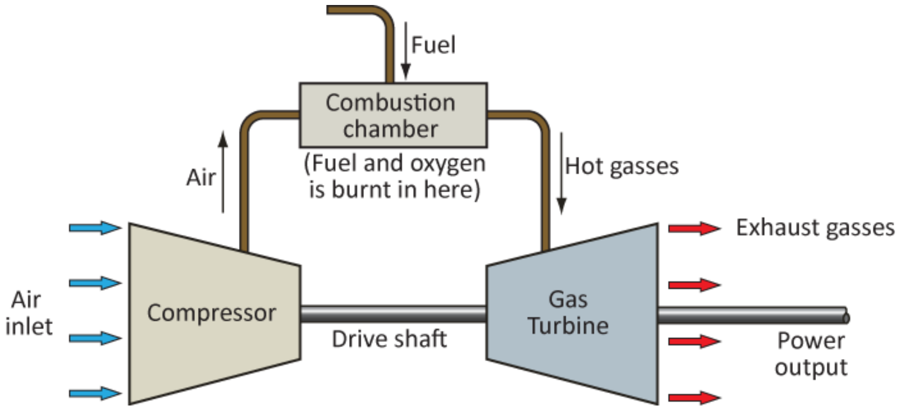
Gas power

Gas has been used in two ways. Initially it was burnt like coal and oil, which heated up the water, as explained on previous pages.

Nowadays, the gas itself is heated up and driven through the turbine, which produces the electricity, the gas being further burnt off later.

These gas-driven power plants are popular for two main reasons:

- they can be built smaller than the average power station
- they can be run up to full power very quickly, whereas coal stations need plenty of notice to make sure that they can deliver power at the right time.

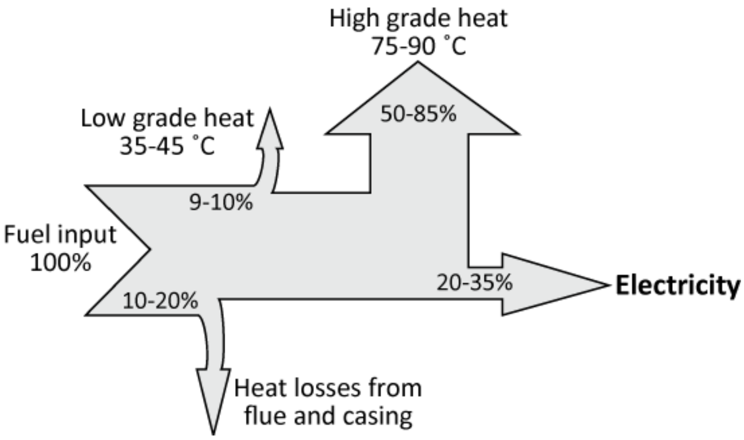


Combined heat and power

CHP (Combined Heat and Power), is the simultaneous generation of useful heat and electricity through the process of combustion.

This generates electricity whilst retaining the by-product heat

To turn the waste into usable power a CHP plant needs a fuel source, which can be natural gas or biomass. The heat loss can be seen in power stations by the steam clouds which are usually above them



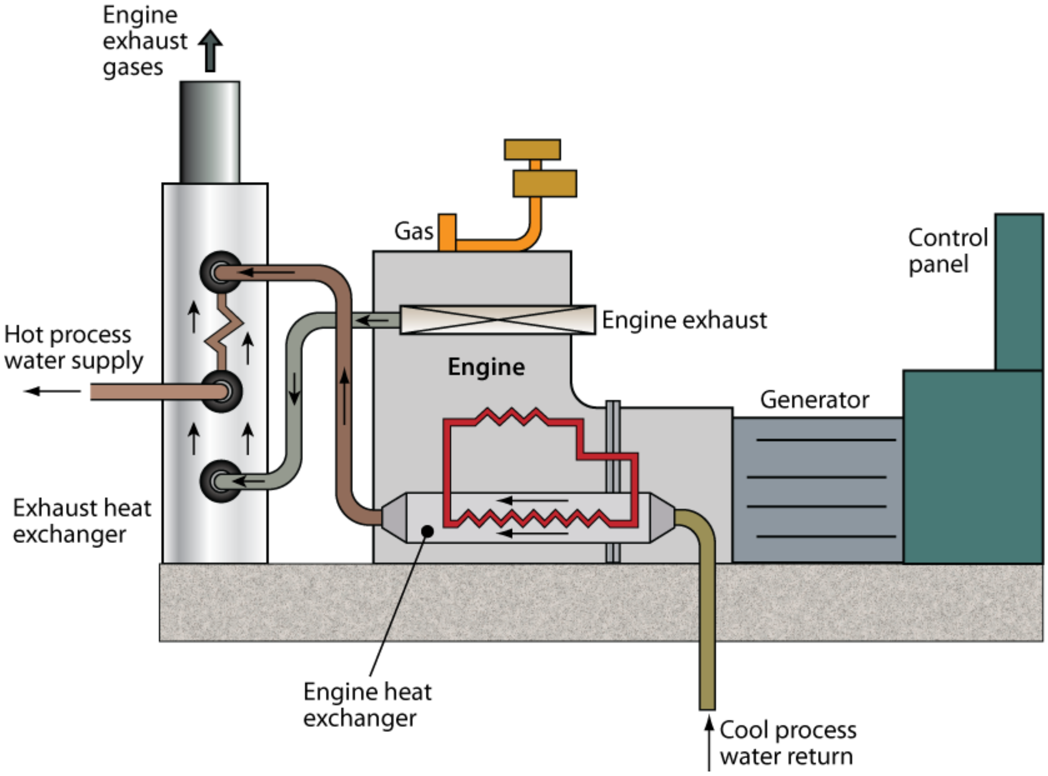
To give us some idea of the amount of energy wasted in the UK, it is estimated that the waste heat from the generated electricity capacity is sufficient to heat all the homes within the UK.

The benefits of CHP are:

- Local generation of electricity.
  - Reduced transportation costs of fuel.
  - Reduced transmission costs.
- Use approximately two-thirds of the waste heat.
  - Reduction in the amount of pollution.
- Improved national energy efficiency.
- Preservation of non-renewable energy reserves.
- Reduced dependence of imported fuels.

The problems associated with CHP are:

- A commitment to a set investment over a significant number of years.
- Changes in demand may affect the amount of electricity or heat required.
- Large capital costs including pipework etc.
- Maintenance costs.
- Noise and pollution.



A CHP plant requires;

- An engine
- Generator to produce electricity
- Heat Recovery system to obtain useable heat from the engine
- Cooling system –to get rid of the heat
- Combustion and Ventilation air systems - provide fresh air and remove exhaust air.
- Control System - maintain a safe and efficient operation
- Enclosure which will provide a physical barrier and a form of protection

Micro CHP

Micro CHP systems are primarily used to provide space heating and water heating requirements for the average home, while also generating electricity.

Micro CHP generates its energy from an energy source while a combustion engine, Stirling engine or fuel cell generates the electricity.

Once a CHP system has fully warmed up it can power all the lighting and appliances in a typical home, while any electrical generated not used can be exported back to the national grid.

Some Benefits of Micro-CHP

Unlike other renewable energy technologies micro CHP does not rely on building orientation or weather conditions to generate electricity.

- Generates electricity at times of peak electrical demand in the home
- Maximises greener and cheaper on-site use, helping to alleviate fuel poverty
- Reduces reliance on grid electricity
- No planning permission required
- Reduces carbon emissions

Wind power

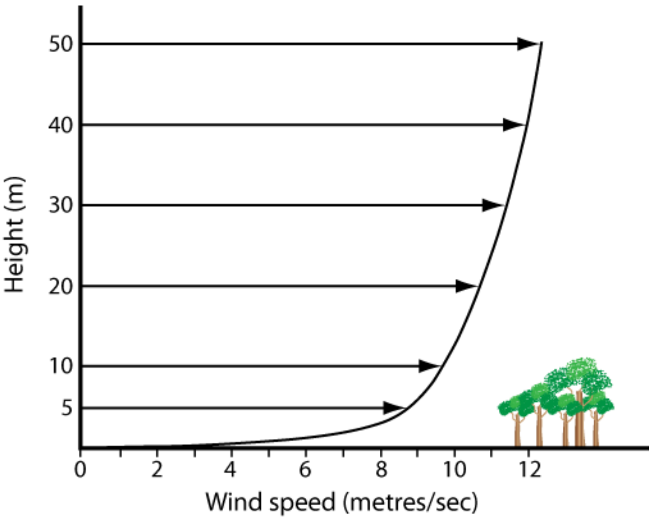
Wind turbines produce electricity by using the natural power of the wind to drive a generator.

Wind is a clean and sustainable fuel source, it does not create pollution and it will never run out

There are a range of types of wind generator:

1) Horizontal axis wind turbines (HAWT)
2) Savonius vertical axis wind turbine (VAWT)
3) Giromill/Darrieus vertical axis wind turbine (VAWT).

The power available from the wind is a function of the **cube** of the wind speed. Therefore a doubling of the wind speed gives **eight** times the power output from the turbine. All other things being equal, a turbine at a site with an average wind speed of 5 m/s will produce nearly twice as much power as a turbine at a location where the wind averages 4 m/s.



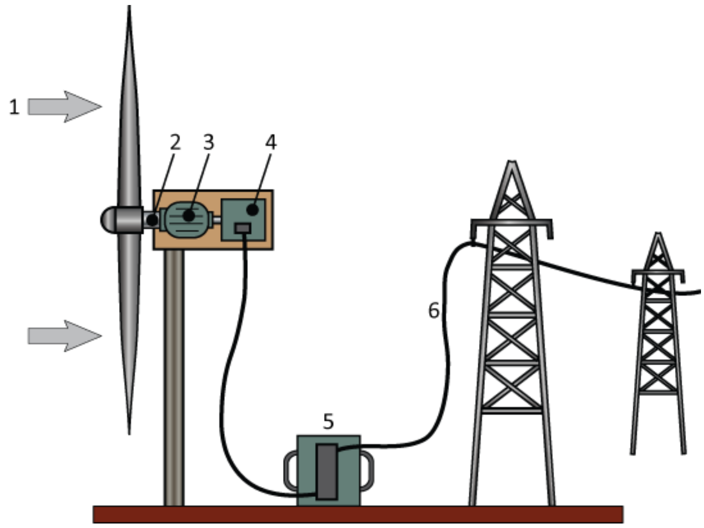
To this end the positioning of wind turbines is critical. Where the turbine is too near to the ground, the wind speed is reduced due to ground drag. Where turbines are in close proximity they may interfere with one another's air flow.

Wind farms are large groups of wind turbines, usually sited in places with a regular and consistent flow of wind such as out to sea. Such wind farms maximise the output from the available wind energy.

The UK is the windiest country in Europe; so much so, it is thought that we could power our country several times over using this free fuel.

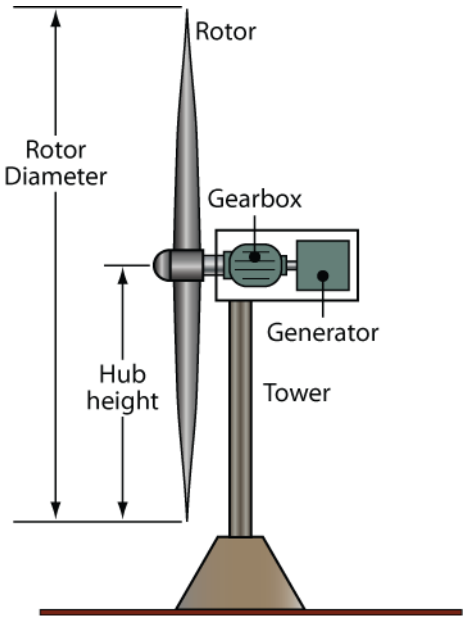
A modern 2.5 MW turbine at a reasonable site will generate 6.5 million units of electricity each year, enough to meet the annual needs of over 1,400 households, make 230 million cups of tea or run a computer for 2,250 years

How wind turbines work



1. The wind blows on the blades and makes them turn
2. The blades turn a shaft
3. The shaft goes into a gear box
4. The generator converts the rotational energy into electrical energy
5. The power output goes into a transformer, which converts the electricity coming out of the generator at around 700 V to the right voltage for the distribution system, typically 33.000 V
6. The national grid transmits the power around the country

Horizontal axis wind turbine



The modern HAWT looks very familiar to many. It usually has three arms (although this can be just one or two) set at an equal distance from one another (typically 120° for a three blade arrangement)

Wind turbines rotate at between 10 and 30 revolutions per minute. For large turbines this translates to a blade tip speed of around 91 m/s. Commercial wind turbines range from a few hundred kilowatts to over 2 megawatts. Smaller scale domestic turbines can generate just a few kilowatts.

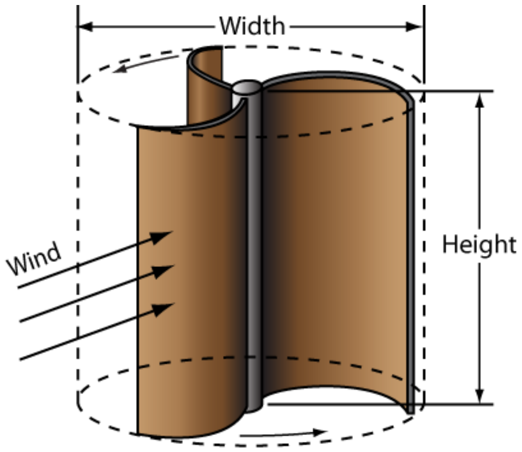
- The rotors can be up to 80 m in diameter
- They can have one, two or three rotor blades, usually three
- Blades are made out of fibreglass reinforced polyester or wood.
- Power is controlled as the wind speed varies
- They are stopped at very high wind speed to prevent damage
- Yaw mechanisms can turn turbines to face the wind.
- Most towers are cylindrical and are usually painted grey.
- The longer the rotor blades the greater the energy output.

Vertical axis wind turbines

Vertical axis wind turbines (VAWTs) come in a range of types:

- Darrieus
- Savonius
- Combinations of darrieus/savonius.

Savonius type



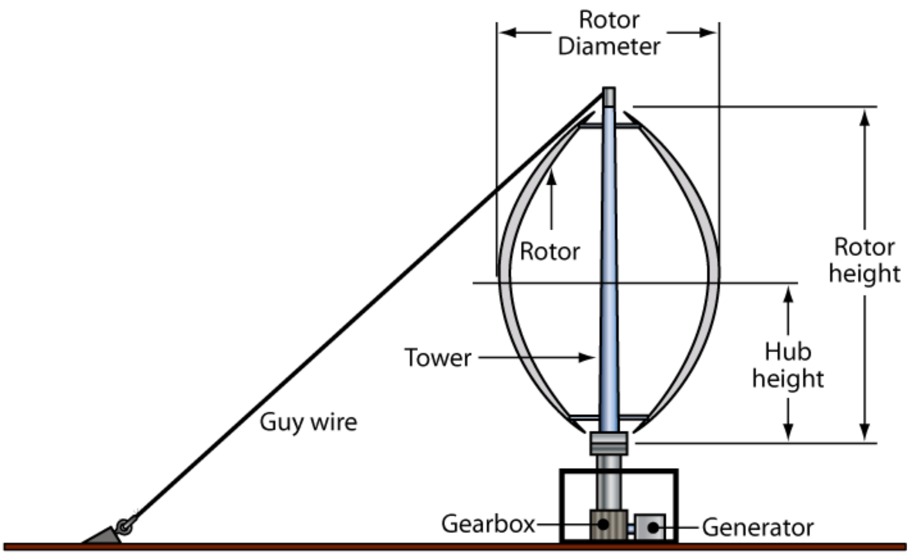
Vertical Axis Rotor

The Savonius wind turbine is the simplest type of wind turbine. They operate as a drag-type device like an anemometer. They are not efficient and are not always self-starting.

Darrieus type

The Darrieus type wind turbine utilises two or more aerofoils, as might be seen on an aircraft wing. The change in pressure across the surface of the blade causes rotational movement.

One of the original Darrieus type wind turbines used straight aerofoils: this is called the Giromill or H-bar design.



The other variant of the Darrieus type wind turbine looks more like an egg-beater, with the blades connected at the top and bottom of the shaft. Such a wind turbine is not generally self-starting and will usually require either mechanical brakes or other means of speed control as at a certain velocity resonance builds up leading to stress fractures.

Micro wind generation

There are two types of domestic-sized wind turbine:

- **Mast mounted:** these are free standing and are erected in a suitably exposed position, often around 2.5kW to 6kW
- **Roof mounted:** these are smaller than mast mounted systems and can be installed on the roof of a home where there is a suitable wind resource.

  Often these are around 1kW to 2kW in size.

Most wind turbines generate direct current (d.c) electricity. A converter changes it to alternating current (a.c.) so it can be used in the home. Micro wind turbine systems can either be connected to the national electricity grid, or connected to a battery.

There are safety issues concerned with installing a micro generator.

- There must be warning labels that show the installation includes a microgenerator so that precautions can be taken to avoid electric shock.
- Both the mains supply and the microgenerator must be securely isolated before electrical work is performed. If the turbines are turning electricity will be produced.
- Live parts need insulating or have an earthed or insulated enclosure
- Metallic enclosures of a class 1 microgenerator needs to be connected to a c.p.c

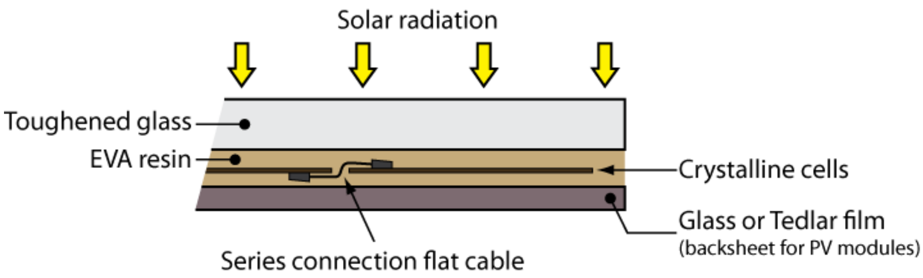
Solar power generation

Solar power is a clean, reliable form of renewable energy generated by converting energy from the sun's radiation into electricity.

Photovoltaic cells are grouped and connected together in a single frame called a panel or module.

These cells are comprised of special semi-conductive materials, which is most often a piece of silicon positioned under a layer of thin glass.

During the day, rays of sunlight shine on each of these photovoltaic cells. The silicon in each cell absorbs a portion of the sun's energy and releases particles, called electrons, in the semiconductor, enabling them to flow freely.



When the sunlight hits the cell some of it is absorbed into the semiconductor, this is converted into energy.

The energy loosens electrons allowing them to flow freely along a flat cable.

The electrons flow in a particular direction, based on one or more electric fields contained in the solar cells.

Small wires run along the top and bottom of each solar cell and harness these electrons to form an electric current when connected in a circuit.

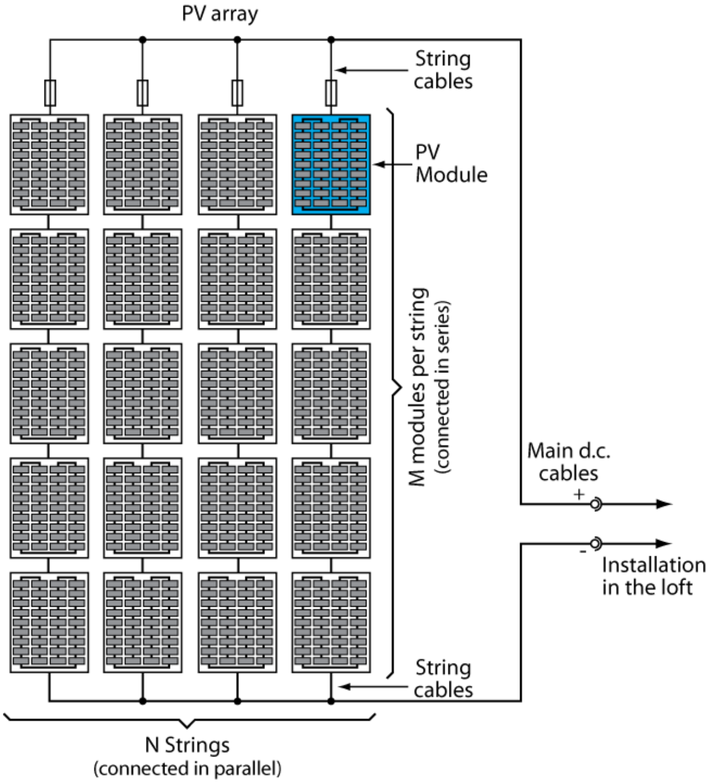
Solar panels

Whilst there is a wide range of solar panel types, all of them generate a direct current (d.c.) voltage. This d.c. supply is then converted to alternating current (a.c.) via an inverter or inverters.

When solar panels are installed within a property it is always necessary to have them aligned with the sun in such a way that the maximum amount of solar radiation will fall on the panels.

Panels in the UK should be installed on south and western (ideally south western) facing walls and ceilings to maximise the solar energy received.

Panels on a roof or elsewhere will need to be carefully installed to maximise their efficiency.



Solar panels are grouped into a series of strings. These strings are a series of interconnected solar panels connected in series.

This means that each individual voltage of each panel is added up. Therefore:

$$\text{Series voltage} = P_1 + P_2 + P_3 + \ldots$$

Where it is desirable to increase the capacity of the solar panel array the strings can be connected in parallel thus increasing the current that can be drawn from the array.

Wave power

Sourced from – energy resources

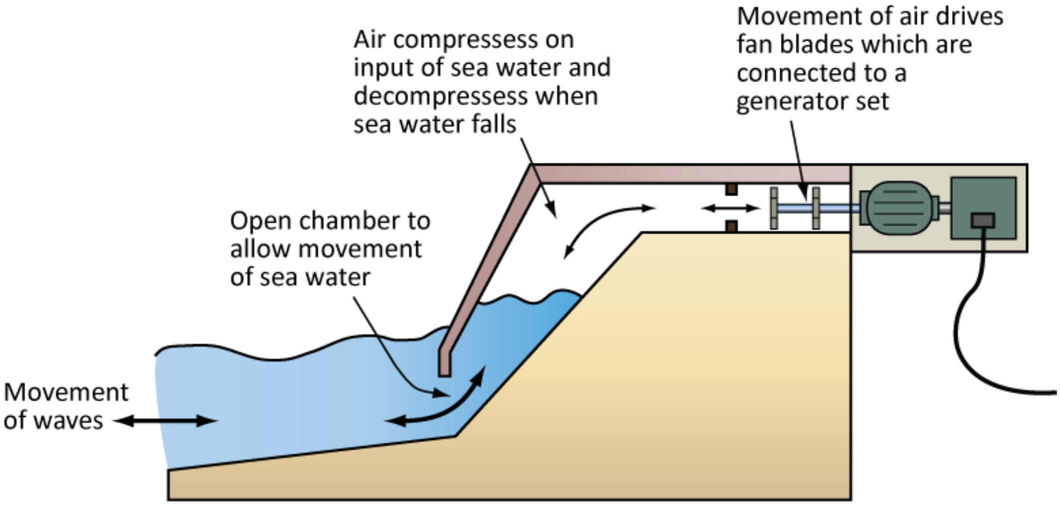
Waves are produced from the effects of the wind on the oceans and seas. The energy contained within the waves is huge. To build a generator to capture this could solve all our energy needs, but as waves are not consistent, only small scale schemes are available at the moment.

The problem is that it's not easy to harness this energy and convert it into electricity in large amounts. Thus, wave power stations are rare

There are **several methods** of getting energy from waves.
One of them works like a swimming pool wave machine in reverse.
At a swimming pool, air is blown in and out of a chamber beside the pool, which makes the water outside bob up and down, causing waves

At a wave power station, the waves arriving cause the water in the chamber to rise and fall, which means that air is forced in and out of the hole in the top of the chamber.

A turbine is placed in the hole which is turned by the air rushing in and out



Pelamis

A company called Pelamis is developing a method of off shore wave energy collection, using a floating tube called 'Pelamis' This long, hinged tube (about the size of 5 railway carriages) bobs up and down in the waves, as the hinges bend they pump hydraulic fluid which drives generators.

Another type of wave power is 'The Oyster' wave energy device

The action of the waves moves the device, pumping hydraulic fluid to a shore station to drive a generator.

Advantages of wave power

- The energy is free
- Not expensive to operate or maintain
- Can produce a great deal of energy

Disadvantages

- Dependant on the waves
- Needs a site where the waves are consistently strong
- Can be noisy, but so are waves
- Must be able to stand bad weather conditions

Nuclear power

Sourced from – energy resources

Sizewell nuclear power station

Nuclear power is generated using Uranium, which is a metal mined in various parts of the world. The first large-scale nuclear power station opened at Calder Hall in Cumbria, England, in 1956. Some military ships and submarines have nuclear power plants for engines. Nuclear power produces around 11% of the world's energy needs, and produces huge amounts of energy from small amounts of fuel, without the pollution that you'd get from burning fossil fuels.
Nuclear power stations work in pretty much the same way as fossil fuel-burning stations, except that a "chain reaction" inside a nuclear reactor makes the heat instead.
The reactor uses Uranium rods as fuel, and the heat is generated by **nuclear fission:** neutrons smash into the nucleus of the uranium atoms, which split roughly in half and release energy in the form of heat.

Carbon dioxide gas or water is pumped through the reactor to take the heat away, this then heats water to make steam. The steam drives turbines which drive generators
Modern nuclear power stations use the same type of turbines and generators as conventional power stations.

In Britain, nuclear power stations are often built on the coast, and use sea water for cooling the steam ready to be pumped round again. This means that they don't have the huge "cooling towers" seen at other power stations.
The reactor is controlled with "control rods", made of boron, which absorb neutrons. When the rods are lowered into the reactor, they absorb more neutrons and the fission process slows down. To generate more power, the rods are raised and more neutrons can crash into uranium atoms
Modern reactors use "enriched" uranium fuel, which has a higher proportion of U-235.
The fuel arrives encased in metal tubes, which are lowered into the reactor whilst it's running, using a special crane sealed onto the top of the reactor.

With an AGR or Magnox station, carbon dioxide gas is blown through the reactor to carry the heat away. Carbon dioxide is chosen because it is a very good coolant, able to carry a great deal of heat energy. It also helps to reduce any fire risk in the reactor (it's around 600 degrees Celsius in there) and it doesn't turn into anything nasty when it's bombarded with neutrons

Advantages

- Nuclear power costs about the same as coal, so it is not expensive
- Does not produce smoke or carbon dioxide, so it does not contribute to the greenhouse effect
- Produces huge amount of energy from small amounts of fuel
- Produces small amounts of waste
- Is reliable

Disadvantages

- Although not much waste is produced, it is very, very dangerous.
  It must be sealed up and buried for many thousands of years to allow the radioactivity to die away. For all that time it must be kept safe from earthquakes, flooding, terrorists and everything else. This is difficult.
- Nuclear power is reliable, but a lot of money has to be spent on safety - if it **does** go wrong, a nuclear accident can be a major disaster.
  People are increasingly concerned about this - in the 1990's nuclear power was the fastest-growing source of power in much of the world. In 2005 it was the second slowest-growing.
- Nuclear energy from Uranium is **not** renewable.
  Once we've dug up all the Earth's uranium and used it, there isn't any more.

Batteries

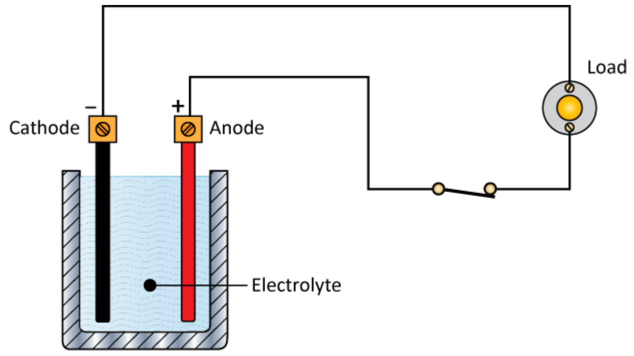
There are two types of batteries: primary batteries (disposable batteries), which are designed to be used once and discarded, and secondary batteries (rechargeable batteries), which are designed to be recharged and used multiple times. Batteries come in many sizes; from miniature cells used to power hearing aids and wristwatches to battery banks the size of rooms that provide standby power for telephone exchanges and computer data centres.

Secondary battery

battery

Primary

A battery is made up of cells; the diagram below shows a single cell in its simplest form. Whether it is a primary or a secondary cell depends upon the electrolyte used. The electrolyte needn't be a liquid; it can just as easily be a paste



Simple cell

The anode is always the positive terminal of a cell or battery and the cathode is the negative.

When electric current passes through an electrolyte it '***breaks down***' and hydrogen ions (positive) are collected at the cathode. Sulphate ions (negative) are collected at the anode; the anode and cathode merely being the two dissimilar metals. The passing of current through an electrolyte is called '***charging***'.

If a load is connected between the plates then current will flow from the anode to the cathode. Chemically, the opposite occurs to what has just occurred with charging. The delivery of current to a load is called '***discharging***'.

The energy supplied from a battery may be used to supply a load but will only be sufficient for a limited time, as the chemical qualities of the electrolyte deteriorate with use. Secondary cells cannot be re-charged indefinitely, after a number of charges and discharges the secondary cells become unable to hold their charge and the battery is finished. Primary cells become finished as soon as they lose their stored energy.

Batteries can be used in standalone power systems - such as a rooftop solar power system or wind turbine system. In a standalone solar power system, the energy created during the day is stored in a battery bank for use at night. Sometimes batteries are used in grid connect systems as a backup.

Batteries are also used for back up emergency systems separate from the main power source.

Exercise 1.

1) State five energy sources used to generate electrical energy.

2) What are the problems or benefits associated with each of the energy sources you have chosen for Q.1?

3) It is proposed to build a new nuclear power station. What are the factors that will affect the position of the new station?

4) Coal and gas are non-renewable sources of energy. What are the problems associated with using renewable sources such as wind and solar energy in the UK?

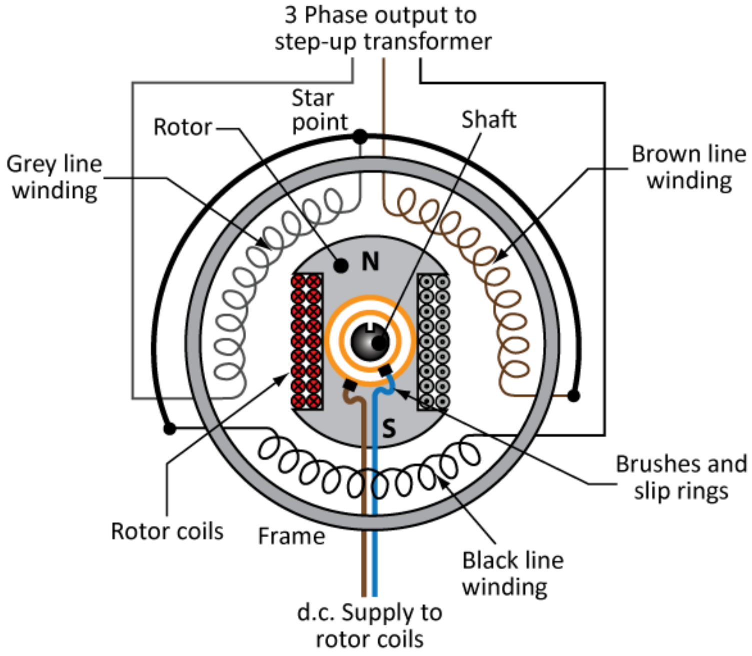
5) Why would you use batteries in emergency lighting systems?

2: Power generation

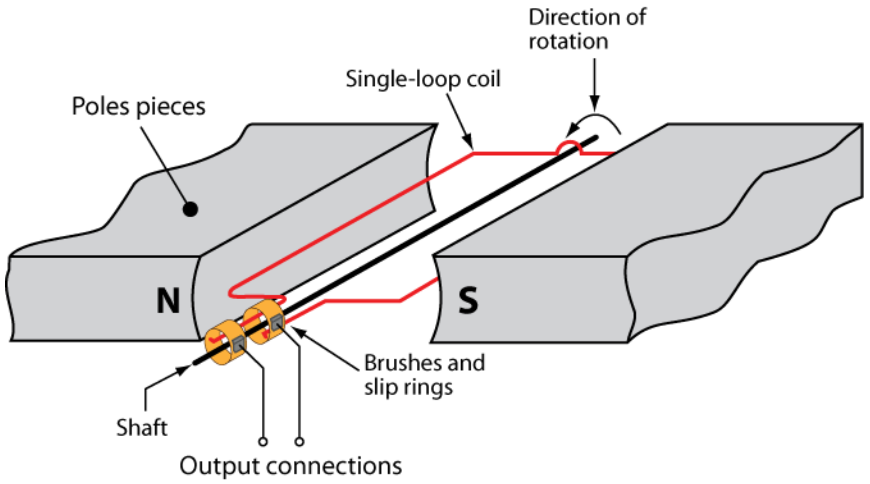
In this session the student will:

- Gain an understanding of how power is generated and transmitted within the U.K.

Power is generated in a particular way. The generators have three coils or windings which each produce a voltage. This is a very much-simplified way of putting it. These voltages are called lines and are given general labels, which are, L1, L2 and L3. Most electricians will however call them brown, black and grey phases.



Alternating current is produced when a coil is placed in a magnetic field and allowed to rotate



The coil is free to rotate within the magnetic field, as the coil turns current is induced in the coil. This is tapped off at the slip rings.

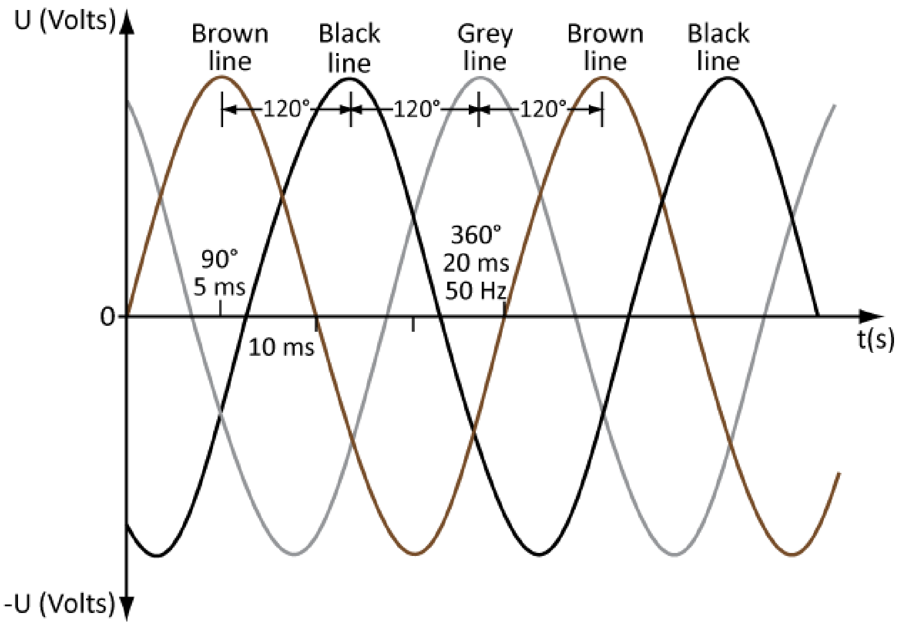
The current in the coil varies depending on how much of the magnetic field is being cut.

As the d.c. winding on the rotor is turned by the turbine a three-phase a.c. supply is generated in the stator windings. It is this that provides the electrical energy that we use.

A d.c. supply is required for the rotor field. This is supplied either from a small d.c. exciter generator attached to the machine shaft or via a separate power supply. The process is as follows:

- A d.c. supply is provided to the rotor. This creates a magnetic field
- The rotor is rotated by the prime mover
- The d.c. supplied magnetic field cuts the coils in the stator, generating an a.c. supply.

Each set of windings creates an induced emf: each induced emf is set 120º apart.



This is a typical three-phase supply, which will then pass to the first of the three-phase transformers before being boosted to transmission voltages.

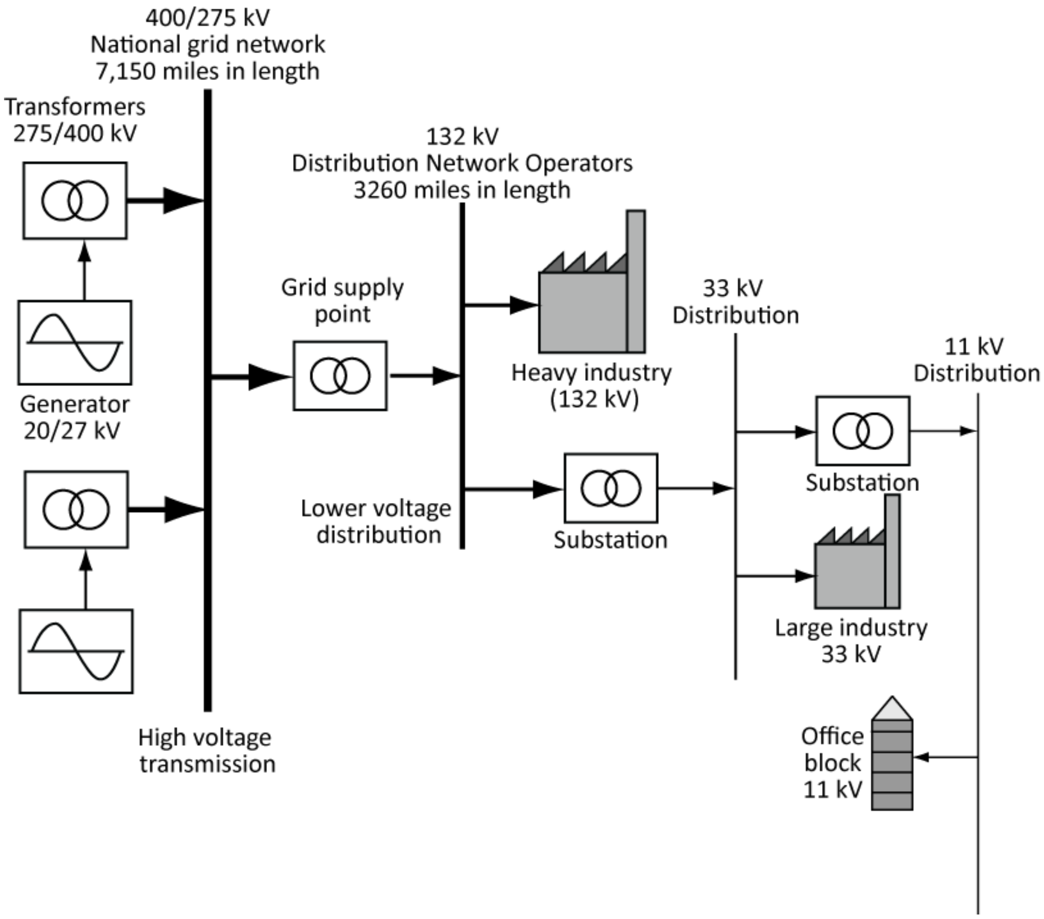
National Grid

The **National Grid** is a system that links all the power stations together. The national grid then sells electricity to distribution companies which provides the supply to consumers This sounds so very simple that we can lose sight of just how complex a system the grid is.

The National Grid was, before privatisation, part of the **CEGB** (Central Electricity Generating Board). After privatisation, it has become a separate company, which was owned by the twelve area companies, although now even it has become privatised with just a few 'big players'. The **National Grid Company** (as it now is) buys power from power stations and then sells it on. In this way, supposed, greater efficiency is gained.

In the UK power is generated at a voltage between 20 kV and 27 kV. This is transformed up to either 275 kV or 400 kV and then transmitted around the country. At a variety of further points this voltage is then transformed down to more usable levels. The transformation of voltage is to reduce the losses that occur due to the resistance of the cables.

The transmission is the bulk movement of electricity at very high voltage, whereas the distribution network operators are the ones who have a statutory duty to connect any customer requiring electricity within a defined area. This more can be shown using either a block diagram.



You can see from the block diagram that the grid voltage varies from 230 V right up to 400 000 V (400 kV). To understand the reasons for the variation in voltages it is necessary to follow what happens when electricity is transmitted over a distance.

The generated voltage is **transformed** up to 275 000 V (275 kV) or 400 000 V (400 kV). At these very high voltages the grid is called the ‘supergrid’.

At a variety of points the voltage is transformed down to 132 000 V (132 kV) and 33 000 V (33 kV), some larger consumers take a supply at 132 kV. The voltage is further transformed down to 11 000 V (11 kV), which is used by major users, and finally 400 V/230 V, which is the level at which homes are supplied.

Transmission lines are not usually buried, but carried on electricity pylons. The reasons for this are:

- increased costs from burying cables. Size increases four-fold. Digging costs are high.
- using pylons, you can eliminate the insulation as no one can touch the conductors.

The problems from pylons are that they are ugly and use up areas of land, particularly farmland. There are other problems particularly where leisure activities may take place: for example, people have been electrocuted by using carbon fibre fishing rods near pylons.

It is important to know why it is that electricity is transmitted at such high voltages. About 8% of the power generated in the UK never reaches the consumer. This is because heat is given off through the resistance of the cables etc.

Reasons for transformation of voltage levels

Assume that each of the transformers that are used to change the voltage from level to level are 100% efficient, and that no power is lost in them.

Therefore, the power into a transformer is the same as the power out of the transformer.

$$P_{\text{In}} = P_{\text{Out}}$$

We also know that:- $P = IU$

Where:- $I = \text{current}(A)$
$U = \text{voltage}(V)$

If there is 1 000 kW of power into the transformer, then there is 1 000 kW coming out of the transformer.

If the voltage at the input voltage of the transformer is 11 000 V and the voltage at the output is 400 V there must be some effect on the current. So:

In P = I U   1000 kW = I x 11000
Out P = I U   1000 kW = I x 400

The two currents are different. The current into the transformer will be 91 A and the current out of the transformer will be 2 500 A.

The difference can be enormous. If the larger current had been passing through the supply cables all the way then the power lost in the cables would have been enormous because the losses are dependent on the current^2 $\left(P = I^2R\right)$ $\left(\text{i.e.}\ 2500^2 = \underline{\underline{6250000\text{A}^2}} \quad 91^2 = \underline{\underline{8281\text{A}^2}}\right)$.

In this instance, that would make the losses 750 times greater. Obviously, this is unacceptable. What is needed is the smallest number of losses and for this we need large transmission voltages.

It is unacceptable that the ordinary consumer is fed at voltages that are very high. The risk to life would be great and the economic cost of increasing the level of insulation would be prohibitive. A compromise is settled for where the general supply voltage is kept to 400 V/230 V.

Exercise 2.

1) A 600 kW generator has an output of 1 000 V.
   a) Determine the current flow
   b) How might the current flow be reduced to 60 A?
   c) What would be the turns ratio to reduce the current to this value?
   d) If the resistance of the transmission line is 0.85 Ω, what would be the loss if the voltage were not transformed and when it is transformed?

2) Use any sources available to you and investigate the nature of cables used for both overhead and underground transmission of hv supplies.

3) Why do large industrial plants want to be supplied at high voltages?

4) Sketch a block diagram of a typical transmission system showing the levels of voltage at each stage.

5) Why is it useful for all the power stations in the UK to be connected together?

6) Why don’t birds sitting on a bare transmission wire get electrocuted?

3: Distribution

In this session the student will:

- Gain an understanding of how power is distributed at high voltage within the U.K.

On large industrial sites and within towns and cities, power is distributed to local sub-stations at voltages generally in the region of 11 kV.

To safely distribute such large amounts of power it is necessary to have sufficient control of the distribution system. To do this we make use of switchgear. Quite simply, switchgear performs four key functions:

- isolate faulty equipment
- divide large networks into smaller sections to allow for maintenance
- control the way in which networks receive power, using switchgear to direct power to appropriate points – a little like a railway signal system
- to control equipment.

At a basic level all switchgear must be capable of closing or opening an electrical circuit.

From the viewpoint of BS 7671, when we consider voltages in excess of 1 000 V a.c. we are dealing with high voltage!

Switchgear itself is split into two types:

- Primary – the initial intake position
- Secondary – takes power from the primary switchgear to the various parts of the network where it can be further transformed down to manageable voltage levels.

Typical switchgear types are:

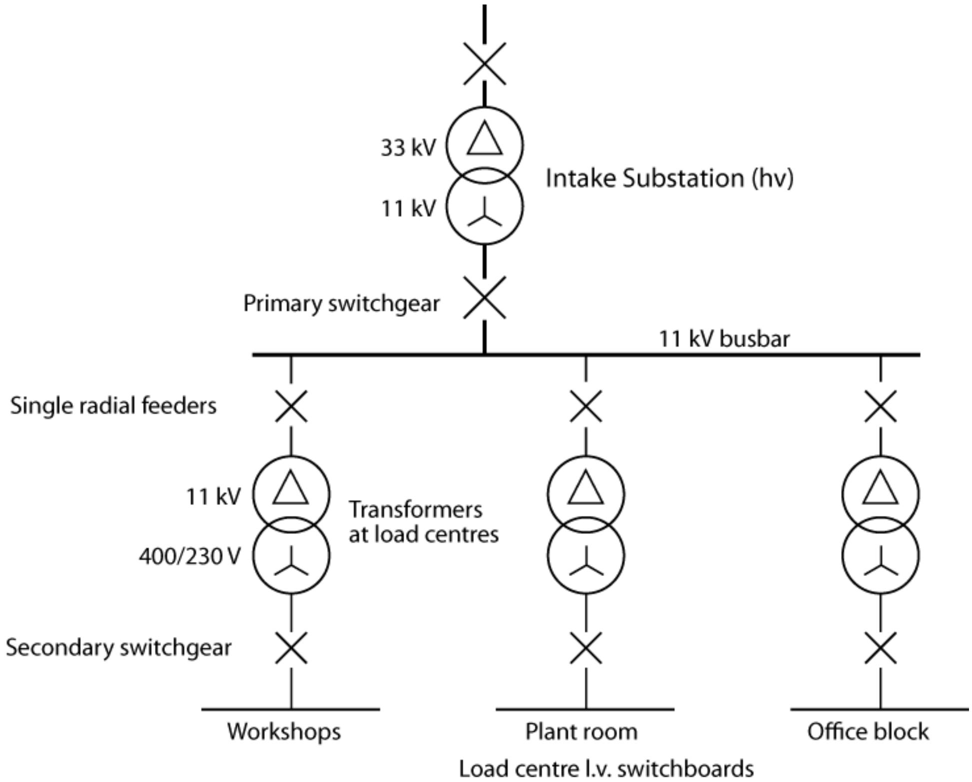
- Circuit breakers:
    - Indoor
    - Outdoor
- Disconnectors – an off-load device
- Fuses – an off-load device.

All switchgear is either metal-enclosed, where the switchgear is enclosed in earthed metalwork or metal-clad, where metal-enclosed switchgear is compartmentalised.

Before we focus on an individual 11kV transformer we need to consider how we spread the hv supply around a site. There are three possible ways in which an hv supply can be spread around a site. These are:

- Radial
- Ring main
- Duplicate feeder.

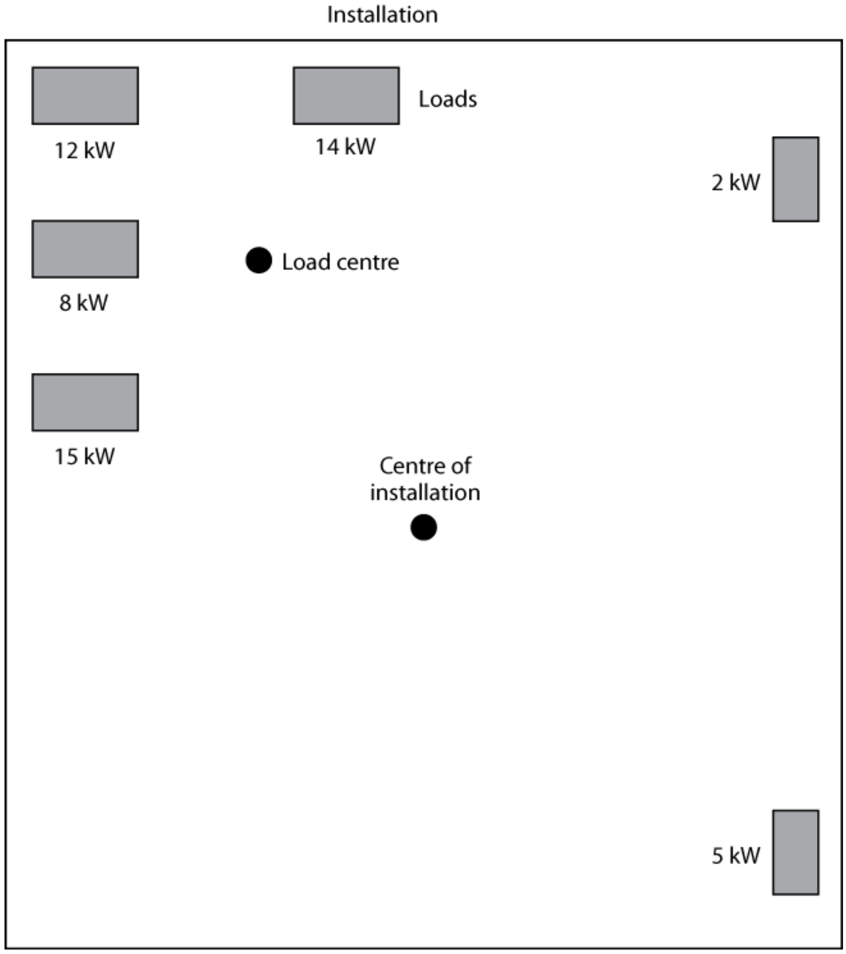
Radial distribution



From the diagram above you can see the nature of a radial feeder. The 33 kV feed comes into the transformer that reduces the voltage to 11 kV. The 11 kV is then distributed around the site to a variety of 11 kV/400 V transformers.

The radial feeders will provide '**load centres**'. Load centres are positions where the majority of the electrical load is based. They are quite literally the centres of the load.

Load centres



It is important that load centres are used. It reduces the volt-drop for the final circuits and the length of cables required.

There is one advantage and a couple of disadvantages with the radial distribution system.

Advantage:

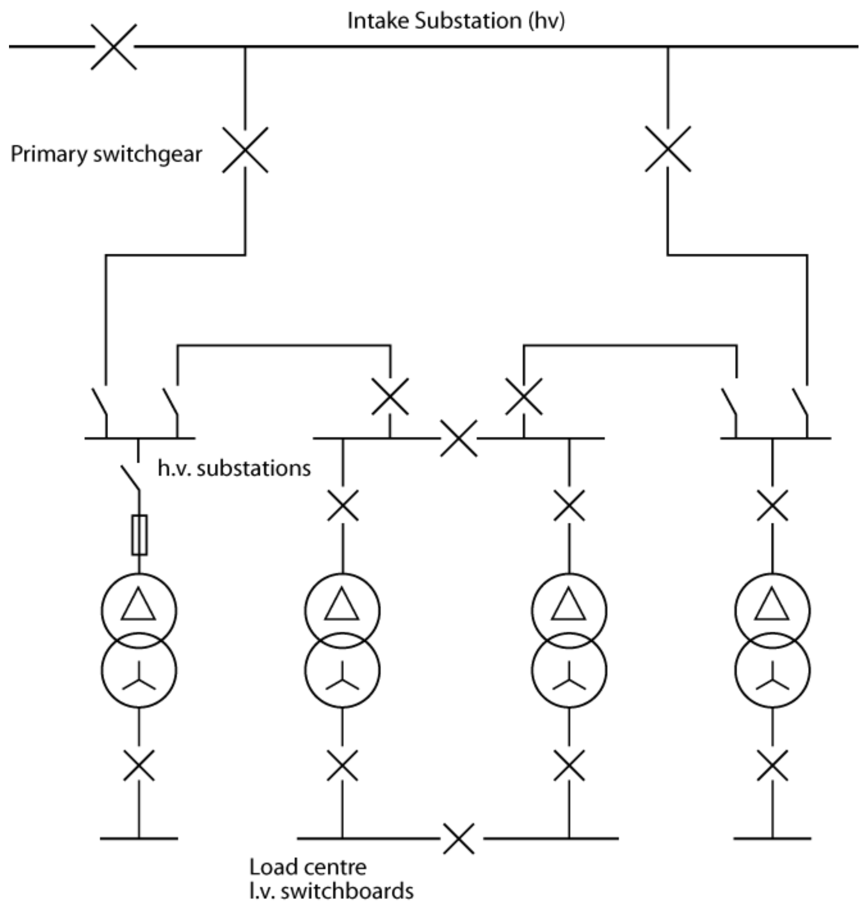
- Less cables needed.

Disadvantages:

- The supply is lost should part of the system breakdown
- Volt drop can be excessive.

Ring main distribution

You have no doubt spent much time calling ring final circuits that feed socket outlets, '**ring mains**'. This has been inaccurate. Ring mains are exactly what they say, a ring of mains. A ring main is a hv arrangement to distribute power around a site.

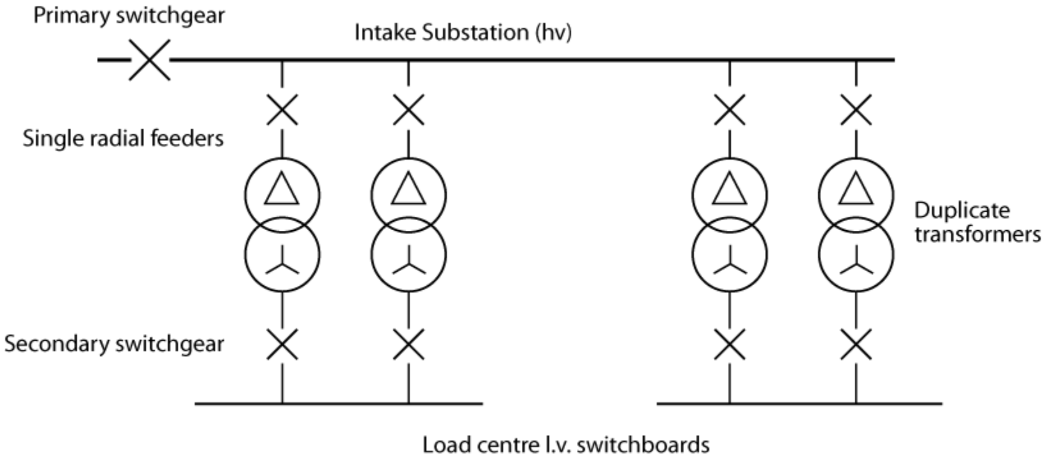


This arrangement is used to overcome the two disadvantages of the radial arrangement. The ring main enables smaller cables to be used and reduces the voltage dropped in the cables. It also allows for supplies to be maintained under fault conditions. If a fault were to occur on one leg, then that leg could be isolated from the rest of the ring main and essential maintenance could be carried out without any loss of supply.

As with the radial arrangements the transformers will be based as close to the load centres as possible.

Duplicate feeder distribution

This is the most expensive design of substation. However, it has the main advantage of providing a guaranteed supply.

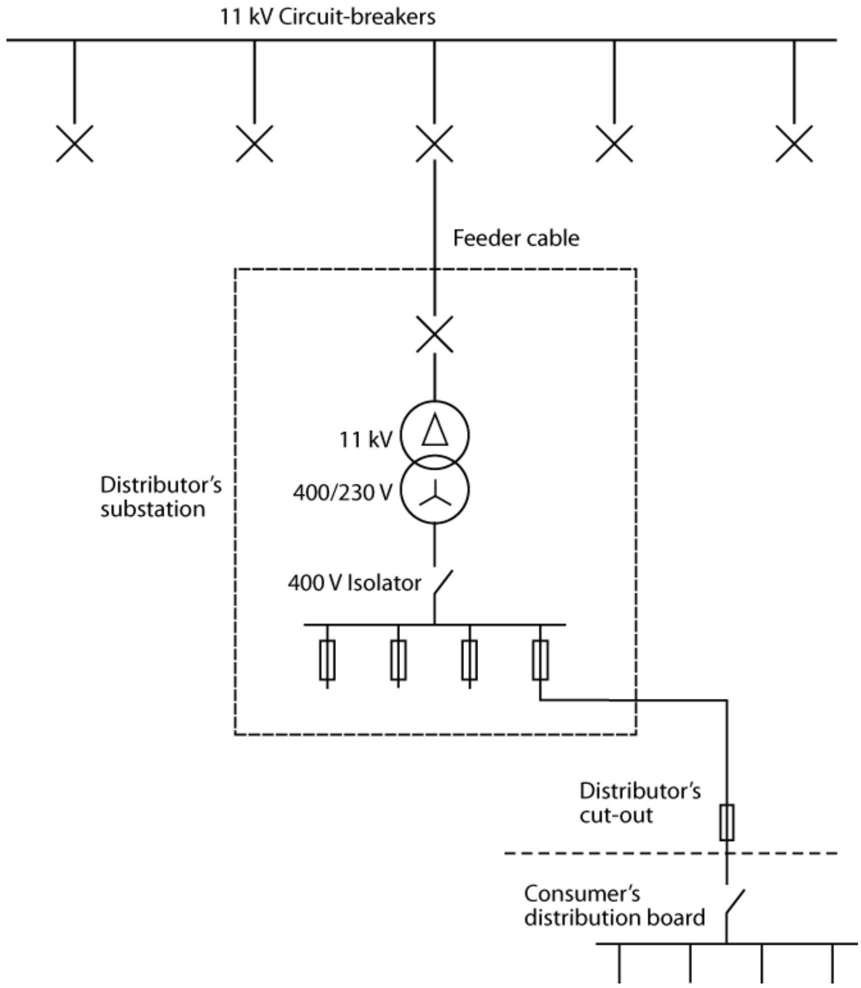


This arrangement requires that each part of the supply must be capable of carrying the whole supply. In many ways it can be assumed to have the current carrying capacity of the radial with the supply guarantee of the ring main. However, as its name suggests the costs associated with this arrangement are high.

We'll now move on and focus on the individual 11 kV/400 V transformer switch room, and again, we can split the arrangement into three for each of the types, ring, radial or duplicate.

Radial distribution control

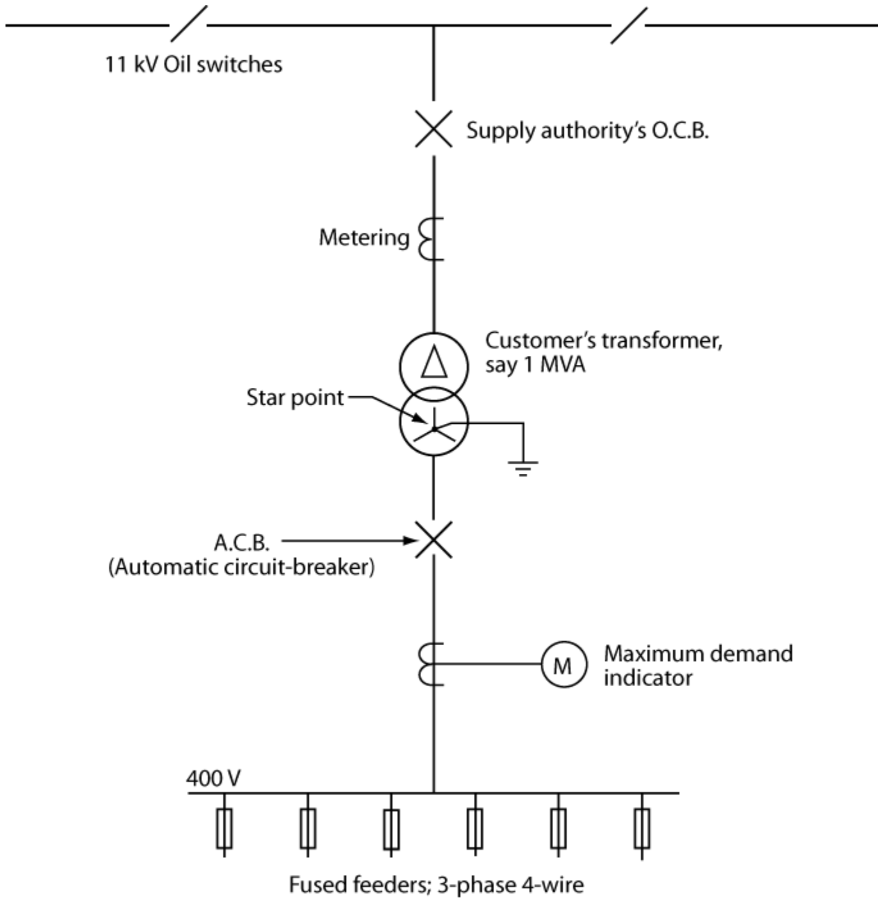
We now consider what happens at the actual switchroom. Have a look below at the diagram showing the way in which a lv supply may be drawn from the transformer.



This is the basic arrangement from a radial or single cable supply.

Ring main distribution control

Again, you need to look at the diagram below. Here the ring main supply comes into the distributors' circuit breaker. The supply then is transformed before feeding off to the various supplies.



The feeders may be arranged differently for ring main and radial arrangements. However, the transformers themselves are the same.

Distribution transformers range in value from 15 kVA (3 300 V/400 V) to 12.5 MVA (11 kV/3.3 kV). However, most are less than 2 000 kVA, the norm being 750 kVA.

The difference between primary and secondary switchgear is due to its position and function.

- Primary switchgear is positioned at the junction between the hv network and the hv supply to the network
- Secondary switchgear manages the supply from the primary switchgear to the various transformers around a site.

Both of these deal with hv supplies and are not situated at lv levels.

Exercise 3.

1) State the three types of arrangement used to deliver high voltage supplies around a large site.

2) In the light of Q.1 what are the advantages and disadvantages of each system?

3) What is a load centre, and why does it need careful consideration?

4) Draw the basic arrangement for a ring main.

4: Electrical supplies

In this session the student will:

- Gain an understanding of three phase power supplies.
- Understand how three phase systems can provide single phase supplies.
- Explain the importance of the neutral conductor.

This session takes a look at how a three-phase supply and single-phase supply can be connected. No doubt, you are already familiar with the concept that a single-phase supply has a nominal voltage of 230 V and that a three-phase supply will typically have a nominal voltage of 400 V. Where does this value come from? How many ways are there of connecting three wires to a load?

A three-phase supply is a natural function of the generation process. A generator consists of three distinct electrical windings. This was covered in the previous session.

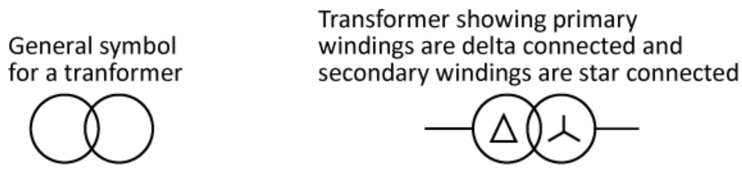
The reason why three phases are generated is to allow industry to reduce the size of the machines that it uses. With a reduction in the size of machines, there will be a corresponding reduction in the size of the cables used to supply the machines. A three-phase system also allows the distributors to reduce their cable sizes and balance the loads attached to their distribution system.

So far we have considered the transmission and distribution of power within the UK and seen that it is essential to guarantee supply and to reduce losses that power is efficiently carried around the country from power stations to the consumer.

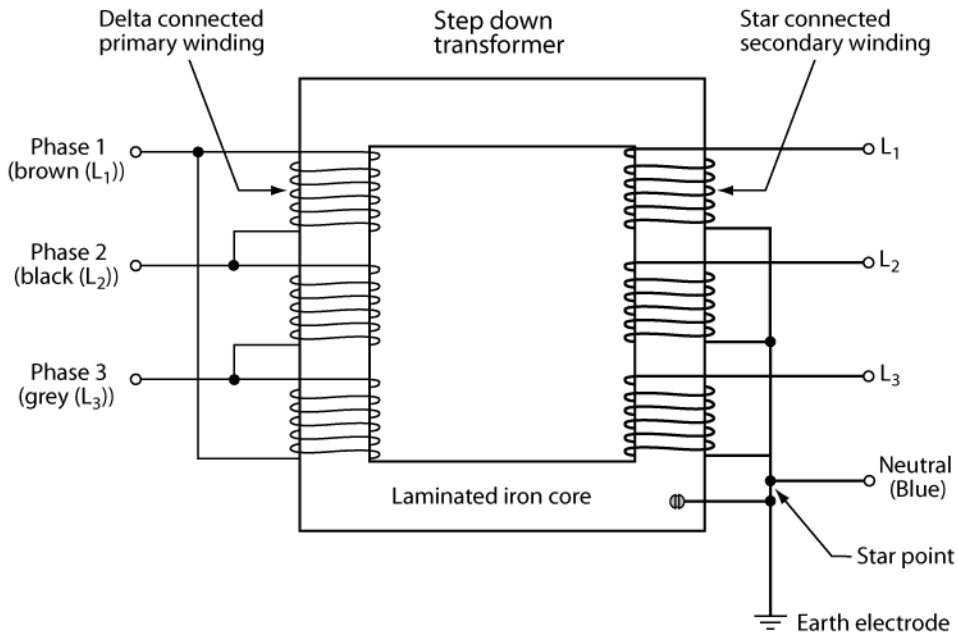
How supplies are provided to typical installations

When we reach the 11 kV transformers from our HV supply, there are usually three phases coming into the transformer and three phases coming out of the transformer, although there are some split phase supplies (two phases at 440 V). The difference in voltage between 230 V and 400 V occurs when we consider how we add up the voltages.

There is a general symbol used for a transformer.

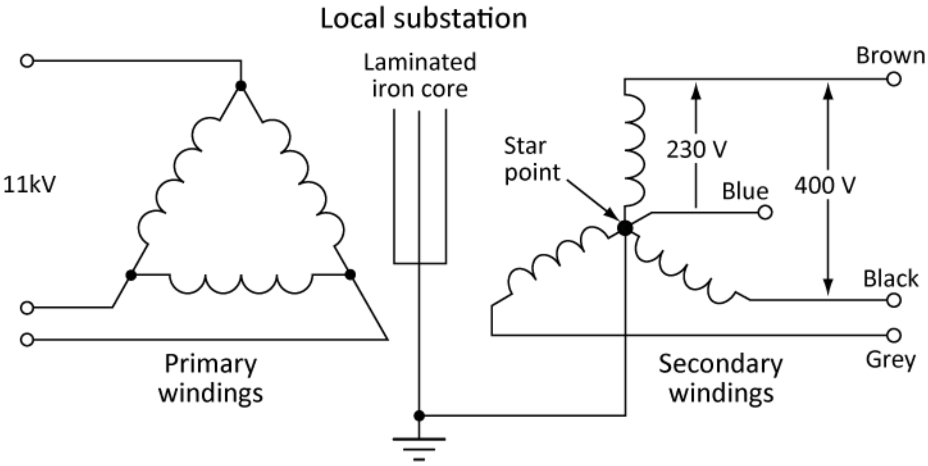


We can see a simplified version of the situation at an 11 kV transformer.



From the diagram above you can see that the supply into the transformer and the coils are connected in a form called **delta** and that there are only three wires. The supply from the transformer has four wires and the coils are connected in what is called **star**. The supply from the transformer is called a **three-phase four-wire system.**

Below is a simplified step-down transformer with the connections labelled



- The **primary** is connected in **delta** and the **secondary** is connected in **star**.
- The voltage between any two or three lines is 400 V. A 400 V supply between any two lines is called a **400 V two-phase supply**. A 400 V supply between all three lines is called a **400 V three-phase supply**.
- The voltage between any line and neutral or Earth is 230 V. This form of supply is called a **230 V single-phase supply**.

The relationship between 230 V and 400 V is such that if you multiply 230 V by $\sqrt{3}$ you will get 400 V. So:

$$\sqrt{3} \times 230 \approx \underline{\underline{400\text{V}}} \quad \text{and} \quad \frac{400}{\sqrt{3}} \approx \underline{\underline{230\text{V}}}$$

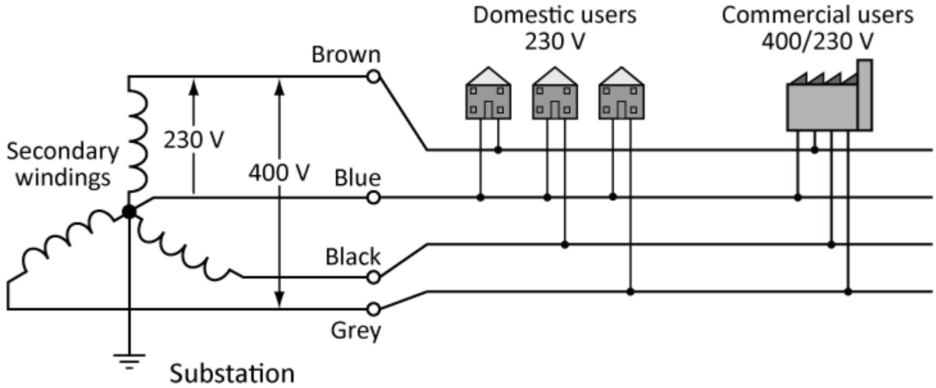
This form of supply is very useful for a number of reasons:

- it allows for an even spread of loads across a number of consumers. For example, it would be unreasonable to connect all houses down one street to the brown phase, or black or grey. If this did happen, one of the phases would be overloaded. This would be called an **unbalanced supply**
- it allows businesses to make use of more efficient machines because they can have a three-phase supply
- it enables smaller cables to be installed.

We can see that any alteration of supply naturally leads to significant changes in so many other areas of the installation.

Single-phase and three-phase supplies

We are not going to look at three-phase and single-phase supplies in much detail at present, but we do want to just take a few moments to think about the loading of an installation.



Here you can see a three-phase, four-wire supply. The fourth wire is the neutral and the other three are the brown, black and grey lines usually labelled for supply as L_1; L_2; L_3. Between each of the three lines to the neutral there is a nominal 230 V supply. This is what we call a single-phase supply and is most common in domestic installations.

Neutral wire

It is worth just spending a moment considering the **neutral wire**. The neutral is connected at the **star** point of the transformer, which in turn is connected to **earth**. Earth has an assumed **potential** (voltage) of 0 V.

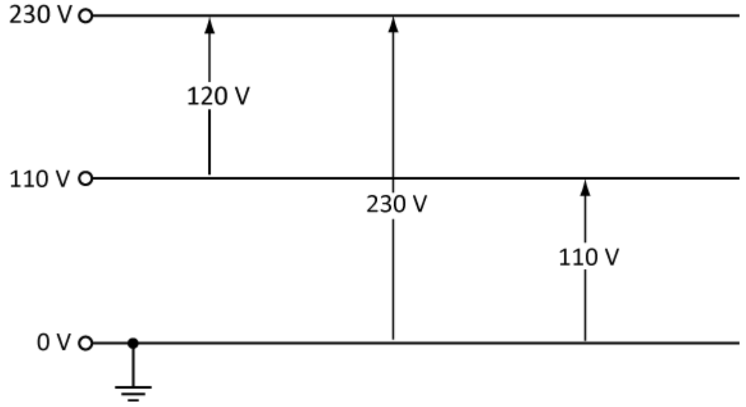
The neutral has a number of purposes, some more difficult to understand than others:

- it enables us to have a variety of single-phase supplies
- it 'ties' the neutral down to a known voltage because it is connected to earth (0 V)
- it allows neutral current to flow. This is important in single and unbalanced three-phase supplies.

The final type of supply is a three-phase four wire supply. Here all the conductors come into the installations and you can get the full range of single phase and three-phase supplies. This type is most commonly used in businesses, farms, industry etc.

Voltages

When we state that we have a voltage or a potential of 230 V, what does it mean? What we mean is that the voltage has been raised to a point 230 V above the value of zero.



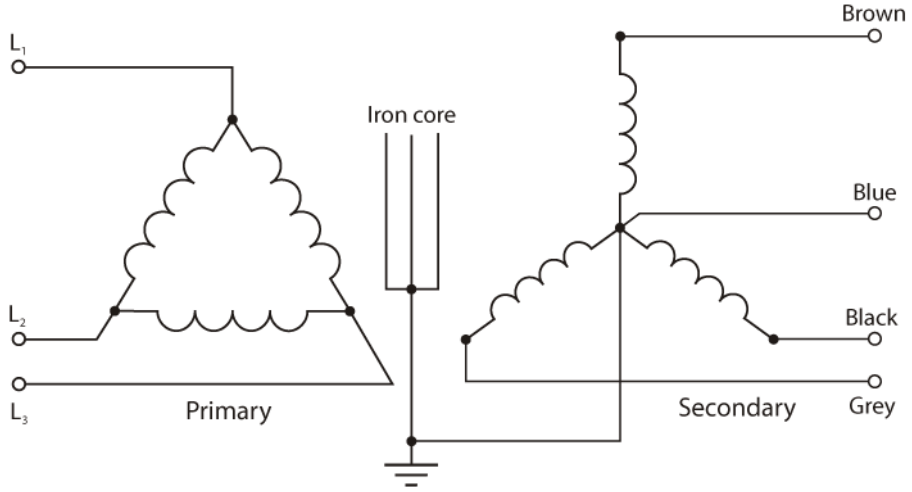
If a voltage is raised above another voltage, we can be dealing with any number of values.230 V above zero (earth) is only 120 V above 110 V, if we were to take 110 V as the reference point.

As already stated, Earth provides a reference point against which we can measure our voltage. It also provides us with the means to clear ***line to earth*** faults by operating protective devices when sufficient current flows (we will deal with this later on).

Earthing

In the electrical system in the UK it is the responsibility of the consumer and/or the electrical contractor to make sure that an installation is adequately earthed, however an Earth is often provided by the distributor via their supply cables. Under the *Electricity Safety, Quality and Continuity Regulations 2002* (*ESQCR*), distributors are required to provide an Earthing facility to new installations unless there are reasons of safety for refusing one. Distributors will commonly ask for an Electrical Installation Certificate to assess whether the installation is indeed safe.

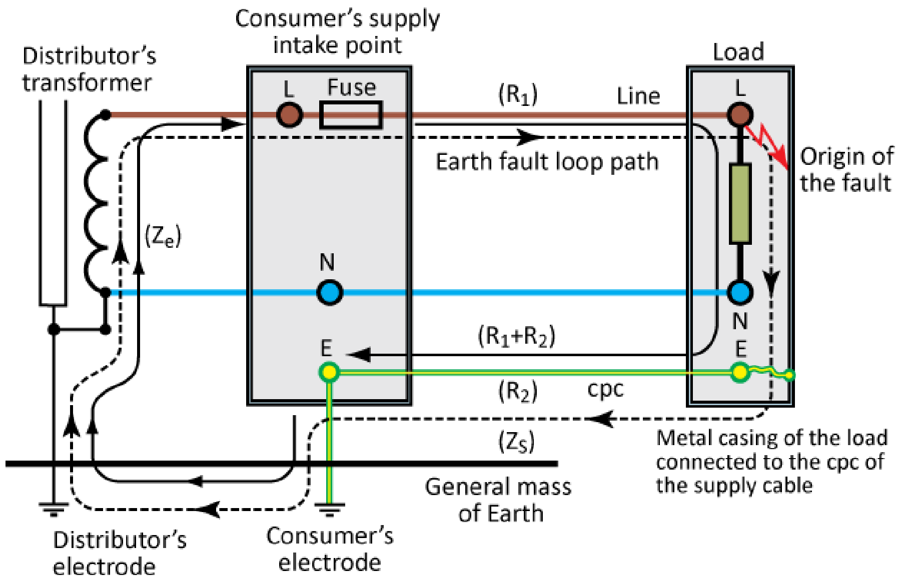
Reference point



There are a number of issues that arise even from such a simplified diagram as this.

- The ‘***star***’ point of the distributor’s transformer on the secondary side (low voltage LV) (neutral) is connected to or tied down to the ‘***Earth***’, which is accepted as being 0 V.
- On the primary of the distributor’s transformer (high voltage hv), there is an Earth provided and this is connected to the structure of the transformer. Although this is far beyond what you need at this level, it is maybe worthwhile being aware that the hv and the LV earth are set a good distance apart, usually in excess of 9 m; this makes sure that there is no overlap between the lv and hv earth electrode resistance areas.

Below we can see what is called the ***earth fault loop***. The earth fault loop is the circuit, which begins at a fault, passes through the earth conductor then into the sub mains and then back to the point of fault. It should have a low value of impedance.



So why do we need to know all of this?

Correct earthing enables sufficient current should flow under an earth fault that the protective device (fuse or circuit-breaker) operates within a pre-defined time

This is the key reasons for providing earthing in an installation.

Nominal Voltages

The nominal voltages in the UK are:

- single-phase 230 V
- three-phase 400 V

BS EN 50160 (Voltage characteristics of electricity supplied by public distribution systems) recommends that the suppliers of electrical energy should not vary their supply voltage by more than ±10%.

Nominal Voltage	Range
230 V	253 V
	207 V
400 V	440 V
	360 V

However, Appendix 2 of BS 7671 declares that the limits on supply voltage are +10 % to -6 %. This is the voltage you should be aiming for.

Nominal Voltage	Range
230 V	253 V
	216.2 V
400 V	440 V
	376 V

Frequency

All a.c. supplies are set at a certain frequency. In the UK, whilst the supply voltage can vary between +10 % and -6 % of the nominal voltage (230 V), the frequency at which the supply is generated can only vary by 1 %. This means that at a nominal voltage of 230 V, the voltage can be as high as 253 V and as low as 216.2 V, but that there can only be a ±0.5Hz difference around the 50 Hz norm for the frequency.

Frequency change is more significant in a.c. supplies than many people realise, particularly when dealing with inductive or capacitive circuits. As both inductive reactance and capacitive reactance are affected by frequency change significant problems can occur. Excessive currents, resonance and a decrease in current are all possible.

Exercise 4.

1) Consider the following installations:

   a) A medium-sized industrial installation drawing a total of 2 100 A
   b) A commercial installation drawing a total of 300 A
   c) A farm situated at a significant distance from the supply, requiring a total of 185 A
   d) A domestic installation rated at 19.2 kW.

   State what type of supply that would be appropriate in each instance, giving reasons for your choice/s.

2) Consider what might happen if the neutral on the supply cable failed in:

   a) A single-phase installation
   b) A three-phase installation.

   [Consider both breaks at the consumers' end and in the supply cable]

3) What advantages are there for industry in using a three-phase supply?

5: Transformer theory

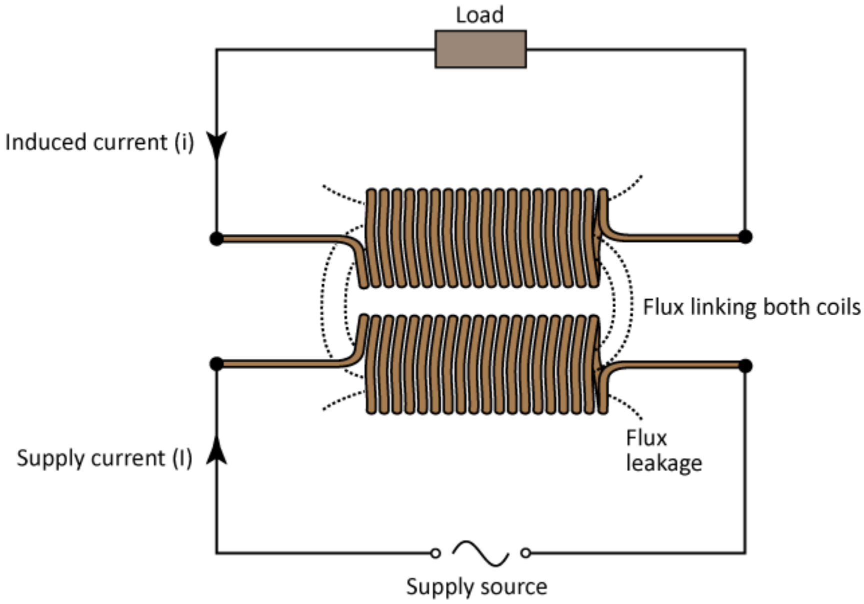
In this session the student will:

- Gain an understanding of how transformers work.

We are now going to take a closer look at how transformers work.

Mutual induction

Here we have two coils brought into close proximity. One coil is connected directly to the supply. The supply current creates a magnetic field around itself. This magnetic field 'links' with a second coil and an emf is induced in that coil.

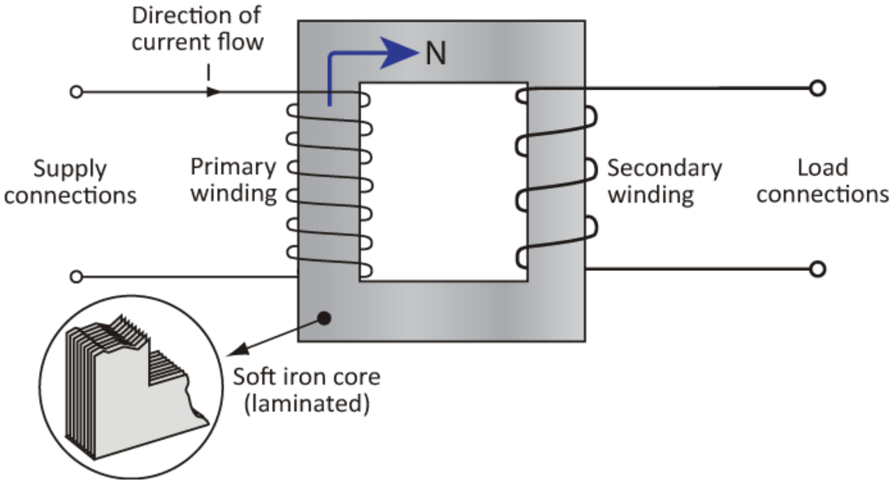


The effect is more obvious when an a.c. supply is connected to the coil because with an a.c. supply the current is constantly changing and therefore, so is the magnetic field.

This is called mutual induction. This is the basic principle of operation of a transformer. The induced emf produced via mutual induction again depends on a number of things.

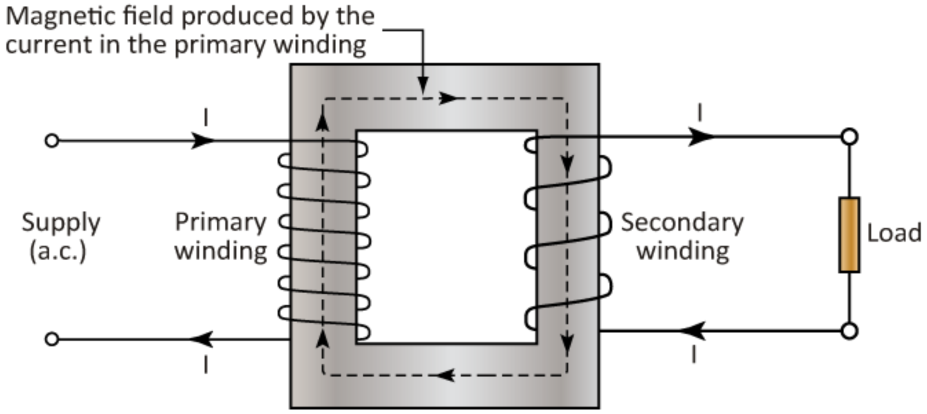
Application of a transformer

Let's consider Lenz's law as a more fundamental way of determining what is happening within the transformer. Have a look below.

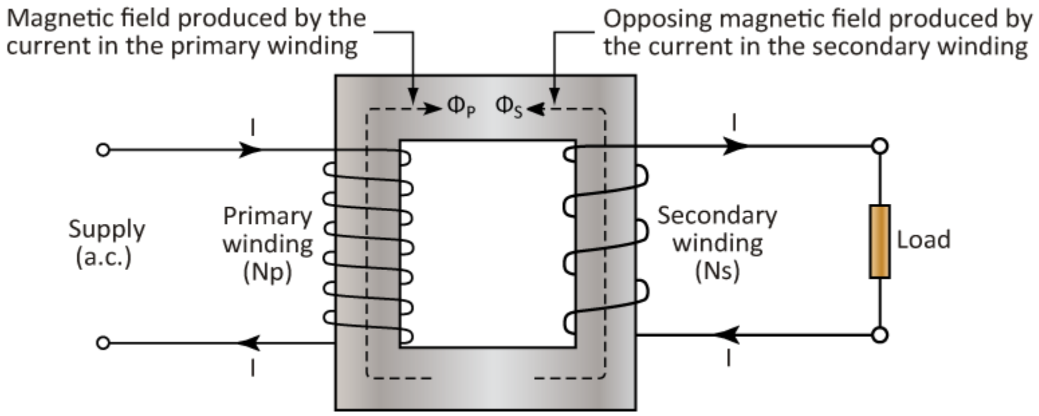


You can see that there is a supply or primary side, and a load on the secondary side. We'll assume that a supply has been connected to the primary side.

In this example the current in the primary winding produces a magnetic field, with the north seeking pole going in a clockwise direction.



We know that this ‘**primary**’ magnetic field is linking with the secondary winding and that an emf is induced in that winding. This induced emf in the secondary winding produces a constantly changing current, which flows in the conductors. This constantly changing current produces a further magnetic field around the secondary. It is this magnetic field that now ‘**moves**’ in an anti-clockwise direction, opposing the initial magnetic field (Lenz’s Law).



This final diagram shows the varying magnetic fields and in which direction they are moving.

Voltage, current and the number of turns of the coil in a transformer

Now we’ll start to look at the principle of operation of the transformer. We have looked at the basic principle of mutual induction and Lenz’s law, now we’ll consider the relationship between flux, voltage and current.

We have already seen that when an alternating voltage is applied to the terminals of the primary winding of a transformer, an alternating current flows and an alternating magnetic field is set up within the core.

The core of a transformer is usually a piece of laminated, magnetically hard material. This will usually be based on iron. The core is laminated to reduce the eddy current losses, which we have looked at previously in the work with magnetism.

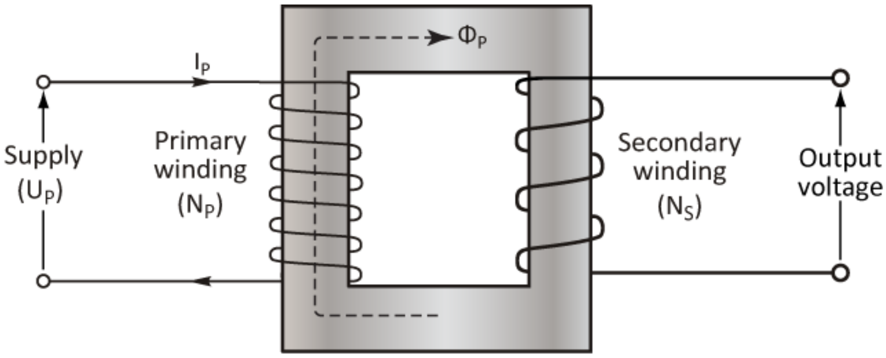
The flux links both the primary and secondary windings.

This means that the rate of change of flux linkage is the same for every turn of each winding. This can be described in terms of an expression.

$$\frac{\text{Primary induced voltage}}{\text{Secondary induced voltage}} = \frac{N_P}{N_S}$$

$$\frac{N_P}{N_S} = \frac{\text{Induced volts/turn} \times N_P}{\text{Induced volts/turn} \times N_S}$$

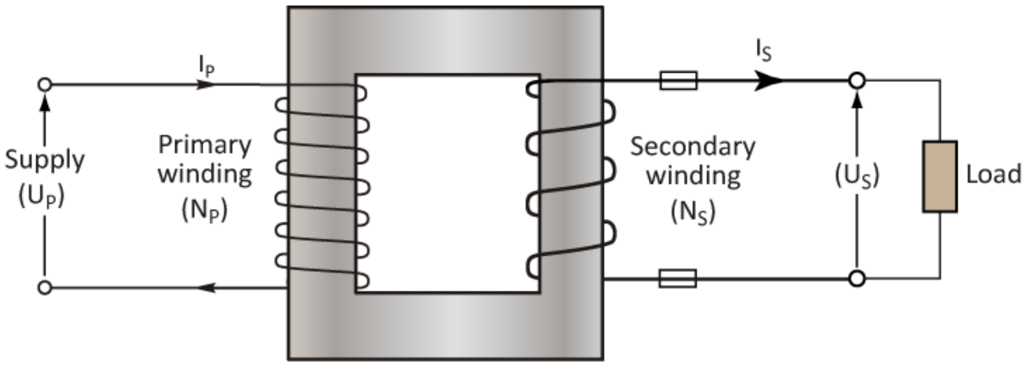
With a double wound transformer, when there is no load connected, there is no secondary current. This means that the voltage that appears at the secondary terminals is equal to the induced voltage.



In the primary winding the induced voltage is almost the same as the applied voltage. The difference between the two is just sufficient to allow the magnetising current to flow in the primary winding. This will be impedance rather than a pure resistance. This means that, on no-load, the voltage and turns' ratios are related.

$$\frac{U_P}{U_S} = \frac{N_P}{N_S}$$

When a load is connected to the secondary winding of the transformer then current will flow.



When a current flows, then power must also be dissipated. If we ignore any losses (we can ignore the losses at this stage as transformers are generally 95 % efficient), this means the input power is very nearly equal to the output power. We can express the relationship of power in terms of an equation, see equation 1 below.

There are three equations for a transformer.

1	2	3
$P_{in} = P_{out}$	Volts/Turn	Ampere-turns
$U_p I_p = U_s U_s$	$\frac{U_p}{N_p} = \frac{U_s}{N_s}$	$I_p N_p = I_s N_s$

Where p = primary

s = secondary

Remember that these equations relate to an ideal transformer which is 100% efficient and has no losses.

Example.

A single-phase transformer has 1 250 primary turns and 200 secondary turns. If the primary voltage and current are 230 V and 3 A respectively, determine the secondary voltage and current.

Secondary voltage;

$$\frac{N_P}{N_S} = \frac{U_P}{U_S} = \frac{1250}{200} = \frac{230}{U_S} \quad \text{transpose for } U_S$$

$$1250U_S = 200 \times 230 \quad \text{transpose}$$

$$U_S = \frac{200 \times 230}{1250} = \underline{\underline{36.8V}}$$

Secondary current;

$$\frac{U_P}{U_S} = \frac{I_S}{I_P} = \frac{230}{36.8} = \frac{I_S}{3} \quad \text{transpose}$$

$$36.8I_S = 3 \times 230 \quad \text{transpose}$$

$$I_S = \frac{3 \times 230}{36.8} = \underline{\underline{18.75A}}$$

Exercise 5.

1) Describe in basic terms how a transformer works.

2) Power is generated at 20-25 kV and transmitted at 275 kV. For an assumed power output from the alternator of 500 kVA, can you determine why the transmission voltage is so much higher than the generated voltage level? Give reasons for your decision.

3) A transformer has the following details;

Primary voltage	230 V
Primary current	5 A
Primary turns	100
Secondary turns	20

Determine;

a) Secondary voltage
b) Secondary current
c) Input power
d) Type of transformer

6: Transformer losses

In this session the student will:

- Gain an understanding of how transformers losses occur.

In the last session we considered in some detail the basic principles of operation of a transformer. Towards the end of the session, and particularly if you managed to do the experiment, it would have been obvious that even a transformer is never 100% efficient.

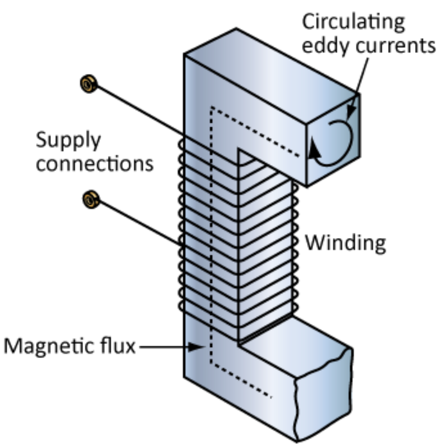
Think about the work you did in the last session.

Iron losses

There are three types of iron loss that need to be considered. These are:

- Eddy current loss
- Hysteresis loss
- Leakage and fringing.

When a piece of metal is used as the core of an inductor, then that material has a magnetic circuit within it. When we look at equipment such as transformers, we want the magnetic effect; it's just that we don't want the heating effect that goes with it.

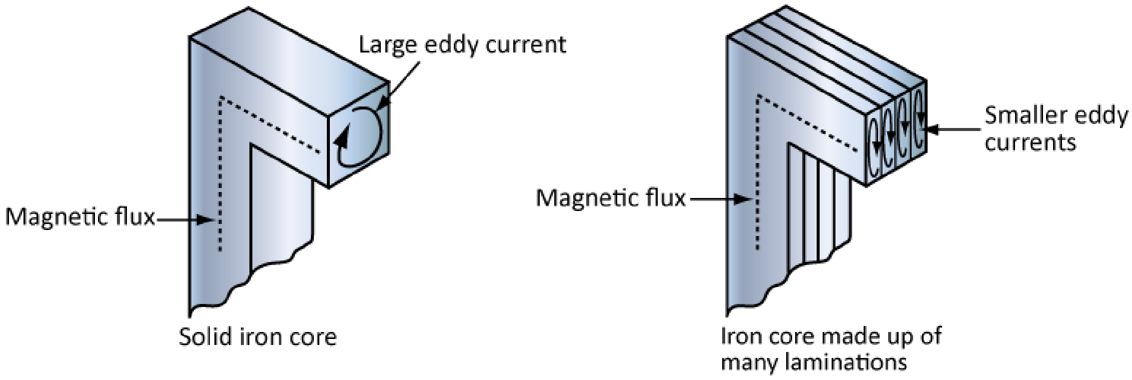


In the diagram we can see this effect. This circulating current shown in the cut out section, is called an '**eddy current**'.

An eddy current is produced when there is a changing flux, the type that occurs when there is an a.c. supply. This changing (alternating) current produces a changing magnetic flux. This changing flux sets up this circulating current. The circulating eddy current produces a second magnetic flux that opposes the initial magnetic flux produced by the supply.

The eddy current, particularly within a material such as iron, can cause quite a large increase in temperature, and consequent power loss.

It has been found that if we take the core material, usually iron or steel-based material, and split it into thin strips called laminations and then stick the thin strips together with a thin layer of insulation between each strip, then the eddy currents are dramatically reduced.



The laminations are separated by a thin layer of varnish or oxide, and the thinner the lamination the smaller the eddy current. There is a limit on the thickness of the lamination however, and this is about 0.4 mm.

This use of laminations and reducing the thickness of the layers of steel is not arbitrary. The loss in watts is related to the thickness of the layers: eddy current loss is proportional to the square of the thickness of the laminations up to a certain limiting value, $\left(P \propto T^2\right)$, where T=thickness of laminations. In addition the eddy current loss is proportional to the square of the frequency of the supply, $\left(P \propto f^2\right)$ where $f =$ frequency. Therefore, if the frequency increases by just a small amount the loss, given off as heat will increase dramatically.

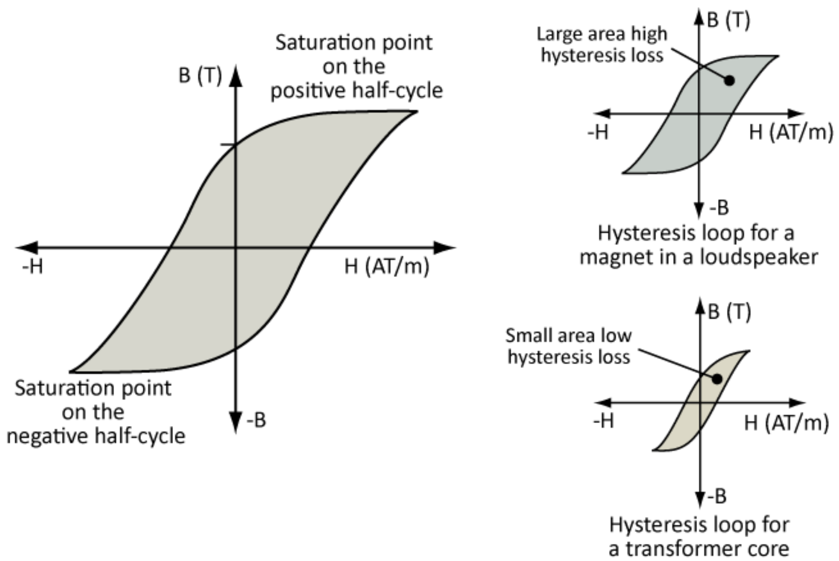
Eddy current losses are also reduced by the use of steel, which usually has a high resistivity and a silicon content of 4 %.

The second type of iron loss is called the **hysteresis loss**. This type of loss depends on the type of material of the core, as well as the frequency of the supply.

Hysteresis loss occurs whenever the magnetic state within a material is changed, and is directly related to frequency. Hysteresis losses are directly increased by an increase in frequency where; $P \propto f$.

When a coil has an alternating supply provided to it, the core material has a changing magnetic flux set up within it. Because the supply is alternating fifty times every second, then the magnetic circuit is also being forced to change fifty times every second.

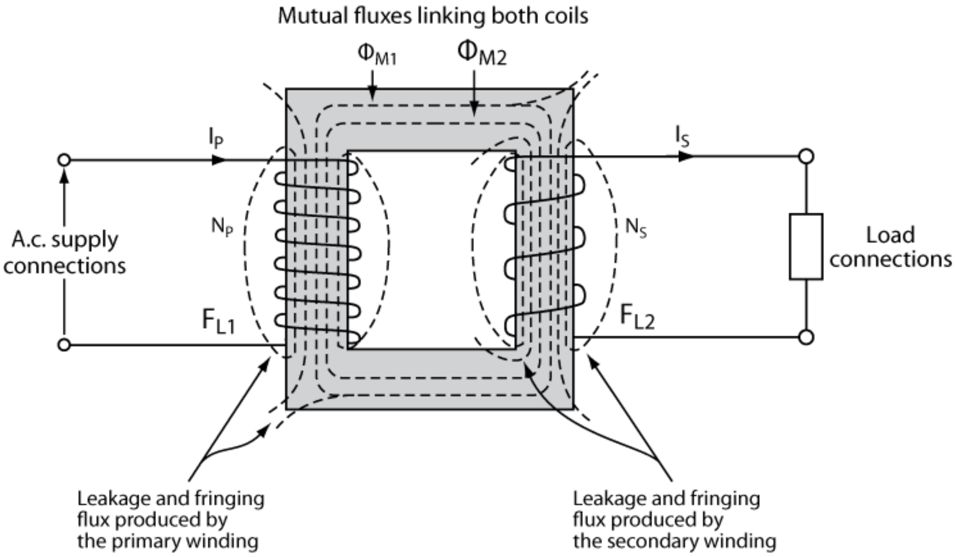
There is an inherent delay in the magnetic circuit magnetising in one direction and then back in the other direction as the current varies; it is this ‘lag’ that brings about the loss.



Here we can see the result of the total loop as the a.c. supply moves through its cycle. Notice that it is symmetrical. This loop continues endlessly as long as the supply is turned on. The area of the loop is a measure of the loss, the larger the area the larger the loss; the smaller the area the smaller the loss.

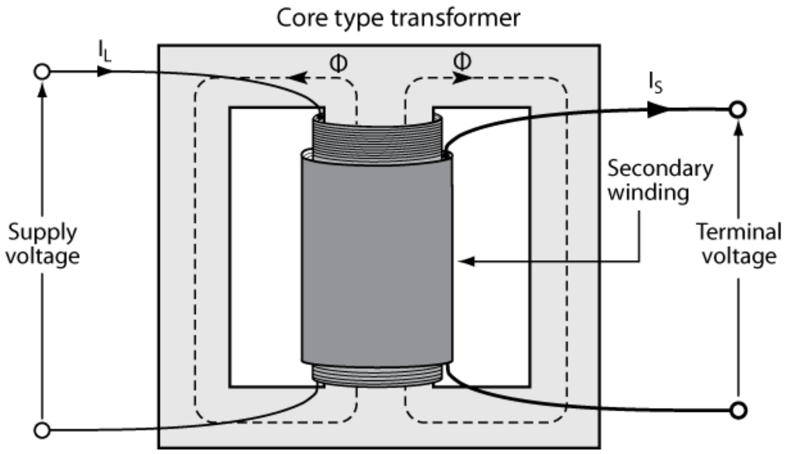
The loss is not only related to frequency, as previously stated, it is also increased if the maximum flux density is high and if the volume of the core is large.

The third type of iron loss is the smallest and is called **leakage and fringing**. Have a look below.



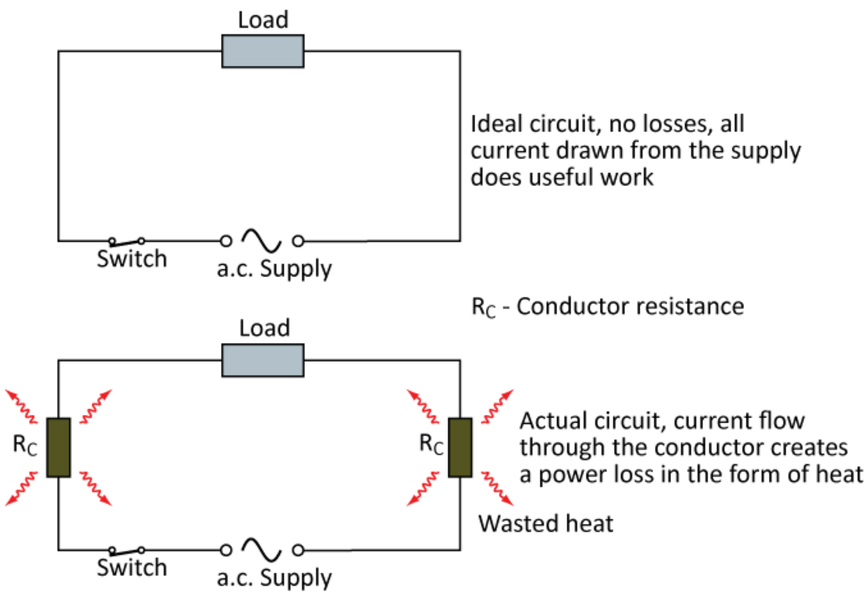
Fringing doesn't occur in toroids (doughnut shapes) but rather where there are edges. This means that in all power transformers there will be some loss from fringing.

Leakage occurs when some magnetic flux fails to be focussed in the core material but rather is created in the surrounding air. To reduce the leakage loss the two sets of windings are laid on top of each other.



Copper loss

The final type of loss is not caused by the magnetic circuit, but rather by the more obvious flow of current in both the primary and secondary windings. This loss is related to the heat given off when any conductor has current flowing through it. It is also sometimes called the $\left(I^2R\right)$ loss.



Copper losses are never affected by frequency. They are solely dependent on the resistance of windings etc.

Many losses cannot be changed. They are part of what makes up the piece of equipment, and as such, they just have to be accepted.

Exercise 6.

1) The frequency of a supply changes from 50 Hz to 100 Hz, what will be the effect on the eddy current, hysteresis and copper losses? [HINT: Consider not the actual values but whether the losses will increase/decrease/stay the same]

2) Name the three parts of a transformer.

3) A 3 kVA 50 Hz transformer has 200 turns on the primary and 480 turns on the secondary. If the required secondary voltage is 240 V determine:
   i) The supply voltage
   ii) Primary current
   iii) Secondary current.

4) If a transformer has a secondary current of 1 A, and primary and secondary voltages of 100 V and 240 V respectively what will be its' primary current?

7: Transformer types and their ratings

In this session the student will:

- Gain an understanding of transformer types and their ratings.

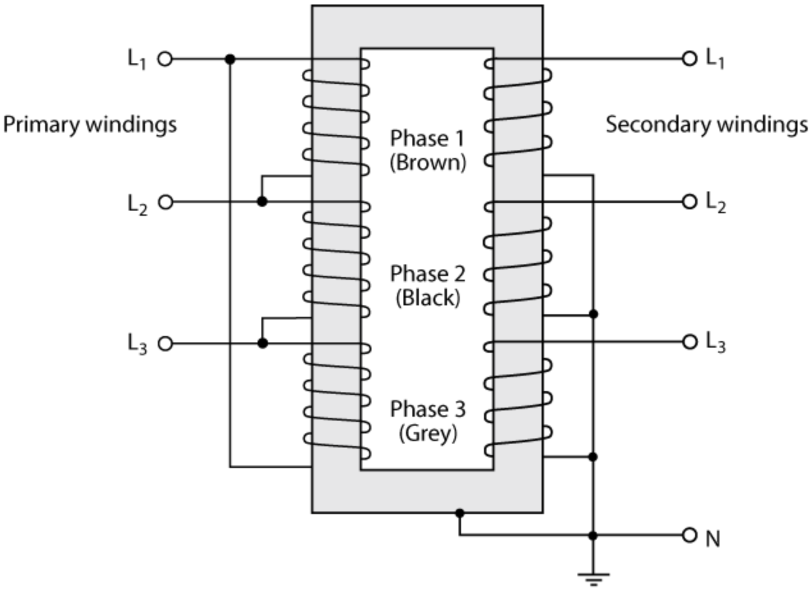
A **transformer** is a device that converts alternating voltage at one level to an alternating voltage at a higher or lower level (usually); although it can be used as an isolating transformer separating the supply voltage from the secondary voltage (no direct electrical connection between each side).

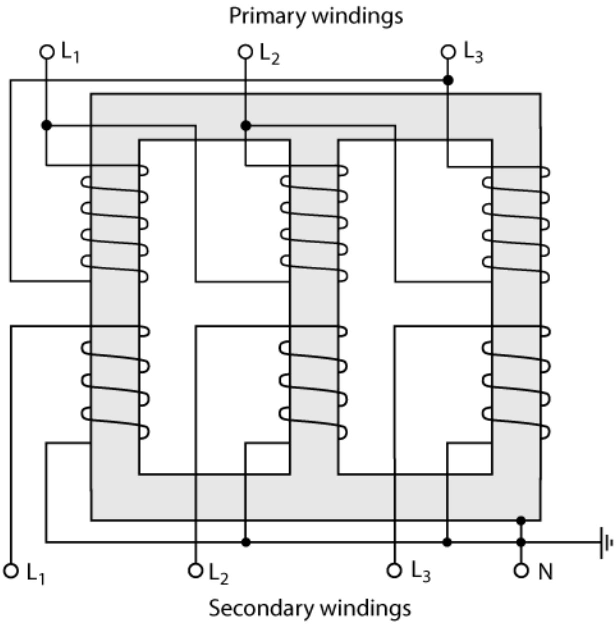
There are many types of transformers around, double wound, autotransformers, electronic transformers. Some are used in electronics, others for power transmission. They are an essential piece of plant in the electrical industry.

Power transformers

Power transformers are generally set to operate at frequencies of less than 100 Hz and are both efficient and heavy! Most of the work that we have considered recently has been based around single-phase transformers. In reality there are, of course three-phase transformers.

The set-up of a three-phase transformer is slightly different, although the principle of operation is the same. As you would expect there are a series of three windings on the primary side and the secondary. Have a look at the diagram over the page.



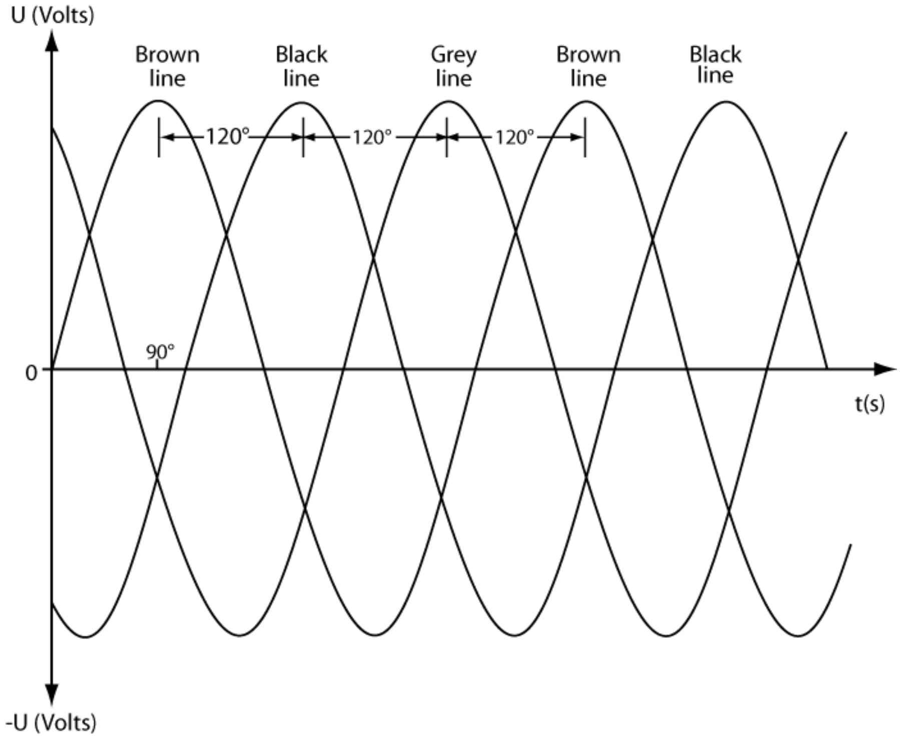


It is common for the primary winding to be connected in **delta** and the secondary winding in **star**. This arrangement provides a variety of options when wanting different voltages.

The windings of the transformer are either sandwiched or wound on top of each other when they are on the limbs of the transformer. This helps with the distribution of magnetic flux.

With a three-phase supply, there are effectively three supplies all rising and falling at different times. You may wonder how it is that the secondary windings can differentiate between the varying magnetic fields that must be produced.

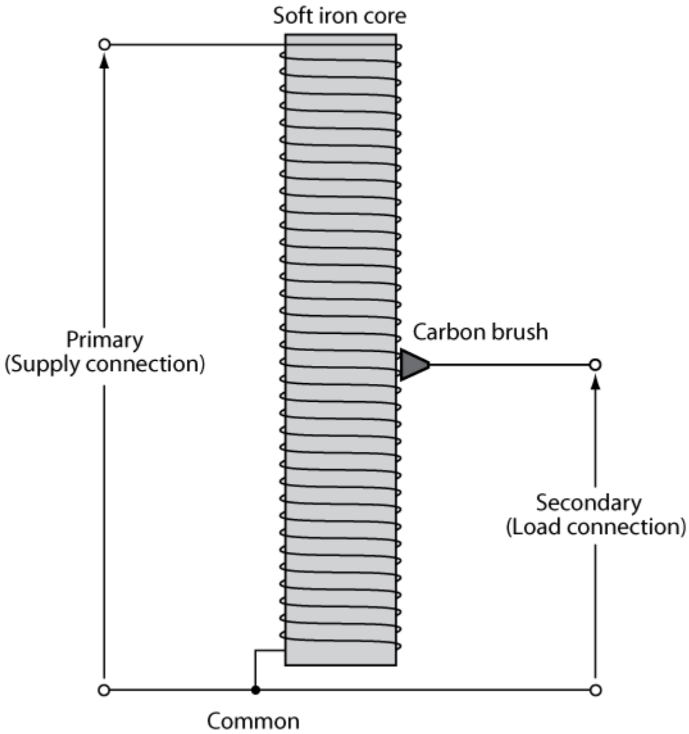
The reason that the secondary windings can differentiate between the varying magnetic fields is that there are three magnetic fields, each produced by a particular phase, and these fields are at a maximum and minimum at different times.



You should remember however that we are still operating on the basic principle of mutual induction. It doesn't matter whether we are looking at a single-phase or a three-phase supply.

Autotransformer

There is a variant on the standard transformer. The autotransformer is different from the normal double-wound transformer in that there is only one winding.



To get different voltages there is no reduction in the number of turns on the secondary but a direct connection to the coil at a particular point.

The particular advantage of this type of transformer is that you can reduce the overall size of the transformer.

There is one major disadvantage with this type of transformer. Under fault conditions, the full supply voltage can appear across the secondary. This means that this transformer can't be used for isolation purposes. There is, in effect, no electrical separation of the primary from the secondary.

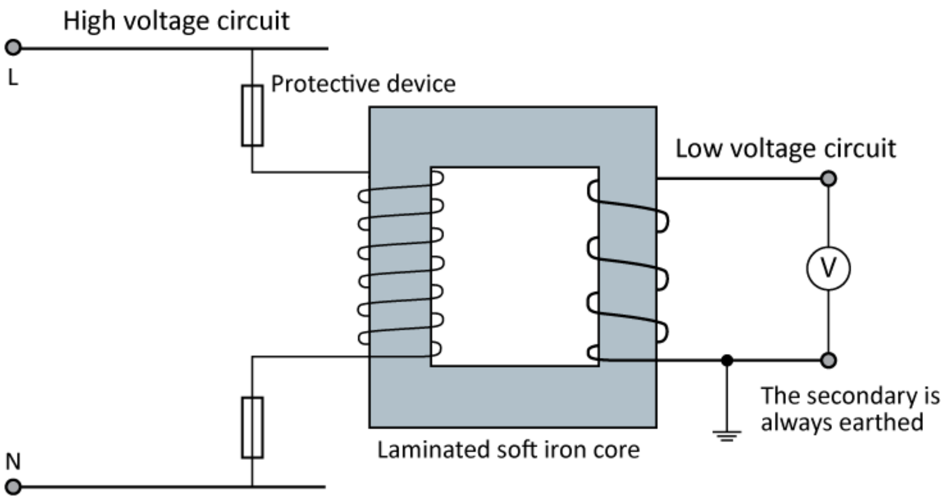
Instrument Transformers

In large power circuits it is not possible to measure either the current or voltage. This is because the meters used would have to be very large for the levels of voltage and current. In addition, the effect that the meters would have on the circuits would be too great.

When measuring instruments placed in the circuit are not appropriate, such as when there are large voltages and currents, then '**voltage transformers**' and '**current transformers**' are used.

Voltage transformer (VT)

The voltage transformer is very similar to the normal double wound transformer. However, its primary side is rated at the supply voltage (lots of turns on the primary) that is to be measured whilst the secondary is rated at 110 V.



Above we can see how the VT would be connected. You should note that there is a direct connection to the supply and the primary is protected via fuses. You should also note that there is only one instrument connected to the VT.

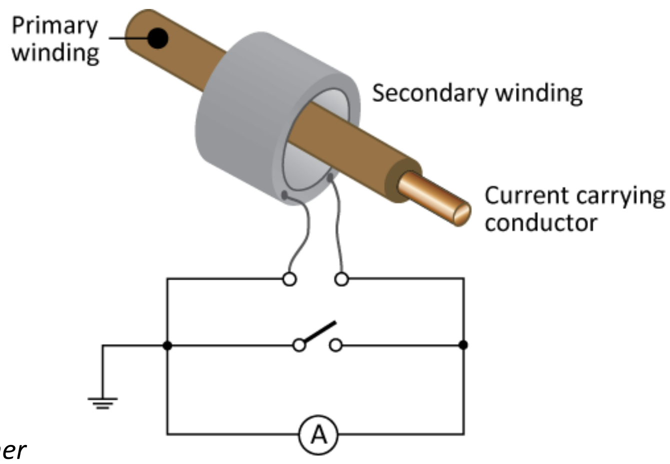
Current transformer (CT)

This type of transformer uses the supply conductor as the primary winding, as you are aware every current carrying conductor has a magnetic field surrounding it and the CT makes use of this.

Where the VT was a step-down transformer, the CT is a step-up transformer, in terms of its primary to secondary turn's ratio. With the CT, there is commonly a 200/5 ratio. This means that for a maximum of 200 A on the primary there will be a 5 A output on the secondary.

Tong Tester or Clamp tester

Typical current transformer



Current transformer connected into a circuit

Above we can see a very simple type of CT. Notice that the ammeter is connected across the secondary of the transformer. The normal rating of the secondary is 5 A.

In practice, however, the switch is not usually placed in the circuit as working on live conductors has to be justified in accordance with the Electricity at Work Regulations 1989 (EWR), and is not recommended under most circumstances, so the supply would usually be turned off (isolated) before working on an instrument.

The problem with CTs is that if the ammeter is removed and no shorting of the secondary takes place, then a very large voltage will appear across the open terminals. This rise in voltage is in the region of kilo-volts. Circulating magnetic currents will also increase the heat in the transformer.

The bar primary type of CT can measure thousands of amps, whilst the smaller type with a wound primary winding are rated at 10 A, 15 A, 20 A, 30 A, 50 A or 75 A. The secondary current ratings are 1 A, 2 A or 5 A.

Transformer ratings

Transformers are rated in **volt-amperes** (VA), **kilovolt-amperes** (kVA) or **megavolt-amperes** (MVA). The reason for the use of VA instead of W (watts) is the need to take account of the power factor of the load.

- True power, measured in watts, depends on the actual load connected and is a measure of the useful power.
- Apparent power, measured in volt-amperes, is a measure of the current demand and the voltage, and varies according to the power factor of the load.
- Reactive power, measured in volt-amperes reactive is a measure of the power absorbed by the inductor and then given back to the supply.

If the power factor improves to a value nearer one or unity, then the apparent power comes closer to equalling the true power. If the power factor moves away from unity, then the apparent power rises along with the current demand.

We rate transformers in VA to show the maximum demand that they can take. If we allow a poor power factor then we end up needing to increase the size of the transformer just to take account of the losses due to poor power factor.

Exercise 7.

1) How does an autotransformer work?

2) What are the key problems associated with autotransformers?

3) Why are CTs and VTs used and what are the problems associated with them and the precautions that must be observed?

4) Draw how a load of 11 kV and current flow of 300 A might be measured.

B&B Training Associates

Engineering Learning Materials

Attempt all questions.

All marks are shown in the right-hand margin.

1). What are the relationships between voltage and current in star and delta systems? 4

2). For a star-connected system determine the line values for the following: 5

Phase current	10	12.5	5.6	124	215
Phase voltage	110	230	24	750	12

3). For a delta-connected system determine the line values for the following: 5

Phase current	10	12.5	5.6	124	215
Phase voltage	110	230	24	750	12

4). Briefly describe the operation of a transformer? 2

5). Name three types of transformer and comment on where they might be used. 6

6). A 3 kVA transformer has a primary voltage of 230 V and a turns ratio of 4.6. What is the secondary voltage, the primary and secondary currents? 6

7). Name three types of loss inherent in transformers. 3

8). What effect does frequency have on the losses in transformers? 4

9). Show how you might measure the voltage and current for a supply drawing 300 A at a voltage of 3.3 kV. 4

10). What is the principle of operation of a coal-fired power station? 4

11). Explain how electrical energy is transmitted around the U.K. 6

12). Why is power transformed to very high voltages when being transmitted? 4

13). Why are power cables carried on pylons rather than being buried? 2

14). Why is a neutral conductor provided for a typical installation? 2

15). What are the benefits of a three-phase system? 3

Total marks 60