Traction Current

Earths and Sectionalisation

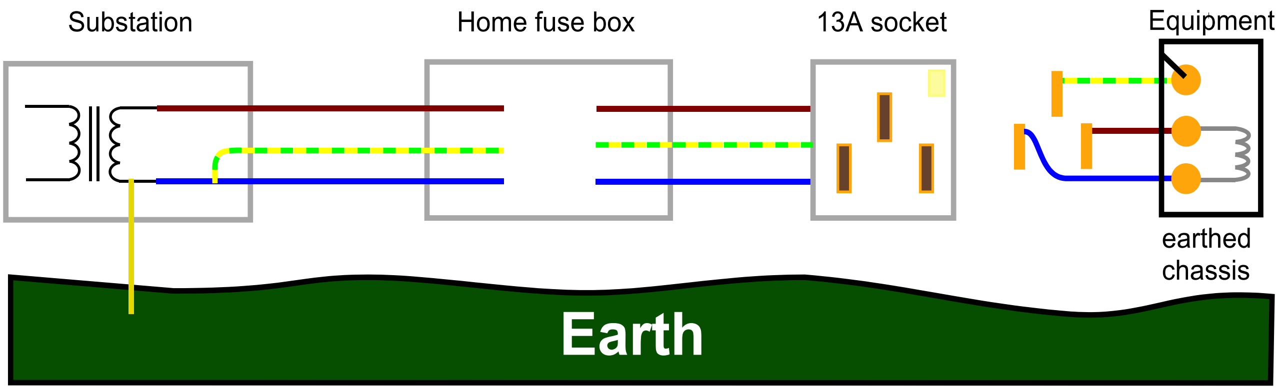
07/09

Earths and sectionalisation

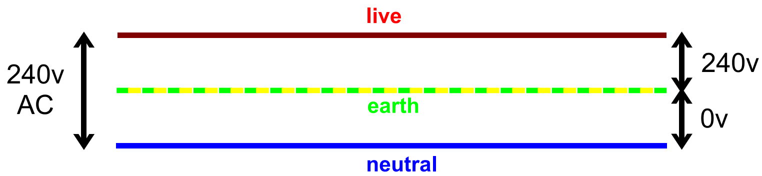
This booklet is an introduction to two traction current items - earths and sectionalisation. Earths are something that happen on a regular basis, for whatever reason, and can affect the running of the service. The basics of earthing in general are covered, together with what earths are in relation to the train service.

These notes are not meant to be technical. The technical amongst you will realise that a few liberties have been taken, a sort of poetic license if you like!. Rather, they are designed to show the basics in a simple way.

Basic earthing principles



In a household supply, there are three wires: Live, Neutral and Earth. The earth is connected to the metal chassis of equipment if the equipment needs to be earthed. At the substation, the neutral and earth wires are connected together, and there is also a connection with the earth itself via a buried earth rod at the substation. The soil (or earth) conducts electricity and is often used as a path for the current. This is where the earth wire gets its name from. In the USA, it is called Ground.

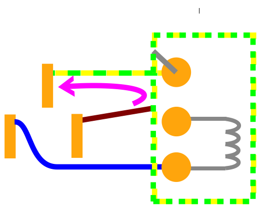


The normal flow of current is through the through the live and neutral wires. If you were to measure the voltage between live and neutral and live and earth, the reading would be the same (around 240v for the household mains). In theory, the reading between neutral and earth would be 0v, but this can't be guaranteed.

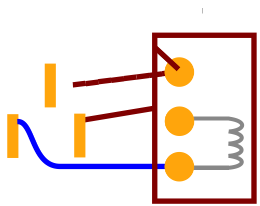
Although the ground is shown as the earth path, it can be many things that are conductive to earth in one way or another that can form a path to earth. For example concrete, wood or metal that are touching the ground can be conductive to earth if touched by any part of the body at the same time as another part of the body is touching a live wire. The amount of current that flows (and how severe the shock) depends on many things, but it basically depends on how good the conductivity is between you and earth. Standing on wet concrete and touching a live wire is more likely to pass a heavier current through your body than if you were standing on dry concrete. Likewise, you are more likely to get a shock if you are standing in your bare feet, than if you were wearing rubber soled shoes; rubber being a good insulator.

Many metal objects are earthed in one form or another. Some are earthed because they go into the ground - such as a metal post that has been buried in the ground or metal water pipe. Others are earthed because they are “bonded” to earth. I.e., the metal is connected to earth via a cable. This is often the case with pipe work, sinks and baths in a house. In the same way, the metal chassis on equipment such as a washing machine, electric fire, etc. is connected to earth via the earth pin in the plug.

Because there is a real risk of electrocution if you touch something that is live whilst another part of you is touching an object that is earthed, or even just standing on something that is connected to earth, such as the ground itself, most equipment that has a metal chassis or covering is earthed.

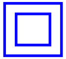


Short circuit between live and earth
the live wire is touching the chassis
current flows to earth via the earth wire



Open circuit on the earth wire
There is no earth connection at the socket or the earth wire is disconnected somewhere
The chassis is live and a person touching it could be electrocuted

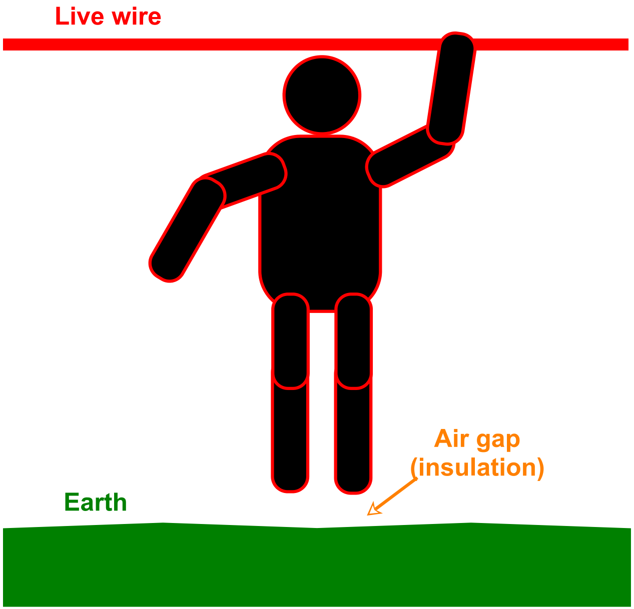
The purpose of the earth wire is to “earth” equipment etc. so that if there should be a short circuit between the live and the chassis in the equipment, the earth wire will conduct the current to earth. If the live wire comes into contact with an earth, there is a short circuit and the fuse will blow or MCB trip. If the live wire comes into contact with the chassis and the chassis is not earthed, the chassis becomes “live”. If you touch it, the current will run from the live wire through the chassis and you to earth. Electricity will normally take the easiest path to earth, or “the path of least resistance” as the saying goes. If the chassis is correctly earthed, there will be very little resistance and the electricity will flow straight to earth via the earth wire.

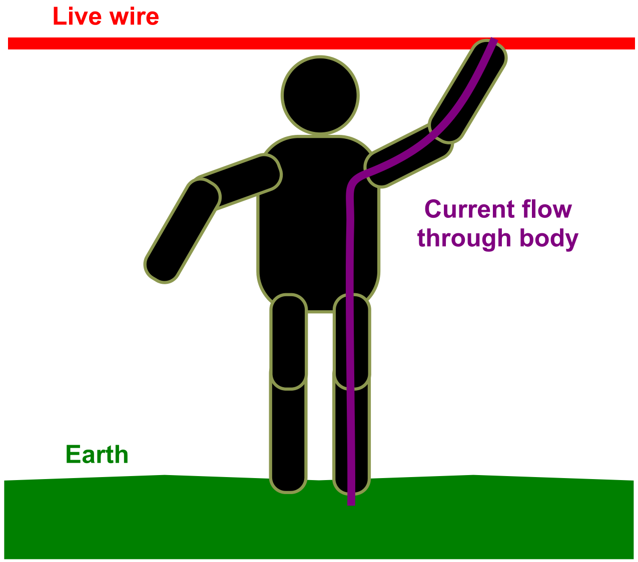
Some household appliances or tools, although metal, may not be earthed. These are double insulated and there should be no way that a live wire can come into contact with the chassis. These normally have the double square symbol on them: 

As long as you are not earthed in any way, you could touch a live wire and not be affected because there is no path through you to earth for the current to flow. You could hang suspended from a live cable and it would have no effect - there would be no path for the current to flow because the air between you and the ground would be an insulator. (This is not guaranteed as, at higher voltages and in humid conditions, the air could become a conductor. (lightning is conducted through the air). This is why it is important to stay away from high voltage cables, such as overhead cables and catenary wires).

If you were standing on the ground with well insulated shoes and touched a live cable it would probably have no effect as the shoes would insulate you. You could walk along a current rail barefoot (or even naked if it took your fancy!) and it would have no effect on you as long as you didn’t touch the ground or anything else - there is no path to earth. However, if you still had one foot on the rail and touched the ground with the other foot, the path between the current rail and the earth would then be made through you and you could be electrocuted.

It’s a similar reason why you see birds sitting on the overhead pylons and cables, or standing on the current rails without any ill effects - there is no current passing through them.





The person is hanging from a live cable. There is no current path through them because they are insulated from the ground.

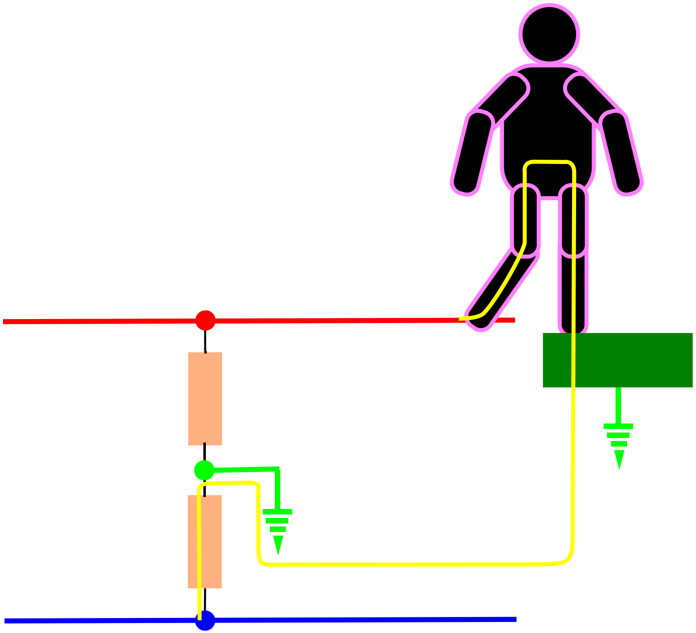
Their body is live, and should they come into contact with an earthed object, current will flow through their body.

The person is touching a live cable. They are also earthed via the ground.

Current flows through their body between live and earth. Shock or electrocution could occur.

Their body is live and although they are earthed, it is still possible current could also flow through them to earth via another path.

Because the person could be live, you should never touch anybody you suspect may have been electrocuted unless you are certain they are away from the supply, the supply is off or, in emergency, you use something that is dry and insulating to move them with.



Standing with one foot on the positive rail and one foot on the ground.

Unless you are well insulated through your shoes, your body can conduct electricity to earth. In fact, your body is creating a positive earth. The current is flowing from the positive supply, through you, through the earth, through the resistor, to the negative supply.

Depending on how much current is flowing, you could easily be electrocuted.

The same principle applies if you were standing with one foot on the negative rail, except you would be creating a negative earth..

Years ago as a Shunter, and before the company shoe issue, like many people I used to regularly step on the current rails when when crossing the track to pull the points levers. However, I learnt my lesson one day when I stepped onto the positive rail in the rain one day and got a shock. Being wet, my shoes were no longer a good insulator and became a partial conductor, completing the path between the positive rail and earth through me.

The amount of current that can flow through the body depends on various things, such as the voltage, the resistance of the body, the resistance of the current path from source to earth etc.

Some materials have a high resistance and act as insulators - PVC, rubber, porcelain, etc.
Some materials have a low resistance and act as conductors - most metals.
Other materials are in between.

Some materials can change their resistance / conductivity, depending on different situations.
Paper can act as an insulator when it is dry, and conduct when wet.
Pure water may not conduct electricity (it used to be taught that the fire extinguishers on the trains were safe to use near the 630v traction current rails because they contained de-ionised water). Normal water, because of the impurities it contains, can act as a conductor, although how well it conducts depends on its resistance.
Rain water and flood water etc. are full of impurities and can therefore conduct electricity. This is the reason why traction current is switched off if floodwater reaches the bottom of the negative rail (which is lower than the positive rail). Flooding also causes problems for the signalling because if the water is touching both running rails, it can effectively short out the track circuit in exactly the same way as if a train was on the rails. This causes signals to remain at danger or, in certain circumstances, to "bob".

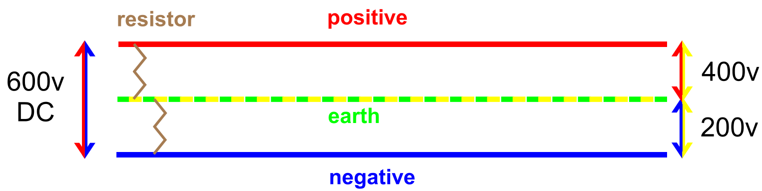
In dry conditions, air acts as an insulator. In humid conditions, the moisture in the air can act as a conductor. Even if the air is dry, it can still act as a conductor at very high voltages. This is the principle of how a spark plug works. The high voltage breaks down the resistance of the air causing an arc (or spark) to jump across the terminals.
An even better example is lightning. Given the right conditions, static electricity builds up in the cloud, positively charging it. When the voltage reaches a certain point, it is high enough to break down the air resistance and jump across to a negatively charged cloud (creating sheet lightning) or to the negatively charged earth (fork lightning). Lighting has a voltage of around 1 million volts. The lightning is the spark. When you create a spark by touching two wires together, it makes a noise light a short crack. Thunder is the noise made by the lightning spark - the "crack of thunder".

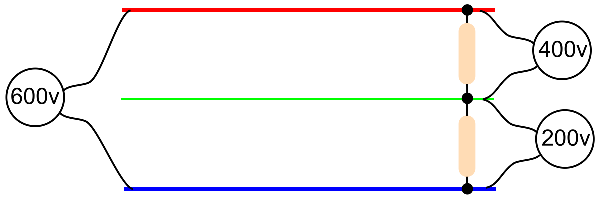
On the tube

The Underground has traction current supplied to the trains at 630v DC. This is a nominal voltage and can vary and may often be more like 600v. For convenience, in the readings below, I have used the more common figures of 600v, 400v, and 200v that are used within the electrical department.

The traction current supply arrangements are different to the domestic supply.

There is no direct connection to earth, like in the domestic supply. Instead, the positive and negative supply is connected to earth via bleed resistors to create a potential difference. Basically, this means that three different voltages can occur, as shown in the diagram. One of the advantages of this system is that when there is a short circuit to earth it does not affect the running of the trains or other equipment. More importantly, it means that if there was a short circuit between the positive and the chassis of the train, it would not be the full 600v.



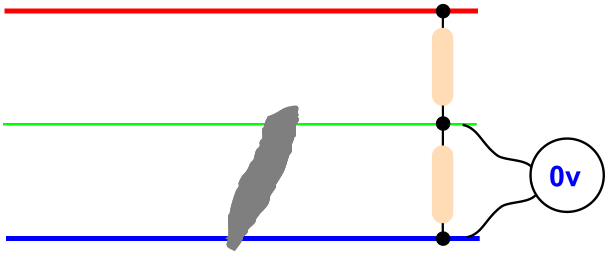


diagrammatic view of the normal voltage readings

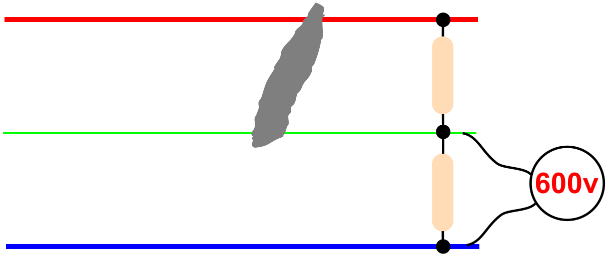
An earth connection can be:
the chassis of the train
the tunnel
a running rail
an earth on fixed 630v equipment
etc.

If you were to measure the voltage between positive and negative, that would give you the full 600v.
If you were to measure the voltage between positive and earth, that would be around 400v, and around 200v between negative and earth. These voltages are approximate and can vary in different circumstances., especially in open sections during wet weather.

If there is a short circuit between the supply and earth, this is referred to as a positive earth or negative earth.
The cause of the earth has to be identified. Equipment detects where the earth is. An earth will be shown as being somewhere in a sectionalisation area. If the earth moves from one sectionalisation area to another, the most likely cause is an earth on a moving train. If the earth is static and remains in one sectionalisation area, the likely cause is an earth on the track or fixed equipment, or a stationary train if there is a train stabled somewhere within that sectionalisation area.



Short between negative and earth causing a full negative earth



Short between positive and earth causing a full positive earth

Meter readings taken between the earth and negative supply during earth faults.
A partial negative earth may give a low reading
A partial positive earth may give a high reading
(These figures are given purely as an example and in reality may be different)
Equipment, based on the meter reading, is used to detect when there is an earth on the section

Earth on a train. The cause is normally the supply shorting out to the chassis in one form or another. The path to earth is from the chassis, through the wheels, to the running rail. On newer stocks, the train detects an earth and closes the main contactors on that car. This is like turning off a mains switch and the 630v equipment that is fed from that car is isolated. If the earth is between the shoes / receptacle box and the contactor, the only way that this can be isolated on the running line is by lifting the shoes that feed that car. However, it is very unlikely that a specific car can be identified. A common cause for this in the past, was a loose pigtail connection from the shoe that shorted against the chassis or tunnel wall.

Static earth. There can be various reasons for a static earth. A metal obstruction on the track shorting out the current rail to the running rail, or the positive rail to the metal tunnel wall. The positive rail is quite near the tunnel wall. Sometimes a can can get caught between the positive rail and the tunnel wall. Eventually the current flowing through the can may melt it and the earth will disappear. A shoe that drops off can short between the positive rail and the side of the running rail / chair. A faulty insulating pot (that the current rail rests on) may cause an earth between the current rail and the sleeper (and thus to earth). A fault on 630v equipment can also cause an earth. Sometimes there can be other indications of a possible earth that help to pinpoint where it is. . A driver might report arcing on the track, or there might be a smell of burning.

The important thing is to ensure that there is never a positive earth and a negative earth in the same sectionalisation area. A positive earth and a negative earth together is like having a 630v short circuit. Several thousand amps current may flow. Depending on the circumstances, this may not be enough to trip the circuit breakers and switch off the current.

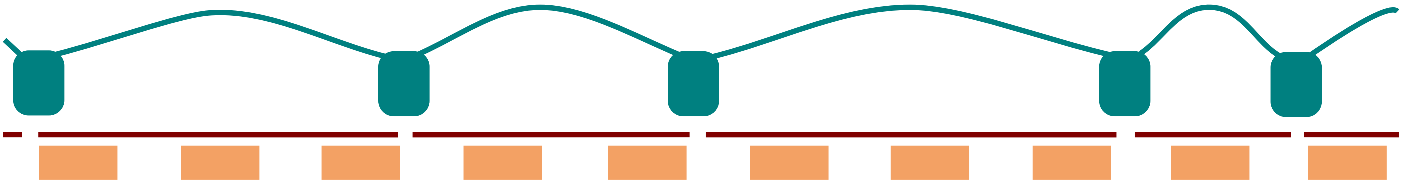
SECTIONALISATION - the supply

A train needs traction current to move. A substation supplies this current. Only one substation is needed on a line and this can be connected anywhere on the line.

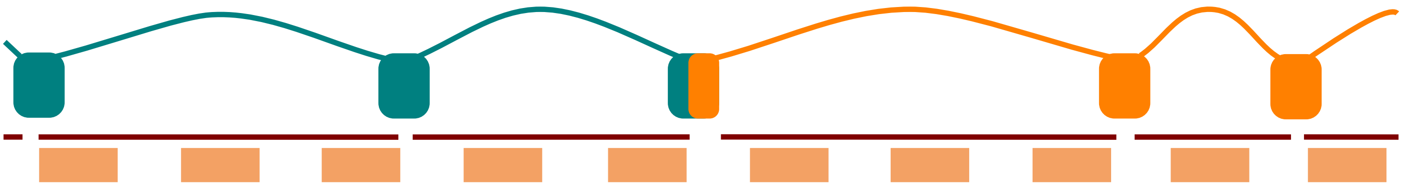
However, there are disadvantages to this. Like all conductors, the current rails have a resistance. This resistance will limit the amount of current that will flow. Although this resistance is small, it can make a lot of difference over a long way. The further a train is from the substation, the less current may be available to it. Trains use a lot of current when motoring. The more trains being fed from the substation, the more current will be required. The higher the current, the more expensive the equipment such as switches and cable along the line. Eventually it gets to a point where it just isn’t practical to use this method.

One way to improve this would be to put a substation at each end of the line - this would divide the required current between the two substations. This is fine for a short line, but more current is required if many trains are to run. In reality, what happens is that substations are provided along the length of the line in order to provide sufficient current. This also means that, should there be a problem with a substation, it will not normally affect the line as adjacent substations may be able to supply the additional current.

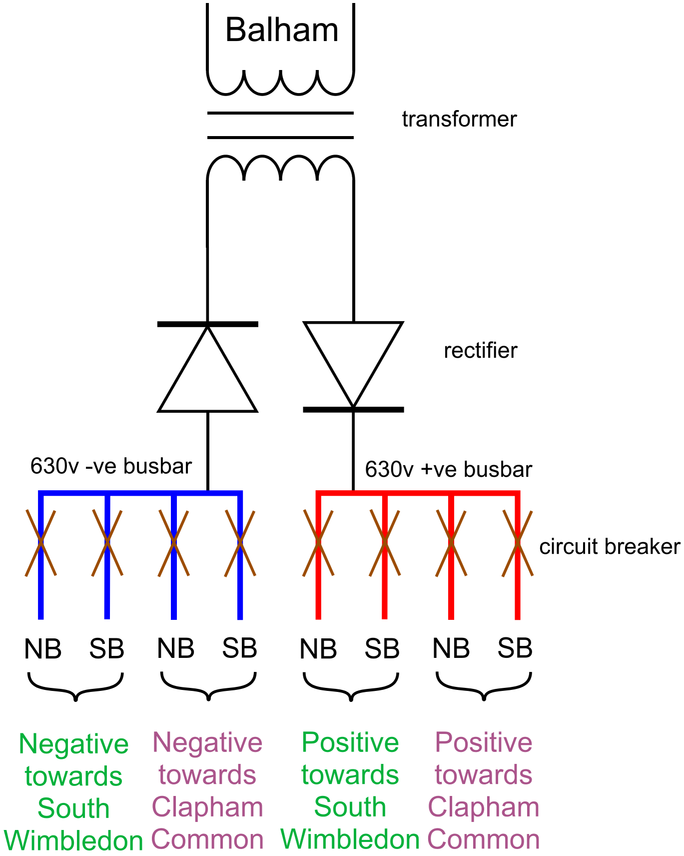
Originally, most sections were joined together electrically via the substations. This meant, in theory at least, that current could flow from one substation to any other substation on the line, NB and SB. This gave problems in that a fault, such as earth anywhere on the line would affect the whole line, even though the line was divided into sections. This could be potentially dangerous, especially if there was a positive earth and negative earth at the same time.

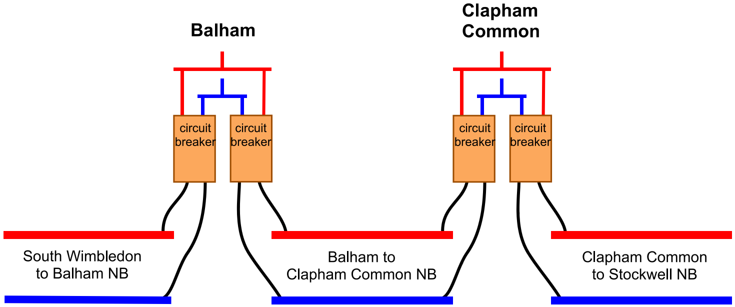


To solve this problem, all of the underground system was divided into **sectionalisation** areas. Each sectionalisation area contains a group of traction current sections and each group is physically isolated from the other in the substation (although it may be possible to join the two sectionalisation areas together if required). If a fault occurs, it will be contained within that sectionalisation area. The rail gaps between sectionalisation areas, known as sectionalisation gaps, are long enough so that they can't be bridged by the shoes on a car. That way there is no chance of two sectionalisation areas accidentally being connected.



On the Northern Line, the running line is divided into six sectionalisation areas, and the five depots / stabling sidings also have their own separate sectionalisation.



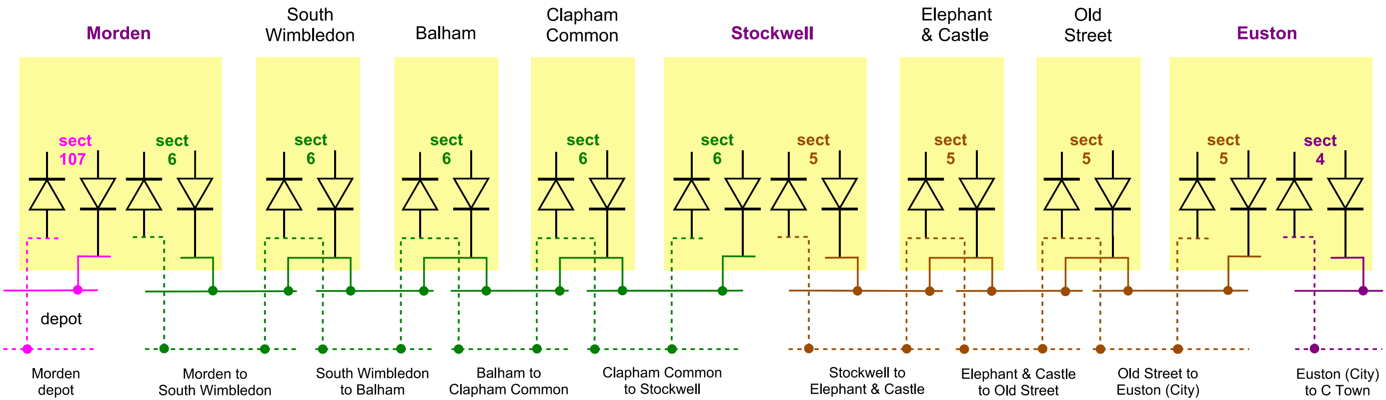


An example showing three NB traction current sections and their connection

A typical substation, showing the 630v supply. High Voltage AC is transformed and rectified to 630v DC traction current and sent to the busbars. The substation feeds the NB and SB current sections ahead and to the rear. The feed is via circuit breakers which can be opened as required to switch off the supply. All the negative feeds are joined together and all the positive feeds are joined together via the busbars as long as the circuit breakers are closed. there may be other feeds taken from the 630v busbars, such as to station equipment etc.

The actual number of rectifiers and other equipment may vary. The simplified layout of a substation and the current sections shown here is used purely as an example. The actual layout may differ slightly.

Sectionalisation areas Morden to Euston



The circuit breakers are not shown for clarity
The solid line is the positive feed, the broken line is the negative feed.
This diagram shows the NB traction current supply. The SB traction current supply is exactly the same, the 630v feed to the current rails come from the same busbars as the NB feeds.

As can be seen, there is a connection between all the substations in a sectionalisation area
Although there are rail gaps at each substation, the bus bar in the substation bridges the gap

Theoretically, as long as all the NB circuit breakers are closed, current could flow from the Morden substation, through the bus bar at each substation as far as Stockwell

Because Stockwell feeds two sectionalisation areas, there is no connection between the two in the substation. There is a large rail gap (called a sectionalisation gap) to ensure that the shoes of a car passing over the rail gap cannot bridge the two sectionalisation areas.

An earth that occurs anywhere in a sectionalisation area, will affect all of that sectionalisation area

A fault in one sectionalisation area cannot be passed onto another sectionalisation area in normal circumstances (e.g. coupling switches not closed)

Northern Line traction current sectionalisation and substations