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[00:00:01] Hi and welcome to this introduction to earthing. My name is Ian Griffiths, I am the principal consulting engineer here at GreyMatters and I am delighted that you have chosen to take part in this course.

[00:00:16] Now, whether you are an old hand or new to this topic we will take you from zero to hero in nice easily manageable bite sized chunks. We found this approach works really well because in a modern day busy schedule as it is difficult to get large amounts of time without distraction or demands; and when things are broken down into smaller chunks they become easier to absorb, easier to learn and we naturally learn more - hopefully in a shorter time. So, don't worry if you are new to earthing or new to the electrical engineering discipline, what we aim to do in this course is to learn about the fundamentals intuitively.

[00:01:01] So, what are we going to cover? Charge, the basics about voltage, current, resistance, Ohm's law, all that good stuff. The earth electrode (or the ground electrode), geology and what a key role this has in earthing design. We will also touch on fault theory, some of the international standards, testing methodologies, and most importantly safety. So, we will also cover why these elements are important as well as what to look out for, what does a good earthing design look like, what does a bad one look like, for that matter, and the applicable standards that need to keep on the radar.

[00:01:52] So, once you have completed this course, you might not be an earthing guru at the first attempt, but do take the first step, take control, be comfortable participating in conversations about earthing during project meetings, for example.

Understand the basics at an intuitive level which will serve you well to give you the credibility and command of the subject that you may need as well as appreciating the practicalities of what a good earthing design should look like and what to expect from the people that are delivering that to you. And if you are the person that's on the journey to delivering earthing designs, then take this first step and understand the basics. So, let's get started.

Session 1: Back to Basics electricity

Welcome to the session. This session is about the basics of electricity.

[00:00:01] Okay, maybe this is your first exposure to anything electrical, which if that is the case, then this segment aims to strip back, back to basics to understand on an intuitive level what is electricity, what are constituent parts, how does it work? Although, at this point in time, we are not going to be doing any calculations or anything like that so don't worry about that, this is just purely to understand and get the basics.

[00:01:00]

This session takes about 10 minutes and there will be a quiz as part of it just to check that you have understood the key points. So, feel free to pause the video at any time, pick up any points that you need to drill down into.

This session forms part of the introduction to earthing module. As previously mentioned, the aim of this session is to strip back and provide you with a building block of awareness in case you have not met this subject in your career so far - so nothing too heavy at this stage.

So, let's begin.

[00:01:30] Electricity is made up of atoms which make up materials, materials and a charge. This charge can be positive or negative and we know some materials made up of atoms can be more useful as conductors than others.

Copper for example has a nucleus of 29 protons, as you can see here and surrounding it you have got the electrons; 29 of those. But, one of them happens to be a free electron which flows through materials particularly easily. Now, I am not going to go into that at this stage, that's a subject or topic for another day. But, he is a slippery sucker, he can travel through pretty much any material bouncing from atom to atom as it goes along and this is what generates the flow is the movement of these electrons.

[00:02:29] So, what are the characteristics of this dude, the electron is that he is pretty grumpy, he doesn't have a very good attitude; in fact, he is very negative and I'd like to think about putting another electron of equally negative attitude together, what you get in between is a sense of tension or a pressure between them. And just as the magnets you put two like poles together they will repel each other, same way with electrons, you put two electrons or more electrons of same charge i.e. negative you get a force which repels them from each other which if we harness we can get a flow from, we can get some movement from, i.e. flow.

[00:03:22] So, we have covered two concepts here, the pressure or tension which we shall call voltage and movement, flow. It is probably useful to think of these two items in the context of a hosepipe. For example, the hose is the copper conductor and the water being the electrons which can flow through the pipe and the water pressure, the pressure behind it pushing the electrons along is the voltage.

[00:04:00] So, another useful way of thinking about voltage is if you take Mr. Electron and place him on the top of a mountain and we are going to roll him down that mountain. So, the thing that has quite a major influence is that obviously the height of the mountain that gives Mr. Electron that potential energy or voltage which is going to translate into a rolling speed or displacement as he goes down the mountain.

Now, one of the things; as he rolls down the mountain is he is going to knock into some trees and stuff. He has got work to do really to get to the bottom and these obstacles can be considered as resistances to his displacement on his way down. In electrical terms, these obstacles, like the trees, like the resistance of the wind as he travels through the air is often called load and in circuit terms, it is the resistance that is causing Mr. Electron to work and that working energy is called load. In real terms, this could be like a motor or a kettle etc.

[00:05:15] So, just to recap, we have 3 items now covered, voltage V, current A for amps, and resistance or load depending on which way you look at it which is represented by the Greek letter omega, again taken from a 18th century physicist, German physicist called George Ohm who developed Ohm's law. Now, Ohm's law is often represented in the form of a triangle where you have got V voltage over Amps times Ohms. Voltage over current multiplied by resistance. And this is one of the cornerstones, the foundational block of electrical engineering. So, it is a pretty useful formula or rule to learn and memorize, if you can. No problem, if you can't at this stage as long as you know where you can lay your hands on this rule. V voltage equals at the bottom of the triangle A times resistance. Voltage equals current times resistance. Now, we have go resistance Ohm equals voltage divided by the current amps. And then finally, if we are looking to find out what the current is in a particular circuit, then it is amps equals voltage divided by the resistance.

[00:07:00] There you have it, three mini equations that are used extensively in all things electrical. So, a really useful one to try and get your head around.

[00:07:18] Well done! This concludes this section.

Session 1: Back to Basics electricity

Let's just recap what we've covered here…

- Electricity - what is it - the electrons, atoms, and charge
- Little bit of an analogy on how to visualise voltage, what current is... as well as what resistance is, and
- we introduced the fundamental law from Geog Ohm - Ohm's law.

There is a short assessment after this just to make sure that you have understood the concepts and look forward to seeing you in the next session where we really start to explore Earthing or Grounding concepts.

Session 2

[00:00:17]

Welcome to this session. This session is about the earth or ground electrode part 1 and we'll discover what is an earth electrode, what is in an earth connection, and what are the major influencers around the mechanism surrounding the connection itself. So, this video is a relatively short one, it should only take no more than 5 to 6 minutes. This video forms part of the introduction to earthing module, it is intended to provide an awareness at an intuitive level so hopefully you shouldn't feel too uncomfortable with the content especially if this is your first time on these kinds of concepts. There will also be a quiz as part of this just to check that you have understood the key points. So, feel free to pause the video at any time, pick up any points that you need to drill down into and have some fun.

[00:01:09]

Okay, so let's start. What is an electrode? If you are in America, this might be called a ground electrode. However, the British term is an earth electrode. Now, that's interesting, there is no kind of difference between a ground electrode and an earth electrode. It is just those differences in language, tomatoes, tomahtoes, they all mean the same thing.

[00:01:30]

So, an earth electrode is an electrically conductive connection to the planet earth. So, you could imagine taking a spike of some sort and driving it into the earth and the interface between the earth and the spike there is a surface area where electrons can flow. It is pretty important that the connection itself is relatively low impedance or low resistance so that the electrons can pass freely through the electrode into the earth and vice versa. This means the electrode connection usually has to offer minimal resistance for that to happen in low resistance earthing systems which form the majority of all earth electrodes. So, you can already see that for the electrons to flow through this earth electrode connection the one thing that will have a major impact on its effectiveness is the geology, right. Why is this? Well, this is what the electrode is actually sitting in, the very medium so it stands to reason that if the geological structure is causing a blockage or resistance to the flow of electrons then the connection is going to be poor. This means the structure of the geology has a massive impact on earthing performance.

[00:02:55]

Now, the measure of a geology's ability to resist or facilitate electron flow is called resistivity, resistivity of the soil which we are going to look in a little bit more detail later in the module but for now we are sticking to the conceptual side of things. So, what are variables, what are the influencers within the geology that can make a difference? Well, we know that moisture is a pretty good conductor so the moisture content in the geology itself that's going to have a big influence. The other influencers include temperature because if the ground is going to be and when I say ground I mean the geology, if the geology is going to be frozen then this will increase the resistance so the ability for the electrons to flow through the connection is going to not be so good, it is going to deteriorate. So, we have to look at the seasonality of connections in earthing. Another influencer is the chemical composition of the geology. So, what kind of minerals are present, also what the acidity is, this doesn't necessarily affect the connection but it certainly is a consideration when you are looking at is the ground hostile to copper and copper is one of those materials that is used extensively in low resistance earthing systems.

[00:04:19]

Excellent, well let's recap what we have covered in the short session today:

1. One, the earth electrode provides an electrical connection to the underlying geology which allows the electrons to flow through the electrodes into the geology and vice versa.

2. Two, this means that the geology itself, i.e. the structure of the ground is super critical to earthing design, I can't stress that enough. And finally;

3. Three, for a given voltage the resistance of the electrode connection determines how the current will flow into the geology. This is particularly important when understanding how much energy is going to be discharged into the geology and how much is going to choose an alternative routes for example during an electrical fault - Now, we look at other return paths as part of the fault theory session later in the module and by then things should start to click together.

[00:05:16]

For now, well done. Have a go at the quick quiz and we will see you in the next session.

Session 3: Electrode

[00:00:20]

Welcome back to Part 2.

In this session, we are going to talk about "why" around the topic of electrode. That is to say, what is its purpose in the electrical systems design? What is its purpose in life? This means we are going to discuss safety, what the hazard is, what are the effects on the human body as a result and how the earth electrode does its job to try and make sure this doesn't happen?

Again, this is going to be done in an intuitive way, at this level the hard numbers will come later in the course, so you shouldn't find this content too intimidating even if you haven't been exposed to any electrical concepts in your electrical career yet anyway.

[00:01:00]

The video is going to take about just under 15 minutes and there will be a quiz afterwards just to check that you have grasped the key learnings before moving on. With that in mind feel free to pause the video at any time to go over any points as many times as you need. This starter learning is designed to run at your pace.

[00:01:19]

Okay, before getting stuck in just reviewing the previous video in the series, in part 1 we saw how important the geology is to the properties of the electrical connection between the earth electrode and the ground itself; which don't get me wrong is great but why do we need an electrode in the first place?

Well, the purpose of the electrode is to provide two fundamental functions:

1. For the electrical equipment to **operate** properly, and;

2. To control and **manage** where and how the electrical energy is dispersed during an electrical problem. When I say electrical problem - in technical terms, we know this as a "fault". And for the purposes of this session a fault is defined as…*"an unplanned release of electrical current".*

So, the second function of the electrode can be summed up in one word - **safety**.

In order to understand safety, first of all we have to understand what the hazard is and it is pretty clear the hazard in electrical systems is electrocution. No surprises there! It is going to be worth a quick look of what it means to be electrocuted - What's happening? What are the process at work? Because this is serious stuff, a sudden *unplanned release of electrical current* is fierce. So, let's take a step back and look at the basics behind what happens when somebody is unlucky enough to get electrocuted.

[00:02:50]

Electrocution is the passage of electrons or current through the body. For this flow to happen there must be at least 2 points of contact, right? A place for the energy to enter and another place for it to exit. Otherwise, there simply wouldn't be a flow.

In the example we are showing a hand to hand scenario but equally this could be hand to foot, knee to hand, head to hand, head to foot. Basically, any two parts of the body - one that's in contact to the item causing the problem and the other forming a path to the electrons to return to the source.

So, with the 2 contact points in place you have got the setup for an electrocution to happen. Okay, let's simplify this picture a little bit and take Mr. Einstein out but let's leave one of his vital organs behind. Now, I guess you can see what is going to happen here, right? Those electrons are going to pass through the heart, all around the heart and the heart was never intended for this; it was never intended to take any external electrical impulse from outside its own little system. So, the burning question I hear you ask is how much can the heart take?

[00:04:05]

This was something that Professor Charles Dalziel studied back in the 50s. He was obsessed with finding out how much the heart could take before failure and failure for the heart is known as fibrillation. This is when it loses the ability to beat to a rhythm because it is interrupted in such a catastrophic way that over a very short period of time the heart gives up, it stops beating.

Now, unsurprisingly Mr. Dalziel didn't get too many volunteers for his studies but he actually performed many of the experiments himself, on himself. Yep, I am not joking here! But without his work, we simply wouldn't be where we are today knowing how much current at various points a body can withstand. So, we have got a lot to thank Mr. Charles Dalziel for - And before you ask, he lived to a ripe age of 82, so you know, he doesn't look like the experience had too much of a negative impact on him.

[00:05:15]

Sadly, that can't be said for all people. I am just reading some stats out from the HSE that reported on 6 percent of last year's 137 fatalities were a direct result of electrocution. What does this mean? It means that 8 people died last year in the UK. For the States this figure is closer to 450 and a whopping 1.1 million people die each year across the globe from work related accidents. Not all electrical, I get that but regardless of the number a properly designed earth electrode is something that can literally save lives. And this is something I am particularly passionate about that a good earthing design can and does save lives. So, the more people that know about this stuff the more people will not have to suffer such a horrific death.

[00:06:28]

Okay, so we have covered the hazard and its effects, now how about we take a look at the role of the electrodes in preventing this from happening. Firstly know this, an electrode can comprise of as little as a spike pounded into the ground to a whole ensemble of interconnected conductors, grids, vertical rods, plate electrodes, clamps, conductors, you name it, it can have it. So, here are a few types of electrodes that can be used to form a much bigger, more complicated form of arrangement which ironically can also be called an electrode.

[00:06:43]

So, we start with a conventional *vertical rod electrode*. This is usually driven into the ground but it can also be placed into a predrilled hole. But the key thing here is that it looks like a rod and it is usually oriented into the vertical plane.

The opposite of the vertical electrode is, you have guessed it, the *horizontal electrode,* which can take the form of a solid copper plate or lattice. So, if it is the solid type it can be known as plate electrode. Again, usually they are installed in the horizontal plane but not always.

The third type of electrode we are going to look at is the *grading electrode*. This is a simple conductor, usually copper that gets buried into the ground horizontally to help manipulate the surface voltages. Now, let's back up, surface voltages will be covered in another module.

Then the fourth type of electrode are usually a little bit more specialist, you have got the *chemically activated electrode*, and these guys are used for particularly difficult geologies and look like vertically oriented pipe, which means that they also need a predrilled hole to be installed in and the unit chemically saturates the immediate surrounding volume of soil with electrolytes and minerals which are designed to improve the conductivity of the soil surrounding the electrode.

Session 3: Electrode

There is also something called a *foundational electrode,* which utilises a structure's (unsurprisingly) foundation as part of the arrangement. So, in the foundation there might be some reinforcing bar in concrete and this can be incorporated with other conductors to provide another form of electrode.

Finally, an electrode can also be any combination of one or more of these types of electrode, because let's face it, the electrons that pass through really aren't that fussy so long as they have got a pathway to follow, they are happy. Whatever we humans might call these electrodes.

[00:08:50]

Now, the roles that all these electrodes have in common is two-fold:

1. one is to leak current. To leak the electrons that are created from the fault and to leak them into the geology itself.

2. Secondly, another role of the electrode is to *manipulate* the voltage of the surface that we stand on in a given location. And this is best shown in this image here.

So, let's run through what is happening in this image. We have got a high voltage overhead line which is attached to an earth electrode underneath the tower and there are two scenarios shown. One, where the person is touching the tower on the right hand side and the other where the person is simply just walking by - not touching the tower, just minding their own business.

So, it is pretty useful to know that these two scenarios are the **two fundamental risk scenarios** that earthing designers all over the world now have to consider as a key measure of a successful, safe earthing design. They are sometimes referred to as *stress voltages* but more commonly they are known as <u>*touch and step*</u>, or *step and touch voltages.*

Okay, so buckle up for this one, this could be a bit of a bumpy ride but don't worry, it will start to make sense, very briefly - because this is going to be covered in later modules - The electrode underneath the tower is doing two things, can you remember what they were? It is **leaking the current** from the fault. The voltage between where the person is touching the tower and the point at which the person is standing on the ground by the exit point - the voltage between these two points is reduced.

Now, without going into too much detail the voltage is reduced because the portion of the current is going to take the route of the electrode rather than the person. Now, why might this be? This is because the path through the person is at a higher resistance than the copper pathway provided by the electrode underneath so it follows that less of the electrons will take the path of the person and more and more will take the path down the tower leg into the electrode and this is what we want. We don't want the electrons to flow through the body; we want them to take alternative routes. Makes sense, right?

The second situation on the left hand side is where a person is just walking past by the tower but by chance they happen to be in the wrong place at the at the wrong time. Meanwhile, that might be because of a local lightning strike to the tower. Just imagine that, just walking past a tower, struck by lightning, all of a sudden this massive amount of energy causing a rise in earth potential that one strides difference is enough to create a significant voltage for current to flow up one leg and down the other. But in terms of earthing design thanks to Dr. Delziel's work a successful earthing design is one that will protect *the majority* of the human population from a fatal electrocution. Notice I say the majority of population. It is a sad fact that some people are more sensitive to being electrocuted than others. There is a probabilistic element to this.

[00:12:15]

Well, we have covered some ground on this one. So, let's just recap. We have talked about the electrode and its purpose in life. We have covered the various types of electrode and how they can be combined to create an overall electrode and I guess this squares the circle by protecting the majority of human life from the harmful effects of electricity by manipulating where and how the fault current is distributed.

[00:12:48]

So, that completes this session. Well done, as usual there will be a short assessment just to check that you understand the concepts presented and we look forward to seeing you in the next session.

Session 4- Earth Testing

Welcome back. In this session, we are going to talk about EARTH (or ground) TESTING. More specifically, we're going to be covering the Fall-of-Potential method of earth testing.

There are other methods but Fall-of-Potential (FoP) is by far the more commonly used method across the sectors. So, I'm going to define:

- 'what is an FoP earth test'
- How does it work (at an intuitive level - don't worry)
- What does an FoP look like in real life

[00:01:00]
The video is going to take about 25 minutes and there will be a quiz afterwards just to check that you have grasped the key learnings before moving on. With that in mind feel free to pause the video at any time to go over any points as many times as you need. This style of learning is designed to run at your pace.

As a reminder, before getting to far in - this session forms part of the **Introduction to Earthing**, so it is aimed at an intuitive level to provide you with an awareness of what goes into an earth test.

[00:01:36]
So… what is an Earth Test?

An Earth (or ground) test is *a resistance measurement of an electrode to determine the quality of the connection to the geology*, planet earth. Another term commonly used is connection to the 'general mass' of earth but it means the same thing.

[00:02:00]
This symbol for an earth or ground electrode (see video). Just to confuse things, this can sometimes be called *earth termination* or *ground termination*, depending on where you come from.

Now, there are a couple of things going on in that statement. Firstly, the electrode… from previous sessions we know an 'electrode' can be ANY arrangement of individual or combination of components, such as rods, plates, conductors, lattices, even foundations. These can form an electrical connection with the geology, which forms the electrode.

And secondly, the quality of this connection will determine how efficient/effective the electrode will be at allowing electrons to flow into the geology itself, which I guess makes sense, right?

[00:02:58]

So, summarising - What the Earth Test does for us is to quantify how good this connection is to the geology, by measuring the *'resistance'* of the geo-connection compared with or referenced to, the general mass of earth or to put it another way, planet earth.

What this means is that the earth test is a relative test. Given, the entire planet will have a baseline resistance and what we're trying to do is actually measure an incremental relatively small difference over and above that baseline.

[00:03:31]

Let's take a closer look - let's say you've got an Earth electrode arrangement in Europe somewhere. Now, I'm only showing a simple single individual rod for simplicity but remember, this could be a huge combination of grids, rods, foundations and conductors, so please bare that in mind… an electrode can be anything from a single rod, as shown here, to an complicated arrangement on a vast scale - the important thing to remember is that the *electrode is the connection to earth itself*. And it can use any combination of hardware to achieve that.

[00:04:08]

OK, back to the example. HOW are we going to measure this connection to earth?

First of all, we're going to insert two probes some way away from the electrode under test. One, we're going to call the '*Current probe*', because this one is going to be injected with a small amount of current. An important point about this current probe is it's really important to try and get as much distance between the electrode under test and the current probe itself.

How much distance will vary depending on the size and geometry of the electrode but a typical rule of thumb is that the current probe needs to be anywhere from 2.5 times to 10 times the largest dimension of the electrode. If the electrode is a single simple rod like this, then 10 times the depth should be an easy distance to achieve.

However, if the electrode is a grid spanning many 10's or even 100's of meters long, then one would take the diagonal distance of the grid, which could mean deploying the current probe 1 to 2 km's away from the grid itself. Or even further for that matter.

[00:05:22]

So, you're probably asking yourself - why? Why do we need to go out so far? If you remember from earlier, I said the Earth Test is a *relative* measurement, what we're trying to do, is measure the electrode's resistance relative or referenced to, planet earth, which means that we have to escape the localised electrical influence that the electrode has over the local patch of geology.

(There's quite a lot going on there and we're not going to go into too much theoretical detail, that will be covered in subsequent modules).

[00:05:58]
In order to do this we have to run the leads out PAST this zone or areas of influence. And get it into some dirt that isn't being influenced.

So, with the current probe in place. The second probe is the 'voltage probe'. This one will be moved incrementally between the electrode and the current probe. I should add this happens once the leads are actually connected to the probe and we usually start at 10% of current probe distance and then incrementally move, deploy and reinsert the probe at various stages between the current probe and the electrode, which you'll see later.

[00:06:40]
Once the probes are in the dirt, for their first measurement. The instrument can be connected via the leads. The Earth Test instrument can look something like this but what I'd like to do is show you what's happening in under the bonnet (or hood).

[00:06:58]
We've got a source of power (batteries in this case), which can deliver a controlled current to the current probe. We're call this controlled current, a '*signal current*'. Now, the signal current is nothing more than a bunch of electrons but they are organised in such a way that they have their own style or signature. This is so the instrument can differentiate the returning signal and not some noise from the electrode or electrical system.

The other part to the Earth tester is the voltmeter, which is (unsurprisingly) connected to the voltage probe. And this measures any minuet differences in voltage; however small.

OK - with the earth tester, the probes and leads in place we can now start and actually do a test.

[00:07:47]
What happens next is the instrument sends a signal current to the current probe. The electrons in the signal current disperse into the geology and cause a very small rise in potential which the voltage probe picks up, and registers as a voltage. This voltage is

the first part of the measured value. But we've only got the voltage, right? What we need is the resistance! So, how are we going to do that?

Well, enter stage left Ohm's law! We've got a known current (in amps) at a known voltage, the signal current. We've also got a voltage reading on the earth tester at the voltage probe, so, if we plug these into and apply Ohm's Law; what we'll have is a calculation to derive the resistance.

Thankfully, modern earth testers do all this for you, so, what you see on the tester display is the resistance value after calculation.

[00:09:00]
For a Fall of Potential earth test, this process is repeated numerous times moving the voltage probe each time and relocating it at a different space between the electrode and the current probe. And the reading is repeated.

What this gives you is a resistance 'profile' which can be plotted onto 2 axis graph, resistance (in ohms) by voltage probe distance. And when I say the probe distance, I mean the **voltage** probe distance. We'll come back to this after a short clip to see this process happening in real life.

[00:09:40]
So, let's take a look at the equipment that we've got laid out today. First off, we've got a table with a dielectric rating so that's always helpful and saves bending over and stressing your back. We've also got some earth testers. We've got a selection here - one that's got a GPS locational feature which is useful to know where you are when it comes to analysing the reports and the conventional DET2/2 which is very well recognised and accepted in the industry.

[00:10:35]
Moving on. We've got the distance measuring device so we know how far we're deploying the leads/probes. You can use a GPS but this works absolutely fine.

Dielectric boots. We'd only need if there was a hazard (impressed or touch). In this case we're not using them as there isn't a hazard.

Spare sets of patch leads and equipment for repairs.

A Backpack to put your drinks in, as it's a hot day. Or, sunscreen as necessary.

CAT and Genny (cable avoidance tool and signal generator) - now with FoP earth testing you are penetrating the ground; only a little bit, 3-4", but you still need to know what's under the ground. And it's also relevant for picking up conductive structures that might interfere with the actual readings themselves.

We've got the leads and the probes. A typical probe that comes with the instrument with 4mm shrouded banana connectors. The leads, silicon insulated type leads for flexibility.

You can use copper probes as well. There's no limits (other than they must be conductive) to what you can use for probes. Steel, is perfectly adequate. Copper, maybe a little lower impedance, which is even better.

A hammer (maybe). The ground is pretty tough today - it's dried out clay. So they won't hand push in. you might need a bit of persuasion with the hammer, that's what that's there for.

That's the equipment. So let's hook the stuff up and see what kind of results we get...

[00:13:13] - Pre-site 'Scan'

[00:13:45] - Setting out

We're just going to walk-out 50m. These reels are 50m a piece. One probe and we start walking out.

We need to escape the influence of the electrode. The electrode in this case is really small, maybe 0.5m or so. So we don't need to go out too far out but it's got to be a minimum of 2.5 times the diag distance or longest distance of the electrode up to 6-10 times the distance to escape the electrical influence depending on what the ground composition / structure is and its resistivity.

[00:14:50]
OK, so we've got the current probe deploy out to 50m. The next task is for the potential probe. That is going to be 10% (of the current probe distance) for the first reading and we take it in stages up to 90% of the 50m (current probe distance). So it starts at a 5m, then probably end at 45m away. So the first thing to do is measure out 5m.

Now the ground is not too bad (hardness). You can actually hand-push the probes in. We've already pre-CAT scanned the area so we know there's no buried services or structures. And with the other lead, we're just going to put it in line with the other for now. This is the basic layout. What you have to be aware of is that there could be some inter-cable coupling when it start to send the signal down - that comes in more advanced techniques later in the series. But for now, we're just going to run it as a basic layout.

The other consideration is the overheads.

[00:16:55]
It's important NOT to be parallel with the overheads lines. So you don't pick up an induced voltage which would also skew your results.

[00:17:28] - Connecting the instrument

[00:18:54] - Processing the data
We've done one half of the FoP test - we've acquired the readings from the field.
Now let's move onto the next stage of the process, which is the data processing.

Looking back at the test in the field, we had the electrode under test and we ran out the current probe to about 50m away from the electrode (remember to escape its electrical influence). And the voltage probe somewhere in between the current probe and the electrode. In our case, we started at about a 10% of the current probe distance, which was about 5m. Once all the leads were connected up to the earth tester, we took a reading.

Then incrementally moved the voltage probe to the next location and took the next reading. We basically repeated this until all the readings for that particular interval between the current probe and the electrode were acquired.

[00:20:00]
In reality, you may wish to enter the test readings into some form of spreadsheet which can make the plotting of the data a little bit more convenient. In this example, you can see the form has a kind of aide memoire about how to deploy the probe

leads and you simply enter the readings taken against the distance and the corresponding curve is plotted onto the graph.

The graph is a simple 2-axis resistance over the voltage probe distance. Provided you've deployed to a sufficient distance away from the electrode, what you should get is something that resembles an 'S' curve. The S-curve shown here has a form of plateau, where it levels out in the mid-part of the 'S'. This is a really key part of hte curve because this is where you determine what the resistance of the electrode is. This plateau will vary in size and gradient with every test but the important thing is that there is some kind of leveling that takes place in the S-curve because this represents the earth electrodes resistance with respect to the general mass of earth. So anything before the plateau falling within the electrical influence of the electrode itself, which is under test. This would provide a false-positive reading because it's not reading to the wider mass of earth, in fact it's just reading to the zone of influence of the electrode.

This is where there's a little bit of skill and judgement because if the plateau isn't playing ball, provided you have clearly escaped the zone of influence you can apply the 61.8% rule.

[0022:53]
Remember, we defined the earth test as a resistance measurement of the electrical connection of an electrode to the general mass of earth. So making sure the current probe escapes the electrical influence zone of the electrode is really very important. Otherwise, we're simply measuring the electrode with respect to the zone of influence and not the wider general mass of earth.

Again, there's a lot to grapple with here. If you'd like to know where the 61.8% rule comes from then we will cover that in future series. But for now, let's just recap on what we've covered here so far.

- We went into the basics of what a FoP earth test is and defined it.
- We also looked at how it works - sending a signal into the geology and measuring the returning signal's voltage, then, applying Ohm's law to determine a resistance value.
- We also covered what a FoP looks like in real life, with the equipment and some of the procedures including the data-processing needed in order to derive the final single valid resistance reading for the electrode under test.

[00:24:15]
Wow, this was a bigger one than normal. Well done! There's a short assessment just to make sure that you've understood the concepts, the theories and the practicals and look forward to seeing you in the next session.

Session 5- Geology

Welcome to the session. This session is about the role geology plays in earthing design.
[00:00:19]

- In this session we are going to discover what Soil Resistivity;
- We're going to touch on how the geology is typically characterised in a soil model;
- And finally, where soil resistivity sits in the design process and why it is sooo important to arrive at an accurate soil model.

[00:01:00]

The video takes about 15 minutes and there will be a quiz as part of it just to check that you have understood the key points. So, feel free to pause the video at any time, pick up any points that you need to drill down into. I should also mention at this point that this session forms part of the **introduction to earthing** module. The aim of the session is to provide you with an awareness of Geology's role within the Earthing Design Process, which means we're not going to go too deep at this stage.

In previous sessions we covered that the earthing (or grounding) system performs a critical safety role as well as allowing AC equipment to function correctly AND that the Earth (or Ground) electrode sits in the geology, so, the structure, the nature and the properties of the geology has a massive impact on earthing performance.

OK - so let's start with lightning things up a little with an interesting fact - according to some scientists, we've been walking this earth for some 60k years, as modern humans… so we should know a thing or two about its formation by now, right? Well, it's only really been recently within the last 300 years or so that the study of Geology has really gathered some pace and understanding.

Now 300 years might sound like a long time but if we relate 60k years into a 200 page booklet, then we've only just past one page of understanding.

Now I'm going to be using a number of terms that seem like they're referring to the same thing, so let's try to clear things up going forward…

> **Geology** - geology is a huge subject, but for the purposes of this session I talk about geology rather than the 'ground' because in certain countries ground refers to the electrode, i.e. the hardware itself. So, to avoid any doubt, I am using the word *geology* to refer to the ground structure or soil under our feet.

> And this brings me on to the subject of **Soil** - for our purposes, *Soil* is the structural composition of the geology, i.e. its the layers that go into making up the ground under our feet.

OK, with that cleared up...

> **Resistivity** - For our purposes as designers of Earthing (Grounding) systems, we need to understand how the subsurface layers are going to behave ELECTRICALLY under fault conditions, right? So a useful measure of how a material, like soil, behaves electrically is to use the unit resistance of the ohm; and when applied across a unit distance of material, we call this resistivity.

[00:03:55]
Imagine this, take a meter or soil… stick two electrodes either side and apply a known current across the electrodes. The resistance across the soil can be measured... Ohm's law in action.

So the result would be whatever the resistance measured was, let's say it was 100 ohms of resistance, times by the unit distance… in this case, 1m. This would equal 100 ohm.m.

Ohm.m is the typical unit used across the sector that defines the *resistivity of a soil*.

So this is what SOIL RESISTIVITY is… it's the resistance by unit distance of a given sample of soil.

Now, mother nature has a way of making things super interesting by injecting variability into the mix. It would be great if she just gave us simple to understand stuff from the get-go but she doesn't do that - which is one of the reasons why geologists try to simplify variability into a form of a model that is more useful and allows categorisation, calculation, and comparison to be made with other models.

It's useful to use soil models as geologists do in earthing (grounding) design.

Let's take a look at a typical Soil Model shown here it's almost always made up of multiple layers, from the parent material at the bottom to the topsoil at the top.

What does this mean?

It means, you going to see different resistivities at each soil layer and depth. Which means each site's earthing system is going to sit its own unique SOIL MODEL representing the sites individual geological signature - in electrical terms.

This means that each site will have its own unique soil model representing the soil resistivities for that particular area.

[00:06:28]
Let's check out an example of this happening in real life. We visit the Severn Bridge in the UK which links England with Wales during a very cold winter's day…

(Walking across Severn Bridge to view geology)

[00:08:14]
Excellent! Hope you enjoyed the short clip - it didn't come across how bitterly cold that day was! So, Let's recap…

- We've defined **WHAT is Soil Resistivity** is - as the Resistance by unit length, usually in Ohm-metres.

- We then looked at **WHAT a Soil Model is**; together with a real-life example of layerisation near the River Severn in the UK.

- Finally, we discovered **WHERE Soil Resistivity fits** into the Earthing/grounding Design Process, and a few things to look out for.

[00:08:55]
Well done!

There is a short assessment after this just to make sure that you have understood the concepts and I really hope that you have enjoyed the content that we have put together for you and look forward to seeing you in the next session.

Session 6: fault-theory

[00:00:24]

Now we are going to let this sequence run so you can pick up a few things. Maybe this is the first time you have seen this. Then we'll come back, dissect it and see what's actually going one. So, for now just enjoy the ride.

[00:01:38]

Okay. So, let' walk through what you've just seen. Firstly, we get to see the wind turbine spinning and feeding the current into the grid via mini substations next to the overhead tower. Now in this video we can consider this mini substation as being the ***source*** substation. Why this is important is simple. All the free electrons from a fault feel compelled by the laws of nature to return to this spot, the source; and equalise themselves now in terms of charge when they're eventually arrive there. So, you will see the process of these electrons returning to the source a little better, deeper into the video.

[00:02:15]

We see this energy firing down the overhead lines. These lines are called phase conductors until it reaches the local distribution substation that feeds the town. So, big problem here! One of these phase conductors gets dropped. Maybe the attachment failed because of corrosion or something or possibly the stresses of a weather event causes it to fail. Either way this single conductor drops the ground. So, what do you think is going to happen? Yeah, that's right. All the energy that was going flowing down the phase conductors are now going into the ground. And it sets something in motion. It's basically freed all those free electrons to scatter and go absolutely anywhere where they want.

[00:03:00]

We are now deep into what's known as a fault or a fault event. Let's put this in some kind of time context. This is all happening in microseconds and is based on the assumption that the protection systems within the electrical system are going to sense this sudden unplanned flow of energy and cut the feed to it. Basically, clear the fault. For us what this means is that there is a finite amount of current that is going to flow into the ground before power shut off and it returns back to zero, a bit like turning the tap off on a hose pipe.

[00:03:41]

So, returning to the video what we're seeing is the fault current entering the geology and being absorbed by the ground itself. As it gets absorbed because it is only a finite amount the voltage starts to decay as the volume of ground affected expands. So, the voltage decreases because there are only so many electrons and they are being distributed across a wider area, right? This sets up a surface voltage or a *rise of earth potential* otherwise known as a *ground potential rise (GPR)* or an ***earth potential rise*** *(EPR)* and this is depicted here in the video by these color contours.

With the current shuts off the feed to the town can't be maintained so the light starts to go out. In this video they are shown slowly but it reality this happens pretty much nearly instantaneously.

[00:04:44]

Back at the substation we are seeing an interesting scenario unfold where the surface voltage is now extending quite some considerable way. Can you see on the tower there are some lights that are heading west? Now this is a representation of some of the electrons actually taking the path of maybe there's an earth wire across each tower on the overhead line. Remember that the electrons that feel compelled to return back to the source where they were made.

So, the electrons don't just follow the path of the ground itself. They can take other conductive routes back to the source and as we'll see these can be basically anything conductive that they can hitch a ride on. What this means is that when the voltage contour approaches built up environments like towns and cities and stuff, you can get conductive structures such as lamp posts, handrails, shelters, seating, anything conductive that picks up this voltage. If it hasn't decayed sufficiently then there could be a hazard there of electrocution. There might be enough of voltage held in the actual structure itself that when a human being or somebody or something touches it, it sees the voltage.

So, this is what earthing or grounding consultants look at worldwide. They are looking at the **surface voltages**. They are looking at the propagation of these voltages across a wider area and see who might come into contact with this and quantify it. Does it present enough of a hazard that something has to be done to lower the voltage and make it safer?

[00: 06:29]

So, that completes this session. Well done! As usual there's a short assessment just to check that you understand the concepts presented and we look forward to seeing you in the next session.

Session 7: process & standards

[00:00:18]

Welcome to the session. This is about the earthing design process and if you are from the States then it is the grounding design process. Earthing - Grounding, it's one of those things that they mean the same thing.

[00:00:34]

In this session we are going to be covering what does the design process look like? Which parts can get overlooked all too easily? Which leads on to, what are the business risks of not following the process?

But before we look at the process we will explore the relevant top tier standards or guidelines that are often the measure of a successful design. So, what standards are applicable? What do they cover and maybe what they don't cover? Where in the world do they apply?

[00:01:15]

The video takes about 15 minutes and there will be a quiz as part of it just to check that you have understood the key points. So, feel free to pause the video at any time, pick up any points that you need to drill down into. I should mention at this point that this session forms part of the **introduction to earthing** module. Whilst it is important to get some idea about which standards apply we are not going to get too bogged down with the detail inside the standard, it is just going to be about what standard is applicable. Unpicking the detail of the standard is going to be covered in the later module.

[00:01:52]

It is important to understand that there are simply hundreds of variants and supplemental standards that sit alongside the ones we are going to see today. Not only country specific but also sector specific, for example, any number of utilities may have their own standards which whilst based on the top tier international standards will have some form of additional requirement to make it compatible if you like with their network. So, this can apply for rail, gas, nuclear, you name it. So, we aware what we are covering today is purely the top tier standards and that many, many others exist that sit behind these.

The other thing to think about is that pretty much all of these recognized standards are in a constant state of development because new insights and ways of thinking emerge every time. What was done maybe 20 years ago was good practice then won't necessarily work in today's context. So, new insights and new learnings are being captured over time and getting incorporated in the newer versions. So, always check that the copy you are using for your project hasn't passed its best by date if you like or sell by date.

[00:03:09]

Right, so what is a standard? I like to think of standard as kind of a recipe book, a bunch of recipes helping to cook a consistent design that meets a minimum publicly accepted outcome. Bit of a mouthful but the standards of today are usually peer reviewed so they can be used as accepted code to practice, not only by the engineers but by lawyers as well. A sobering thought maybe.

But what these standards are not is a recipe for best practice. Now, what do I mean? They are written so the majority of people can achieve 'adequacy' not 'excellence'. If you want excellence you have to start with the standards and then build on them. So, in a similar way that a chef might add some extra chili oil into a particular dish to give it a bit of extra zing; in earthing terms you might need to incorporate some extra headspace on a safety factor or similar to exceed the minimal requirements of a standard. There is a big difference here which is all too often overlooked so be aware compliance does not equal best practice. These standards are the minimum to keep you out of trouble and the emphasis is on minimum.

[00:04:30]

Okay, so let's take a look at who the main standards organisations are, who happen to look after these top tier standards for the industry.

Firstly, the IEC, International Electrotechnical Commission. Based out of Switzerland in Europe, these guys work in association with Cenelec to roll out the national variants of the European versions, those 'EN' standards. But the base reference is held at the IEC.

The other standards body is the IEEE, the Institute of Electrical and Electronic Engineers and they are based out of New York in conjunction with the NFPA which is the National Fire Prevention Association and also the ANSI, the American National Standard Institute. Naturally enough the IEEE versions are dominant across the central North Americas whereas the IEC seem to have sown up the remaining 70 percent of the world. So, these guys are the main players and in some countries it is not uncommon to call for compliance to both sets of standards simultaneously IEEE and the IEC shown in purple here.

[00:05:54]

Session 7: process & standards

Now, let's take a look at which are the main top tier standards that apply to earthing. EN 50522, last released in 2010, this covers the earthing or grounding depending on which part of the world you are from, of **power installations exceeding 1000 volts**, a.c. So, anything over 1000 volts, this is the one.

We can technically call this high voltage, so this is high voltage earthing anything over 1000 volts. And just to clarify the abbreviation a.c. is alternating current and d.c. is direct current.

Okay, the American IEEE counterpart to 50522 is known as Standard 80 and 81. One of these guys deals with the design (80) in a.c and the other handles how to get some of the inputs to be able to do the design (81), but together they are loosely comparable to the single standards, the IEC standard 50522. Okay, so what about the voltages below the magic 1000 volts? Well, in the UK and many parts of the commonwealth the British Standard BS 7430 caters for anything in the low voltage domain, LV.

[00:07:18]

And the last domain I would like to take a look at is on the high frequency domain, that of lightning and lightning protection. So, lightning protection standards often overlap both the high voltage and low voltage standards. After all as I have said before electrons they really can't read so they don't respect the neatness around how we humans like to organise ourselves, we like to kind of bunch things into little things that we can get our heads around; whereas electrons they just go and they behave however they want so it is a useful thing to bear in mind.

[00:07:56]

Now, the IEC has dedicated standards on lightning protection, 62305. Now, this is in 4 parts, nearly 380 pages for lightning protection which does also consider both the HV and LV domains, it is how the 2 actually fit. In the states there is a separate standard by the NFPA, it certainly doesn't go into as much detail as the 62305 but it is accepted standard for North American areas, the States obviously, Canada, and Japan.

Sometimes the designer must exercise a little bit of judgment to exceed a given standard and this is maybe because the side has a particular site specific risk that the recipe doesn't really cover but these cases I have got to say are few and far between, mostly the standards have already seen most conceivable situations already. So, they do form a kind of a good sound starting point.

[00:09:00]

As I have said before an important point is that the standards are a basic recipe, they do not represent best practice so you might want to consider any standard as a minimum to stay above water and not drown. They rarely afford much in the way of spare headroom.

[00:09:14]

So, let's take a step back and just recap. There are 3 domains we have just covered; HV, high voltage, LV, low voltage, and lightning. Within each of these domains there is an overarching standard for each one of them - managed, produced, and developed by a standards body. Depending on where you are in the world it might be the IEEE or the IEC. And behind these half-dozen top tier standards sits a plethora, an absolute plethora of local subset standards which could be sector specific, country specific or actually client specific and might have some additional requirements that you need to be aware of.

[00:10:01]

This completes the first part of this session. This is probably a good time to hit pause and ready yourself for the next part which is covering the process itself and applying the standards that we have just talked about previously.

We start with what does a typical design process look like? Which parts of this can get overlooked? And what might be the business risk and the implications of doing this?

So, let's take a look at the process itself, the first and probably the most important step in the process is the soil measurement to determine the soil model. The soil model itself is used in the initial grid design and every calculation that follows, so you must get this bit right. It is the essential building block, so if this bit goes slightly out of shape then everything else that follows will be wrong, every safety assumption, every performance measure. And when you are dealing with human safety this could mean lives.

[00:11:10]

So, once we are comfortable with the validity of the soil model then the next step is to have a go at the first initial design option. At this stage it doesn't have to be perfect. As you can see the process is iterative which means you have got to try something in the first instance, measure its response and adjust accordingly. So, we have to start somewhere.

Session 7: process & standards

With the initial design in place we can run a few calculations against this arrangement to estimate the earth electrode's or ground electrode's impedance sitting in the geology and then see how this design responds to being hit with a theoretical fault.

So, once you are happy that as many iterations as is necessary have been completed and the design works on the levels that it needs to work on, then and only then can you move on with the final design together with a lightning protection. And the reason why we leave the lightning protection design until last is that the earthing configuration might have to shift in its geometries and its dimensions. So, until these are hammered out the LP, the lightning protection has to wait.

[00:12:24]

Okay, so the final design reaches an acceptable level, it has been issued for construction. Great, what next? Well, skipping along on the timeline and assuming that the construction has all been done, the system has been installed, there is usually quite a lag time between design and completion on the construction side, this could take months, it could even take years on larger projects. So, when the earthing system reaches a point where it is nearing practical completion it is sensible to ask the question, has it been installed to design and does it perform as predicted? And these two fundamental questions form the ***validation and verification*** process which are important steps within accepted standards.

Sadly maybe due to time lag, pressures to complete or simple forgetfulness the verification validation sometimes it falls through the cracks and it doesn't get done. Now, the business risk of this being missed is quite clear. Without proof that it has been installed to design how can one even begin to say it is going to perform as predicted. Maybe the geology has been disturbed at a certain location, maybe the geometries of the earth and the electrode has to be changed because of some sort of clash, maybe parts of the system have been stolen or simply not installed? All these things need to be factored in and the whole point of the verification and validation process is that kind of final sign-off that it will perform and should perform as predicted which is the key design criteria.

This is where theory meets reality, it is okay saying it is going to work in such a way, there has to be proof that it is going to work in the way that one predicts. So, leaving out the verification validation step prevents you from squaring the circle. Let's face it, if something does go wrong any investigator worth his salt is going to ask some really uncomfortable questions. Show me your design, show me your design calculations, now show me the measurement that proves that the real world scenario stacks up to that of the designed theoretical version. So, miss the verification and validation step out, prepare for a bumpy ride.

Session 7: process & standards

[00:14:50]

Okay, so let's recap where we are. In part 2 of this session, we have covered what the design process looks like for an earthing design or grounding design. We have also covered which parts can get overlooked and consequently the business risks of not following this process through which can leave one wide open.

[00:15:15]

Well, that completes the session, well done again. There is a short assessment after this just to make sure that you have understood the concepts and hey, listen, I really hope that you have enjoyed the presentation and the content that we have put together for this module and sincerely hope that you will take it to the next level and increase the knowledge and share any feedback with us that we can use to improve the program.

In the meantime I have been Ian Griffiths, the principal consulting engineer at GreyMatters and it has been my absolute pleasure protecting life and critical assets from the harmful effects of high voltage. Look forward to seeing you in the next

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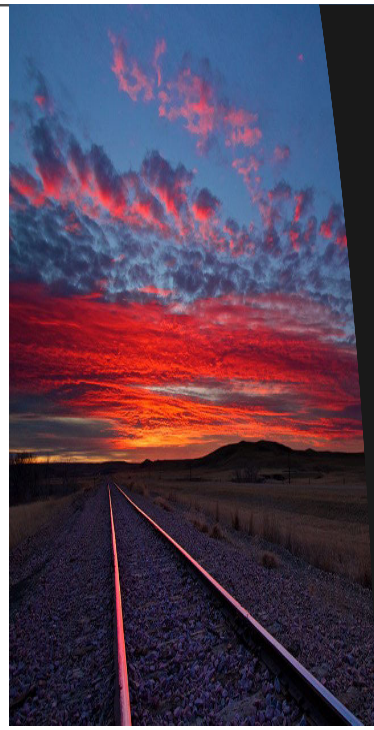

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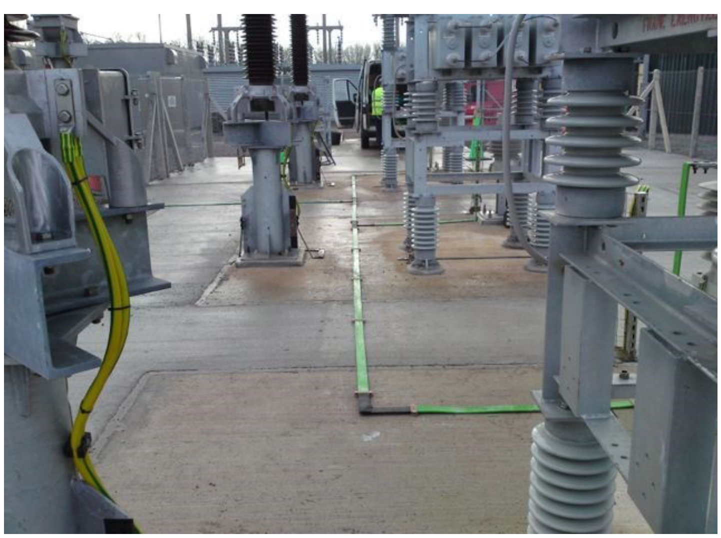

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