Earth electrode

and

earth loop impedance testing

Theory and applications

Megger

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Introduction

As two of the most common testing subjects debated amongst electricians - as well as generating the highest percentage of calls to the Megger Technical Support desk - this series of presentations and supporting booklet hope to clarify some of the obstacles faced by an electrical contractor, or test and inspection engineer, out testing today.

The intention is not to delve in to the physics of the tests, but rather look at the practical issues relating to the measurements. We will also clarify the different test techniques, detail some of the reasons why fluctuating values will be seen and hopefully instil a greater confidence in the day to day results obtained when testing in the field.

This booklet, although designed to be read in isolation, is in no way a definitive guide. There have been written a plethora of articles and application notes and it is recommended that should further information be required, a quick search of the internet will return a wealth of additional material, from basic “How To” guides, to complete scientific papers on the subjects.

Earth electrode testing

Resistivity v resistance

When talking about earth electrode testing, there are two basic test types: earth resistivity and earth system resistance. In a nutshell, resistivity testing is used when looking to site a new earthing system and system resistance testing is used to check an existing resistance is low enough for a desired application.

Resistivity

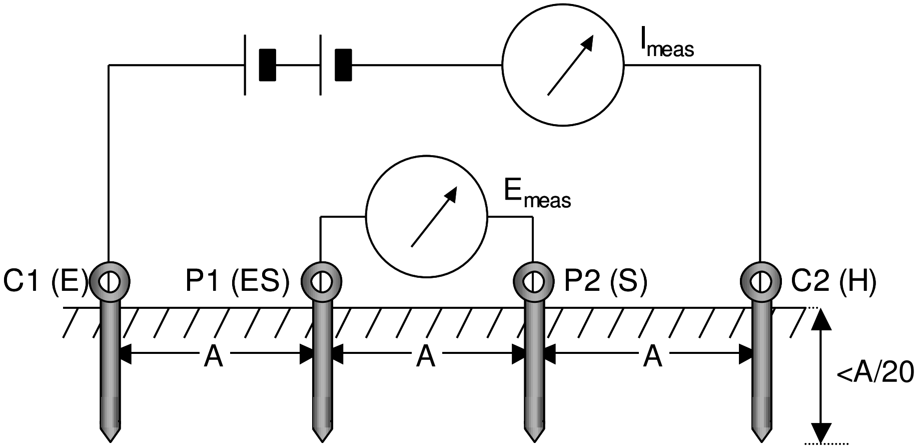
Resistivity testing is primarily used when surveying an area, prior to sinking rods, mesh, mats etc. Soil resistivity can vary across a site by significant amounts and the cost implications involved make surveys invaluable in identifying the optimal location to locate the new installation. There are numerous factors that will influence the resistance readings obtained – the soil composition, the moisture level and temperature as well as geographic features within the ground.

In addition, when surveying, the variables of moisture content, water table level and temperature have to be accounted for as these will change dependent upon the season. Fairly obviously, as the moisture content of the soil increases, the resistance value decreases, so an allowance would have to be made for readings taken in mid-winter as opposed to a reading taken through the summer months.

The most popular method for earth resistivity surveys is the 4-pole (Wenner method), utilised with the standard formula for average earth resistivity:

$\rho = 2 AR$

Where:
is average earth resistivity to depth A in ohm-cm
A is the distance between the spikes
R is the resistance read from the earth tester



This cm value is of interest to a design engineer, because by re-arranging the formula and utilising published tables, the resistance of the earth electrode required can be calculated:

$\rho = 2 AR$ (Ωcm) therefore electrode resistance $R = \rho / 2 A$

Earth system resistance

It is important to remember why earth resistance testing is being undertaken and why a low resistance value is normally required. In essence, the earth is provided to either enable protective devices to operate, reduce ground potential rises or to provide a safe passage to earth for lightning strikes and static charges etc. Different applications will call for different maximum permissible earth resistance values and there are numerous variables that will contribute to this. Published standards or specific design criteria will dictate what values are necessary and these should be referred to in all cases.

Earthing systems fall within 2 categories: Simple or Complex. Simple systems consist of either a single or small number of electrodes driven in to the ground, whereas a complex system will have multiple earthing points.

So what makes up an earth electrode resistance value? There are 3 main components involved:

1. Resistance of the electrode itself (dependent on material) and the connections to it
2. Contact resistance between the electrode and the soil it is driven into
3. Resistance of the surrounding body of soil

1 - Electrode resistance will vary slightly due to the type of material used. Copper is the preferred material for earth rods and mats, but it is not uncommon to find steel or iron used. The resistance value between the materials is measurable but not normally significant. Contact resistance between connections is where issues may arise – primarily down to incorrect termination techniques or corrosion.

2 - Contact resistance is often thought of as one of the main contributors to high earth resistance readings, but provided the electrode is free from paint and grease and the earth is packed firmly, the value is negligible

3 - Finally, an electrode driven in to the earth of uniform resistivity will radiate current in all directions. By envisaging the electrode surrounded by shells of earth of equal thickness, it is easy to realise that the nearest shell will have the smallest surface area, but as you move further away the surface area of each shell is somewhat larger and offers less resistance. Finally, a distance from the electrode will be reached where additional

shells will not add significantly to the resistance of the earth surrounding the electrode. It is this critical volume of soil that determines the effectiveness of the electrode.

In most cases, the greatest influence on the earth resistance value will be the depth of the electrode. Doubling the depth can see a reduction of up to 40% in the measured value. If multiple rods are required, as a rule of thumb, the spacing of the rods needs to be at least equal to the driven depth.

Effect of temperature

C	Resistivity (Ohm-cm)
20	7,200
10	9,900
0 (water)	13,800
0 (ice)	30,000
-5	79,000
-15	330,000

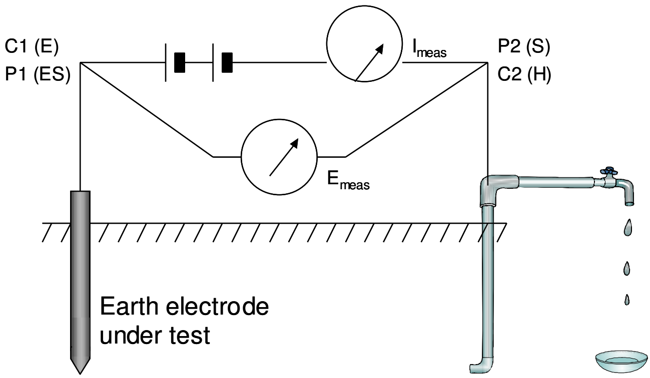
Resistivity of different soil types

	Resistivity (Ohm-cm)
Surface soils, loam, etc.	100 - 5,000
Clay	200 - 10,000
Sand and gravel	5,000 - 100,000
Surface limestone	10,000 - 1,000,000
Shale	500 - 10,000
Sandstone	2,000 - 200,000
Granites, basalts, etc.	100,000
Slates, etc.	1,000 - 10,000

2-pole or direct measurement (Dead Earth)

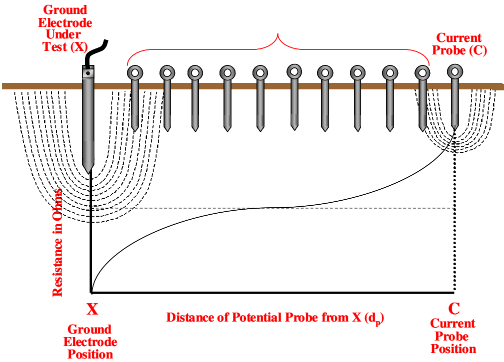
Although the simplest form of resistance testing, this method is generally used as a "last resort" as it requires using unknown factors and involves making certain assumptions.

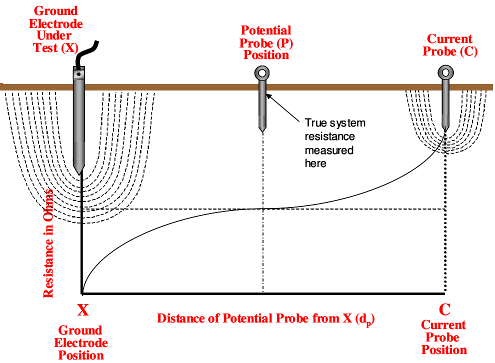
In essence, a measurement of two electrodes in series is made – with one of the electrodes being an existing earth i.e. a water pipe. For the reading of the electrode under test to be accurate, an extremely low resistance value would be needed from the existing earth – but this cannot be proven. Although an extensive metallic water pipe system may indeed have a low resistance value, there would be no guarantee that non-metallic couplings have been used and without comprehensive schematics, the electrode under test could be placed firmly within the sphere of influence created by the existing earth.



Fall of potential method

This is the classic method for measuring resistance of a single electrode, or a system of electrodes, to Earth. Two auxiliary spikes are driven into the ground in line with the electrode/s under test. Current is generated by the instrument between the electrode/s under test and the auxiliary C spike. The resultant potential across the soil resistance is then measured between the electrode under test and the auxiliary P spike. However to measure the true resistance of the electrode/s under test, the auxiliary C spike must be far enough away from the electrode/s under test for the spheres of influence not to interfere with each other. This is determined by moving the P spike in steps between the electrode/s under test and the C spike and plotting the resistance curve caused by the ‘fall of potential’. The plotted curve must have a flat, see diagram, and the true resistance of the electrode/s is measured here. If there is no flat the distance between the electrodes under test and the C spike must be increased until there is.





When testing a single earth electrode the C spike can usually be placed 15 m away from the electrode under test, with the P spike placed 9m away. With a small grid of two electrodes, C can be placed about 100 m from the electrodes under test; P spike about 62 m away. Larger earth systems consisting of several rods or plates in parallel required the distance for C to be increased to possibly 200 m and P to some 125 m.

Lazy spike method

Megger earth testers can operate with high temporary spike resistances and still give accurate, reliable results. This means auxiliary spikes do not have to be inserted too far into the ground. However another advantage is that in urban concrete locations where driving in spikes is impossible the spikes may be laid flat on a wet patch of concrete and a measurement made. However, structural steelwork and buried metal piping could affect readings and should be taken into account.

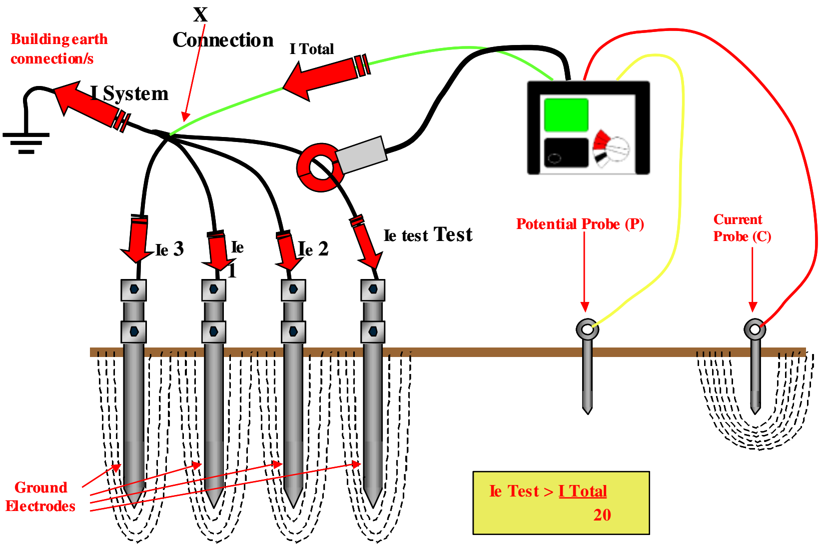
61.8% rule

Assuming the C spike is far enough away from the electrode under test, the soil mass is homogenous, and there are no buried objects the correct P spike position will always be at 61.8% of the distance from the electrode/s under test and the C spike.

This is definitely a rule to be treated with great care.

ART – Attached rod technique

Based on the Fall of Potential method, instruments with ART capability use the ICLAMP to measure only the instruments test current flowing down the electrode under test, negating the requirement to disconnect the electrode under test.

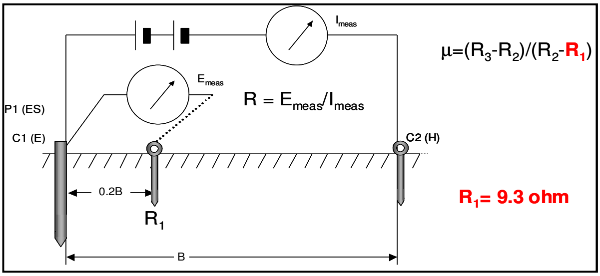


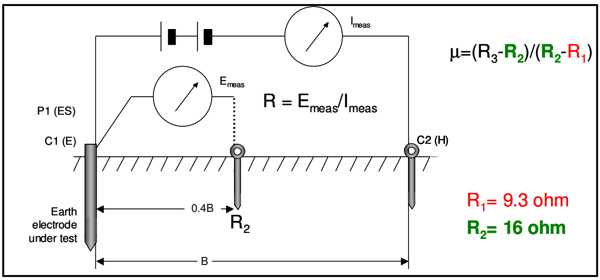
Earth system leakage and current range

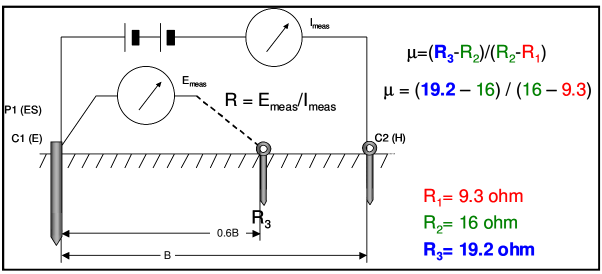
Instruments equipped with ART and ICLAMP also have a current measurement range. This is an important feature; it enables the operator to check if there is current flowing, should an electrode have to be disconnected from a system, ensuring his safety

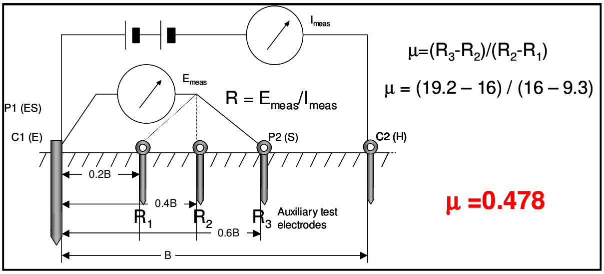
The slope method

When testing very large earth systems, such as that encountered on large substations, it may be impractical to get the required auxiliary P and C spike distances. The result is that the plotted resistance curve would not have a flat area, remain a 'slope'. In this method three measurements are taken, inserted into a formula and a value calculated. This value can then be looked up in a table to find the correct P spike distance required to measure the true resistance of the system under test.









The resulting value of u (which in this example = 0.478) is then looked up in the table shown below. In this example the correct earth system resistance would be measured with the P spike at 0.632, or 63.2% of the C spike distance from the electrode under test.

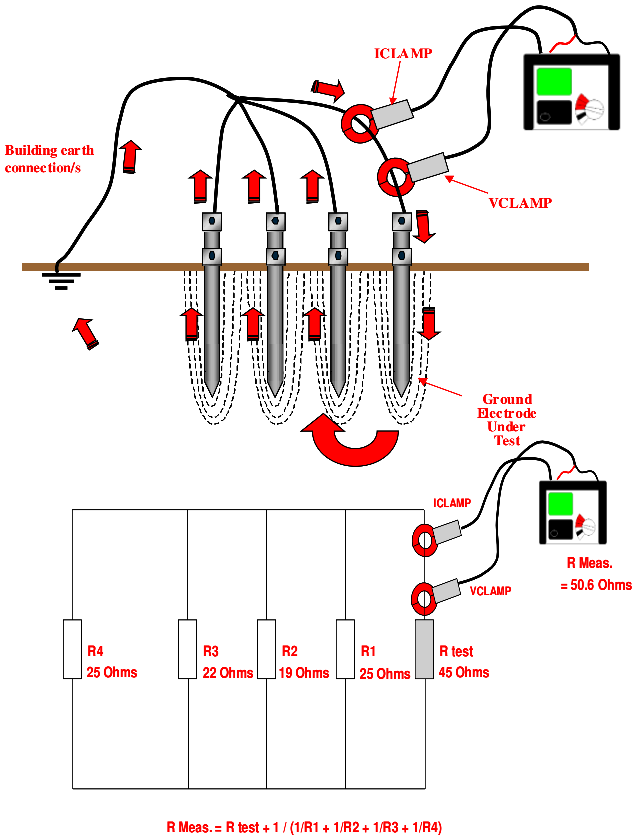
Chart for use with the Slope Method

Values of P_t / d_c for Values of μ						Values of P_t / d_c for Values of μ					
μ	P_t / d_c	μ	P_t / d_c	μ	P_t / d_c	μ	P_t / d_c	μ	P_t / d_c	μ	P_t / d_c
0.4	0.643	0.8	0.58	1.2	0.494	0.6	0.614	1	0.542	1.4	0.431
0.41	0.642	0.81	0.579	1.21	0.491	0.61	0.612	1.01	0.539	1.41	0.427
0.42	0.64	0.82	0.577	1.22	0.488	0.62	0.61	1.02	0.537	1.42	0.423
0.43	0.639	0.83	0.575	1.23	0.486	0.63	0.609	1.03	0.535	1.43	0.418
0.44	0.637	0.84	0.573	1.24	0.483	0.64	0.607	1.04	0.533	1.44	0.414
0.45	0.636	0.85	0.571	1.25	0.48	0.65	0.606	1.05	0.531	1.45	0.41
0.46	0.635	0.86	0.569	1.26	0.477	0.66	0.604	1.06	0.528	1.46	0.406
0.47	0.633	0.87	0.567	1.27	0.474	0.67	0.602	1.07	0.526	1.47	0.401
0.48	0.632	0.88	0.566	1.28	0.471	0.68	0.601	1.08	0.524	1.48	0.397
0.49	0.63	0.89	0.564	1.29	0.468	0.69	0.599	1.09	0.522	1.49	0.393
0.5	0.629	0.9	0.562	1.3	0.465	0.7	0.5797	1.1	0.519	1.5	0.389
0.51	0.627	0.91	0.56	1.31	0.462	0.71	0.596	1.11	0.517	1.51	0.384
0.52	0.626	0.92	0.558	1.32	0.458	0.72	0.594	1.12	0.514	1.52	0.379
0.53	0.624	0.93	0.556	1.33	0.455	0.73	0.592	1.13	0.512	1.53	0.374
0.54	0.623	0.94	0.554	1.34	0.452	0.74	0.591	1.14	0.509	1.54	0.369
0.55	0.621	0.95	0.552	1.35	0.448	0.75	0.589	1.15	0.507	1.55	0.364
0.56	0.62	0.96	0.55	1.36	0.445	0.76	0.587	1.16	0.504	1.56	0.358
0.57	0.618	0.97	0.548	1.37	0.441	0.77	0.585	1.17	0.502	1.57	0.352
0.58	0.617	0.98	0.546	1.38	0.438	0.78	0.584	1.18	0.499	1.58	0.347
0.59	0.615	0.99	0.544	1.39	0.434	0.79	0.582	1.19	0.497	1.59	0.341

SAFETY NOTES

There is always the possibility that a fault in a power system will cause high current to flow into the ground system while the test is in progress. This may cause unexpected high voltages to appear at the current and voltage probes and also at the terminals of the instrument. The person responsible for the tests, taking into account potential fault current and expected step and touch potentials, must evaluate this risk, take suitable precautions, and observe safe systems of work.

The clamp on or stakeless method

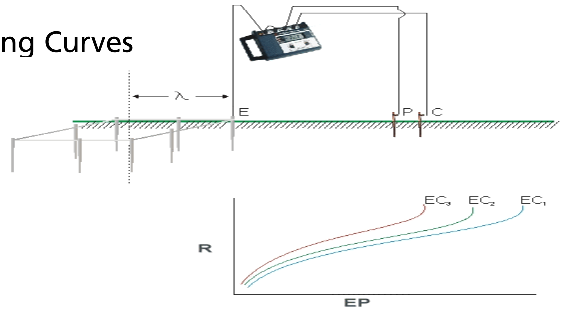


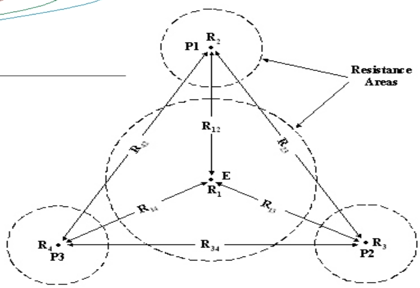
This method measures the resistance of the loop including all connections and cables and is ideal for many applications, including lightning protection. The readings taken are ideal for comparative condition monitoring testing.

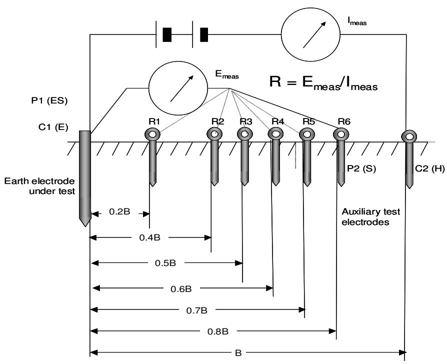
Intersecting curves, star delta and four potential methods

These 3 methods are either very complex, time consuming or both! Details of their specific applications, advantages and disadvantages – along with their operational procedures - can be found in the Megger publication “Getting Down To Earth”, available as a free PDF download from http://bit.ly/earthtestingguide

Intersecting Curves







Selecting Earth System / Electrode Test Method Chart

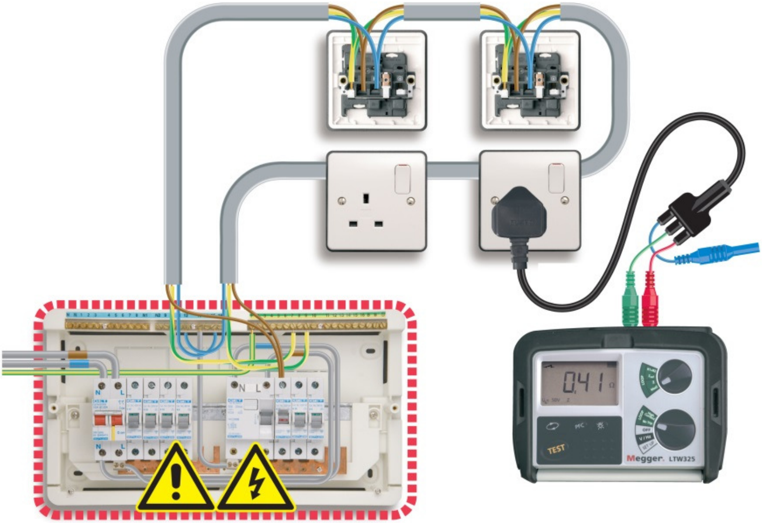
Method	Best Application	Advantages	Limitations
1. Fall of Potential	Small electrode systems; Complex system if full resistance curve is plotted.	Extremely reliable; conforms to IEEE 81; ART (with clamp) no requirement to disconnect electrode.	Requires long distances (and long test leads) on medium and large systems; time consuming.
2. Simplified Fall of Potential	Small and medium electrode systems	Easier than Fall of Potential; much faster.	Ineffective if the electrical centre unknown. Less accurate than Fall of Potential.
3. 61.8% Rule	Small and iedium electrode ystems	Simplest to carry out; minimal calculation; fewest number of test probe moves	Assumes perfect conditions; ineffective if electrical centre is unknown; soil must be homogeneous; less accurate
4. Slope	Large systems ke substations	Knowledge of electrical centre not required. Long distance to probes not required	Susceptible to non-homogeneous soil; less accurate; requires maths
5. Dead Earth (2 pole)	Not recommended	Quick and simple to perform	Problems with resistance overlap.
6. Intersecting Curves	Large systems like substations	Knowledge of electrical centre not required. Long distance to probes not required	Numerous calculations and drawing of curves
7. Star Delta	Ground systems located in urban areas and/or rocky terrain	Long distances for test probe positioning not necessary	Resistance areas should not overlap; a number of calculations required
8. Four Potential	Medium to large ground systems	Knowledge of electrical centre not required	Long distances to test prob required; a number of calcu
9. Clamp-on / Stakeless	Simple ground system with existing return path through multiple grounds	Quick, easy; includes bonding and overall connection resistance	Effective only in situations with multiple grounds in parallel

Earth loop impedance testing

When looking at making measurements of Earth loop Impedance, or Prospective Fault Current (PFC) for that matter, it is always worth remembering why the reading is being taken. All too often time is lost on site because the principle of what the test is expected to prove is lost.

Loop testing could be described as a "Dark Art" – it is the most difficult measurement taken by the electrical contractor on his day to day business. By difficult, it should be clarified that the difficulty remains in the method of obtaining the elusive, stable, repeatable reading we all look for, not the application of the test itself. When you look at and compare the principles of continuity, insulation, loop or RCD testing, loop tests should not cause the level of consternation that they do. It is a simple test. What is the resistance that a fault between live and earth will be subjected to? Earth loop testing has been carried out for decades, so why do we still get fluctuating readings on certain circuits or worse still, readings that on the face of it would condemn an installation?

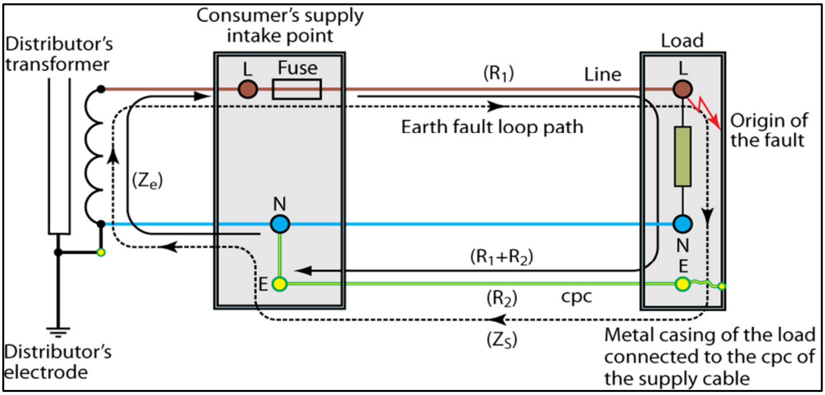
Test equipment manufacturers continue to search for the Holy Grail of earth loop test techniques – one test that can be used on any circuit, at any location, on any voltage, that will give us the stable accurate reading we desire. With each technological advance in testing, circuits and their components change, throwing obstacles in to the path of the poor loop impedance tester! What we hope this booklet will do is give you an insight into the different techniques that are available on the market today and arm you with the knowledge to go about your daily routine, confident in the readings being taken and recorded.



What is the loop and why do we test it?

If a fault occurs in an electrical system, we must prove that the over-current device will operate within the prescribed time by ensuring that the circuit impedance is low enough to allow sufficient current to flow. The required values of impedance and time will change dependent upon the type of installation (TN/TT etc.) and the type of protection, whether it be a miniature circuit breaker (MCB), cartridge fuse or re-wireable fuse for example. The fault current can either be in the Line-Neutral or Line-Earth circuit, so there is a need to confirm the loop impedance of each.

Earth fault loop return path – TNC-S installation



The testing of the Line-Neutral loop impedance does not throw up many issues as the circuit has no earth leakage protection and a straight forward high current test returns repeatable, stable readings.

Loop impedance tests methods

As it stands today, most contractors will use one of 5 different test techniques when loop impedance testing:

- 2-wire high current test
- 2-wire "No-Trip" d.c. saturation test (Obsolete)
- 3-wire "No-Trip" test
- 2-wire "No-Trip" test
- 4-wire grid impedance test

Determining which test to use will depend upon a number of factors, not least being which one is available on the test meter being used! The following information will hopefully go some way to explain some of the applications and limitations of these different options when in the field.

2-wire high current test

This is the traditional loop impedance test. Using a test current of up to 20 A and a simple 2 wire connection, it is by and large the fastest, most accurate test available on a day to day basis. Most standard loop impedance testers will incorporate this type of test. Because of the relatively high test current, the readings are not generally influenced by external factors and will return repeatable, stable readings in most scenarios.

Unfortunately, it does have its limitations. When first conceived, earth leakage monitoring RCDs and RCBOs were not part of the electrical installation and because it relies on a short between Line-Earth for the earth loop test, albeit only for 2 cycles (or 40 ms) of the AC waveform, the test will cause the RCD/RCBO to operate. In addition, some early instruments whose test time was not so tightly restricted had cause to operate some of the low current MCB's as well. Where earth leakage protection was in place, the contractor was left with no option but to bypass it to allow for the test to be undertaken – a time consuming and rather un-safe practice as it left the system unprotected for the duration of the test.

That said, this test still has its place in a contactors toolkit and should be the go to solution wherever possible. When carrying out a Ze measurement of an installation or taking a Zs reading on an unprotected circuit, this is still the most accurate, easiest test to use.

2-wire “No-Trip” d.c. saturation test

To overcome the problems caused by the introduction of earth leakage protection, a test technique was developed whereby a DC test current was injected in to the circuit prior to carrying out a standard 2 wire high current test. The aim of this DC test was to saturate the monitoring coil within the RCD, allowing enough time for the high current AC test to be carried out. This ”anesthetising” effect proved very effective. At the time, there were claims that the saturation left the coil in a potentially unresponsive state, but this was never substantiated.

However, due to the increase in electronic RCDs, this method now has limited applications – with some newer RCDs and RCBOs specifically monitoring for DC voltage being present on the system. This technique is no longer incorporated within the current range of instruments on the market.

3-wire “No-Trip” test

The 3 wire method of no-trip loop testing has become the norm over the past 20 years. This test method overcame the need to by-pass even the new electronic protection devices by utilising a low current Line-Earth test current, whilst still returning a degree of accuracy. Not having to by-pass the RCD/RCBO obviously introduced a time saving factor. In addition, by having the requirement of connecting to Line, Neutral and Earth, the testers were now able to confirm the presence of all three as well as indicate if there was a reverse polarity at the test point and, due to the limited test current, there was no issue with tripping the MCB.

There remain limitations with the 3-wire test however. Due to the lower test current, readings became more susceptible to external factors (much more on these later) introducing instability on certain circuits and a reduction in consistency. In some circumstances the internal impedance of the RCD can be seen or existing system earth leakage can combine with the test signal to cause the protective device to operate.

2-wire “No Trip” test

The 2 wire no-trip option has come and gone in various guises over the years. Some testers opted for a low current test, but this affected accuracy on the low end, where as other techniques never proved accurate and were dropped as soon as they were launched.

The latest 2-wire no-trip units have a much improved technique offering far better repeatability, but still suffer from limitations. Obviously, they will allow for testing most RCDs and RCBOs without having to bypass them. With no neutral connection required, they maintain a true 2-handed operation, but will no longer indicate reverse polarity or warn of a missing neutral. The test current does not “combine” with existing leakage, so there is no accumulation effect, as suffered by the 3 wire test. Although the physical test time is similar to that of the 3-wire method, the time saving of not having to bypass the RCD still makes for a more efficient test. External factors can again affect the reading taken, but the simplicity of 2 handed testing can outweigh this limitation in a lot of cases.

The Megger range of loop and multifunction testers also incorporate an “Auto-Start” feature, whereby once the probes are connected and the voltage verified, the test will automatically start alleviating the need to clip one of the leads to free up a hand to press the test button

4-wire grid impedance test

This new method of testing will only be undertaken in certain circumstances. The test uses a 4 wire Kelvin connection, negating internal lead and contact resistance; such is the accuracy of the test. With test currents up to 1000 A, measurements down as low as 10 mOhm can be accurately made. Consequently, there is no "No-Trip" option with this test method. With specific applications being measurement in sub-station/switch room environments, this tester gives the test engineer the ability to take accurate readings when sited next to the main transformer – something that has caused problems for many years when trying to sign off jobs with readings based on design engineers calculations down as low as 0.001 Ohm!

As stated, this test set will have a limited market, notwithstanding the size and cost of the unit, but also the safety aspect of working in HV environments.

Test instrument accuracy

Having an understanding of the published accuracy and uncertainties for the test equipment you use is paramount. Test equipment manufacturers have an obligation to stamp on the instrument the accuracy the operator can expect on any given range and interpreting this can alleviate a number of queries raised when deducing results.

BS EN61557-3 requires that loop testers measure no worse than 30% accuracy across a stated range, in the presence of operational uncertainties. Achieving this is no great feat, but manufacturers realise that this would fall far short of the repeatability in readings required to instil confidence when using their instruments. As such, the accuracy statements you see will far exceed this requirement.

It should be noted, however, that accuracy will normally be shown across a measuring range so, for example, on the Megger MFT1700 series multifunction tester, for a high current loop test the accuracy is claimed for the range 0.1Ω to 1000 Ω, compared to 1 Ω to 1000 Ω for non-trip testing.

Guidance Note 3 "Inspection & Testing" talks about basic measurement accuracy of 5%. Here, the discrepancy between basic and operational accuracy is introduced. To clarify, basic accuracy can be deemed to be achieved within controlled "laboratory" type conditions, whereas operational accuracy looks at real world, field readings. It goes on to state that operational accuracy is always worse than basic accuracy.

The Electrical Safety Council publication back up this measurement discrepancy in their published "Best Practice Guide No.7 – Test Instruments for Electrical Installations: Accuracy and Consistency" where they state that readings on a high current test will be susceptible to errors once readings below 0.2 Ω are being made, whereas on the no-trip test ranges, anything below 1.0 Ω will be subject to significant errors. They recommend taking multiple readings if there is any concern about the result of a test.

Real world example

Accuracy needs to be looked at and understood. Here are 2 examples:

Example A: Range: 0.1 Ω to 1000 Ω Accuracy: 5% +/- 0.05 digits

Example B: Range: 0.1 Ω to 1000 Ω Accuracy: 3% +/- 0.1 digits

In this example, we have a known clean loop impedance value of 0.5 Ω

Example A: **5% +/- 0.05 digits**

5% accuracy = 0.03Ω add the 5 Digits = +/- 0.08Ω
Therefore, before any external influence, any reading between 0.42 & 0.58Ω is acceptable! (Variation 0.16 Ω)

Example B: **3% +/- 0.1 digits**
3% accuracy = 0.015Ω add the 0.1 Digits = +/- 0.115Ω
Therefore, before any external influence, any reading between 0.385 & 0.62Ω is acceptable! (Variation 0.23 Ω)

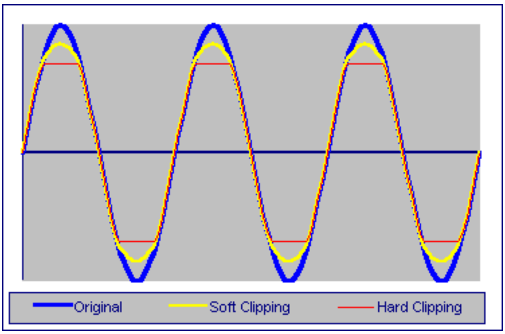
What this goes to prove is the acceptable range that an instrument can be deemed to be accurate and just as importantly, a claimed 3% accuracy against 5%, pales in to insignificance when you take account of the +/- digits.

External factors influence measured values

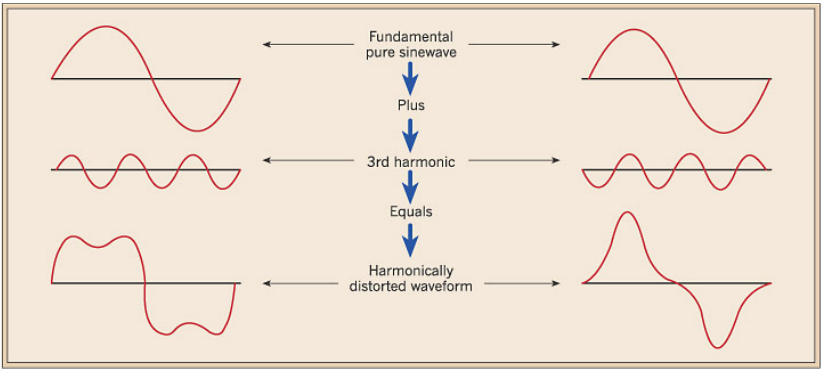
When making a loop impedance measurement, there are numerous challenges that the test signal has to overcome. Some are physical and some are man-made. Having an understanding of the limitations of the various tests that are available goes some way in overcoming some of these obstacles.

Just as importantly, knowing the significance of the desired value (usually stipulated by regulation) and an appreciation of the measured value in the real world will help to maintain confidence in the recorded value. Below are a number of factors that will directly influence the readings being taken on a day to day basis, and the challenge is appreciating these and the fact that some are unavoidable and outside of your or the test equipment's control.

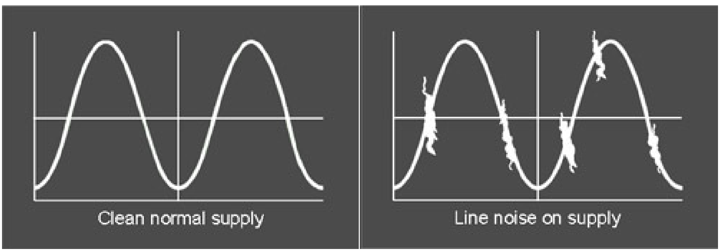
Line waveform distortion – In the UK we rely on the 50Hz supply being a smooth sinusoidal waveform. Unfortunately, due to the explosion of switch mode power supplies, power factor correction equipment and inverter drives, this is no longer the case. Clipped or distorted waveforms can have a significant influence on the test signal. Repeat testing can usually average out any issues arising from waveform issues.



Harmonic disturbance – This has now earned the right of a section within the 17th Edition and the problems severe harmonics can cause are being formally documented to a far greater extent. The detrimental effect on a loop test signal can be significant, but repeat testing, again, can often overcome this.



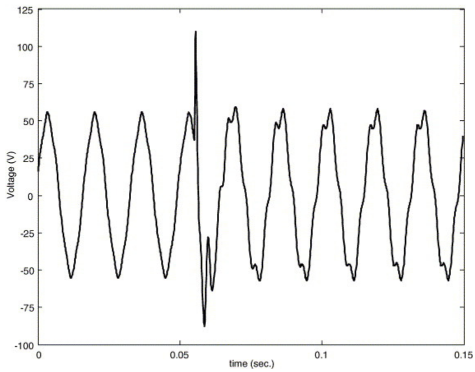
Line noise – Somewhat different to harmonic disturbance, line noise can be a general background signal, superimposed over the normal 50Hz supply. Again this can play havoc with a test signal – especially the no-trip techniques. Testing at different times is probably the best solution, as noise will often fluctuate throughout a 24hr period.



Proximity of transformer – As stated earlier in this booklet, we are not looking to venture into the physics of the testing, but suffice to say, when in close proximity of a transformer, the hand-held units available on the market today will struggle to return repeatable readings, when the calculated value is in the realms of milliohms and well below the stated range of the instrument. A work around is shown a bit later in this booklet.

Ambient temperature – Probably the most overlooked factor that can influence a reading. The changes due to ambient temperature may not be huge, but when making comparative readings, it is always worth bearing in mind when the original values were obtained.

Line transients and spikes – These do not have to be massive over voltages. More often than not they may well be recorded as sags and swells by line monitoring equipment. Most are man-made and are due to switching either at the substation or from larger industrial complexes running from the same grid. Again, repeat testing will help to alleviate any issues with readings.



Test lead resistance – The one part of any manufacturers test equipment that will be slated more than anything else is ordinarily the test leads. They are the one mechanical component that will be subject to wear and tear, over and above any other component of the test kit. Regular checks should be carried out, especially against known values, as deterioration of lead contact resistance is rarely picked up as it is a gradual phenomenon. Some operators will replace their leads 2 or 3 times a year, whereas some look to change them only when a major issue arises. Regular inspection and checks should overcome any problems the leads may end up giving.

Contact resistance – This may be a subjective issue, but can be proven on most installations. Whether the resistance is generated by accessibility to the test point, or due to wear on a socket, it is easily rectified. Firm, constant pressure is required across the contact points and even applying a test probe to the centre of a screw as opposed to the outer edge can have a significant affect. With regards to a double socket, always look to test on both as it may be that one is favoured by the usual operator (the cleaner using 1 socket daily, for example). Other examples may be RCD internal resistance due to oxidisation. Testing and resetting can often overcome this factor.

Inductance and capacitance – These can often be unknown quantities when testing. Capacitance can be seen to be charged by the test signal, therefore directly affecting the reading taken. Inductance would not ordinarily affect a standard test (it is primarily associated with coils of cable) but when testing a third party installation it is a factor that could influence the result if found to be present. Repeat testing at various points on a circuit can usually alleviate the discrepancy seen.

When some of the issues faced when taking a simple loop impedance test are listed out, you start to get a better understanding of how these can easily influence the reading being taken. Added to this, the variation that the instrument can show whilst still be working within design /accuracy standards, it is easy to see why the loop test causes more head scratching than any of the other readings being taken.

The digital age has been our undoing in all this. If we return to the 1970s when we had our traditional analogue balanced moving iron coils, if the reading swung anywhere below 1 or 2 ohms we were happy.

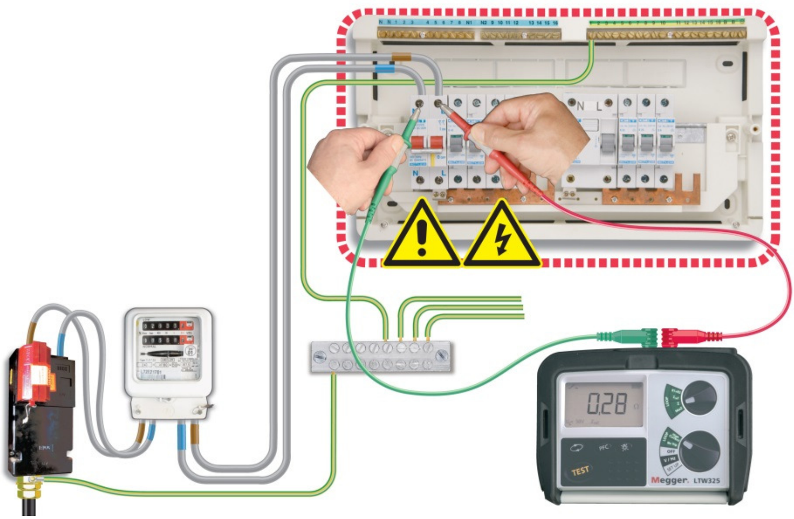
Testing at source – simple work-around

One technique that goes someway to obtaining a more stable, repeatable reading when taking measurements close to the source of supply is to add additional resistance to the circuit being measured. Notwithstanding the stated accuracy of the instrument range, if a known resistive value is placed in series with the test circuit, by deducting this away from the measured value a reading for the circuit can be obtained. In some instances, the additional resistance need not be great, for instance, a long test lead set with a known value of 0.15Ω may be sufficient. The 2 wire high current test must be used and numerous readings taken to give an average.

PFC and PSCC testing

Prospective fault current and prospective short circuit testing are measurements that are made to calculate the current that will flow in the event of a fault. Too little current and protective devices may fail to operate in time (if at all) and too much current will cause damage to equipment, may cause fire or prevent the breaker from operating.

Interestingly, the calculation should be made using the nominal supply voltage value and not the measured voltage.



Loop impedance, either earth loop or line-neutral, will have a greater influence on the PFC/PSCC value the smaller they get, causing issues when taking measurements below the stated range of an instrument. Any PFC measurement should be taken using the high current option – no-trip test ranges should only be used for verification. If a critical measurement is being made, it should always be confirmed by calculation against design specifications.

PFC v Earth Resistance (230 V Supply)

@ 50 ohms to earth
PFC = 230/50 = 4.6 A (0.0046 kA

@ 0.5 ohms to earth
PFC = 230/0.5 = 460 A (0.46 kA

@ 0.1 ohms to earth
PFC = 230/0.1 = 2300 A (2.3 kA)

@ 0.05 ohms to earth
PFC = 230/0.05 = 4600 A (4.6 kA)

Loop testing summary

This booklet started out by saying that when loop impedance testing, you should not lose sight of why the test is being carried out. All too often a fluctuating reading or a reading higher or lower than you would have expected causes additional time to be spent on site, when in essence; the difference can be seen as negligible. Again, this harks back to the digital age – our brains process 0.39 Ω to be VASTLY different to 0.51 Ω as a reading, yet in essence, with a difference of 0.12 Ω this could be explained as an accuracy fluctuation.

It is worth remembering the requirements laid out in BS7671:2008

Typical 32A Circuit with BS EN 60898 Breaker

Type B – Zs < 1.16 Ω (Domestic)

Type C – Zs < 0.58 Ω (Inductive/Resistive Loads)

Typical 6A Circuit with BS EN 60898 Breaker

Type B – Zs < 6.16 Ω (Domestic)

Type C – Zs < 3.09 Ω (Inductive/Resistive Loads)

Values from GN3 Table B4 (80% Rule Applied)

And remember……

Maximum Zs to Ensure (Non-Delayed) RCD operation to BS EN 61008-1 & BS EN 61009-1 for final circuits not exceeding 32 Amp

30mA on 230V circuit < 1667 Ω*

100mA on 230V circuit < 500 Ω*

300mA on 230V circuit < 167 Ω

(based on a touch voltage limit of 50 V)

*A value exceeding 200Ω may not be stable.

I hope this booklet has proved interesting and perhaps useful in clarifying some of the issues faced day to day when undertaking earth and loop measurements. If you need more information on any of the subjects, a quick visit to the internet using your favourite search engine will return plenty of additional technical papers, delving in to the physics of what we have brushed upon today.

If I can ask you to take one thing away from reading this booklet, that I believe will make your life easier when out testing, it would be the following:

When testing use the best available test in the following order of preference

- 2 Wire High Current Test
- 3 Wire No-Trip Test
- 2 Wire No-Trip Test

One final statement.

Where the possibility of accidentally tripping an RCD is NOT ACCEPTABLE, loop impedance testing should not be performed, as it is impossible to absolutely guarantee an RCD will not trip during a loop impedance test.

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