Earth ground testing for mine sites with Fluke 1625

Application Note

All mine sites have grounded electrical systems, so that in the event of a lightning strike or utility overvoltage or ground fault, the current would be able to find a safe path to earth or the neutral of the transformer. To ensure a reliable connection to earth, electrical codes, engineering standards, and local standards often specify a minimum resistance for the ground electrodes. This application note looks at how one of the world's leading mining and exploration companies uses Fluke's earth ground testers to maintain a safe working site.

Rio Tinto is one of the world's leading mining and exploration companies. They find, mine and process the earth's mineral resources—metals and minerals essential for making thousands of everyday products that meet society's needs and contribute to improved living standards.

Products include aluminium, copper, diamonds, energy products, gold, industrial minerals and iron ore.

The company's activities span the world but are strongly represented in Australia and North America with significant businesses in South America, Asia, Europe and southern Africa.

The Pilbara region

Rio Tinto has been at the forefront of sustained innovation and growth in the Pilbara region for more than forty years.

Rio Tinto's iron ore operations in the Pilbara have expanded to an annual capacity of 220 million tonnes, with advanced plans to further expand. With a network of 12 mines, three shipping terminals and the largest privately owned heavy freight rail network in Australia, the company's Pilbara operations make up a major part of iron ore activities globally. Its operations began in 1966 and have expanded to meet the growing needs of the world's iron and steel industry.

Rio Tinto is a world-class asset manager, operating and maintaining all mining, rail, power and port facilities in the Pilbara on behalf of asset owners Hamersley Iron and Robe River.

Grounding systems

Regular earth testing is a very important practice for mining companies such as Rio Tinto. The purpose of a ground, besides the protection of people and equipment, is to provide a

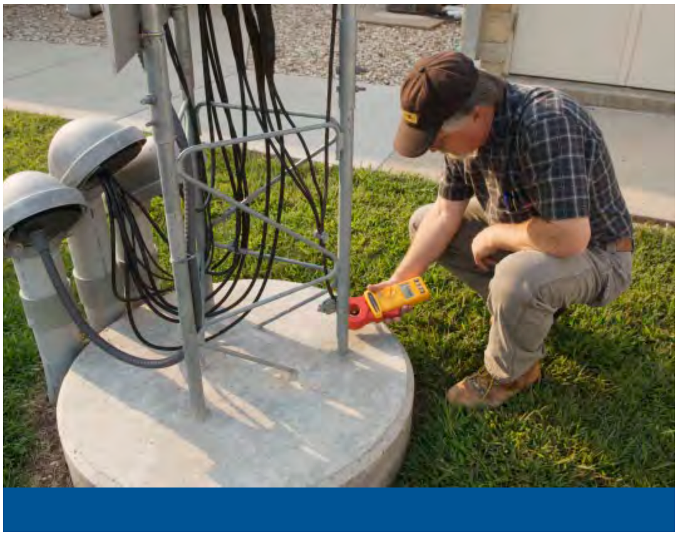
Taking care of an at-risk dam

Application Note

Completed by the U.S. Army Corps of Engineers (USACE) in 1962 as a flood-control measure, Tuttle Creek Dam sits on the Big Blue River, five miles north of Manhattan, Kansas. Made of rolled earth and rock fill and resting on an alluvial foundation, it's about 137 feet high and 7500 feet long. The dam holds back Tuttle Creek Lake, which amounts to 335,100 acre-ft at normal pool and approximately 1.9 million acre-ft during flood events.

Here's the problem: It's 12 miles from the Humboldt fault zone, a localized seismic "hot spot" that has a small but real probability of producing an earthquake of magnitude 5.7 to 6.6. Such an event would cause what's known as liquefaction, in which the earth (mostly silt and sand) on which the dam rests changes from a relatively solid base to what amounts to quicksand.

During the 1989 Loma Prieta earthquake in San Francisco, the soil under the city's Marina district liquefied, causing many buildings to collapse. A similar event at Tuttle Creek could cause the dam to fail. According to 2006 USACE estimates, this would release 381,000 cubic feet of water per second, flood parts of downtown Manhattan to depths of 17 feet, result in the deaths of up to 400 people out of a population of 13,000, and cause damages downstream of $458 million. The dam has even been featured on The History Channel's "Mega-Disasters: Dam Break" show.



Bob Frazey uses the Fluke 1630 to check all the grounding wires around the building that all the communications come into from various points around and across the dam. These include remote sensors, video feeds, and visual and audio warning stations.

In 2002 the Corps set out to make the dam safe, using a variety of methods, including the construction of soil-cement transverse panels to strengthen foundation soils beneath the toe of the dam. But it would take years to finish that, and in the meantime the area downstream would still be at risk. The answer was to put in place a Dam Failure Warning System that would sound an alert in time for the people to evacuate.

The Corps of Engineers contracted for the Tuttle Creek Dam Failure Warning System with the global engineering, construction and technical services firm URS Corporation. With 55,000 employees worldwide, the company has three divisions: URS Engineering Corporation; EG&G, a defense services company; and Washington Division, a large contracting company and builder. URS Engineering Corporation offers services to rehabilitate and expand public infrastructure, including surface, air, mass transit and rail transportation networks, and ports and harbors. The division also provides program management; planning, design and engineering; and construction and construction-management services for water supply, conveyance and treatment systems.

The Dam Failure Warning System is made up of a number of components and subsystems, starting with geotechnical instruments.

Automated geotechnical instruments

These devices include sensors to measure seismic shaking, detect embankment/foundation deformation, and monitor changes in foundation pore pressures. The data from these devices is sent to the Critical Systems Building (CSB) via radio, and many are solar-powered, which not only makes them immune to power outages but also eliminates possible voltage surges via ac power lines.

Pore-pressure sensors

For pressure sensing, URS often uses vibrating wire piezometers. Housed in sturdy metal cases with pointed ends, they are pushed 30 to 50 feet into the earth near the toe of the dam. They are connected via cable to a solar-powered datalogger which in turn sends its data to the central computer in the CSB for storage and analysis. The sensors' output signal is a frequency, which can be read at fairly long distances despite cabling losses. In addition, they have built-in protection against lightning surges, and when coupled with good lightning protection and grounding systems, give very stable readings for many years.

But they have a drawback, says Jim Hummert, Jr., PE, Vice President-Systems Engineering with URS Corporation: It takes about one second to get a reading from each sensor. While this is not a problem for applications like long-term performance monitoring for dam safety (which generally involves taking several readings over the course of a day), it's too slow for an early warning system, which must record a pore pressure signature immediately following an earthquake.

"We need to read these devices more quickly and be able to process the results and run through some type of algorithm or alarm-checking protocol for notifications," Hummert explains. For that reason URS added a set of strain gage pressure sensors with 4-20 mA output. These can be read 10 to 15 times per second or more with standard dam-safety data-acquisition equipment.

Remote controlled video cameras

The availability of economical wireless video cameras has been of great benefit in this area. In the Dam Failure Warning System, three video cameras provide remote visual inspection of the dam spillways, structural elements and weir flows following an earthquake. They transmit video via a 5.8 GHz radio link and receive operator commands to pan, zoom and tilt via 900 MHz spread spectrum radio. Video outputs are available using IP protocols so they can be viewed by all the stakeholders.

Automated data acquisition system (ADAS)

This solar-powered unit receives all the geotechnical instrument data and transmits alarm annunciation.

Deformation monitoring equipment

During an earthquake-induced failure, the crest of the dam could drop by as much as 30 feet. The early warning system includes four ways to monitor such an event. One is distinctly low-tech: A string of solar-powered "runway" lights along the crest and toe of the dam (officially called "Embankment Alignment Indicators"), which can be seen at night.

The second is slightly more complicated: A linear series of nested-loop cables is strung through a series of concrete weights extending 4000 feet along the dam crest, buried about two feet below grade. Officially called the "Dam Crest Integrity Monitor," these are simple twisted-pair cables shorted at one end, and their electrical resistance is constantly monitored by the data acquisition unit. "We measure the resistance on these cables, and they're varying lengths," says Hummert, "so if the dam were to breach we would be able to tell approximately where the breech occurred and about how wide the breach is."

The third is a set of Time Domain Reflectometry (TDR) cables to measure potential post-earthquake displacement in the downstream toe area. TDR cables can be used to measure variations in soil moisture and horizontal or vertical deformations continuously along a given length of cable. Individual cable lengths are limited to about 2000 ft. This type of device makes it possible to measure along a continuum instead of only at discrete points, which is a limitation of most geotechnical/structural instruments being used today.

The fourth is a set of automated inclinometers placed along the toe of the dam. An inclinometer measures the "tilt" of a hole or pipe in the hole. The inclinometer instrument is slid down this pipe using small grooves in the pipe. Over time, if the pipe moves sideways at some point it indicates that the ground is moving and shifting sideways—a clear warning sign of other issues. Inclinometers are installed about ten feet apart; taking repeated readings at each ten-foot increment shows the tilt at each level with depth over time.

Other features of the system include:

- Dam Safety Status Indicators (DSSIs), which are alert-notification units custom-built for First Responders.
- A web portal which provides remote access to instrument data, dam safety status, recent earthquake information, video camera images, and lake level data.
- The seismically hardened Critical Systems Building, which integrates the ADAS with DSSIs and computers at remote locations. It processes and transmits alarms, data and video to the remote users via a private wide area frame-relay network and backup satellite network. All internal communication in the CSB is via Ethernet. The CSB is equipped with uninterruptible power supplies and a propane-fueled backup generator.
- A siren warning system with six 4500-Watt solid-state tone- and voice-capable sirens located in the evacuation zone; siren tones include voice, tornado warning and evacuation.

Bob Frazey works in one of the sensor service panels that lay across the base of the dam. These service panels are all low voltage panels that house ground swell sensor communications and support systems. He uses the Fluke 189 DMM to check the 12 V dc battery charging system that comes from a nearby solar panel. He also uses the Fluke 771 Milliamp Process Clamp Meter to check the 4 mA to 20 mA signal from the pressure sensors and transducers.

The Fluke 1630 is also used to check the grounding wire on the mast of the radio antenna and solar charging panel. Frazey also uses the Fluke 189 DMM with a Fluke i410 current clamp to look at the current output of the solar panel to the battery charger inside the service panel.

- Indoor tone alert units at facilities that require special evacuation attention, such as schools, daycare centers, and facilities for the elderly and handicapped.
- An education and evacuation plan for nearby communities.

What happens when the alarm sounds

If the dam's strong motion accelerograph (SMA) units detect ground shaking corresponding to a significant earthquake (greater than about 4.5 magnitude), an autodialer will call key personnel and play a pre-recorded message detailing the conditions detected at the dam. In addition, the DSSI units will provide remote locations with information on the status of the dam using colored indicator lights to represent various safety conditions.

If the SMA units detect ground shaking corresponding to a severe earthquake (>5.7 magnitude) and damage to the dam is detected, the DSSI units will also display a countdown timer with a delay of between 30 minutes and 2 hours before automatic activation of the downstream warning sirens. The delay provides time for USACE to assess the dam and potentially stop automatic activation (or initiate manual activation) of the siren warning system.

Keeping things working with Fluke equipment

All these subsystems and components require careful setup, maintenance and troubleshooting, and the URS people on site use Fluke equipment almost exclusively for the purpose. Take lightning protection and grounding, for example. This part of Kansas is subject to severe thunderstorms, so surge protection of the equipment is a must.

"We spend a lot of time designing the grounding systems and the lightning protection systems for these systems," says Bob Frazey, field superintendent with URS Corporation. "These are pretty sophisticated data acquisition units, remote-located out on the embankments of the dam, for the most part, or down in the instrumentation galleries or in the power house," he continues, "so when we're designing the grounding systems, and the grounding conductors and so forth, we're checking resistance to ground, bonding resistance between the various connectors that we're using." Frazey uses a Fluke model 1630 Earth ground clamp meter to check equipment ground and lightning-protection grounding installation.

Frazey uses a number of Fluke instruments to check the 4-20 mA measurement loops on the strain gage soil pore pressure sensors and the equipment they feed. He uses a Fluke 707 Loop Calibrator to check and calibrate both 4-20 mA instruments and controls, and a model 771 process clamp meter to monitor, test and adjust 4-20 mA system controls without breaking into the current. "We always check and verify that you get zero and full scale and some intermediate value as well when you do the installation," says Jerry Zimmer, Senior Consultant with URS Corp.

Frazey uses a Fluke 189 Digital Multimeter (DMM) with its accessory Fluke i1010 amp clamp for general volt ohm testing and for checking the output frequencies of the direct-push vibrating-wire pressure transducers. He also uses the 189 with an ac/dc amp clamp to check amperage draw on solar charging systems and batteries. There's another way to check solar charging systems with the 189, adds Zimmer: Hook everything up and then check that the battery voltage is increasing over time. "We usually stand and watch that for five or ten minutes to make sure things are moving along like we would expect," he explains.

"The 189 DMM is also used to occasionally check electronic components and a temperature probe is used to check small air conditioning systems on a few of our pump control boxes," adds Frazey.

A Fluke Networks MicroScanner 2 Cable Verifier and the Microprobe signal tracer accessory are used on Ethernet systems to make, check and repair the CAT 5-6 ethernet cable. The MicroScanner has been of great help, says Zimmer, "to verify our Ethernet cables before those get connected, because we always make those to length, we don't just buy little 3-footers; we're always stringing cables out, and I know at Tuttle Creek, as an example, we had to verify before we pulled them through some conduits underground." It was the MicroScanner, he continued, that alerted them to a problem with one brand of Ethernet cable connectors and led them to change suppliers. The MicroScanner is used to test for length to an open or short, and occasionally to check and repair coax cable.

Frazey uses a Fluke 971 Temperature Humidity Meter to monitor environmental conditions in dam galleries that may cause condensation inside control boxes. In addition, he has built a mobile electronics lab and small machine shop to use when installing and doing maintenance on the systems.

Results

The Tuttle Creek Dam Failure Warning System was completed in March 2005. The system won the 2006 grand award with the American Consulting Engineers Council (Missouri chapter of ACEC). URS has put together a number of similar systems in other locations, including the Wolf Creek dam in Kentucky.

The foundation modification work at the dam site has recently been completed. Later this year, once the walls have hardened and the buried collector system has been completed, the DFWS will be decommissioned. The siren system is being turned over to Riley County and will become part of the existing county tornado siren warning system. In the mean time, URS continues to provide operations and maintenance support.

The URS people seem pretty well sold on Fluke equipment. "I've recommended Fluke equipment for a number of years," says Zimmer, "but when we're outside working on equipment I don't even think about the thing not working, because I know that Fluke stuff just works all the time. So I always feel really good, I always buy that, because I don't have to worry about it breaking."

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Printed in U.S.A. 1/2010 3610922A A-EN-N

Checking ground electrode impedance for commercial, industrial and residential buildings

Application Note

Most facilities have grounded electrical systems, so that in the event of a lightning strike or utility overvoltage, current will find a safe path to earth. A ground electrode provides the contact between the electrical system and the earth. To ensure a reliable connection to earth, electrical codes, engineering standards, and local standards often specify a minimum impedance for the ground electrode. The International Electrical Testing Association specifies ground electrode testing every three years for a system in good condition with average up-time requirements. This application note explains earth/ground principles and safety in more depth and then describes the principle testing methods: 3 and 4 pole Fall-of-Potential testing, selective testing, stakeless testing and 2 pole testing.

Why Ground?

The US National Electrical Code (NEC) gives two principle reasons for grounding a facility.

- Stabilize the voltage to earth during normal operation.
- Limit the voltage rise created by lightning, line surges or unintentional contact with higher-voltage lines.

Current will always find and travel the least-resistance path back to its source, be that a utility transformer, a transformer within the facility or a generator. Lightning, meanwhile, will always find a way to get to the earth.

In the event of a lighting strike on utility lines or anywhere in the vicinity of a building, a low-impedance ground electrode will help carry the energy into the earth. The grounding and bonding systems connect the earth near the building with the electrical system and building steel. In a lightning strike, the facility will be at approximately the same potential. By keeping the potential gradient low, damage is minimized.

If a medium voltage utility line (over 1000 V) comes in contact with a low voltage line, a drastic overvoltage could occur for nearby facilities. A low impedance electrode will help limit the voltage increase at the facility. A low impedance ground can also provide a return path for utility-generated transients. Figure 1 shows a grounding system for a commercial building.

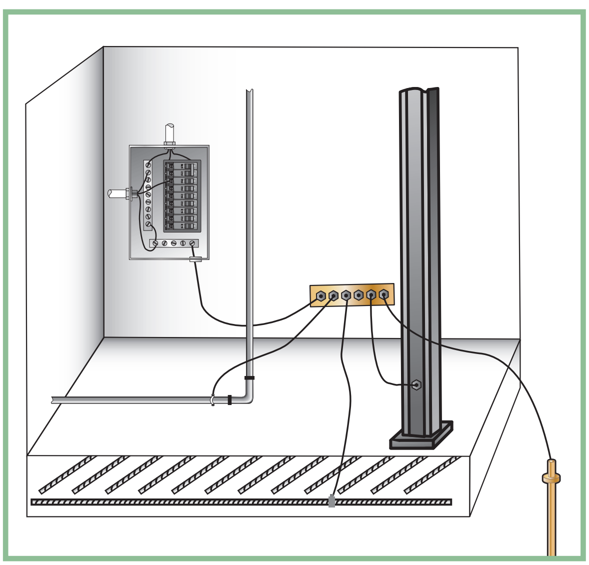

Figure 1: A grounding system combining reinforcing steel and a rod electrode

Ground Electrode Impedance

The impedance from the grounding electrode to the earth varies depending on two factors: the resistivity of the surrounding earth and the structure of the electrode.

Resistivity is a property of any material and it defines the material's ability to conduct current. The resistivity of earth is complicated, because it:

- Depends on composition of the soil (e.g. clay, gravel and sand)
- Can vary even over small distances due to the mix of different materials
- Depends on mineral (e.g. salt) content
- Varies with compression and can vary with time due to settling
- Changes with temperature, freezing (and thus time of year). Resistivity increases with decreasing temperature.
- Can be affected by buried metal tanks, pipes, re-bar, etc.
- Varies with depth

Since resistivity may decrease with depth, one way to reduce earth impedance is to drive an electrode deeper. Using an array of rods, a conductive ring or a grid are other common ways of increasing the effective area of an electrode. Multiple rods should be outside of each other's "areas of influence" to be most effective (see Figure 2). The rule of thumb is to separate the elements by more than their length. For example: 8-foot rods should be spaced more than 8 feet apart to be most effective.

The NEC specifies 25 ohms as an acceptable limit for electrode impedance. The IEEE Standard 142 Recommended Practice for Grounding of Industrial and Commercial Power Systems ("Green Book") suggests a resistance between the main grounding electrode and earth of 1 to 5 ohms for large commercial or industrial systems.

Local authorities including the authority having jurisdiction (AHJ) and plant managers are responsible for determining acceptable limits for ground electrode impedance.

Note: Power distribution systems deliver alternating current and ground testers use alternating current for testing. So, you'd think we would talk about impedance, not resistance. However, at power line frequencies, the resistive component of the earth impedance is usually much bigger than the reactive component, so you will see the terms impedance and resistance used almost interchangeably.

How do ground impedance testers work?

There are two types of ground impedance testers. Three and four point ground testers and clamp-on ground testers. Both types apply a voltage on the electrode and measure the resulting current.

A three or four-pole ground tester combines a current source and voltage measurement in a "lunch box" or multimeter-style package. They use multiple stakes and/or clamps.

Ground testers have the follwing characteristics:

- AC test current. Earth does not conduct dc very well.
- Test frequency that is close to, but distinguishable from the power frequency and its harmonics. This prevents stray currents from interferring with ground impedance measurements.
- Separate source and measure leads to compensate for the long leads used in this measurement.
- Input filtering designed to pick up its own signal and screen out all others.

Clamp-on ground testers resemble a large clamp meter. But they are very different because clamp-on ground testers have both a source transformer and a measurement transformer. The source transformer imposes a voltage on the loop under test and the measurement transformer measures the resulting current. The clamp-on ground tester uses advanced filtering to recognize its own signal and screen out all others.

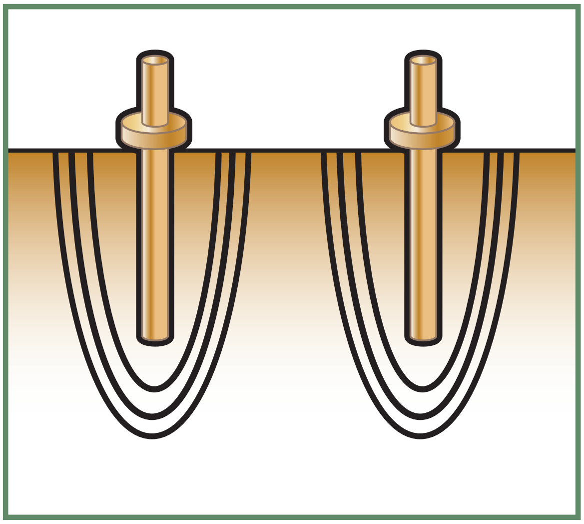

Figure 2: Ground electrodes have "areas of influence" that surround them

Ground Testing Safety

Always use insulated gloves, eye protection and other appropriate personal protective equipment when making connections. It is not safe to assume that a ground electrode has zero voltage or zero amps, for reasons given below.

To perform a basic ground test (called Fall-of-Potential) on an electrode, **the electrode must be disconnected from the building**. New selective methods allow accurate testing with the electrode still connected. See "Selective Measurements."

A ground fault in the system might cause significant current to flow through the ground conductor. You should use a clamp meter to check for current before performing any impedance testing. If you measure above 1 amp you should investigate the source of the current before proceeding.

If you must disconnect an electrode from an electrical system, try to do so during a maintenance shutdown when you can de-energize the system. Otherwise, consider temporarily connecting a backup electrode to the electrical system during your test.

Never disconnect a ground electrode if there is a chance of lightning.

A ground fault in the vicinity can cause voltage rises in the earth. The source of the ground fault may not even be in the facility you are testing, but could cause voltage between the test electrodes. This can be especially dangerous near utility substations or transmission lines where significant ground currents can occur. (Testing grounding systems of transmission towers or substations requires the use of special "Live Earth" procedures and is not covered in this app note.)

Ground impedance testers use much higher energy than your standard multimeter. They can output up to 250 mA. Make sure everyone in the area of the test is aware of this and warn them not to touch the probes with the instrument activated.

Checking Connection Resistance Leading Up to the Electrode

Before testing the electrode, start by checking its connection to the facility bonding system. Most Fall-of-Potential testers have the ability to measure 2-pole, low ohms and are perfect for the job. You should see less than 1 ohm:

- At the main bonding jumper
- Between the main bonding jumper and the ground electrode conductor
- Between the ground electrode conductor and the ground electrode
- Along any other intermediate connection between the main bonding jumper and the ground electrode

The Fall-of-Potential Method

The Fall-of-Potential method is the "traditional" method for testing electrode resistance. The procedure is specified in the IEEE-81 standard "Guide for Measuring Earth Resistivity, Ground Impedance and Earth Surface Potentials of a Ground System." In it's basic form, it works well for small electrode systems like one or two ground rods. We will also describe the Tagg Slope Technique which can help you draw accurate conclusions about larger systems.

Remember: for this method, the ground electrode must be disconnected from the building electrical service.

How it works

The Fall-of-Potential method connects to the earth at three places. It is often called the "three-pole method." You may want to use a fourth lead for precise measurements on low-impedance electrodes, but for our initial discussions we will consider three leads.

The connections are made to:

- E/C1 – the ground electrode being tested
- S/P2 – A voltage (potential) measurement stake driven into the earth some distance away from the electrode. Sometimes called the potential auxiliary electrode
- H/C2 – A current stake driven into the earth a further distance away. Sometimes called the current auxiliary electrode

Figure 3 shows this schematically and Figure 4 shows the three connections made using a typical ground tester.

The ground tester injects an alternating current into the earth between the electrode under test (E) and the current stake (C2). The ground tester measures the voltage drop between the P2 stake and E. It then uses ohms law to calculate the resistance between P2 and E.

To perform the test you position the C2 stake at some distance from the electrode under test. Then, keeping the C2 stake fixed, you move the P2 stake along the line between E and C2, measuring the impedance along the way.

The tricky part comes in determining where to drive the stakes to get a true reading of the resistance between the electrode and the earth. At what point does the dirt surrounding the electrode stop being a contributor of resistance and become the vast earth? Remember that we are not interested in the resistance between the electrode and our stakes. We are trying to measure the resistance that a fault current would see as it passes through the mass of the earth.

The current probe generates a voltage between itself and the electrode under test. Close to the electrode, the voltage is low and becomes zero when the P stake and electrode are in contact.

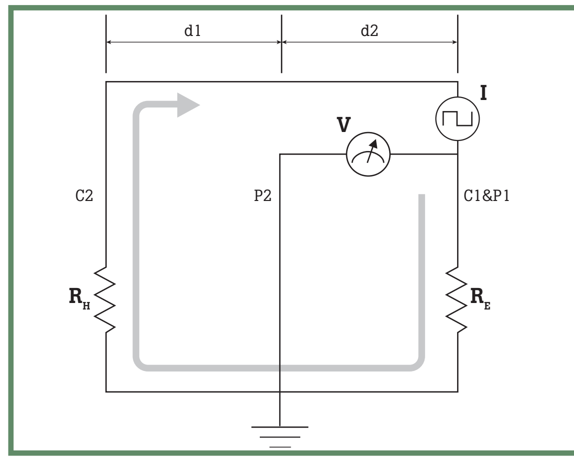

Figure 3: 3-point measurement

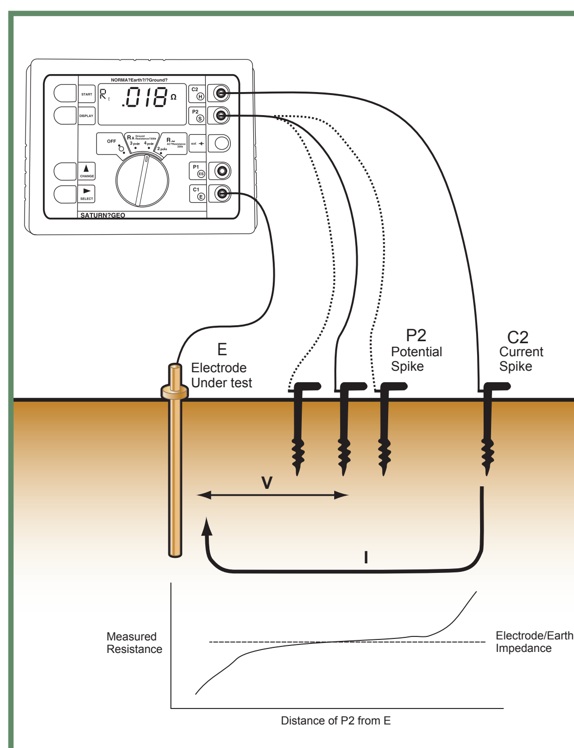

Figure 4: A plot of measured impedances versus position of the potential stake allows us to see the earth impedance

Measurement Tips

- Bring a good, long tape measure.
- Finding the horizontal part of the curve will require at least 5, but more likely 7 or 9 measurements.
- It's a good idea to take three of your resistance readings with the P2 stake at 20 %, 40 % and 60 % of the distance between E and C2. This will allow you to use the Tagg Slope Technique.
- When placing the stakes make sure the current stake, the potential stake and the electrode under test form a straight line.
- If you get a very high impedance measurement or over-range, try pouring some water around the test stakes to improve their contact to earth. This isn't cheating since our intention is not to measure the resistance of our stakes, but to measure the resistance of the electrode.
- Keep the potential and current leads separated to avoid signal coupling between the two.
- At a new construction site, you may want to take multiple sets of measurements. Resistance may drop over time as the earth settles

Close to the electrode, the potential probe is said to be within the influence of the electrode. Close to the current probe the voltage is almost the full voltage output by the tester. But somewhere in the middle, something interesting happens.

As we move from the influence of the electrodes and into the mass of the earth, the test current no longer causes significant change in potential. If you plot a series of measurements, moving the potential stake away from the electrode under test, and towards the current stake you will notice a flattening of the curve. An ideal curve is shown in Figure 3 (see previous page). **The flattest part of the curve is where we read the earth resistance.** In reality, the curve never goes entirely flat but reaches a very gentle slope where changes in resistance are small.

The extent of the influence of the electrode depends on its depth and it area. Deeper electrodes require that the current stake be driven farther away (see Table 1). For large ground rings, grids or arrays the influence of the electrode may extend for hundreds of feet. Table 2 gives suggested starting points for current and potential stake placement.

Because of the possibility of interaction between an electrode rings, grids or arrays, and the measurement stakes you should not take shortcuts – plot the Fall-of-Potential graph to be sure you are getting accurate results.

In testing a bonded array of electrodes the combined resistance of the array will be less than the lowest reading you measure for any individual electrode. If, for example, you have two 8-foot rods spaced more than 8 feet apart you can be confident that the combined resistance will be substantially less for the combined system.

The three-wire measurement will deliver good results if you use a short C1 lead, or if you don't mind having a fraction of an ohm of lead resistance in your reading. For ground resistance measurements over 10 ohms, the effect of the resistance of the C1 lead will be small. But for very precise measurements, especially at low resistances, a four-wire tester allows you add a fourth lead to eliminate the contribution of the C1 lead. By running a separate potential lead (P1) to the electrode under test you can take the drop along the C1 current lead out of the measurement.

Table 1: Approximate Distance to Auxiliary Stakes using the 62 % Rule (in feet)

Depth of Electrode under Test (E)	Distance from E to Potential Stake (P2)	Distance from E to Current Stake (C2)
6	50	82
8	62	100
20	81	131
30	100	161

Table 2: Approximate Distance to Auxiliary Stakes for Electrode Arrays (in feet)

Widest Dimension (Diagonal, diameter or Straight-line) of Electrode Array under Test (E)	Distance from E to Potential Stake (P2)	Distance from E to Current Stake (C2)
65	100	165
80	165	265
100	230	330
165	330	560
230	430	655

The 62 % Rule

You may be able to use a shortcut if your test meets the following criteria:

- You are testing a simple electrode (not a large grid or plate)
- You can place the current stake 100 feet or more from the electrode under test
- The soil is uniform

Under these conditions you can place the current stake 100 feet or more from the electrode under test. Place the potential stake at 62 % of the distance between the current stake and the electrode under test and take a measurement. As a check, take two more measurements: one with the potential probe 3 feet closer to the electrode under test, and one 3 feet farther away (see Figure 5). If you are on the flat portion of the fall-of-potential curve then the readings should be roughly the same and you can record the first reading as your resistance.

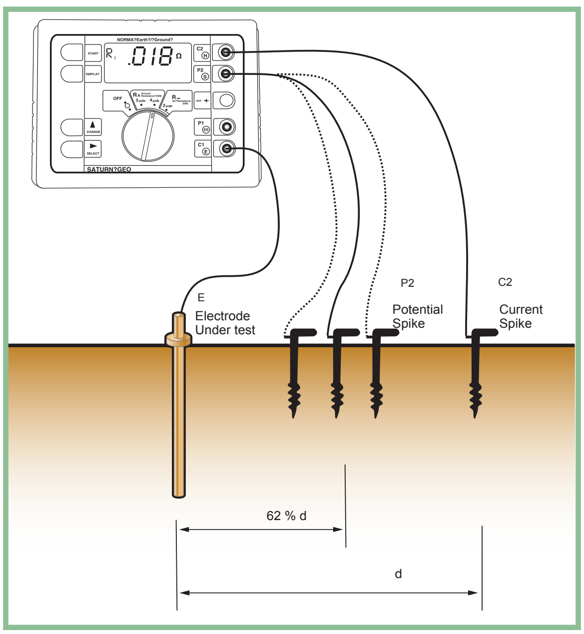

Figure 5: Stake positions for the 62 % rule.

The Tagg Slope Technique

Large electrodes or grounding systems require some special consideration. If you've plotted resistance readings for nine different P2 locations and there is no clear flattening on your graph, then the Tagg Slope Technique (also called the slope method) can help establish the earth impedance. Figure 6 shows an example dataset for which there is no obvious flat section. This curve is characteristic of a test in which the current and potential probes never get outside the influence of the electrode under test. There can be a number of reasons for a curve like this:

- For electrode systems that cover large areas it may be difficult to place stakes far enough away
- You may not be able to place the C1 stake at the center of the electrode
- The area you have to place stakes may be limited

If you have resistance readings at the 20 %, 40 % and 60 % points between E and C2, then you can apply the procedure to the data you've already taken.

Calculate the slope coefficient (µ) using three resistance measurements from 20 %, 40 % and 60 % of the distance from the electrode under test to the C2 current stake.

$$\mu = \frac{(R_{60\,\%} - R_{40\,\%})}{(R_{40\,\%} - R_{20\,\%})}$$

Then go to the table in the back of this application note and look up the P2/C2 ratio that corresponds to your µ. This will tell you where to look on your graph to ascertain the earth resistance. For the sample data in Figure 6:

$$\mu = \frac{(6.8 - 5.8)}{(5.8 - 4.4)} = 0.71$$

If we go to the table, for µ = 0.71 the corresponding P2/C2 percentage is 59.6 %. So the approximate earth resistance would be measured at (59.6 % X 300 feet), or at 178 feet. This is very close to our 60 % point at 180 feet, where we read 6.8 ohms. So it would be safe to say the earth resistance for the electrode under test is roughly 7 ohms.

Distance From Electrode Under Test			Resistance
C2 (feet)	P2 (feet)	P2/C2	R (ohms)
300	30	10%	3.7
300	60	20%	4.4
300	90	30%	5.3
300	120	40%	5.8
300	150	50%	6.5
300	180	60%	6.8
300	210	70%	7.0
300	240	80%	7.7
300	270	90%	8.8

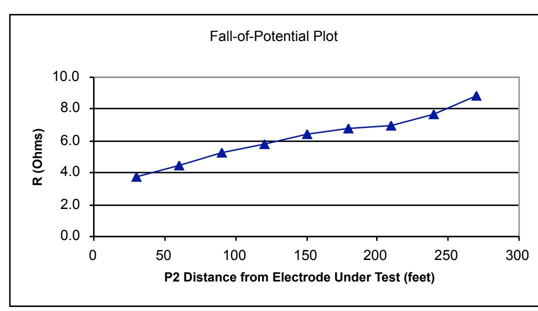

Figure 6: Earth impedance can be found from this curve by using the Tagg Slope Technique

The Selective Method

The Selective Method is a variation of the Fall-of-Potential method, available on high-end ground testers like the Fluke 1625. Testers with this capability can measure the ground impedance of a specific ground electrode without disconnecting it from an array or from a structure's distribution system. This means you don't have to wait for a shutdown to test or risk the safety hazards of disconnecting the electrode from a live system.

The same rules for current stake and potential stake placement apply as with Fall-of-Potential. If the conditions are met for the 62 % rule (see previous page) then it can help reduce the number of measurements. Otherwise it's a good idea to build a complete Fall-of-Potential plot. You can use the Tagg Slope Technique if your curve does not flatten out.

Both the Fall-of-Potential method and the Selective Method use stakes to inject current and measure voltage drop. The big difference is that selective testing can accurately measure the test current in the electrode under test.

The utility neutral, building steel and ground electrode are all bonded and grounded. When you inject a current into this system of parallel ground connections the current will divide. In a traditional Fall-of-Potential test you have no way of knowing how much current is flowing between any particular electrode and the C2 current stake. Selective testing uses an integrated, high sensitivity clamp-on current transformer to measure the test current in the electrode under test. Figure 8 shows how the current transformer fits into the test circuit. The selective ground tester digitally filters the current measurement to minimize the effects of stray currents. Being able to accurately measure the current in the electrode under test effectively isolates the electrode and allows us to test it without disconnecting it from the system or from other electrodes.

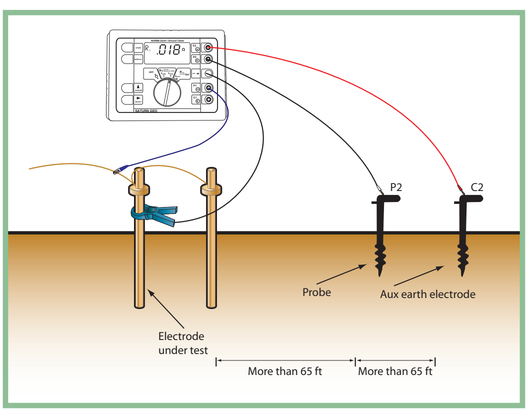

Figure 7: Connections for selective ground electrode measurement

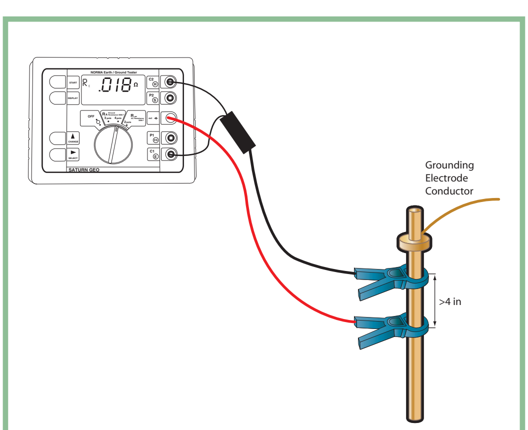

Figure 9: Connecting the Saturn GEO X for a stakeless measurement

Stakeless or Clamp-on Method

The "stakeless" or "clamp-on" method allows you to measure the impedance of a series loop of ground electrodes. The test is simple and it may be performed on an electrode that is connected to a working electric service.

To make the measurement the tester uses a special transformer to generate a voltage on the ground conductor at a unique test frequency. It uses a second transformer to distinguish the test frequency and measure the resulting current through the circuit.

This method is available in some Fall-of-Potential testers (like the Fluke 1625) or in a single clamp on unit. Figure 9 shows the connection of the source and measure clamps of the Fluke 1625.

Figure 10 (see next page) shows the equivalent test circuit for the stakeless method. When you test a building ground electrode using this method, you are actually testing a loop including:

- Electrode under test
- Ground electrode conductor
- The main bonding jumper
- The service neutral
- Utility neutral-to-ground bond
- Utility ground conductors (between poles)
- Utility pole grounds

Because this method uses the service as part of the circuit, it may be used only after the service has been completely wired, that is, it cannot be used prior to hook-up to the utility. In this method the clamp checks the continuity of the interconnections of all of the components above. An abnormally high reading or an open circuit indication on the instrument points to a poor connection between two or more of the aforementioned critical components.

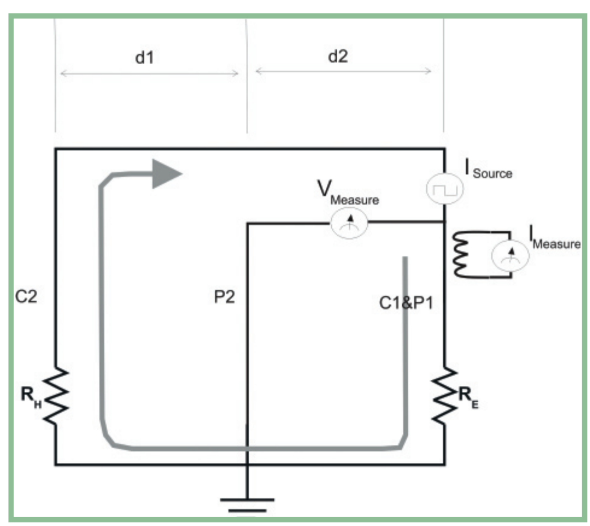

Figure 8: Connections for selective Electrode Impedance Mesaurement

This method requires a low-impedance path in parallel with the electrode under test. The ground electrode of most facilities is in parallel with numerous utility ground electrodes. These electrodes can be pole electrodes, pole butt plates or un-insulated neutral conductors. The impedance of the utility ground electrodes usually combines into a very low impedance.

Let's take an example. Say you have 40 pole electrodes of roughly 20 Ω each, and these electrodes are connected together by a low-impedance ground wire from pole to pole. The equivalent resistance of the 40 electrodes in parallel is:

$$R_{eq} = \frac{1}{40 \times 1/20\Omega} = 1/2\Omega$$

Since half an ohm is small compared to the resistance we expect for our electrode under test, we can assume that most of the measured resistance is due to the earth resistance of the electrode under test. There are some potential pitfalls for this method:

- If you measure in the wrong place in the system, you might get a hard-wired loop resistance, for example on a ground ring or on a bonded lightning protection system. If you were intending to read earth resistance, measuring the conductive loop would give unexpectedly low resistance readings.
- You may get low readings due to the interaction of two very close, bonded electrodes, like buried conduit, water pipes, etc.
- The quality of the measurement depends on the availability of parallel paths. If a building is solely supplied by a generator or transformer that has only a single electrode, the assumption of multiple paths won't work and the measurement will indicate the earth resistance of both electrodes. This method will not measure earth resistance.
- A problem with the utility grounding system might interfere with readings.

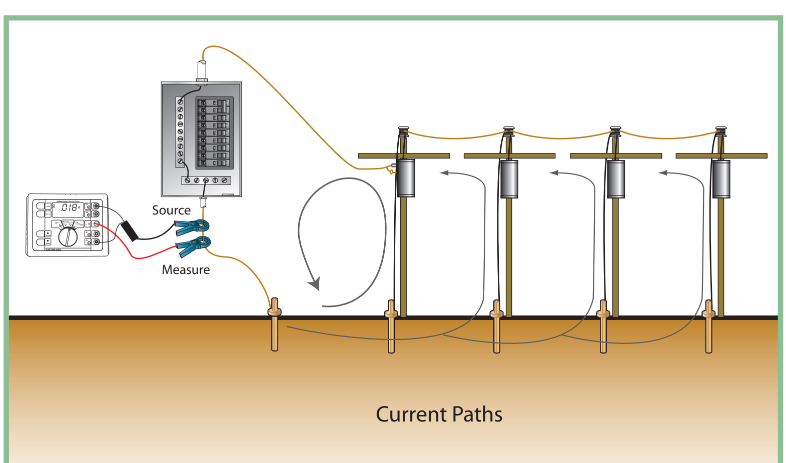

Figure 10: Test current paths in the stakeless method

In general, if you get readings below 1 ohm, double-check to make sure you are not measuring a hard-wired conductive loop instead of the earth resistance.

Two-pole Method

The two-pole method uses an "auxiliary electrode" such as a water pipe. Figure 11 shows the connections. The tester measures the combined earth resistance of the electrode under test, the earth resistance of the auxiliary electrode, and the resistance of the measurement leads. The assumption is that the earth resistance of the auxiliary electrode is very low, which would probably be true for metal pipe without plastic segments or insulated joints.

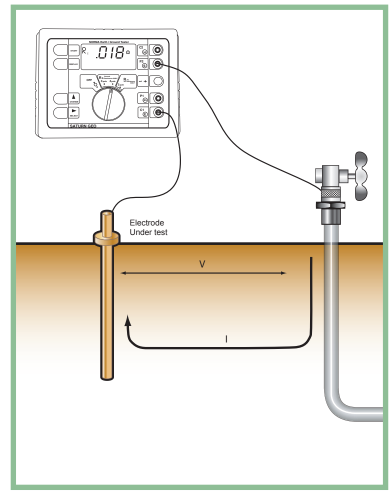

Figure 11: Equivalent circuit for two-point measurement

The effect of the measurement leads may be removed by measuring with the leads shorted together and subtracting this reading from the final measurement.

Although it's convenient, be very careful using the two-pole method:

- A water pipe may have PVC components, which could greatly increase its earth resistance. In this case the two-point method would give an excessively high reading.
- The auxiliary electrode may not be outside the influence of the electrode under test. In this case the reading might be lower than reality.

Because of the unknowns involved in this technique, it is recommended only when the grounding system and auxiliary electrode are well known.

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Summary of Ground Electrode Test Methods

	Advantages	Drawbacks
Fall-of-Potential	• Widely accepted • When you see the characteristic curve you know you've got a good measurement.	• You have to disconnect the ground • The stakes may not be easy to drive • There may not be space around the ground electrode to drive the stakes
Selective Method	• Don't have to disconnect electrode • Widely accepted • When you see the characteristic curve you know you've got a good measurement.	• The stakes may not be easy to drive • There may not be space around the ground electrode to drive the stakes
Stakeless Method	• Convenience	• Assumes a low-impedance parallel path • Possible to get very low readings by mistakenly measuring on a hard-wired loop
Two-pole Method	• Convenience	• Impossible to judge the integrity of the "auxiliary electrode." • Can't be sure you are outside the area of influence

Table for the Tagg Slope Technique (for 2 decimal places)

µ	P2/C2	µ	P2/C2	µ	P2/C2	µ	P2/C2	µ	P2/C2
	%		%		%		%		%
0.40	64.3	0.65	60.6	0.90	56.2	1.15	50.7	1.40	43.1
0.41	64.2	0.66	60.4	0.91	56.0	1.16	50.4	1.41	42.7
0.42	64.0	0.67	60.2	0.92	55.8	1.17	50.2	1.42	42.3
0.43	63.9	0.68	60.1	0.93	55.6	1.18	49.9	1.43	41.8
0.44	63.7	0.69	59.9	0.94	55.4	1.19	49.7	1.44	41.4
0.45	63.6	0.70	59.7	0.95	55.2	1.20	49.4	1.45	41.0
0.46	63.5	0.71	59.6	0.96	55.0	1.21	49.1	1.46	40.6
0.47	63.3	0.72	59.4	0.97	54.8	1.22	48.8	1.47	40.1
0.48	63.2	0.73	59.2	0.98	54.6	1.23	48.6	1.48	39.7
0.49	63.0	0.74	59.1	0.99	54.4	1.24	48.3	1.49	39.3
0.50	62.9	0.75	58.9	1.00	54.2	1.25	48.0	1.50	38.9
0.51	62.7	0.76	58.7	1.01	53.9	1.26	47.7	1.51	38.4
0.52	62.6	0.77	58.5	1.02	53.7	1.27	47.4	1.52	37.9
0.53	62.4	0.78	58.4	1.03	53.5	1.28	47.1	1.53	37.4
0.54	62.3	0.79	58.2	1.04	53.3	1.29	46.8	1.54	36.9
0.55	62.1	0.80	58.0	1.05	53.1	1.30	46.5	1.55	36.4
0.56	62.0	0.81	57.9	1.06	52.8	1.31	46.2	1.56	35.8
0.57	61.8	0.82	57.7	1.07	52.6	1.32	45.8	1.57	35.2
0.58	61.7	0.83	57.5	1.08	52.4	1.33	45.5	1.58	34.7
0.59	61.5	0.84	57.3	1.09	52.2	1.34	45.2	1.59	34.1
0.60	61.4	0.85	57.1	1.10	51.9	1.35	44.8		
0.61	61.2	0.86	56.9	1.11	51.7	1.36	44.5		
0.62	61.0	0.87	56.7	1.12	51.4	1.37	44.1		
0.63	60.9	0.88	56.6	1.13	51.2	1.38	43.8		
0.64	60.7	0.89	56.4	1.14	50.9	1.39	43.4		

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Printed in U.S.A. 3/2007 2550440 A-EN-N Rev C

safe path for the dissipation of fault currents, lightning strikes, transient over-voltages, static discharges, EMI and RFI signals and interference.

A ground is a conducting connection, whether intentional or accidental between an electrical circuit or equipment and the earth, or to some conducting body that serves in place of the earth. It helps by stabilising the voltage to earth during normal operation, and limits the voltage rise created by lightning, line surges or unintentional contact with higher-voltage lines.

In the event of an electrical fault or lightning strike anywhere in the vicinity of the mining area, a low-impedance ground electrode will help carry the energy into the earth. By keeping the potential gradient low, damage is minimised.

Without an effective grounding system, workers could be exposed to the risk of electric shock, not to mention instrumentation errors, harmonic distortion issues, power factor problems and a host of possible intermittent dilemmas. If fault currents have no path to the ground through a properly designed and maintained grounding system, they will find unintended paths that could include people.

Poor grounding not only contributes to unnecessary downtime, but a lack of good grounding is very dangerous and increases the risk of equipment failure. A good grounding system will improve the reliability of equipment and reduce the likelihood of damage due to lightning or fault currents.

The need for earth testing

Over time, corrosive soils with high moisture content, high salt content, and high temperatures can degrade ground rods and their connections. Previous faults may have melted connections that aren't easily visible. So although the ground system when initially installed had low earth ground resistance values, the resistance of the grounding system can increase if the ground rods are eaten away from causes due to corrosion of ground rods, breaks in interconnecting wires and water table changes.

Earth resistance is the resistance of the earth to the passage of electric current, and test results show the resistance offered by the earthing rods with the connection leads, which should be less than 1 Ohms in the case of Rio Tinto's installation. Resistivity defines a material's ability to conduct current, which is a complex property to measure within the earth as it is affected by several factors, including soil composition, mineral content, temperature and depth.

Intermittent electrical problems at a mine site could be attributed to poor grounding or poor power quality.

That is why it is highly recommended that all grounds and ground connections be checked upon installation and on an annual basis. During these periodic checks, if an increase in resistance of more than 20 per cent is detected, the technician should investigate the source of the problem, and lower the resistance by replacing or adding ground rods to the ground system.

Rio Tinto conducts regular earth ground tests to ensure the operational safety of a mine. This is the first line of defense. The ability to detect and monitor ground connections can provide valuable data for undertaking appropriate risk assessments for mining operations.

Ground beds provide safety grounding of electrical equipments in mines. The goal in ground resistance is to achieve the lowest ground resistance value possible that makes sense economically and physically. Ideally a ground should be of zero ohms resistance.

David Oxley, electrical supervisor at the reliability assurance department at Rio Tinto's Cape Lambert site in the Pilbara region, oversees these inspections.

David said, "We need to ensure that earth grounding at all substations is at its peak performance, and that we are comply with statutory rules onsite."

David and his team perform checkups at their substations regularly.

The process

Special instruments make it simple and easy for maintenance and safety teams to measure earth-resistance and troubleshoot problems.

For Rio Tinto, the Fluke 1625 is used to measure the capability of the earth ground system at the substations.

Earth resistance measurement: the Fall-of-Potential measurement

The classic Fall-of-Potential test method is used at Rio Tinto's Cape Lambert facility to measure the ability of an earth ground system or an individual electrode to dissipate energy from a site.

Typically the earth electrode of interest must first be disconnected from its connection to the site. Second, the tester is connected to the earth electrode. Then, for the 3-pole Fall-of-Potential test, two earth stakes are placed in the soil in a direct line—away from the earth electrode, normally with a spacing of around 20 meters. By using the Fluke 1625 to generate a current through the two outer ground stakes (the auxiliary earth stake and the earth electrode), the drop in voltage potential is measured between the two inner ground stakes. Using Ohm's Law (V=IR), the Fluke tester automatically calculates the earth resistance.

Earth resistance measurements are often corrupted by the existence of ground currents and their harmonics. To prevent this from occurring, the Fluke 1625 uses an Automatic Frequency Control (AFC) system. This automatically selects the testing frequency with the least amount of noise enabling you to get an accurate earth ground value.

Saving time with selective testing

The Fluke 1625 is a distinctive earth ground tester. Not only does it measure ground resistance using the classic fall of potential test but also enable time saving testing using the selective method. Selective testing does not require the electrode under test to be disconnected during the measurement, thus increasing safety.

The selective method allows testers to measure the ground resistance of a specific ground electrode without disconnecting it from an array or from a structure's distribution system. This means that safety hazards are minimised as there is no risk from disconnecting the electrode from a live system.

With selective measurement, two earth stakes are placed in the soil in a direct line, away from the earth electrode, of around 20 metres. The Fluke 1625 is then connected to the earth electrode of interest, with the advantage that the connection to the site doesn't need to be disconnected.

Instead, a special clamp is placed around the earth electrode, which eliminates the effects of parallel resistances in the grounded system, so only the earth electrode of interest is measured. A known current is generated by the Fluke 1625 between the outer stake and the earth electrode, while the drop in voltage potential is measured between the inner earth strake and the earth electrode. Only the current flowing through the earth electrode is measured using the clamp. The generated current will also flow through other parallel resistances, but only the current through the clamp is used to calculate resistance.

"The Fluke 1625 also allowed us to perform testing without the need to shut down any of our 20 substations. This capability minimised downtime and gave us the freedom to conduct testing for all substations at any one time."

Steve Hood, managing director at Fluke Australia said, "The Fluke 1625 is intended for electrical utilities or other high energy environments as it has extra versatility for more demanding applications.

"Under these circumstances, the selective method is a much safer and easier method for earth ground testing for Rio Tinto, as there is no need to disconnect or shut down any of the substations in order to perform this test. The earth testing conducted to ensures a safe environment for all workers, and at the same time, maximises profit to investors by operating responsibly, with no downtime."

David said, "The team learned how to use the Fluke 1625 tool almost immediately. There was a lot of training and support from Fluke to ensure that our requirements and needs were met. It is now an indispensable tool for us at the mines."

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Printed in U.S.A. 10/2010 3931841A A-EN-N