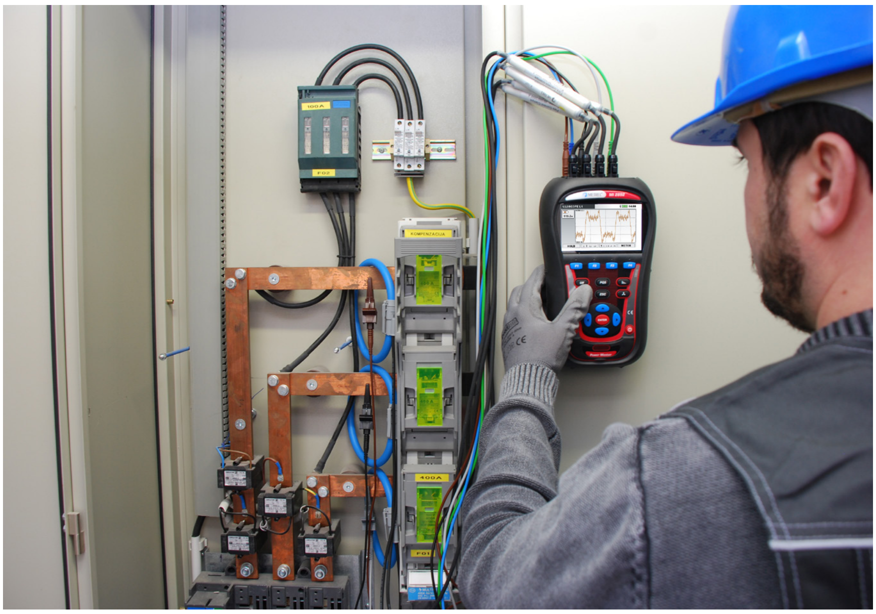
Application Note

Earthing and lightning protection tests with MI 3155

A hospital is generally a complex of buildings huddled together, often evolved rather than planned. Constructing, maintaining and testing grounding protection in such an environment is a worthy challenge. The system is complex and filled with redundancy, designed for power reliability and safety of the users.



Lightning protection and earthing systems

Hospital as a complex is generally a TT earthing system when viewed from the outside. They often have internal transformer substation where earthing for the whole complex is constructed. This system has a particularly low earth impedance. The solution is simpler for earthing electrode maintenance and earth resistance measurements. On the other hand, each building could have its own connection to earth. This can lower interference through earth for sensitive instruments, but it also has higher resistance and makes maintenance more complex with many locations to cover. Courtyards and other open spaces have to be kept on an equalized potential to prevent step voltage hazard in case of a large fault or a lightning strike.

Earth electrode should be a wide underground device like a loop, mesh or a plane with multiple parallel connections to it. There should be a lattice of conductors throughout the foundations with its own way to earth, keeping the base potential of each building constant. The ground electrode is usually a loop or a mesh and covers most of the area under the building. Lightning protection design depends on the roof of the buildings' and grounds shape.

Inside, the critical rooms must have full Faraday cage protection both to limit the disturbances and to keep them safe from overvoltage. Machines like MRI are very sensitive to electromagnetic radiation that other devices, like RTG, can produce. Designer has to keep that in mind. Operating theatres have their own insulated networks that need to be grounded as a whole.

Lightning strike is a very extreme case for the installation. There is no absolutely guaranteed protection, only some measures that can help limit the damage. System of heavy conductors leading directly to the ground is the main one, but it cannot prevent voltages inducing anywhere in the installation or side flashes from one conductor to the other. Similar effects can be caused by lightning strikes on other parts of the distribution system. Surge protectors are therefore installed before or in the devices to further divert the current to the ground. In the distribution parts, they are called lightning arresters. There is a number of different constructions. Most common are varistors, made with metal oxide, and gas discharge tubes. Metal (most commonly zinc) oxide varistor is a semiconductor device that can conduct very large currents once the voltage passes its rated voltage. They should be used in conjunction with a fuse that will prevent them from failing due to overheating. For protection in distribution, they are stacked in large porcelain containers. Gas discharge tubes use the high voltage to ionize the gas and cause it to start conducting. It can pass higher current for its size than other protective devices, but it is slow to react, so other protective measures should be taken apart from it. Reaction time is in range of 100 ns.

Lightning protection and earthing systems:

Lightning

Lightning surge is usually fast and extremely high-powered, reaching into hundreds of kilo volts and kilo amperes. However, since it passes so quickly, permissible voltage on accessible conductive parts of the equipment can be quite high. Some values with regard to fault duration are collected in Table 1. Lightning flashes last 0.2 s on average, usually made up from a number of shorter flashes of 60 – 70 μs.

Phase to ground fault

Second important fault that needs to be considered when designing the grounding is phase to ground fault. It can cause dangerously high voltages on enclosures or any grounded conductive surfaces. Grounding system must have low enough resistance to pull the voltage down to safe levels. Since it is a type of fault that lasts until fixed, permissible touch voltages in Table 1 are much lower.

Measuring methods

There are a number of methods for measuring earthing resistance that differ by complexity and accuracy, or are particularly suited for a specific grounding system.

3-wire (fall of potential) method

3-wire method, also called fall-of-potential method, is a common way of measurement that gives quite accurate results for well-defined potential funnels. It uses the earth electrode and two others, often labelled P (for potential) and C (for current). Current one is set further away from the measured electrode than the voltage. Alternating current is then passed from it and the potential measured. The earth resistance is then simply calculated using the Ohm's law. However, the positioning of the electrodes can be hard to achieve and the result is influenced by many factors that are hard to quantify. Multiple measurements and averaging are a must to achieve accuracy. Minimum is three measurements: the P electrode in the original position, moved 10% closer to the measured electrode, then moved 10% away from it in regard to original distance. Proper positioning can be recognized by little variation from measurement to measurement when the electrodes are moved. If it is not achieved, the stakes need to be moved further away or, if the disruption comes from buried objects, at least in a different direction.
In a perfect scenario, the C electrode stands so far from the measured one that the P electrode would not be influenced by any of their areas of effective resistance, and there are no buried metal objects (pipes, fences).
The method only works well for small systems that don't cover a lot of area. The larger the measured object, the longer the distances between the stakes. They become impractically large very quickly, e.g. for an object 50 m across, distance to P

electrode would be 100 m and to C electrode 200 m from the electrical centre of the object, which is not always known. In urban areas, it is not common to have this much space available.

2 clamps method

Methods with clamps are much quicker and easier to perform. They do not require disconnecting the earth electrode or special instruments, only a current clamp and a current generator. Current is injected into the earthing leg as close to the electrode as possible. A voltage-inducing clamp can be used, or any kind of connector that can be applied to the wire without disconnecting it.

The measurement taken is a loop measurement. The induced voltage causes current in the whole earthing system. In this case, it goes from the transformer secondary throughout the network and back underground along the earthing system. The more parallel earthing rods there are in the system, the closer to resistance of a single rod the measured value will be.

It is a quite straight-forward consequence of essentially measuring a leg of series-parallel circuit that is a power network in a building.

If the measured electrode has high resistance, that will be immediately obvious. However, if one of the others is defective, or if there is another error in the loop, the change in measured value might not stand out. It can still be easily noticed if there is evidence of previous measurements, or if we have a good prediction of the expected value.

Contact voltage – P-S probe method

The third option to check quality of the earthing system is not about measuring earth resistance, but contact voltages. Contact voltage is a measure of danger to the user. It is the potential difference between a point of contact with an accessible conductive surface (e.g. a housing) and the earth in case of a fault.

It can be described in terms of fault loop impedance and prospective fault current, or as actual measured voltage when a current is injected into grounding system. The measured values are then scaled to expected fault current in case of a lightning strike.

The method is applicable to any system, but particularly sensible for large systems with a lot of unknown variables. It doesn't measure the earthing system, but simply establishes danger or no danger in case of a fault for any measured spot.

Contact voltage is measured in chosen positions as current is injected into the fault loop. This is again a loop measurement, so the measured spot is connected to a number of resistances in series or parallel on the network. For the worst-case scenario calculation, the current is not measured in the leg where the contact voltage is taken, but considered as injected. Human body can be simulated using 1 kV resistance in parallel to the voltmeter.

Using MI 3155

MI 3155 is a multifunctional installation tester that can cover every aspect of the installation from its inception to years of regular maintenance. Amongst its many features are also three methods for measuring earth resistance. It comes equipped with a number of different probes and test leads for easy testing.

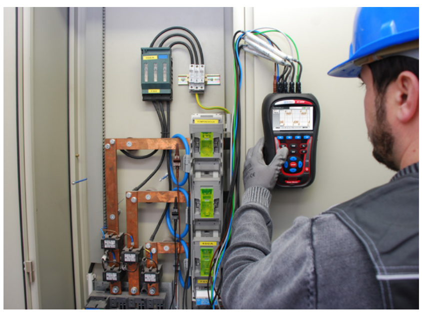
3-wire measurement

Instrument is standardly equipped with 20 m long cables and rods for earth resistance measurements. Optional extensions are available.

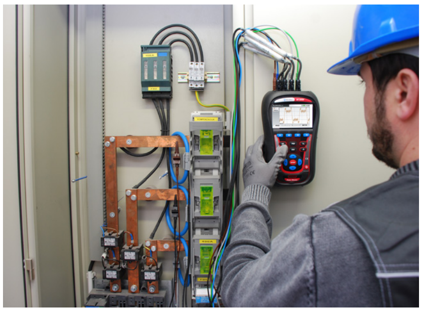
Software contains option to set a maximum resistance limit and gives a pass/fail signal. The measurement is automatic at a press of the button, and the result can be saved. Further processing is not possible on the instrument, but can be done by exporting the results to the PC. Instrument also displays resistances of each measurement electrode for reference.

The procedure starts by examining any documentation on the existing earthing system. Electrical centre of building in question has to be either learned or determined. Rods are set to proper distances and connected with cables. The instrument is connected to each of them.

Port designations are H for current electrode, S for voltage electrode and E/ES for measured electrode.



2-clamp method
A pair of clamps is also a part of the standard set for MI 3155. They are mainly different in connectors: A 1018 has integrated test wire for connection to the instrument, and A 1019 has connectors for standard test leads. The only settable parameter is maximum acceptable resistance for pass/fail indication. The measurement is entirely automatic, and it is not important which clamp comes top or bottom. Use the three-wire test lead and insert it into the test connector on the top of the instrument. Connect the banana connectors one on top of the other and insert into the clamp. Use the current clamp connectors (black and red) to connect the other clamp. Push the button to measure, and save the result as desired.



Contact voltage with P-S probe method
The measurement is performed between earthed accessible conductive part and earth at a distance of 1m. MI 3155 has the P/S connector for the earth probe for contact voltage measurement. The three-wire lead goes to accessible metal part. It injects the current as well as serves as voltage terminal. The measured voltage is then scaled to the expected fault current.

$U_{touch} = U_m \times I_{fault}/I_{test}$

U_{touch} – resulting contact votage
U_m – measured voltage
I_{fault} – projected fault current
I_{test} – test current

Standard IEEE-81.2012 part 9 defines permissible body current, which can be measured using a body simulator like Metrel A 1597, or a 1 kOhm resistor as per the standard. The other option is to calculate it from the measured voltage.

Fault duration (s)	Permissible body current IB (mA)	Permissible touch voltage UTp (V)
0,05	900	716
0,10	750	654
0,20	600	537
0,50	200	220
1,00	80	117
2,00	60	96
5,00	51	86
10,00	50	85

Table 1: Permissible body currents and touch voltages in fault conditions

Checking surge protectors

MI 3155 is equipped with an automatic varistor test. User chooses the maximum voltage to which they mean to test. The voltage during test ramps from 50 V with a slope of 100 V/s (for range 1000 V) or 350 V/s (for range 2500 V). The test is finished when the final voltage is reached or the current exceeds a predefined limit. Default is 1 mA. Other parameters are grounding system, minimum desired breakdown voltage and maximum desired breakdown voltage. The instrument will note a pass or fail status. It is important to note that the object under test will take a brief while to discharge after the high-voltage measurement.