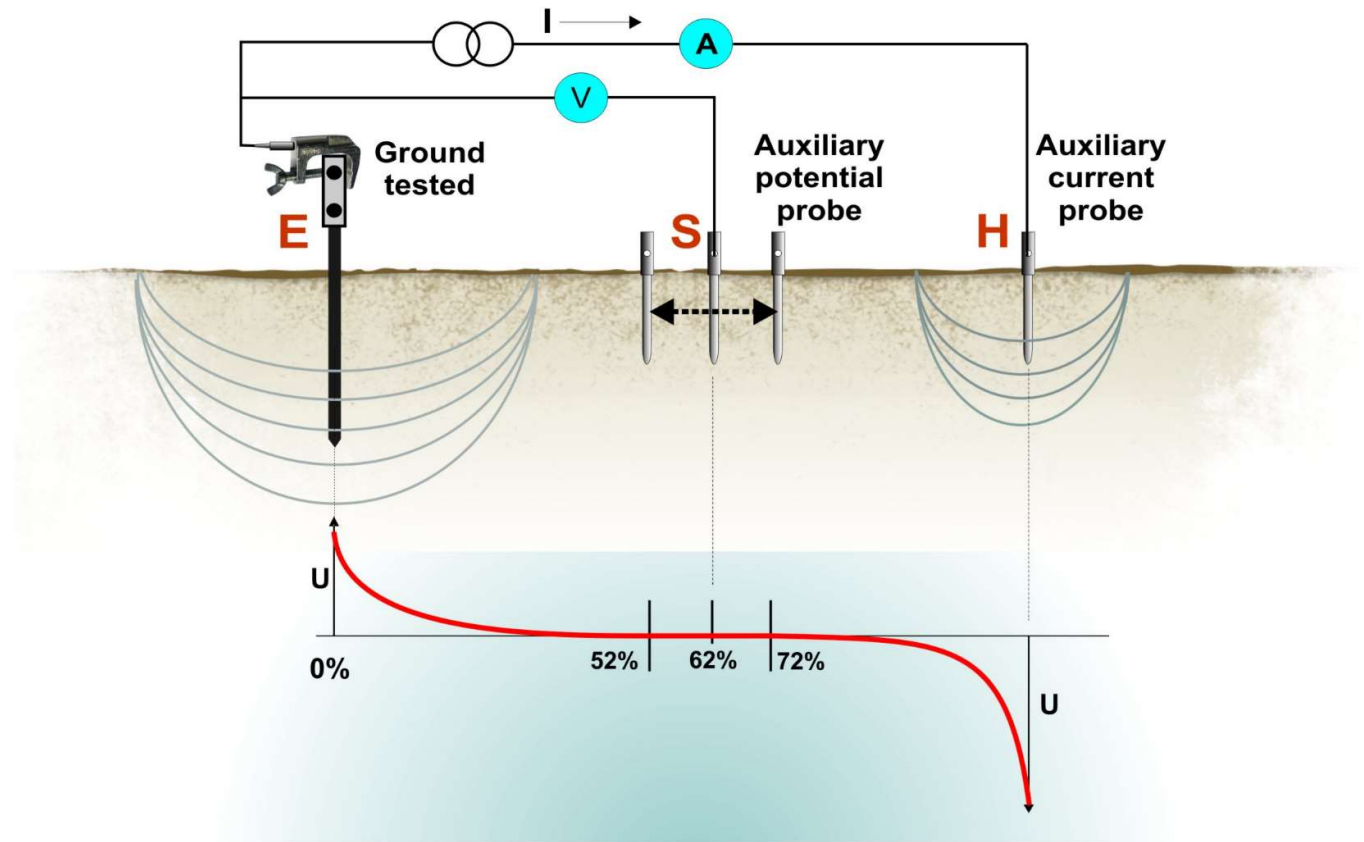


Earth Ground Resistance Measurement - Fall of Potential Method.



The most common method of earth ground resistance measurement is the “Fall of Potential Method”. To measure grounding accurately with this method, it is crucial to follow a rigorous procedure. It can be a time-consuming task that depends on the arrangement of the grounding system, the terrain, and other factors. Taking shortcuts may result in errors. This paper first describes the general procedure for a single earth grounding point, and then describes a modified approach using a current probe for testing ground resistance of multiple-earth-grounding-point systems, such as for lightning protection, or power poles and transmission pylons.

To measure the earth ground resistance of a single ground electrode at “E”, a current is forced to flow to E by driving an auxiliary test probe H into the ground at a certain distance away from the E electrode and connecting the H probe to a current source. In this case the ground resistance test meter is the current source which generates an alternating current. An electrical circuit is formed between H and E with current flowing between them in the ground. At points between E and H electrical potentials are created; there is a resistance path between E and H so a voltage will develop at points along this path due to the current. A second auxiliary test probe S is driven into the ground between E and H to measure electrical potential (voltage). This voltage varies along the path between E and H; maximum voltage occurs at E and zero at H. Hence the term “Fall of Potential Method” since the voltage potential falls away when moving the S probe away from E towards H. With the voltage recorded at S we can determine the earth resistance from the voltage and current values.

Experience has shown that the ground point E must be sufficiently far away from the auxiliary probe H. The reason for this concerns the electrical performance of a probe or electrode inserted into the ground.

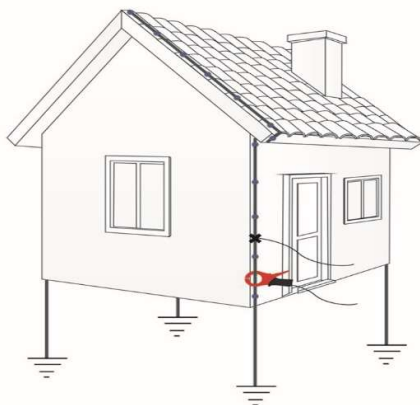
An electrode that is longer and driven more deeply into the ground has a greater ability to allow more current to flow to and from it than a short, shallow probe. The flow of current in the ground is largely electrolytic; obviously greater moisture helps more electrons to flow. Similarly, a long electrode has more contact with the ground around it than a short one so it will permit a greater volume of electron flow. It has been observed that as one measures voltage in the vicinity of an electrode, the closer one gets to the electrode E the voltage gradient increases. As one moves further away from E the voltage gradient begins to level off and falls to zero. The gradient increases again as S approaches the H probe. To avoid confusion on this concept keep in mind we are talking about voltage gradient – not the actual voltage.

In the diagram above note the voltage gradient curves near the electrodes and a plateau, or zero-gradient area, between them. It is in this zero gradient area that we wish to measure voltage to find the ground resistance. It is important that the two electrodes are sufficiently far apart so that the gradients around the electrodes don't overlap or interfere with each other, and that a zero voltage gradient area can be measured. The distance between probes E and H are generally accepted to be 25 or 50 meters apart for a zero voltage gradient to be established. Sometimes depending on the soil and terrain conditions it may need to be longer.

Experience has shown that the first voltage measurement made by S should be made at approximately 62% along the distance between E and H. To confirm the presence of a zero gradient region the voltage probe S is moved a few meters closer to the tested ground point E, and then moved closer to the auxiliary current probe H. At least three tests are required in order to verify the zero voltage gradient zone, and therefore the accuracy of the measurement. Sometimes depending on conditions it may take several measurements; this is why it can be time-consuming! We can accept the measurements as valid when three results of voltage are the same or very close; i.e. within a few percent of each other.

Fall of Potential Method with Current Probe for Multiple Ground Points.

For a single ground point there is usually no practical problems with this method. In other situations the grounding system is more complicated, such as for building structures with multiple grounding points. To follow the exact method above requires measuring grounding points in isolation; i.e. the tested ground point is not associated with other conduction paths to ground which will affect measurement accuracy. It is not always possible to completely isolate each grounding point – either by temporarily disconnecting it or the other ground points. To overcome this challenge the Fall of Potential Method with Current Probe technique is used.



Multiple ground points for lightning protection



Current clamp to measure current at an individual ground point

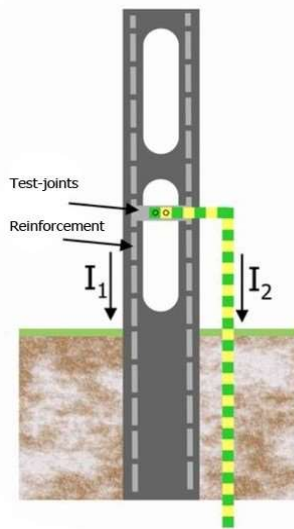
A simple example of an arrangement of multiple grounding points is shown above. This building is designed with a lightning conductor on the roof with four ground termination points, all connected to each other. The Fall of Potential Method depends upon a test current from a source to a single ground point, from which resistance can be calculated. In this situation with multiple paths to ground the test current will flow to all four ground points at the building corners. Now we are confronted with how to isolate each ground point and measure each point individually. Disconnecting each tested ground point from the whole system temporarily, is not desirable, or even practicable.



Flexible Rogowski current probe.

In such a situation it possible to determine resistance of the grounding system without disconnecting multiple building ground connections. This method uses a current probe. The current probe isolates and measures only that current for a specific grounding electrode. The procedure is as follows: in the building situation above a current clamp is placed around the ground conductor of interest, the E probe is attached to the same conductor, the H probe is placed a distance away, and testing is performed using the Fall of Potential Method by measuring the voltage gradient with the S probe. The value of measured current by the current probe is used to calculate resistance instead of the total current generated from the meter. To physically make the current measurement requires access to the conductor and placing a current probe around it. In certain situations a conventional current clamp is too rigid and bulky to get into a confined space. A flexible Rogowski-coil current probe can be used instead of a conventional current clamp to overcome this difficulty.

Fall of Potential Method with Current Probe for Power Poles and Pylons.



Medium-voltage line pylon

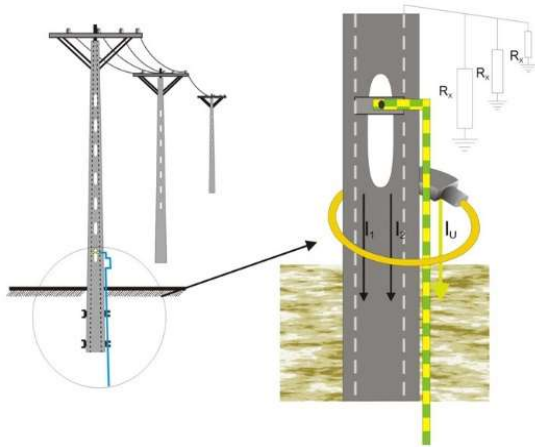


Single grounding medium-voltage line

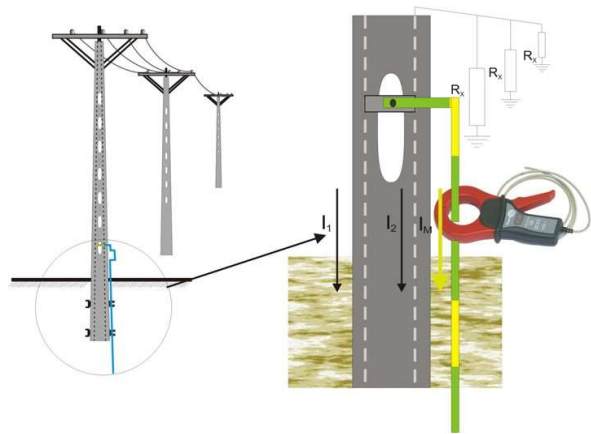
Consider the measurement of ground resistance of power poles and transmission pylons. When can they be considered as a single point ground, and when can they not? The medium-voltage pylon shown here can be considered as a single earth ground point, provided each pylon is not connected to its neighbor. Each pylon is bonded to a ground with a metal electrode which is connected to the internal reinforcement rebar inside the concrete. The concrete itself contains moisture. The water content of the concrete combined with the mineral salts in the concrete create an electrolyte capable of conducting electrical current.

To perform the test, the E meter connection is attached to the grounding electrode. The H probe of the test meter is placed a distance away and the usual Fall of Potential Method is followed. Most of the test current flows in the electrode (I_2) and some flows via a parallel path through the concrete (I_1); even though it will be very small compared to (I_2). Since there are no other paths to ground the test current measured will be the sum of (I_1) + (I_2).

For testing ground resistance of low-voltage pylons the Fall of Potential Method with Current Probe must be employed instead. It may seem at first that each pylon is a single grounding point, since each pylon is a stand-alone structure. However, as in the building example above, there are multiple ground paths to take into account. The difference with the medium voltage situation is that each pylon in a row of pylons is connected to its neighbor via a fourth aerial Protective Earth Neutral (PEN) cable, which is itself connected to ground, plus the other pylons are embedded in the ground. The diagram below represents these multiple paths (R_x).



Correct measurement of low-voltage pylon grounding



Incorrect measurement of low-voltage pylon grounding

When making a resistance test, the test current induced by the meter will flow via multiple paths to ground; i.e. along the aerial PEN conductor to other adjacent pylons, through the concrete in the pylons, and through the ground-bond electrode wire at each pylon. If we measure the fall of potential and calculate resistance using the total current generated by the meter, and not the current for the individual pylon of interest, we will arrive at an incorrect resistance calculation; it will be too low. Similar to the building situation above, we must measure only the current in the pylon of interest by the current probe method so that the current flowing via other paths is ignored. The value of the earth ground resistance obtained using the measured clamp current will be higher, but more accurate.



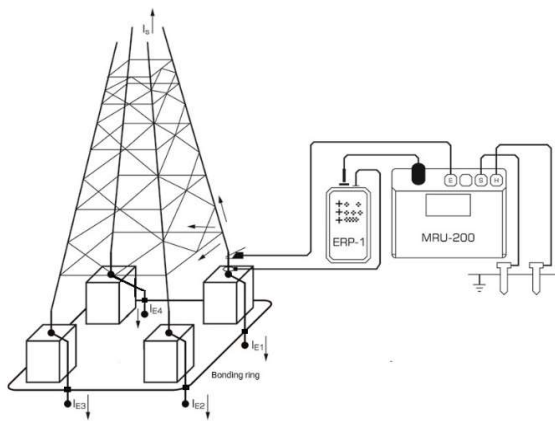
Rogowski coil and ERP-1 Adapter



For best accuracy the probe must go around the pylon to measure the current in the paths through its individual grounding electrode, as well as through the concrete to ground. If the current probe or clamp was only placed around the electrode then the measured test current would not include the current flowing in the concrete, even though as described above it is small compared to the electrode current.

To go around the pylon we need a probe with a very large circumference. Sonel has designed flexible Rogowski current probes that are thin and up to 5 meters / 16 ft. long. These special probes operate with an intermediate module; the Sonel ERP-1 adapter. The ERP-1 comes with 4 FS probes 4 meters / 13 ft. long as standard. The adapter can also operate with Sonel type F, type FS (more sensitive) and customized FSX (highly sensitive) probes. The user can also select the number of turns the probe is wound around the pylon; increasing the number or turns around the pylon increases probe sensitivity.

For measuring ground resistance at high-voltage steel pylons, the ERP-1 is a useful device to automate the resistance calculation for all 4 legs of a steel pylon, the procedure is as follows:



Testing ground resistance of steel HV pylons



A Rogowski current probe is placed around one leg of the pylon. The polarity of the probe is important. The current probe has an arrow indicating the direction of current flow; point the arrow down towards the ground. It is advisable to coil the probe around the leg up to four times for greater sensitivity and better accuracy. The ERP-1 module is connected to a test meter, such as the Sonel MRU-200-GPS. On the ERP adapter select the number of current probe turns. On the meter select the number of legs of the pylon (1-4). Connect the E probe to the first leg, place the H probe a suitable distance away and make the voltage gradient measurements using the usual Fall of Potential Method. The first measurements to establish the zero gradient take the most time. Once the zero voltage gradient is established move the current probe on to the next leg for the next measurement. When moving the current probe from leg to leg keep the same polarity of the current probe (always point arrow down), and keep the E connection on the first leg to take into account the resistance of the pylon. The meter electrode H and the S probe each remain fixed. The meter will display the earth ground resistance for the whole pylon after completing the series of leg tests. The automatic calculation of earth ground resistance for an entire steel pylon is unique in the market to the Sonel MRU-200 series of ground resistance testers. The meter can also recognize the physical break-down, or corrosion of the bonding connector connected to the earth bonding ring of the pylon, which will show up as high resistance measurements.

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