# GROUNDING SYSTEM –KNOWLEDGE OF SOIL RESISTIVITY

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## *ABSTRACT*

*This paper presents techniques important for the design of different grounding systems. Such system can be found in substations, power grids, wind farms, hydropower plants etc. Grounding system can have a lot of reasons of what they are supposed to fulfil. Often it could be a combination of many things. Even if that is the case, a main purpose must be clearly defined and controlled. The main objective for designing a good grounding system is often one of three: personal safety; lightning protection; or functional grounding systems. If we focus on personal safety the step and touch voltage are the main issues.*
*Design of grounding system is dependent of current, soil resistivity, area and proximity to other existing grounding system. Soil resistivity is the factor where electric power engineers have least knowledge. And it is a factor which is difficult to change.*

## INTRODUCTION

There exist a lot of different theories of grounding system and its design. One important thing to know before a decision on the design is taken is under what circumstances will the system be installed and used.
Allowed step- and touch voltage for HV systems can be found in different standards, e.g. [1]. Sometimes the allowed levels differ between different kinds of equipment that are installed at the same place. One reason for that is what grounding is assumed to achieve. Is it; personal safety; lightning protection; functional grounding; electrical bonding. In practice it is in most cases a combination of several reasons.

A method of planning what kind of grounding system one should use for best economic and technical result must be further developed. This paper introduces some thoughts on this, with emphasis on getting information on the soil resistivity.

## MEASUREMENT PROCEDURE ACCORDING TO EBR

How to measure and determine impedance values in grounding systems in Sweden is described by the Swedish Rational Electrical Building code EBR K25-10 [2] for low and high voltage systems in three different ways. EBR K25-10 describes different situations depending on how the area is populated and how overhead line or underground cables are used. A short description of three different situations follows in the forthcoming sections.

### Urban area – continuous cable grid

In an urban area it is common with underground cable for every voltage level. In such case an ordinary method with measurement for each connection to the ground is not needed.
One earth electrode is defined as the primary grounding electrode. This earth electrode should be inside a substation. Only when a new substation is built or if very big changes have been done that could affect the grounding system must a new measurement for the ground impedance of the primary ground electrode be performed.
The impedance measured at the primary grounding electrode is used for calculation with existing earth fault current to find the magnitude of the touch voltage, Fig. 1.
The Distribution Network Owner (DNO) must show that there is a good connection between grounded equipment through the high voltage cable. This is done with a current that is injected in one of the three phases.

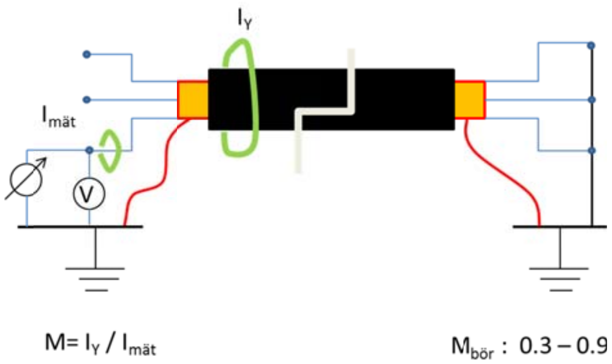


Fig. 1 Measurement setup in urban areas with continuous cable grid according to EBR K25-10

If the value $M=I_y/I_{mät}$ indicated in Fig. 1 is between 0.3 and 0.9, the grounding system is OK.
Measurements and analyses according to this method must be repeated as soon as some work has been done on the high voltage cable. The following equation for voltage calculation is used:

$$Voltage_{Step}=0,15 * current * cable\ length\ (in\ km)$$

The result must be lower than 100V.

## Urban area connected to substation with overhead line at high voltage - continuous cable grid from overhead lines

This method is similar to the method discussed in the previous section. The M value is calculated from the measured $I_y$ and $I_{mät}$. Added is the ground impedance measured at the substation and the impedance measured at the urban area (indicated with A and B in Fig. 2). These values are used in the following equation:

$$Voltage_{Step} = current * (Z_{substation}+Z_{sec\ urban\ area})$$

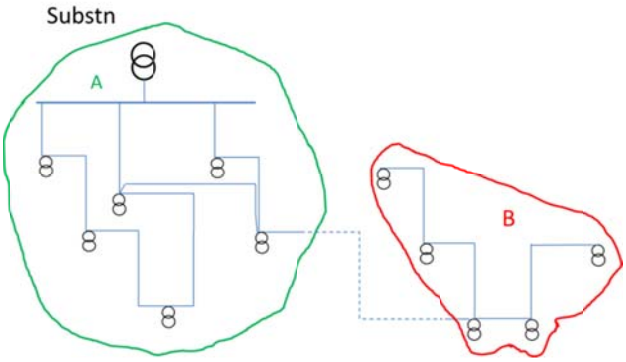


Fig. 2 Measurement setup of touch voltage in urban grid consisting of both cables and overhead lines according to EBR K25-10.

When it is planned for a new cable network away from a substation, EBR gives a method for calculate how much copper that must be used to reach the goal of maximum impedance. The proposed method is not suitable as it gives only a very rough estimation. Also is the result never subject to verification; neither before the new cable network has been taken into operation nor in the form of regular maintenance checks. And all of the underlying result comes from a method far away from what geosciences use when they want more information of the existing soil resistivity at each location.

## Rural area

The methodology proposed for rural areas is the one commonly used in Sweden to measure the impedance of a grounding system. Two measurement electrodes are rolled out 40 meter and 80 meter in the same direction. Different calculations are done depending on what is connected to ground and the value of the ground fault current. The voltage value received must be lower than is the value stipulated by the authorities.

## METHOD FOR CONTROL OF LARGE SCALE GROUNDING SYSTEM

The method for testing the efficiency of large grounding systems will be described in the forthcoming section and as shown in Fig. 3. It is named heavy-current injection method. A generator is used that produces a current at a frequency of about 41 Hz. This current is injected into the overhead line and the response is detected as a voltage between substation A and true earth far away through the measurement line. With this method will the efficiency of the grounding be controlled and documented during the actual operation of the network.

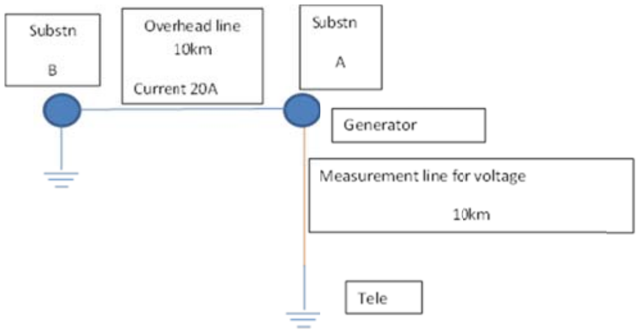


Fig. 3 Heavy current method according to EBR K25-10

This method is however becoming outdated since more and more telephone copper cables are disconnected. This telephone cable is used as a connection for voltage potential against true earth. An alternative method is therefore needed. In cases where there are no telephone cables, a cable is connected to the instrument and rolled out, in steps, to different distances. The instrument gets a value for each step and produces a curve. When the curve flattens out the goal is met. It is then possible to use software to get the resulting impedance and at the same time document the measurement.

Both methods makes it possible to control step- and touch voltage at different assumed places. This is done with a selective voltage meter and a resistance of 3000 **Ω**. This is also done for the telephone grid by the owner of that grid.

## CONNECTIONS INTO THE SOIL TO ACHIEVE A LOW IMPEDANCE

The connection into the soil can easily be made in two possible directions: horizontal and vertically. When to use either method is normally up to the worker making the connection. There are normally no directives on how to do the connections especially for how deep they should force the ground rods. We will come back to this later, when discussing location-dependent soil resistivity.

## MEASURING SOIL RESISTIVITY

### Soil resistivity – according to EBR

EBR K25-10 gives a description of how to measure the soil resistivity [2]. It is recommended to use the Wenner method (also known as "Wenner four-point test") for finding out the average soil resistivity for the whole area that is connected with underground cables. The basic method is to connect four ground rods in a straight line with equal distance between them and inject a current into the two outer ones. The potential difference between the two inner rods is then measured. That value is used to calculate the soil resistivity at a certain depth. The distance between the rods should, according to EBR, be 3 meters. The result is a single estimation of the soil resistivity at a depth around 1.8 meters. As we will see later, the soil resistivity can vary a lot with depth.

A special way of using the Wenner method is to do one measurement at four different places. The distance between the electrodes in this case should be 3 meters. After that an average is calculated for the whole area.

The value of the soil resistivity, ρ, is used to determine how much underground copper wire should be used to achieve accepted values of touch voltage. The equation below will give the required length of copper wire, $L_{wire}$.

$$L_{wire} = 2 * \rho_{average} / R_{needed}$$

Schlumberger method can also be used to find the soil resistivity. It gives more information about the resistivity at different depth and provides a geologic profile of the soil. It is based on the same principle as Wenner method with the main difference being the placement of the grounding rods.

Once an acceptable result is achieved no future control of the impedance is required. An assumption is often done for distances up to 5 km even though there could be a large spread in results.

### Soil resistivity – from a geologist viewpoint

The authors have started a dialog with various people that in one way or the other are involved with geoscience. This dialog must be seen as a first attempt to use their way of looking at soil resistivity. The challenge will be to find a proper way of applying their knowledge in power engineering.

Soil, at least in the northern part of Sweden, consists of many different layers. The layers can have different thickness and almost random value of resistivity. To find out how the soil resistivity is at the location where building is planned a pre study must be done. The measurements that are to be taken during the pre-study should give the answer on how the soil is at the location with regard to number of layers with different resistivity and their thickness. It is possible to use different methods to achieve the information; which one to choose is up to the user. But when a method is chosen a stringent way of using it must be followed.

Depending on the method used it is possible to find out how it looks down into the soil without drilling a hole. Measurements are to be taken in different directions for a good result at one location.

### Location dependent soil resistivity

An example of the measured soil-resistivity as a function of location and depth is shown in Fig. 4. In this case Schlumberger method was used. It gives almost the same result as Wenner does. To get the soil-resistivity at different depth and location four probes must be placed at different distance in a scheme of at least 15 different setups. The depth of what is possible to find out from this method is about 0.2 times the distance between the current electrodes. After the field measurements you need analyze the results. If a lot of points are needed you move the instrument and repeat the measurement procedure.

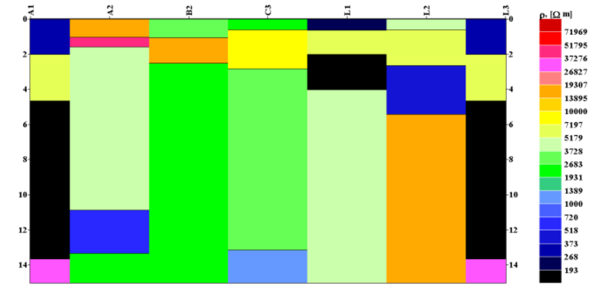


Fig. 4 Soil resistivity as a function of location (horizontal axis) and depth (vertical axis). The color scale indicates different values for the soil resistivity.

From Fig. 4 it is possible to find out, for the location, that the lowest value for the resistivity (about 200 Ωm) is found between 5 and 13.5 meters depth. To drill deeper at this location is pointless as the resistivity increases to approximately 30 000 Ωm at 14 meters depth. At location L1 only horizontal copper wires should be used about 0.6 meter deep in the soil since the lowest value of resistivity is found near the surface.

The availability of this type of data will allow for much more efficient and cost-effective grounding systems. However collecting this data can be very time consuming.

## CVES

An alternative way to get similar information is to use a method named Continuous Vertical Electrical Sounding (CVES). This is a much faster method and requires less personnel resources.

With this method an instrument is used which can handle cables with a lot of outlets where earth probes are connected. The input data is from a method from other disciplines than power engineering about soil resistivity. With existing software is it then possible to analyze the measurement data and to obtain plots of the soil resistivity as a function of location and depth. Such plots can next be used as an input to a grounding design, resulting in a high quality grounding system.

An example of a resulting plot of soil resistivity as a function of location and depth is shown in Fig. 5.

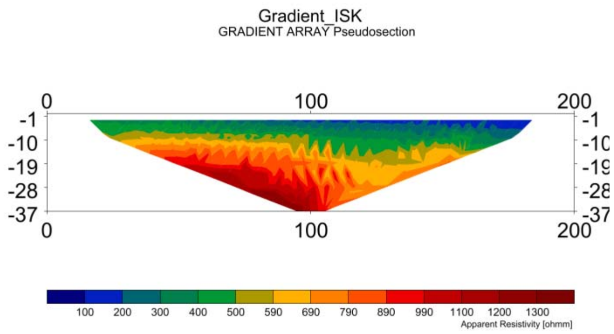


Fig. 5 Soil resistivity as function of location and depth obtained from CVES; the instrument is placed at 100m. Electrodes are placed with 5m spacing in both directions. Horizontal axis: distance on the surface (0 to 200 m); vertical axis: depth from the surface (0 to 37 m). The colors indicate different values for the soil resistivity.

The result will tell the user existing different layers and their resistivity and thickness and it will be possible to use the data for planning the required amount of copper to reach the necessary impedance value.

## CONCLUSION

There are today useful methods to find the geological profile at a specific location. The methods can be used to make better decisions on how to build and design the grounding systems. Still work has to be done to further develop techniques used in other fields, as geoscience, so that they can be adopted and used by the electric power engineers. In some situations shortcuts could be used but they are perhaps not good enough for every location. A first step could be cooperation between network operators in the different Nordic countries.

The future goal is to develop a quick but accurate method for scanning the soil resistivity together with a method of how to use the results in grounding system design for power systems.

Before a new substation is built, knowledge of soli resistivity is a good help for decisions on how to design the grounding system. Knowledge of existing soil resistivity is also useful when an existing substation must be improved according to the results from a heavy current method. One must also know if it is better to do a vertically or horizontally grounding system. Beside this it is also good to get a hint on how much work that has to be done to reach an acceptable level of grounding resistance.

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