High Voltage Pylon earth Measurements

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Abstract

The earth connection of high voltage electrical power line pylons is obviously very important. The different design of pylons can change the earth bond task drastically. This paper will give feedback from an actual experiment conducted with a new design Pylon in South Africa and discusses the difficulty of getting repeatable measurements and knowing that the Pylon is properly earthed.
Electric-power transmission is the bulk transfer of \textit{electrical energy}, from generating \textit{power plants} to \textit{electrical substations} located near demand centres. This is distinct from the local wiring between high-voltage substations and customers, which is typically referred to as \textit{electric power distribution}. Transmission lines, when interconnected with each other, become transmission networks.
Why Ground?

Poor grounding not only contributes to unnecessary downtime, but a lack of good grounding is also dangerous and increases the risk of equipment failure.

Without an effective grounding system, we 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.
Why Test grounding systems

Over time, corrosive soils with high moisture content, high salt content, and high temperatures can degrade ground rods and their connections. 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.

That is why it is highly recommended that all grounds and ground connections are checked at least annually as a part of your normal Predictive Maintenance plan. During these periodic checks, if an increase in resistance of more than 20 % is measured, the technician should investigate the source of the problem, and make the correction to lower the resistance.
What is a good ground?

There is a good deal of confusion as to what constitutes a good ground and what the ground resistance value needs to be. Ideally a ground should be of zero ohms resistance.
What is Earthing?

- Simple definition of an earth is to connect the electric circuit/equipment to the earth’s conductive surface.

- The reason first and foremost is for personal safety and protection of equipment in case of fault currents and lightning strikes.

- In studies done by power quality experts, they will relate that poor grounding/earthing is second only to improper wiring as the leading cause of equipment malfunction.

- There are various methods and systems to do this, starting with simple stakes driven into the ground to multiple grounds rod’s, mesh or grids systems.
Earthing
Earthing

- One of the systems is then chosen taking into consideration of the type of installation. For example a substation, electrical pylon and anything in between.

- Another consideration would be the soil resistivity which is dependent on may factors i.e. Sandy/semi desert and rocky areas, which would be much less conductive (1000 ohms per meter) than say loamy and clay soil (100 ohms per meter).

- These factors are not always constant and can be affected by the climate, rainfall and temperature.

- Changes in the site can also result in the soils resistivity changing - paving, development.
Earthing

- Lightning strikes on equipment with poorly maintained protection systems destroy millions of Rands of equipment and equate to lost production every year.

- Using Earthing/ground testing in a PDM protocol will help prevent possible dangerous situations and loss of downtime (= money)
Soil Resistivity

Soil resistivity measurements have a threefold purpose

1. The data is used to make a subsurface geophysical survey of the area - identify ore location, depth to bedrock and any geological phenomena.

2. Soil resistivity has a direct impact on the degree of corrosion on underground pipes or any metallic structure. A decrease in resistivity relates to an increase in corrosion activity.

3. The resistivity directly affects the design of the grounding system.
Soil Resistivity

Here are some factors that we should take into account which will have an effect on the measurements taken.

- First of these is the physical dimensions & depth of a typical earth electrode assuming all connections to the electrode are in perfect condition and present a very low resistance. This is because the earth is made up of various layers and not all have the same constant resistivity, it follows that the deeper the electrode is driven into the earth the better the resistance will be.

- If the electrode length is doubled the resistance level can be reduced by 40%. The diameter of the rod/spike does not have a big influence
## Soil Resistivity

<table>
<thead>
<tr>
<th>Type of Soil</th>
<th>Soil resistivity $R_E$</th>
<th>Earthing resistance ($\Omega$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\Omega$ m</td>
<td>Earthing rod m depth</td>
</tr>
<tr>
<td>Moist humus soil, moor soil, swamp</td>
<td>30</td>
<td>10</td>
</tr>
<tr>
<td>Farming soil loamy and clay soils</td>
<td>100</td>
<td>33</td>
</tr>
<tr>
<td>Sandy clay soil</td>
<td>150</td>
<td>50</td>
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<tr>
<td>Moisty sandy soil</td>
<td>300</td>
<td>66</td>
</tr>
<tr>
<td>Dry sand soil</td>
<td>1000</td>
<td>330</td>
</tr>
<tr>
<td>Concrete 1:5</td>
<td>400</td>
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<tr>
<td>Moist gravel</td>
<td>500</td>
<td>160</td>
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<tr>
<td>Dry gravel</td>
<td>1000</td>
<td>330</td>
</tr>
<tr>
<td>Stoney soil</td>
<td>30,000</td>
<td>1000</td>
</tr>
<tr>
<td>Rock</td>
<td>$10^7$</td>
<td>-</td>
</tr>
</tbody>
</table>
Soil resistivity

- Second is the sphere of influence. When using multiple earth electrodes it does not necessarily follow that the more electrodes used the lower the resistance will be.
Soil Resistivity & Sphere of influence

Definition of a ground electrode is a conductor or group of conductors in intimate contact with the earth for the purpose of providing a connection with the soil.

• This definition does not refer to an actual ohm resistance value of the electrode. The resistance is determined by the resistivity of soil which the electrode or earthing systems are in contact with.
• When an object is grounded it is then forced to assume the same potential as the earth.
• If the potential of the grounded object is higher or lower, current will pass through the grounding connection until the potential of the object and earth are the same.
• The earth electrode is that connection path.
Sphere of Influence

- The effect of the concentric shell is that it takes a finite amount of earth for the ground rod to fully realise its resistance value.

- This finite amount of earth is known as the ground rod’s sphere of influence.

- The sphere of influence of a ground rod is commonly thought to be a radius around the ground rod equal to its length; the ground rod achieves approximately 94% of its resistance value at this radius. (100% is achieved at approximately 2.5 times the rod length).

- Hence, grounding is necessary to maintain an object’s potential equal to that of the earth’s.
Sphere of influence

The volume formula is: \( V = \frac{(5 \times \pi \times L \text{ cubed})}{3} \)

We can simplify this by rounding PI down to 3 to cancel the 3 below the line. This will leave us with:

\[ V = 5 \times L \text{ cubed} \]

- Using this formula we can calculate that a single 10 foot driven rod would utilize 5000 cubic feet. An 8 foot rod would only utilize 2560 cubic feet.
- Thus for additional electrodes to be effective they must be spaced so that their spheres of influence do not intersect.
- The minimum distance is roughly the depth of the electrode for the second electrode to be effective.
Ground potential Rise

In the case of extremely large fault currents induced into the ground by a phase to earth fault, or by lightning. The ground cannot immediately reduce the potential to zero. This condition is called "Ground Potential Rise". In these conditions not only will the grounding system rise in electrical potential but will radiate into the soil from the centre of the grounding point.
Ground potential rise

This phenomenon is demonstrated by cows in field after a lightning strike, not all of the cows are affected, some are killed and some close by are unaffected. This is because the potential differences radiates outwards from the point of the strike. The cows facing the strike are more likely to be killed as the potential difference between the front and rear legs and across the animal’s heart is greater than the cows standing with their sides towards the strike— their potential difference between the two front legs is much lower.
Ground Potential rise

Step potential

- Voltage between the feet of a person standing near an energised grounded object. Equal to the difference in voltage, given by the voltage distribution curve and a point some distance away.

- Should you be standing in a storm close to a pylon best you stand on one foot- side on to the pylon. The lowest potential difference would be from your left small toe to your big toe in theory.
Ground potential Rise

Touch Potential

- For example, a crane that was not grounded because it was on rubber tyres and that contacted an energized line would expose any person in contact with any metallic part of the crane.

- The full fault current would then pass directly through that person to ground.
Measuring earth Resistance

- Earth resistance is measured in ohms per meter or ohms per centimetre and represents the resistance of a cubic meter of earth. There are a number of methods of measuring soil resistivity of which the Wenner is most popular.
- Wenner simplified formula: \( \text{Rho} = 2 \times \pi \times A \times R \)
- Where \( \text{Rho} \) is the average soil resistivity at depth \( A \)
  \( \pi \) is 3.141
  \( A \) is the distance between the electrodes in cm
  \( R \) is the measured resistance value in ohms.

![Diagram of Wenner method](image.png)
Measuring Earth resistance

- Using the Wenner 4-pole method the depth of the electrodes is typically 6 inches, the distance between the electrodes is also the depth at which the earth resistivity is calculated (A).
- As results are sometimes distorted by geological anomalies and spurious induced currents, various readings should be taken to form a profile.
- Instruments nowadays compensate for harmonics, currents using automatic frequency control.
Transmission Towers

- 765KV & 400KV transmission lines - One operational with overhead earth connected.
- 765KV - Guyed unconnected new tower. One centre point with four guy ropes.
- Earth connections cast in concrete.
- No removable earth straps.
- Reason why there is not a removable earth straps it that the rebar is connected to the stub on which the tower is constructed.
- Overhead earth connections
- Using the fall of potential method when measuring the earth resistance on one pylon foot, all the earthing points together including the adjacent pylons will be measured.
Transmission Towers

Counterpoise Earth

- When an acceptable connection cannot be achieved a Counterpoise earth is used. This provides a high capacitance and therefore a relatively low impedance path to earth.
- The reduction in Impedence will reduce insulator flash over due to lightning strikes.
- The energy from the lightning strike travels down the counterpoise and is reflected at the terminal end. The counterpoise will act as a series resistance with a distributed leakage to ground.
- A counterpoise would be in excess of a grounding electrode system, not in lieu of.
Fall of Potential Method

- This method requires that the earth under test must be disconnected from the system and other earthing points. In this case of a 765KV pylon, if it were possible, this would be a dangerous exercise substantial currents may exist in the earth conductor.
Transmission Towers

Selective Method

• Up and until the 1990’s the established method for measuring earth resistance was the fall of potential method.

• With the Selective method the major significance of this would be that pylon testing can now be carried out on each individually foot separately, without disconnecting any other earthing points.
Transmission towers
Selective Earth Method

- Two earth stakes are placed in the soil in a direct line away from the earth stake of interest.
- Spacing of 20 metres is usually sufficient.
- A known current is generated between the outer stake and earth stake, while the drop in voltage potential is measured between inner and earth stake.
- Only the current flowing through the earth stake of interest is of interest and is measured with the clamp and then calculated as the resistance.
- By this method we can measure the earth resistance of any foot of the pylon without disconnecting any other earth parts.
Beaufort West

- Two separate pylons were measured- one Guyed tower and one Four base tower.
- One with the overhead earth disconnected.
- Both with rebar earthing system.
- Five measurements taken on the Guyed tower.
- Terrain semi desert with sandy soil.
- The setup of the stakes was as follows- 60m and 100m form the measuring point.
- Resistance of both pylons was found to be similar and very low (3.4Ω).
- Multiple measurements were done in various directions and results were similar.
References

- Fluke: earth ground Resistance
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- AEMC: Understanding soil resistivity testing
- Lightning Engineers: earth Ground Systems-Testing & Importance
- The Internet: About Electrical Grounding
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