Methods and Techniques of Grounding: The Case of Production Industry in Tanzania

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Abstract

This paper presents an investigation of different grounding system techniques used by industries in Mbeya region. Mixed methods were used to generate data for grounding techniques and then presented in this paper. The measurements of type of soil and its resistivity were collected and analyzed. Three methods of measuring soil resistivity; Wenner Array Method, Schlumberger Array Method and Driven Rod Method were discussed and results were compiled and analysed. Furthermore, three grounding schemes used in industries; solidly grounding, ungrounded, and impedance grounding were analysed. The results, obtained from the experimental measured data, revealed that cause of failure were due to poor grounding and other different types of faults which were estimated to be 20% to 30%. Selected production industries were Tanzania Breweries Limited, Coca Cola, Pepsi, City coffee and Mbeya University of Science and Technology. Findings show that most of production industries use solidly grounding system, although they tend to corrode due to the presence of high amount of moisture contents ranging from 30% to 60% and salt mineral contents of 2.4% which results in low resistivity. This study concludes that solidly grounding is the best method to be adopted.

Keywords: electrical power; electrical system; grounding; safety; Tanzania.
1. Introduction

Tanzania cannot afford to overlook the importance of grounding techniques for providing personnel safety and equipment protection. Viewed this way, then, there are several benefits for grounding and bonding AC transmission and distribution power systems. For this reason, the foundation for selection of a given grounding system type depends on its ability to provide personnel safety and equipment shelter. Consequently, the electric power industry is touched on with reducing shock and flash hazards to personnel working with electrical systems, limiting damages to the electrical system components due to transient over voltages, and minimizing interruption to the industrial processes that the electrical system supports.

In a review work of Gogom et al. (2020), reports the main contributions taken from the literature for the electrical characteristics of soils, possibly considering also Points of Interests (POIs) such as soil types and resistivity. Table 1 considers the status of currently average resistivities of the different types of soil (Coelho et al. 2015, Hansen et al. 2014 and Samouëlian et al. 2005). Founded on these measures, the prevailing grounding design philosophy is to provide a grounded system over an ungrounded one for satisfying these objectives. However, understanding of the basic functioning of each type of system is necessary for meeting the appropriate grounding topology to the electrical system performance. Industries and commercial buildings, with most of their equipment operating at 380V and less, they seem to have standardized on a solid grounding and bonding approach.

<table>
<thead>
<tr>
<th>Soil types</th>
<th>Resistivity (Ω-m)</th>
<th>Soil types</th>
<th>Resistivity (Ω-m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bare stony ground</td>
<td>1500 to 3000</td>
<td>Micaschists</td>
<td>800</td>
</tr>
<tr>
<td>Clay sand</td>
<td>50 to 500</td>
<td>Plastic clay</td>
<td>50</td>
</tr>
<tr>
<td>Compact limestones</td>
<td>1000 to 5000</td>
<td>Shales</td>
<td>50 to 300</td>
</tr>
<tr>
<td>Cracked limestones</td>
<td>500 to 1000</td>
<td>Silica sand</td>
<td>200 to 3000</td>
</tr>
<tr>
<td>Granites and Sandstone</td>
<td>100 to 10000</td>
<td>Silt</td>
<td>20 to 100</td>
</tr>
<tr>
<td>Humus</td>
<td>100 to 150</td>
<td>Soft limestone</td>
<td>100 to 500</td>
</tr>
<tr>
<td>Marls and clays compact</td>
<td>100 to 200</td>
<td>Swampy land</td>
<td>From some unit to 30</td>
</tr>
</tbody>
</table>

The studies by Geri et al. (1999) and Murray et al. (2009) report that, there are various points on the electrical system available for grounding, such as the midpoint of a single-phase transformer, corner of the delta windings and the centre of the star windings. This is the reason why the points that are considered the neutral point of the system are most commonly used for grounding. On this regard, Roy & Rao (1982) briefly explained about neutral point affects, that it is in turn affected by the other three phases identically on a balanced 3-phase system. By its nature, this presents the best opportunity to realize the two main purposes for grounding the electric power system. In the very same way, the grounding methods described in this paper include impedance-grounded and solidly grounded. The impedance grounded systems are sub-divided into High-resistance grounding (HRG), Low-resistance grounding (LRG), Reactance grounding (RG).
1.1. Grounding

The term grounding/earthing describes an electrical system in which at least one conductor from the system, or point on the conductive system, is connected to either earth or some other conducting body that serves in place of the earth. According to Guo et al. (2006) this connection can be with or without an intermediary impedance device. Because of an exceedingly low-impedance device, the system is said to be solidly or effectively grounded. With an impedance device, the system can be either resistively or reactively grounded as it has been reported by Gates (1936) Thompson & Smith (1973) and Linsley (2011).

According to Lehtonen & Hakola (1996) an ungrounded electrical system or unearthed, isolated or floating neutral system, as it is in the IT system, there is no direct connection of the star point (or any other point in the network) or direct connection between the system conductors and earth, except through the very high naturally occurring reactance due to the line-to-ground capacitive coupling. As a result, ground fault currents have no path to be closed and thus have negligible magnitudes. However, in practice, as illustrated by Bandyopadhyay (2006), the fault current will not be equal to zero: Under normal operating conditions, this way the distributed capacitance causes no problems but it gives a path of relatively high impedance.

Systems with isolated neutral may continue operation and provide uninterrupted supply even in presence of a ground fault (Gates 1936). However, while the fault is present, the potential of other two phases relative to the ground reaches 1.73 of the normal operating voltage, thus creating additional stress for the insulation; insulation failures may inflict additional ground faults in the system, now with much higher currents (Yu & Bolin 2001).

The presence of uninterrupted ground fault may pose a significant safety risk if the current exceeds 4–5 times its normal current. In this regard, an electric arc can produce, which may be maintained even after the error is cleared. For that reason, electric arcs are mostly confined to, underground and submarine networks, and industrial applications, where the reliability need is high and probability of human contact is relatively depressed. In urban distribution networks with multiple underground feeders, the capacitive current may reach several tens of amperes, posing significant risk for the equipment (Van De Sandt et al. 2009).

Regardless of the name’s implication, the Tanzania National Electric Company (TANESCO) still requires the conductive equipment enclosures of an ungrounded system to be grounded for the same reason as grounded system is required to be grounded. This has been reported by Ilskog et al. (2005) that the code also requires an ungrounded system to be bonded similarly to a grounded system to provide a low-impedance path for phase-to-phase fault currents to circulate back to the source. Furthermore, according to Selkirk et al. (2010), Labos et al. (2005) and Al-Hajri et al. (2004), resistance grounding is the most well-known sort of impedance grounding which is accomplished using Neutral Grounding Resistors (NGR). However, the NGRs are likely to failure due to corrosion, vibration, lightning, human error, and high frequency power system oscillations. Neutral Grounding Resistors failure, if not detected, causes significant damage to power system equipments due to risk of ungrounded or solidly grounded neutral (PC37.101- IEEE, 2017). Therefore, various neutral grounding methods and techniques which exist are briefly explained below.
1.1.1. High-Resistance Grounding (HRG)

High resistance grounding of an electrical power system is the grounding of the system neutral through a resistance which limits ground-fault current flow to a value equal to or slightly greater-than the capacitive charging current of that system. This value is chosen because it is the lowest level of ground-fault current flow at which system over voltages can be effectively limited. Increasing the current flow improves over voltage control at the expense of increasing damage at the point of fault. Again, decreasing the current flow reduces point-of-fault damage at the expense of greater risk of over voltage. High-resistance grounding is applicable to low- and medium-voltage power distribution systems serving three-phase three wire loads, or line-to-line single-phase loads. It effectively controls transient over-voltages ranging from 440V to 11kV during ground-faults, minimizes arcing damage and flash hazard at the point of fault, and allows continued operation of the system with a ground fault present at voltages of 5kV and below. In general, increasing the ground-fault current flow improves over voltage control, but elevates the point of fault damage. Conversely, decreasing the ground-fault current elevates overvoltage but decreases point-of-fault damage. Correct application of HRG in the medium-voltage (MV) range of 3.3 to 11kV would require a maximum limit on the single line-to-ground, point-of-fault ground-fault current to a value below 7amp. In addition, the inherent line-to-ground capacitive charging current must be less than or equal to the current through the grounding resistor. Mathematically, the ground-fault current is the vectorial sum of the grounding resistor current and the capacitive-charging current. The capacitive charging current is a function of the electrical system that must be initially estimated. With these quantities and conditions satisfied, the range of HRG ground-fault currents can be calculated.

1.1.2. Low-Resistance Grounding (LRG)

These schemes are designed to limit ground-fault currents in the range of 100 to 400 amps on systems with voltage ranges of 480V to 15kV. With this increase ground-fault current magnitude, the LRG’s aim is to eliminate overvoltage transients at the expense of increasing the point-of-fault, ground-fault damages. In order to minimize these damages, a system of protective devices is formed as part of the LRG scheme. Ideally, the fault is isolated while the rest of the electrical system continues to function. At the higher magnitude of ground-fault currents, the capacitive charging current to ground has very little impact on sizing the grounding resistor. This resistance is then simply the line-to-neutral voltage across the grounding resistor divided by the ground-fault current.

1.1.3. Reactance Grounding (RG)

This is another alternative used on MV systems ranging from 2.4 to 15kV. With this grounding scheme, an inductor is used to limit the flow of ground-fault currents. It has been shown that reactance grounded systems produce transient overvoltages at much higher ground-fault currents than resistive grounded systems. In order to limit the transient overvoltages to acceptable limits, the resulting ground-fault current could be as much as 60% of the 3-phase bolted fault. Since this is much higher than the 400-amp limit for LRG at the same voltage range, reactance is not as commonly used in the electrical industry, except for tuned reactance grounding.

1.1.4. Ground Fault Neutralizer (GFN)

Ground Fault Neutralizer is another form of reactance grounding known as tuned reactance grounding. As the name implies, the inductive reactance is tuned to the ungrounded phase natural
capacitive charging current to ground. This tuning effect by the inductive reactance essentially cancels (neutralizes) the current contribution from the capacitive charging current. This leaves a small portion of the ground-fault current that is essentially resistive in nature. This resistive neutral-to-ground current is in phase with the neutral to ground voltage. The benefit of this phase unison is that an arcing fault to ground is less likely to be sustained by the voltage when the ac current and voltage reach their zero value simultaneously. The GFN application is similar to the HRG application, in that the ground fault is allowed to persist so that the electrical service is continued. Detection of the fault is provided by a coordinated set of ground-fault relays. GFN drawback is similar to RG in that reactance grounding in general tends to increase transient overvoltages. In addition, the grounding circuitry has to be re-tuned after any switching arrangement is made to the electrical system.

1.1.5. Solid Gounding (SG)

This was the solution for more than 60 years ago when engineers were looking for an alternative to address the problem of transient over voltages due to arcing ground faults on ungrounded systems. Even though its application was not as successful in the 3.3 to 11kV range due to high-point-of-fault energy, SG is consistently applied at voltages below 440V even today. In solid or directly earthed neutral, transformer's star point is directly connected to the ground. In this solution, a low-impedance path is provided for the ground fault current to close and, as a result, its magnitudes are comparable with three-phase fault currents (Gates 1936). Since the neutral remains at the potential close to the ground, voltages in unaffected phases remain at levels similar to the pre-fault ones. For that reason, this system is regularly used in high voltage transmission networks, where insulation costs are high (Yu & Bo Lin 2001).

A solidly grounded neutral system will produce the maximum fault current for a given faulted-condition. Therefore, it provides the best opportunity for early detection of arc-flash hazards on the electrical systems. The over current device coordination as an essential part of the SG system ensures that only the faulted circuit is isolated while the rest of the system continues to function.

1.2. Reasons for Grounded and Ungrounded Systems

According to Tanzania National Electric Company (TANESCO) there are two main purposes for grounding the electrical ac system: one is to stabilize the system voltage to earth during normal operating conditions by providing an earth’s reference frame for the system and the other is to maintain within acceptable limits, excess voltages on the system due to lightning, line surges, and incidental contact with higher voltages (Ilsgog, et al. 2005). These two reasons allow the design engineer to meet the two primary goals of equipment protection and personnel safety for the electrical system. A third goal for grounding is to allow the processes supported by the electrical system to continue in the presence of a faulted condition. This is usually achieved by either an ungrounded system or by application of a specialized form of grounding (high-resistance grounding) (Ilsgog, et al. 2005; Van De Sandt, et al. 2009).

2. Problem Statement

Most drawbacks of currently available methods and techniques of grounding are due to inadequate studies of the type of the soil resistivity and earth resistance (Ω) information. So far, personnel safety and equipment protection face problems of overlooking the importance of ground-
ing techniques. A missing safety ground poses a serious problem and usually occurs because the safety ground has been by passed, not studied the type of the soil resistivity and earth resistance (Ω).

3. Materials and Methods

3.1. Soil Resistivity Testing

The purpose of resistivity testing is to obtain a set of measurements which may be interpreted to yield an equivalent model for the electrical performance of the earth, as seen by the particular earthing system. Three methods of measuring soil resistivity; Wenner Array Method, Schlumberger Array Method and Driven Rod Method have been discussed and results were compiled and analyzed. Selected industries were TBL, Coca Cola, Pepsi, City coffee, MUST. Factors such as maximum probe depths, lengths of cables required, efficiency of the measuring technique, cost in terms of the time and the size of the survey crew and ease of interpretation of the data were considered when selecting the test type. Three common test types are shown in Figure 1-3.

3.1.1. Wenner Array Four Pin Test Methods

Resistivity can be calculated as:

\[
\rho = \frac{2\pi a \Delta V}{I} = 2\pi a R
\]

Where:
- \(\rho\) = apparent resistivity (Ω)
- \(a\) = probe spacing (m)
- \(\Delta V\) = voltage measured (volts)
- \(I\) = injected current (Amps)
- \(R\) = measured resistance (Ω)
3.1.2. Schlumberger Array Test Method

Figure 2
Schlumberger array

Resistivity can be calculated as:

\[ \rho = \frac{\pi L^2 R}{2l} \]

Where
\( \rho \) = apparent resistivity (Ωm)
l = distance from centre line to inner probes (m)
L = distance from centre line to outer probes (m)
R = measured resistance (Ω)

3.1.3. Driven Rod Method

Figure 3
Driven rod three pin method
Resistivity can be calculated as:

\[ \rho = \frac{2\pi l R}{\ln \left( \frac{bl}{d} \right)} \]

Where
- \( \rho \) = Apparent resistivity (\( \Omega m \))
- \( l \) = Length of driven rod in contact with earth (m)
- \( d \) = Driven rod diameter (m)
- \( R \) = Measured value of resistance (\( \Omega \))

### 3.2. Selection of Test Method Type

#### 3.2.1. Wenner Array

The Wenner array is the least efficient from an operational perspective. It requires the longest cable layout, largest electrode spreads and for large spacings, one person per electrode is necessary to complete the survey in a reasonable time. Also, since all four electrodes are moved after each reading, the Wenner Array is most susceptible to lateral variation effects. However, the Wenner array is the most efficient in terms of the ratio of received voltage per unit of transmitted current. Where unfavourable conditions such as very dry or frozen soil exist, considerable time may be spent trying to improve the contact resistance between the electrode and the soil.

#### 3.2.2. Schlumberger Array

Economy of manpower is gained with the Schlumberger array since the outer electrodes are moved four or five times for each move of the inner electrodes. The reduction in the number of electrode moves reduces the effect of lateral variation on test results.

Considerable time saving can be achieved by using the reciprocity theorem with the Schlumberger array when contact resistance is a problem. Since contact resistance normally affects the current electrodes more than the potential electrodes, the inner fixed pair may be used as the current electrodes, a configuration called the ‘Inverse Schlumberger Array’. The use of the inverse Schlumberger array increases personal safety when a large current is injected. Heavier current cables may be needed if the current is of large magnitude. The inverse Schlumberger reduces the heavier cable lengths and time spent in moving electrodes. The minimum spacing accessible is in the order of 10 m (for a 0.5m inner spacing), thereby necessitating the use of the Wenner configuration for smaller spacings. Lower voltage readings are obtained when using Schlumberger arrays. This may be a critical problem where the depth required to be tested is beyond the capability of the test equipment or the voltage readings are too small to be considered.

#### 3.2.3. Driven Rod Method

The driven rod method (or Three Pin or Fall-of-Potential Method) is normally suitable for use in circumstances such as transmission line structure earths, or areas of difficult terrain, because of: the shallow penetration that can be achieved in practical situations, the very localised measurement area, and the inaccuracies encountered in two layer soil conditions.

Soil resistivity can vary significantly both with depth, and from one point to another at a site. Therefore, a single soil resistivity measurement is usually not sufficient. To obtain a better picture of soil resistivity variations, it is advisable to conduct a detailed survey. The Schlumberger array is considered more accurate and economical than the Wenner or Driven Rod methods, provided a current source of sufficient power is used.
4. Results and Discussion
The average earth resistance variation of different types of soil in industrial area depending on the resistivity of soil is illustrated in Figure 4 below. Table 2 results shows that earth resistance(Ω) of each industries depend on type of the soil resistivity (Ω-m). In Table 3 typical elements that are evaluated includes: size of transformer (KVA) and types of grounding.

Table 2
Average earth resistance and resistivity of soil in industrial area

<table>
<thead>
<tr>
<th>Location</th>
<th>Earth Resistance(Ω)</th>
<th>Soil Resistivity(Ω-m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TBL &amp; nearby area</td>
<td>24.85</td>
<td>184.06</td>
</tr>
<tr>
<td>Coca Cola &amp; nearby area</td>
<td>40.33</td>
<td>291.08</td>
</tr>
<tr>
<td>Pepsi &amp; nearby area</td>
<td>45.9</td>
<td>260.97</td>
</tr>
<tr>
<td>MUST &amp; nearby area</td>
<td>38.66</td>
<td>280.91</td>
</tr>
<tr>
<td>City Coffee &amp; nearby area</td>
<td>24.31</td>
<td>172.34</td>
</tr>
</tbody>
</table>

Figure 4
Average earth resistance and resistivity of soil in industrial area
### TABLE 3
**Measurement of Grounding and Neutral Grounding Resistance of Transformer Around the Area**

<table>
<thead>
<tr>
<th>Location</th>
<th>Grounding(Ω)</th>
<th>Neutral grounding(Ω)</th>
<th>Size of transformer (KVA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TBL &amp; nearby area</td>
<td>1.2</td>
<td>1</td>
<td>315KVA</td>
</tr>
<tr>
<td>Coca Cola &amp; nearby area</td>
<td>1.4</td>
<td>1.1</td>
<td>315KVA</td>
</tr>
<tr>
<td>Pepsi &amp; nearby area</td>
<td>10</td>
<td>8</td>
<td>500KVA</td>
</tr>
<tr>
<td>MUST &amp; nearby area</td>
<td>9.8 / 9.9</td>
<td>8.7 / 9.8</td>
<td>500KVA*2</td>
</tr>
<tr>
<td>City Coffee &amp; nearby area</td>
<td>12</td>
<td>9</td>
<td>200KVA</td>
</tr>
</tbody>
</table>

### TABLE 4
**Percentage Values of Grounding and Neutral Grounding at Different Areas Around the Industries**

<table>
<thead>
<tr>
<th>Location</th>
<th>Grounding in (%)</th>
<th>Neutral Grounding in (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>City coffee</td>
<td>140</td>
<td>80</td>
</tr>
<tr>
<td>TBL</td>
<td>-316.6</td>
<td>-80</td>
</tr>
<tr>
<td>Pepsi</td>
<td>100</td>
<td>60</td>
</tr>
<tr>
<td>Coca cola</td>
<td>-257.14</td>
<td>-78</td>
</tr>
<tr>
<td>MUST</td>
<td>74</td>
<td>74</td>
</tr>
</tbody>
</table>

Percentage values of grounding and neutral grounding at different areas around the industrial

[Graph showing percentage values of grounding and neutral grounding at different areas around the industrial]
Understanding of electrical grounding system techniques with respect to the faults current occurred it is essential in investigating the different grounding schemes used in the industries. It was also proven that proper system grounding can significantly improve reliability and safety of equipment and system operations.

Solid grounding or effective grounding system is the preferred choice among the grounding techniques used for industries in Tanzania. This method can mostly be applicable for the system supplying 4 wire loads, since it allows users to allocate faults, control of transient overvoltage and ensures that the systems are safe. It also maintains very low impedance to ground faults so as to allow that a relatively high current will flow. Whenever this situation prevails, it ensures safety and protection from protective devices such as the circuit breaker which will clear the fault quickly and therefore minimize damage and shock to personnel.

From six methods of grounding techniques discussed that is, solid grounding, ungrounded system, High resistance grounding, low resistance grounding, resonant grounding and low inductance grounding system and the analysis on various methods of grounding techniques for industrial area in Mbeya, it was revealed that, poor grounding techniques around the area are influenced by seasonal change of temperature which results to dryness of soil and moisture contents. Not only that, but also the situation affects the resistivity of soil which varies considerably at different times of the year. In this paper, through the discussion, it was discovered that earth resistivity is a very variable quantity caused by change of nature of the sub soil. This was clearly shown in this paper and all objectives are met.

5. Conclusion
This paper investigated methods and techniques of grounding to optimize the personnel safety and equipment protection. The analysis of proposed type soil indicates to have a direct effect on the ground system techniques used in industrial area. The evaluation of the resistivity of the type of soil found around the industries has direct impacts on the performance on the type of grounding used. The resistivity of the local soil around the industries has liquid limit ranging between 30% to 60% which results into relative low resistivity (constant). Due to climatically seasonal changes of weather, the temperature and dryness of soil can change drastically throughout the year which affect both electronic and ionic conductivity.

Results also revealed that, soil resistivity is fairly low while the soil conductivity is high which makes the soil to be highly corrosive due to the presence of water and salts contents of 2.4% greater than 1% of normal value which reacts with the ground rods and their connections. Proper grounding system can significantly improve reliability and safety.

In sum, the results obtained at the end of this study constitute a contribution for the Tanzania National Electric Company (TANESCO) and the production industry in Tanzania. For further research a comparison of resistivity of charcoal for different species must be carried out and floating neutral should be considered.
Acknowledgment

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