BETTER GROUNDING

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A grounding system is an essential part of any electric/electronic system. The objective of a grounding system may be summarized as follows:

1. To provide safety to personnel during normal and fault conditions by limiting step and touch potential.
2. To assure correct operation of electrical/electronic devices.
3. To prevent damage to electrical/electronic apparatus.
4. To dissipate lightning strokes.
5. To stabilize voltage during transient conditions and therefore to minimize the probability of flashover during the transients.
6. To divert stray RF energy from sensitive audio, video, control, and computer equipment.

As it is stated in the ANSI/IEEE Standard 80-1986 "IEEE Guide for Safety in AC Substation Grounding," a safe grounding design has two objectives:

1. To provide means to carry electric currents into the earth under normal and fault conditions without exceeding any operating and equipment limits or adversely affecting continuity of service.
2. To assure that a person in the vicinity of grounded facilities is not exposed to the danger of critical electric shock.

A practical approach to safe grounding considers the interaction of two grounding systems: The intentional ground, consisting of ground electrodes buried at some depth below the earth surface, and the accidental ground, temporarily established by a person exposed to a potential gradient at a grounded facility.

An ideal ground should provide a near zero resistance to remote earth. In practice, the ground potential rise at the facility site increases proportionally to the fault current; the higher the current, the lower the value of total system resistance which must be obtained. For most large substations the ground resistance should be less than 1 Ohm. For smaller distribution substations the usually acceptable range is 1-5 Ohms, depending on the local conditions.

The grounding system of power plants and substations is usually formed by several vertical ground rods connected to each other and to all equipment frames, neutrals and structures that are to be grounded. Such a system that combines a horizontal grid and a number of vertical ground rods penetrating lower soil layers has several advantages in comparison to a grid alone. Sufficiently long ground rods stabilize the performance of such a combined system making it less dependent on seasonal and weather variations of soil resistivity. Rods are more efficient in dissipating fault currents because the upper soil layer usually has a higher resistivity than the lower layers. The current in the ground rods is discharged mainly in lower portion of the rods. Therefore, the touch and step voltages are reduced significantly compared to that of the grid alone.

In areas where the soil resistivity is rather high or the facility space is at premium, it may be not possible to obtain the required low impedance of the grounding system by spreading the ground rods and grid over a large area. The possible solutions of that rather complicated problem may be summarized as follows:

1. To change the soil resistivity in the limited area of interest by implementation of the chemically charged ground rods with or without an additional backfill.
2. To establish remote ground grid connected to the main ground system.
3. To use the deep-driven ground rods reaching underground water table or lower soil layers with low resistivity.
4. To use main/remote ground mats.

To analyze the technical and economical aspects of each one of alternatives mentioned above, first one must examine the components of the grounding electrode resistance. There are three general components affecting grounding electrode resistance: (1) The resistance of the electrode, (2) the resistance of the electrode-to-soil interface area, and (3) the soil resistivity.

The resistance of the electrode itself is negligible, although it varies with the length, diameter and deployment of the electrode. **The resistance of the electrode-to-soil interface area** is nearly negligible at temperatures above freezing. However, when the temperature of soil drops below freezing point, a veneer of ice may form on the ground electrode, adding resistance to the electrode/earth interface. Another that affects electrode/soil interface resistance is soil compactness around the ground electrode. A loose backfill or non-compact soil around the electrode will reduce the contact area and increase resistance. **The soil resistivity** is the single most important factor affecting the resistance of the ground system. That is why the most economically sound solution is lowering the soil resistivity to the level required to obtain the specified resistance/impedance of the ground system. In order to work out a practical approach of the soil treatment, the soil characteristics related to electrical conductivity are to be studied.

Soil Characteristics

Most soils behave both as a conductor of resistance R, and as a dielectric. For high frequency and steep-front waves penetrating a very high resistive soil, the earth may be presented by a parallel connection of resistance R, capacitance C, and a gap. For low frequencies and dc the charging current is negligible comparing to the leakage current, and the earth can be presented by a pure resistance R.

A voltage gradient across the earth does not affect the soil resistivity until the gradient reaches a certain critical value varying with the soil material, but usually of several kilovolts per centimeter. If the critical value of the voltage gradient is exceeded (in case of lightning), an arc would develop at the electrode surface and progress into the earth, increasing the effective size of the electrode, until the gradients are reduced to the values that the soil can withstand.

Frequencies under about 30 MHz almost do not affect the impedance of the earth's surface layer, but the depth of penetration varies with frequency f as $(\pi f \sigma \mu)^{-1/2}$. The depth of penetration also depends on the relative resistivity of earth layers below. Soil resistivity is affected by the following five factors:

Soil type. Soil resistivity varies widely depending on soil type, from as low as 1 Ohm-meter for moist loamy topsoil to almost 10,000 Ohm-meters for surface limestone.

Moisture content is one of the controlling factors in earth resistance because electrical conduction in soil is essentially electrolytic. The resistivity of most soils rises abruptly when moisture content is less than 15 to 20 percent by weight, but is affected very little above 20 percent. It must be recognized, however, that the moisture alone is not the predominant factor influencing the soil resistivity. If the water is relatively pure, it will be of high resistivity and may not provide the soil with adequate conductivity.

The soluble salts, acids or alkali presented in soil influence considerably the soil resistivity. The most commonly used salting materials are sodium chloride (common salt), copper sulfate and magnesium sulfate (Epsom salt). Different types of salts have varying depletion rates; consequently, different types may be combined to produce the optimum depletion and conditioning characteristics. Sodium chloride and magnesium sulfate are the most commonly used salting materials. Magnesium sulfate is considered to be the least corrosive. Salting materials will inhibit the formation of ice and will lower the resistivity of the soil. It may take some time for the salting effects to be noticed, although the earth connection will continue to improve over time until the salt content reaches about six per cent by weight. Higher resistivity soils take longer to condition. It takes topsoil about two months, clay four months and sand/gravel five months for the salt minerals concentration to reach about six per cent. Such concentration of salts poses a negligible corrosion threat.

The temperature effect on soil resistivity is almost negligible for temperatures above the freezing points. When temperature drops below water freezing point the resistivity increases rapidly.

Compactness and granularity affects soil resistivity in that denser soils generally have lower resistivity. These factors do not vary over time. Once the resistivity has been assessed these factors can usually be ignored.

From all the factors mentioned above, two factors—moisture and salt content—are the most influential ones on soil resistivity for a given type of soil. Therefore the chemical treatment of soil surrounding ground rods is preferable and in some cases the only economically sound solution in obtaining low impedance of the ground system.

Grounding with Chemically Charged Rods

The chemical treatment of the soil surrounding the ground electrodes may be implemented by any one of the following three ways:

1. To use conductive backfill materials. Several materials exist on the market that are used to replace poorly conducting soil near the ground electrodes. The impact of putting these materials around the electrodes is significant, since that is where the majority of connection to the earth takes place. Four such materials used for conductive backfills around ground electrodes are described below.

Concrete has a resistivity range of 30 to 90 Ohm-meters. Since it is hydroscopic by nature it will tend to absorb moisture when available and keep it up to 30 days, thus maintaining a resistivity lower than the surrounding soil. However, during a long dry season concrete will dry out with a subsequent rise in resistivity. Also, if a substantial amount of fault or lightning current is injected into a concrete encased electrode, the moisture in the concrete may become steam, dramatically increasing in volume and placing a substantial stress on the concrete.

Bentonite is a naturally occurring clay with a resistivity of about 2.5 Ohm-meters. It used widely as a conductive backfill material. Like concrete it is hydroscopic, which makes it subject to the same drying out concern as concrete. Expansion range of bentonite can reach 300 percent, which means that in dry situations it can shrink away from an electrode, resulting in substantial increase of ground resistance.

Clay-based backfill mixtures have generally a resistivity lower than pure bentonite due to the addition of carbon or/and other minerals that provide a greater spectrum of electrically conducting materials. Because these mixtures are clay-based they retain their hydroscopic character to some degree, while the blending of materials dampens the resistance variability with respect to moisture.

Carbon-based backfills materials have generally a resistivity lower than clay-based mixtures. Some of these materials can be mixed with concrete to make concrete more conductive. However, these materials tend to be the most expensive and do not retain moisture nearly as well as clay-based materials.

The amount of the backfill material required is determined in most cases by the Interfacing Volume and Critical Cylinder principles. A ground electrode establishes a connection to earth by affecting only a certain volume of earth, called the Interfacing Volume (IV). For practical purposes for a ground rod the entire connection to earth is contained within an IV whose radius is 2.5 times the length of the rod. Most of the earth connection takes place in a cylinder close to the electrode, called the Critical Cylinder. A study of the influence of soil within the IV demonstrates that six inches of soil along any radial makes up 52 per cent of the connection to earth; a 12 inches makes up 68 percent of the connection. Beyond a diameter of 24 inches there is very little improvement for much larger diameters. Therefore, the recommended diameter for the Critical Cylinder is between 12 and 24 inches, and the calculated amount of the required backfill material is based on that diameter and the length of the ground rod.

2. To use the chemically charged ground rods (CCGR) instead of the conventional ground rods. A CCGR is a copper tube of 2-2.5 inches in diameter with several small holes perforated along the length of the tube. The tube is filled with metallic salt evenly distributed along the entire length of the tube. The moisture absorbed from the air and soil form a solution of the contained metallic salt within the CCGR which seeps out through the holes into the surrounding soil, thus lowering the soil's resistivity and increasing the efficiency of the electrode. Figure 1 illustrates the concept of the CCGR.

Table 1 presents the comparison of the measured grounding resistance of five different ground rods in five different soils with resistivity varying from 9 Ohm-meters to 30,000 Ohm-meters. The last two rows in that table represent performance of the different types of CCGR and clearly achieve the lowest resistance as compared to the conventional types of ground rods with or without conditioning of the soil.

Automated mineral enhancement will permit the achievement of low resistance as long as there is enough moisture available. It does, however, take time for these automated enhancement system to achieve their goal. That time depends on porosity of the soil. Figure 2 shows the variations in the resistance of the CCGR as a function of time. It is evident from that figure that the CCGR required about ten weeks to reach the initial plateau. After that, resistivity continues to drop off at a slower rate for six months or more, depending on soil porosity. The resistance will decrease even during the dry season.

3. To implement a combination of the CCGR with backfill. This ground system demonstrates the excellent stability over numbers of years in keeping ground resistance permanently at a low fixed level. The following example presented in Table 2 illustrates the economical advantage of employing the CCGRs with backfills instead of conventional grounding technique with ground rods and grids. Table 2 shows results of cost estimation for ground system of 1 and 5 Ohms respectively in a dry sand and gravel soil with resistivity of 500 Ohm-meters.

As may be seen from that table, the grounding system based on the implementation of the CCGRs with backfill appears to be the most economical solution in the given conditions of poor conducting soil and low values of the required ground resistance, even without taking into consideration the cost of real estate. Where the appropriate space is not available or too expensive, the CCGRs the only solution in establishing required ground system.

Conclusions

1. The CCGR establishes a relatively low ground resistance and ground impedance which are not subjected to seasonal and weather variations.

2. The use of chemically charged ground rods, with or without backfill, instead of conventional ground rods offers the most cost effective design of any grounding system where the soil has a high resistivity and/or where the space available for grounding is at premium.