Improvement of Substation Earthing

Mohammad Ali Adelian

Abstract— Designing a proper substation grounding system is quite complicated. Many parameters affect its design. In order for a grounding design to be safe, it needs to provide a way to carry the electric currents into the ground under both normal and faulted conditions. Also, it must provide assurance that a person in the vicinity would not be endangered. The grounding portion of substation design will be explored. In order to properly plan and design the grounding grid, calculations of the following will be done: maximum fault current, grid resistance, grid current, safe touch and step voltages, ground potential rise, as well as expected touch and step voltage levels. Background information and guidelines to design a substation grounding grid will be provided. A set of equations will be presented to calculate whether the design is safe, and finally, an example will be provided that can be used as a template.

Keywords- Safety, reliability Step Voltage, Touch Voltage.

I. Introduction

Safety and reliability are the two major concerns in the operation and design of an electrical power system. These concerns also pertain to the design of substations. To ensure that substations are safe and reliable, the substation must have a properly designed grounding system. The two main design goals to be achieved by any substation ground system under both normal and fault conditions are:

1. To provide means to dissipate electric currents into the earth without exceeding any which operating & equipment limits

2. To assure that a person in the vicinity of grounded facilities is not exposed to the danger of critical electric shock [4].

II. PROBLEM FORMULATION

The design process of a substation grounding system requires many steps. The following steps are for the design of the ground grid:

Step 1: The property map and general location plan of the substation should provide good estimates of the area to be grounded. A soil resistivity test will determine the soil resistivity profile and the soil model needed.

Step 2: The conductor size is determined. The fault current 3I0 should be the maximum expected future fault current that will be conducted by any conductor in the grounding system, and the time, tc, should reflect the maximum possible clearing time (including backup).

Step 3: The tolerable touch and step voltages are [to be] determined. The choice of time, ts, is based on the judgment of the design engineer.

Step 4: The preliminary design should include a conductor loop surrounding the entire grounded area, plus adequate cross conductors to provide convenient access for equipment grounds, etc. The initial estimates of conductor spacing and ground rod locations should be based on the current, IG, and the area being grounded.

Step 5: Estimates of the preliminary resistance of the grounding system in uniform soil can be determined. For the final design, more accurate estimates of the resistance may be desired. Computer analysis based on modeling the components of the grounding system in detail can compute the resistance with a high degree of accuracy, assuming the soil model is chosen correctly.

Step 6: The current, IG, is determined. To prevent overdesign of the grounding system, only that portion of the total fault current, 3I0, that flows through the grid to remote earth should be used in designing the grid. The current, IG, should, however, reflect the worst fault type and location, the decrement factor, and any future system expansion.

Step 7: If the GPR of the preliminary design is below the tolerable touch voltage, no further analysis is necessary. Only additional conductor required to provide access to equipment grounds is necessary.

Step 8: The calculation of the mesh and step voltages for the grid as designed can be done by the approximate analysis techniques for uniform soil, or by the more accurate computer analysis techniques.

Step 9: If the computed mesh voltage is below the tolerable touch voltage, the design may be complete (see Step 10). If the computed mesh voltage is greater than the tolerable touch voltage, the preliminary design should be revised (see Step 11).

Step 10: If both the computed touch and step voltages are below the tolerable voltages, the design needs only the refinements required to provide access to equipment grounds. If not, the preliminary design must be revised (see Step 11).

Step 11: If either the step or touch tolerable limits are exceeded, revision of the grid design is required. These revisions may include smaller conductor spacing, additional ground rods, etc. More discussion on the revision of the grid design to satisfy the step and touch voltage limits is given in [Section 2.12]

Step 12: After satisfying the step and touch voltage requirements, additional grid and ground rods may be required. The additional grid conductors may be required if the grid design does not include conductors near equipment to be grounded.

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Additional ground rods may be required at the base of surge arresters, transformer neutrals, etc. The final design should also be reviewed to eliminate hazards due to transferred potential and hazards associated with special areas of concern. The block diagram in Figure 1 illustrates the procedure to design the ground grid.

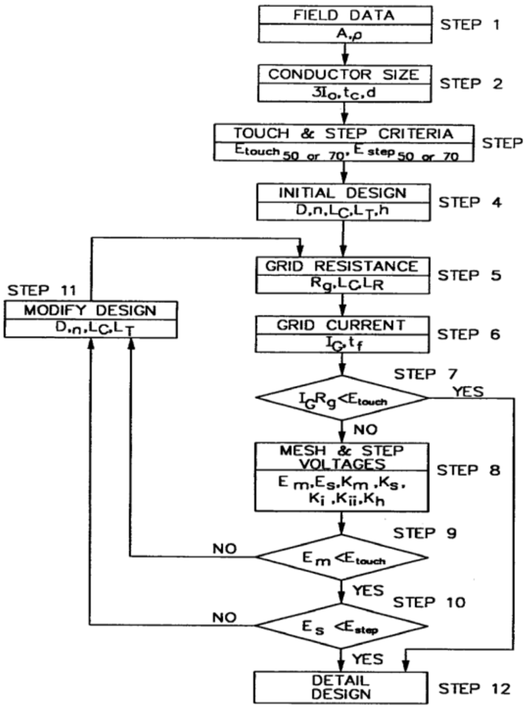

Figure 1: Design Procedure Block Diagram.

Design Modifications: If the calculated grid mesh and step voltages are greater than the tolerable touch and step voltages, then the preliminary design needs to be modified. The following are possible remedies:

(a) Decrease total grid resistance: If the total grid resistance is decreased, the maximum GPR is decreased; hence the maximum transferred voltage is decreased. An effective way to decrease the grid resistance is to increase the area occupied by the grid. Deep driven rods or wells can be used also if area is limited.

(b) Decrease grid spacing's: Decrease the mesh size by increasing the number of parallel conductors in each direction. Dangerous potentials within the substation can be eliminated. For the perimeter, a ground conductor can be buried outside the fence, or increase the density of ground rods at the perimeter.

(c) Increase the thickness of the surface layer: a practical limit may be 6 inches.

(d) Limit total fault current: If feasible, limiting the total fault current will decrease the GPR and gradients in proportion.

(e) Diverting greater part of the fault current to other paths

(f) Barring access to limited areas: if practical, can reduce the probability of hazards to personnel [1, 4].

Tolerable Body Current Limits:

$$I_B = \frac{k}{\sqrt{t_s}} \qquad K=\sqrt{S_B} \tag{1}$$

Where:

I_B : rms magnitude of the current through the body(A)

t_s : Duration of the current exposure (s)

S_B: shock energy

K: constant related to electric shock energy

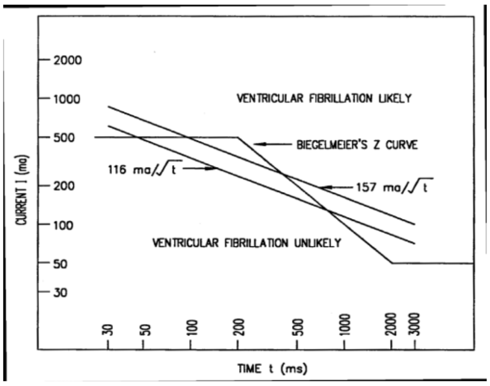

Figure 2: Body Current vs. Time

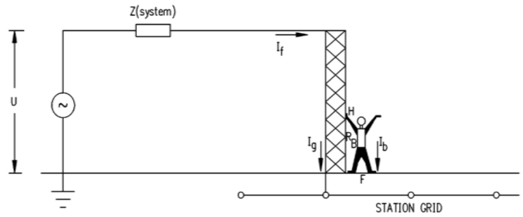

Figure 3: Exposure to Step Voltage.

$$\frac{V_{Th}}{Z_{Th}+R_B} \tag{2}$$

Where: V_{Th}: Thevenin voltage between terminal H and F (V)

Z_{Th}: Thevenin impedance from point H and F (Ω)

R_B: Body Resistance (Ω)

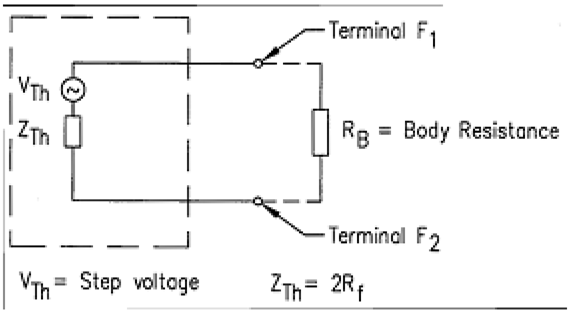

Figure 4: Step Voltage Circuit

The Thevenin equivalent impedance for the touch voltage accidental circuit is:

$$Z_{Th} = \frac{K_f}{2} \tag{3}$$

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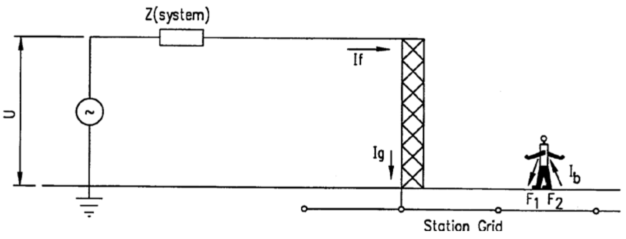

Figure 5: Exposure to Step Voltage.

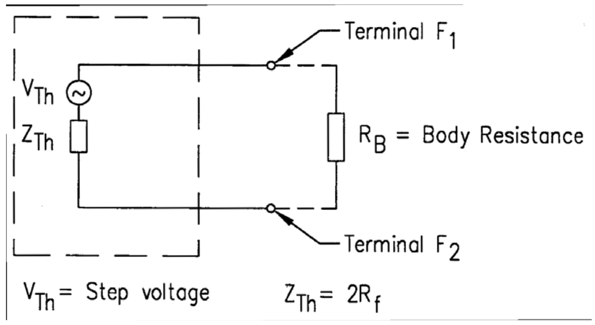

Figure 6: Step Voltage Circuit

The Thevinin equivalent impedance for the step voltage accidental circuit is: $Z_{Th} = 2R_f$ **(4)**

Where: R_f: ground resistance of one foot

In circuit analysis, a human foot is represented as a conducting metallic disc and resistance of the shoes and socks are neglected.

The equation to calculate the ground resistance R_f is:

$$R_f = \frac{\rho}{4b} \quad (5)$$

Where: ρ: Earth's resistivity (Ω-m)

b: Radius of a foot taken as a metallic disk (typically 0.08m)

Using a circular plate of approximately 0.08m, the equations for Zth is:

For touch voltage accidental circuit

$$Z_{th} = 1.5\,\rho \quad (6)$$

And for step voltage accidental circuit

$$Z_{th} = 6\rho \quad (7)$$

Conductor Sizing:

The symmetrical current can be calculated based on the material and the size of the conductor used as:

$$I = A_{mm^2}\sqrt{\left(\frac{TCAP.10^{-4}}{t_c a_r \rho_r}\right) \ln\left(\frac{K_0+T_m}{K_0+T_a}\right)} \quad (8)$$

If the conductor size is given in $kcmil$, the equation becomes:

$$I = 5.07.10^{-3}\, A_{kcmil}\sqrt{\left(\frac{TCAP}{t_c a_r \rho_r}\right) \ln\left(\frac{K_0+T_m}{K_0+T_a}\right)} \quad (9)$$

Where I: rms current (kA)

A_{mm^2}: Conductor cross section (mm^2)

A_{kcmil}: Conductor cross section (kcmil)

T_m: Maximum allowable temperature (°C)

T_a: Ambient temperature (°C)

a_r :Thermal coefficient of resistivity at reference temperature Tr (1/°C)

ρ_r: Resistivity of the ground conductor at reference temperature Tr(μΩ-cm)

t_c : Duration of current (s)

K_0: equals 1/ α0 or (1/ αr)- Tr (°C)

TCAP : thermal capacity per unit volume(J/cm^2. °C)

III. IMPLEMENTATION

IMPROVING EARTHING SYSTEM: Whether improving an existing system or ensuring that a new system the following points can be used to improve the final system performance.

Low soil resistivity is to some extent tied to an electrolytic mechanism with such characteristics as - chemicals composition, soil ionization, homogenous grain size and even distribution, playing a large determinant due to the effect on the retention of soil moisture and packing density in contact with the electrode.

TEMP. (C)	Typical resistivity (Ωm)
20	72
10	99
0(water)	138
0(ice)	300
-5	790
-15	3300

Table1 - Variations in resistivity with temperature for a mixture of sand and clay with a moisture content of about 15% by weight

Obtaining a satisfactory earth resistance has always been a problem in areas of poor soil conductivity. Most National and International Lightning Protection codes require an earth resistance of 10 ohms or less to be provided for a lightning protection installation.

The laying of copper grids, tapes and rods alone may not always provide the desired result. Even if copper materials are used and the specified resistance level is achieved, seasonal fluctuations in soil moisture can cause variations in the resistance level. In dry periods it is possible for the earth resistance to rise above the as installed level. This variation is earth resistance can affect the integrity of the entire lightning protection system. Suitable electrical resistance cannot be simply and economically attained by the installation of a standard earth grid, an application of earth enhancing compound will assist. Such compounds consists of chemical solutions of good electrical conductivity which, when mixed with water and poured onto the Earthing grid and surrounding soil become a gelatinous mass, forming an integral part of the overall Earthing system. Field tests have shown dramatic improvement in earth resistance when such compounds are added to high resistivity soil such as shale or silica. Erica supplies two such compound; Earth Gel and GEM. Earth Gel comes in kit form and comprises of two 5kg parts consisting of a copper solution in one and a complex mixture of chemicals which assists in advantage with this compound is that it will not wash or leach away like many other resistance improving mixtures. This obviates the need to redoes the area with time.

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IV. RESULTS

EXAMPLES OF ACHIEVING SUITABLE EARTHING INSTALLATIONS USING CHEMICAL ADDITIVES:

First obtain a rough determinant of the earth resistivity by driving a test earth rod. By referring to previous tables an estimate of the likely number of rods which will be required can be obtained. It may only be necessary to drive in one copper (or more generally a steel core/copper clad) rod. Dig a hole 500mm deep x 200mm diameter around it and apply approximately 2kg of each part of a kit of compound to fill the cavity. Allow 30 minutes for the compound to gel, and measure the resistance. If the resistance is not low enough, dig a trench 500mm deep x 200mm wide and approximately 5 meters long. Lay a length of copper tape (approximately 3 inch wide x 0.1 in thick) into tins trench, again applying approximately 3kg of each part of a kit of compound. Allow time for the compound to gel and re measure. If necessary, repeat the procedure laying tapes radially outwards from the main electrode until a satisfactory resistance is obtained. The earth tapes should be replaced as far apart as possible from one another and securely connected to the main earth rod.

Example 2:

In rocky/shale ground the best results are obtained by digging a trench approximately 500mm deep and 200mm wide and laying the earthing material in the bottom and covering it with approx 100mm of fine soil or sand. Solution 1 is then poured on and when it has been absorbed. Solution 2 is added in a similar manner. The entire trench is then backfilled.

Example 3:

If a good resistance is required in solid rock or heavy shale, one approach is to drill a hole approximately 75mm wide and 250mm deep and insert the copper rod. Then mix solution 1 and 2 together and pour the mixture down the hole. In effect this will provide a conductive medium of 250 mm x 75mm as an earth. If a suitable resistance is not obtained repeat the above procedure using multiple earth rods and bond together using copper tape lay in a trench.

Example 4:

With existing earth mats expose as much of the grid as possible. Apply Solution 1 wait until it is absorbed, apply solution 2 and then back fill the entire grid.

NOTES ON THE APPLICATION OF CHEMICAL COMPOUNDS:

Before applying the compound, saturate the ground with water to assist with the distribution of the chemicals. It must be stressed that every application is different and therefore results will differ accordingly. Generally speaking, one kit will be sufficient to produce a satisfactory earth resistance over a 5 meter length of earth tape in the worse soil conditions. In better soil conditions, one such kit will generally be adequate to cover 5 meters of earth tape.

Measures for Reducing the Impulse Impedance: Whilst the actual percentage improvement gained will be highly dependent upon local conditions, the following measures can be used to reduce the impulse impedance of earthing systems.

• **The use of flat tape rather than circular conductors**. For a given cross-section of conductor, this increases the surface area in contact with the ground, and hence increases capacitive coupling and reduces the overall contact resistance. It also reduces the high frequency resistance due to skin effects. Flat tape also tends to have a lower inductance per meter than a circular conductor of equivalent cross-sectional area.

• **The use of short-length radial conductors** bonded at the injection point, rather the single long length conductor. This produces the effect allaying a number of conductors in parallel.

• **Terminating radial conductors with vertical electrodes**. This measure is more effective in low to medium soil resistivity.

• **Using large bending radii when changing die direction of horizontal conductors**. Sharp bends tend to increase the inductance

• **Conductors**. Lowering the soil resistivity reduces the resistive component of the impedance and the use of earth enhancing compounds to improve the soil resistivity in the proximity of the hence improves the total impedance.

V. CONCLUSION

Substation grounding is a crucial part of substation design. The design has to be both safe and reliable. There are many steps to design a safe and effective grid. Hand calculations may be a tedious and difficult. Doing calculations and modifications to the design can be a long process. Computer programs have been developed to make the substation grounding design easier, and more accurate.

This paper provides an overview of substation grounding and the most essential elements of a substation grounding grid design based on the IEEE STD and improving it .This paper provides equations that are involved with a grid design. Finally an equation is provided using real world data. This example was designed to meet the design criteria for a safe ground grid.

• The measures to improve the earthing system of substation was Done successfully.• The need and importance of improving earthing system is proposed.• In this paper I have to suggest many ways for the improvement of earthing system and to overcome the difficulties in earthing system by.

a) Providing earth pits at proper position.
b) Always provide water to earth pit.
c) Use Bentonate powder, soft coal, black salt.

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Appendix

Number	Description of surface material	Resistivity of sample(Ω-m)	
		Dry	Wet
1	Crusher run granite with fines (N.C.)	140 x 10^6	1300(ground water, 45 Ω-m)
2	1.5 in(0.04m) crusher run granite (Ga.) with fines	4000	1200(rain water, 100W)
3	0.75-1 in(0.02-0.025 m) granite (Calif.) with fines	-	6513(10 min after 45 Ω-m water drained)
4	#4 (1-2in) (0.025-0.05 m) washed granite (Ga.)	1.5 x 10^6 to 4.5 x 10^6	5000 (rain water, 100 Ω-m)
5	#3 (2-4 in) (0.05-0.1 m) washed granite (Ga.)	26 x 10^6 to 3 x 10^6	10 000 (rain water, 100 Ω-m)
6	Size unknown, washed limestone (Mich.)	7 x 10^6	2000-3000 (ground water, 45 Ω-m)
7	Washed granite, similar to 0.75 in (0.02m) gravel	2 x 10^6	10 000
8	Washed granite, similar to pea gravel	40 x 10^6	5000
9	#57 (0.75 om) (0.02 m) washed granite (N.C.)	190 x 10^6	8000 (ground water, 45 Ω-m)
10	Asphalt	2 x 10^6 to 30 x 10^6	10000 to 6 x 10^6
11	Concrete	1 x 10^6 to 1 x 10^{9} ª	21 to 100

Table 2: Typical Surface Material Resistivity's.

Appendixes, if needed, appear before the acknowledgment.

Acknowledgment

This project was done during my Mtech in electrical engineering in India in Baharti Vidyapeeth deemed University college of engineering pune.I should thanks my family, specially my mother for supporting me during my study.

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I have done my graduation in Electrical Engineering from Iran and done various projects under my course of graduation, such as Research on Electrical Power Breaker. After completing graduation I worked with a Distribution company, named as "**Shahab Industry**". There I worked as supervisor for the comtrol unit of the company. I spent 2 years i.e. from 2007- 2009 and earned a lot of knowledge in the same. In year 2009 I joined " **Pars Azarakhsh**" where I worked as Project Engineer and was responsible for the maintenance and installation of all the electronic medical devices and instruments. Currently I'm in India to pursue my M.Tech in Electrical Engineering from Bharati Vidyapeeth Deemed University, Pune , Maharashtra. This paper is based on the research work done during the course of post- graduation. This is my second research work which is to be published under International Journal of Engineering and Advanced Technology.

The paper "IMPROVEMENT OF SUBSTATION EARTHING" is about using best way during earthing and find a way to make it better and more useful with respect to increasing the reliability in earthing system.

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