CONSTRUCTION OF GROUNDING SYSTEM

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Abstract

The construction of a grounding system is very important while designing of grounding system for high voltage substation. One of tasks of the grounding systems is to maintain the voltage rise due to discharging fault current into grounding grids at the minimum value to ensure the safety of public and personnel. Grounding is the permanent and intentional connection of all metal parts of an electrical power system to the earth with a conductor that has a sufficient current rating to carry any possible fault current and sufficiently low impedance to limit the voltage rise above the ground potential. Under normal conditions, electrical system will satisfactorily deliver power without proper grounding. Grounding problems will become apparent only after a fault occurs and someone is injured or equipment is damaged. The construction of a grounding system will depend on a number of factors, such as size of a grid, type of soil, size of conductor, depth of burial, availability of equipment, cost of labor, and any physical or safety restrictions due to nearby existing structures or energized equipment. This study will briefly explain trench method and conductor plowing method for construction of a grounding system.

Key words: Conductor cross-section, Connection, Grounding grid, Grounding system, Grounding rods, Soil resistivity, Safety

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I. INTRODUCTION

In modern high voltage substations, grounding has become one of the dominant problems of system design. This is because grounding constitutes a significant factor in increasing the reliability of supply service as it helps to provide stability of voltage conditions, preventing excessive voltage peaks during disturbances, and also a means of measuring the protection against lightning. It is therefore essential to develop and apply an accurate design procedure for the substation grounding system. Grounding system is one of the most important points inside the transmission systems and electric power distribution design. The main purpose of power system substation grounding grids is to maintain reliable operation and provide protection for personnel and apparatus during fault conditions. For the installation of grounding grid the commonly used methods are the trench method and the cable plowing method. Both of these methods employ machines. Where there is a lack of space these methods are not used because it is difficult to move them or small size of site. In these situations the ground grid is installed by hand digging. A good grounding grid design should be able to maintain the touch and step voltages inside the substation in permissible limits, which are defined based on fibrillation discharge limit. Due to the non uniformity of soil and measuring error of soil resistivity data and some other factors which cannot be considered in simulating calculations, the designed value of the grounding system impedance must be checked by the measured one after the grounding system is constructed, on the other hand, exist any variables that are in many cases established for designer. The design methods and simplified calculation can originate high construction cost, combining high construction and insecure conditions. The appropriate design methods minimize time and cost construction and they offer great reliability in obtained results [1] - [2].

All metallic objects in the central office and outside plant, i.e. cable tray, structural steel, racks and cabinets, steel support cables, cables and shielding, grounding bus electrodes, etc., must be bonded and grounded to achieve a uniform ground reference. The telecom industry recognized problems with the use of mechanical connections in central office many years ago and has successfully connections for grounding and power. This has resulted in a greater performance level for central office power and grounding through the elimination of loose connections inherent in the use of mechanical type lugs, taps and splices. Outside plant personnel are becoming familiar with compression methods and applying them to such areas as utility steel strand grounding, towers, and grounding electrodes as a replacement for mechanical and exothermic connections. New compression devices are emerging to offer attractive alternatives for other mechanical and soldered joint applications such as cable shielding, pedestals, cable vaults, and lightning protection. Earlier exothermic welding process was used in the construction of primary grounding systems for central office. But compression connector technology is an alternate to the exothermic welding process in the construction of primary grounding systems for central offices [9].

II. PRINCIPLES OF GROUNDING SYSTEM

A safe grounding design has two main objectives:

- To carry the electric currents into earth under normal and fault conditions without exceeding operating and equipment limits or adversely affecting continuity of service.
- To ensure that the person in the vicinity of grounded facilities is not exposed to the danger of electric shock.

The grounding system consists of four basic components:

1. The soil beneath and around the substation site.
2. Ground rods or electrodes connected to the ground grid, and installed vertically beneath the site, usually reaching lower resistivity soil.
3. The ground grid which is a network of interconnected conductors embedded or buried beneath the substation surface.
4. The finished surface covering the site.

The aim of the grounding system design is to retain the step and touch voltages in the tolerable limits, to decrease the danger during fault conditions and to keep small grounding resistances. The purpose of the grounding grid installation is to limit the potential gradient near the buried conductors. The selection of the ground conductor size depends on the conductor material, the type of conductor joints, the time duration of the fault, the maximum current flowing through the conductors and the economic considerations. The intention of the system design after selecting the conductor size and type of joints is to form a grid of horizontally buried conductors at equal distances. A continuous cable should surround the grid perimeter to enclose as much ground as practical. Within the grid, cables (conductors) should be laid in parallel lines, preferably at reasonably uniform spacing, to form a mesh. Deep driven ground rods are also used to control the surface gradients and lower the overall grounding system impedance. These rods are driven at the cross connections along the perimeter of the substation and near the basic substation components. All the metallic structures of the substation, the transformer neutral points and the lightning arresters are connected to the grounding grid. Copper cables or straps of adequate capacity and mechanical ruggedness are usually employed for these ground connections. When selecting the grounding material, the corrosion problems must be considered since a grid of copper or copper clad steel forms a galvanic cell with buried steel structures , pipes and any of the lead- based alloys which might be present in cable sheaths. In such cases the sacrificial metal surfaces must be insulated with plastic tape, asphalt compound or a full cathodic protection of sacrificial metals in the area must be used [5-8].

III. CONSTRUCTION PROCEDURE FOR GROUND GRID INSTALLATION

The construction procedure of a substation grounding grid system involves a significant number of tasks which must be performed in a specific sequence. A ground grid is normally installed after the yard is graded, foundations are poured, and deeper underground pipes and conduits are installed and backfilled. A computational algorithm may be incorporated in the developed expert system to determine how much effort should be put in to the performance of each task and when to schedule it so as to meet a desired completion date at least cost. For this coordination problem, the critical path method (CPM) may be used [4]. This method takes account of uncertainties in task times under special conditions and directly controls the task times by allocating the available resources to tasks in a deterministic context. Despite its limitations the CPM method widely used in a variety of construction projects and can be very helpful to both large and small projects. The following tasks have been identified and implemented for constructing grounding grid of a substation:

- Commence work on the substation site.
- Mark on the ground the network of the grounding grid.
- Excavate the ditch for burying the structural steel
- Prepare the foundations of the buildings and structure steel.
- Bury the grounding conductors in the ground.
- Connect all cross-connections.
- Drive grounding rods in the ground.
- Connect the grounding rods to the grid.
- Join the underground piping system and the structural steel to the grid.
- Build the substation buildings and install the required equipment and machinery.

- Connect to the grounding grid all metallic structures transformer tanks and neutral, lightning arresters, machine frames and substation fence.
- Back-fill and compact all excavations.
- Apply a layer of crushed rock surfacing material.
- Measure the resistance to earth of the grounding system as constructed.
- The security fence may be installed before or after the ground grid installation.
- In cases where deeper underground pipes and conduits are not installed before ground grid installation, an attempt should be made to coordinate the trenching procedure in a logical manner.

The general structure of backfilling is shown in Fig. 1.

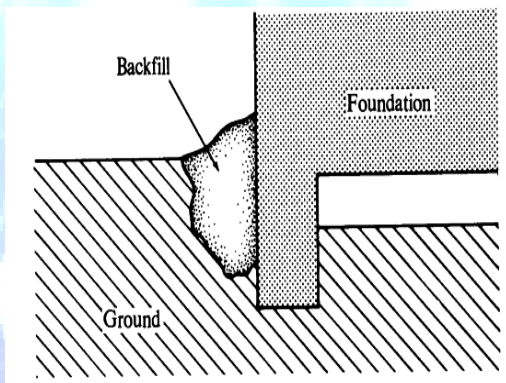

Fig.1 Structure of backfilling

IV. CONSTRUCTION OF GROUNDING GRID METHODS

The commonly used methods for construction of a grounding grid are as explained below:

(A) CONSTRUCTION OF GROUNDING GRID BY TRENCH METHOD

Flags are staked on the perimeter along two sides to identify the spacing between parallel conductors. These markers also serve as a guide for the trenching machine. The trenches are dug using a trenching machine usually along the side having the larger number of parallel conductors. These trenches are dug to the specified depth (usually about 0.5 m or 1.5 ft). Conductors are installed in these ditches and ground rods are driven and connected to the conductors. Pigtails for equipment grounds may also be placed at this time. These initial ditches are then backfilled with dirt up to the location of the cross connections. The next step is to dig cross-conductor ditches (often to a shallower depth), once again using markers as a guide. Care must be taken when digging these ditches to avoid snagging the conductor laid in the backfilled ditches at cross points. The conductors are installed in the ditches and any remaining ground rods are driven and connected to the conductors. Remaining pigtails are also connected to these conductors. Cross-type connections are made between perpendicular conductor runs. The ditches are then backfilled with dirt. An alternative method consists of confining the work to a small section of the total yard and completing this section entirely before moving to a new area. In this event, the trenches are all dug at the same depth prior to any conductor being placed. Installation of conductors and ground rods are the same as described in the conductor plowing method.

(B) CONSTRUCTION OF GROUNDING GRID BY PLOWING METHOD

Another procedure for the installation of ground conductors, which may prove economical and quick when conditions are favorable and proper equipment is available, is to plow the conductors in. A special narrow plow is used, which may be either attached to, or drawn by, a tractor or four-wheel drive truck, if there is sufficient maneuvering room. The plow may also be drawn by a winch placed at the edge of the yard. The conductor may be laid on the ground in front of the plow, or a reel of conductor may be mounted on the tractor or truck, or on a sled pulled ahead of the plow. The conductor is then fed into the ground along the blade of the plow to the bottom of the cut. Another method is to attach the end of the conductor to the bottom of the plow blade, and pull it along the bottom of the cut as the plow progresses. In this case, care should be taken to ensure that the conductor does not work its way upward through the loosened soil. The cross conductors are plowed in at slightly less depth to avoid damage to previously laid conductors. The points of crossing, or points where ground rods are to be installed, are then uncovered, and connections are made. With adequate equipment, and the absence of heavy rock, this method is suitable for all of the conductor sizes and burial depths normally used.

V. INSTALLATION OF CONNECTIONS, PIGTAILS, AND GROUND RODS

Once the conductors are placed in their trenches, the required connections are then made. Generally, the points of crossing require a cross-type connection, while tee connections are used for taps to a straight conductor run located along the perimeter. Types of connections are many and varied and depend on the joint, the material being joined, and the standard practice of the utility concerned. Pigtails are left at appropriate locations for grounding connections to structures or equipment. These pigtails may be the same cable size as the underground grid or a different size depending on the number of grounds per device, the magnitude of the ground fault current, and the design practices of the utility concerned. The pigtails are then readily accessible after backfilling to make above-grade connections. The installation of the ground rods is usually accomplished by using a hydraulic hammer, air hammer, or other mechanical device. The joining of two ground rods is done either by using the exothermic method or a threaded or threadless coupler. The connection between the ground rod and grid conductor can be made using various methods.

VI. SELECTION OF CONNECTIONS

All connections made in a grounding network above and below ground should be evaluated to meet the same general requirements of the conductor used; namely, electrical conductivity, corrosion resistance, current carrying capacity, and mechanical strength. These connections should be massive enough to maintain a temperature rise below that of the conductor and to withstand the effect of heating. The connections should also be strong enough to withstand the mechanical forces caused by the electromagnetic forces of maximum expected fault currents and be able to resist corrosion for the intended life of the installation. IEEE Std. are available which provides detailed information on the application and testing of permanent connections for use in substation grounding. Grounding connections that pass IEEE Std. for a particular conductor size range and material should satisfy all the criteria electrical conductivity, corrosion resistance, current carrying capacity, and mechanical strength for that same conductor size range and material.

VII. SAFETY CONSIDERATIONS DURING SUBSEQUENT EXCAVATIONS

The insulating value of a layer of clean surface material or gravel is an aid to safety underground fault conditions. Therefore, when an excavation is necessary after a rock surfacing has been applied, care should be taken to avoid mixing the lower resistivity soil from the excavation with the surrounding rock surfacing material. During subsequent excavations there are more chances to snag the ground conductor. In such a case a check should be made to determine if there is a break in the conductor and joints. A break in the conductor or joints, or both, must be immediately repaired. A temporary ground connection should be placed around the break before it is repaired. The temporary ground connection should be suitable for the application and installed according to safe grounding practices, because a voltage may exist between the two ground conductor ends.

VIII. FACTORS AFFECTING CONSTRUCTION OF GROUNDING GRID

The construction of a grounding grid is influenced by several factors such as soil resistivity, maximum fault current, conductor selection and grid resistance which are discussed in this section.

(A) SOIL RESISTIVITY

Hazardous voltage differences within a substation result from the current flowing from the grid conductors into the surrounding soil. All soils act both as a conductor of resistance R, and as a dielectric. The resistance of soil is measured as "resistivity" that varies according to the various layers of soil type. Soil resistivity is the prime factor affecting the resistance of the ground system. The electrical resistivity of the soil in which the grounding system is embedded has a great impact on the effect of step and touch potentials. Therefore, when designing an earthing system to meet the safety and reliability criteria, it is vital to consider an accurate resistivity model of the soil. Lowering the soil resistivity is the most efficient and prudent solution to the level required to obtain the specified resistance of the ground system. Typical values of resistivity on a river bank may be as low as 1.5Ω-m, whereas, dry sand or granite may have values as high as 10,000Ω-m.

According to the IEEE Std. 80 - 1986, the soil is said to be uniform, "when the soil resistivity is constant both laterally and with depth to infinity". However, a realistic approach to the situation where resistivity varies with depth is to consider the non-uniform soil model.

The top soil layers are subjected to higher current densities as earthing systems are embedded in the surface of the earth, and therefore, the top soil layers are more significant and require accurate modeling. The purpose of resistivity analysis is to obtain a set of measurements which may be used to interpret an equivalent model for electrical performance of the earth.

Soil resistivity often varies significantly with depth. In most areas, resistivity improves significantly with depth as the moisture content increases, and usually, ground rods are driven down to the water table to provide a very effective ground system. However, in other areas, underlying bedrock significantly increases resistivity at lower level.

(B) CONDUCTOR SELECTION

Selecting the correct size and type of conductors for the grounding system is a vital aspect of the design process. Due to the large cost involved in replacing grid conductors it is wise to take a conservative approach when sizing grid conductors. Thus, the maximum prospective future fault level which allows for expansion such as additional circuits is used to determine the maximum fault current the conductors must carry for each bus/voltage. When selecting conductor sizes for the grounding system, a number of important factors need to be taken into account:

(1) Conductors should have sufficient mechanical strength and rigidity to minimize the possibility of damage, especially during construction.

(2) Current-carrying capacity of the conductors should be sufficient to carry the maximum current for a fault to ground for a minimum period of time under normal fault conditions, resistively earthed conditions and transient fault conditions without damage to the conductor from overheating.

(3) The conductor conductivity should be sufficient so that the voltage drop in the cable under fault conditions will not exceed the voltage rating of the conductor.

(4) Environmental factors such as corrosion and soil movement that have an influence on conductor sizing should be considered.

Conductors are primarily made of copper or aluminum. There are various types of conductors available. For grounding system copper would be ideal to use as it has high conductivity and is resistant to most underground corrosion, as copper is cathodic with respect to other metals that are likely to be buried in the vicinity [1]. For buried ground grids, the conductors used are of hard drawn stranded copper, copper strip or hot-dip galvanized steel strip. In addition, other conductors may also be used such as stranded aluminum conductors or aluminum strip conductors, but aluminum conductors have to be enclosed in cable ducts or used as above ground connecting leads to framework as it corrodes in certain soils.

Steel may be used for ground grid conductors and rods. Use of galvanized or corrosion resistant steel, in combination with cathodic protection, is typical for steel grounding systems. However, copper-clad steel is usually used for underground rods [1].

(C) GROUND RESISTANCE

A reliable grounding system must have low earth resistance to reduce the excessive voltages, known as ground potential rise, which develop during a fault condition that could be hazardous to a being in the vicinity of the substation. In other words a good path to earth is essential in order for the earthing system to operate as required. An ideal grounding grid should have zero resistance to the earth mass. The ground potential rise (GPR) is calculated using Ohms law, thus, the ground potential rise increases proportionally to the fault current. Therefore, a lower of total grounding system resistance must be obtained.

Typical values for ground resistance are 1.0 Ω or less with respect to large substations. For smaller distribution substations, the accepted value ranges form 1-5 Ω, depending on the safety margins that have to be achieved.

The volume of earth near the earth electrode has the most impact on the ground resistance and hence, this is where the most dangerous step voltages are usually found, which is evident from Fig. 2. The variation of resistance and potential with respect to an earth electrode is demonstrated in Fig. 2.

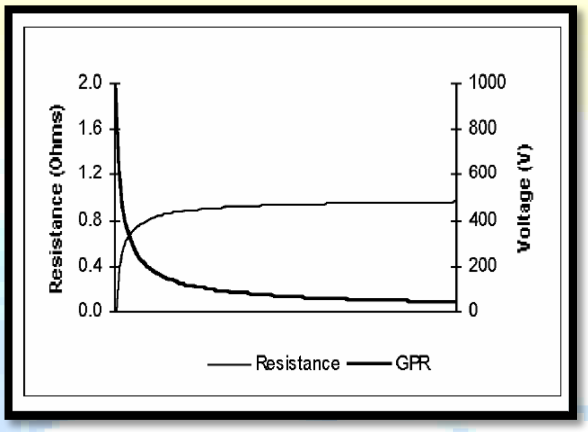

Fig. 2 Variation of resistance and potential from earth electrode

Determining the ground resistance is not only important in keeping the ground potential low, but also gives an indication of the size and basic layout of the grounding system.

A minimum value of the substation grounding system resistance in uniform soil can be estimated by means of the formula of a circular metal plate at zero depth is given by equation (1).

$$R_G = \frac{\rho}{4}\sqrt{\frac{\pi}{A}} \quad (1)$$

Where,

R_G is the substation ground resistance in Ω, ρ is the average soil resistivity in Ω-m, A is the area covered by the grid in m^2.

The minimum value is useful when estimating the maximum component of fault current that will enter the earth grid as shown in equation (2)

$$I_{f-ground}(\max) = \frac{V_{fault}}{R_g(min)} \quad (2)$$

The maximum value of earth resistance was proposed by Nehmann and Laurent, which account for the fact that a meshed earthing system impedance is higher than that of a solid plate, as a function of conductor length [1]. As ‘L’ goes to infinity the equation reverts back to that for the solid plate. This is given in equation (3).

$$R_G \; \frac{\rho}{4}\sqrt{\frac{\pi}{A}} \; \frac{\rho}{L}$$

(3)

Where, L_T is the total length of the buried conductors. Sverak, introduced resistance approximations that take into account the grid depth for horizontal grids buried between 0.25m and 2.5m (based upon a more detailed formula for the solid plate derived by Laurent). This is given by equation (4).

$$R_G = \rho\left[\frac{1}{L_T} + \frac{1}{\sqrt{20A}}\left(1 + \frac{1}{1 + h\sqrt{\frac{20}{A}}}\right)\right] \qquad (4)$$

Where, h is the depth of the buried grid in m.

IX. CONCLUSION

Plowing and trenching are the two basic methods of installing grid conductors for construction of grounding system while designing of substation grounding grid system. Where conditions are affordable, the most economical and quickest method is to plow one or more conductors in to the ground. With adequate equipment, and in the absence of heavy rock, this method is suitable for all of the conductor sizes and burial depths normally used. Trenching and backfilling are required when plowing is not practical. Backfilling must be free of rocks or debris which could damage conductors during compaction. Hand digging is preferred where there is a lack of space (at site) because trenching and plowing methods employ machines.

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