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GROUND POTENTIAL RISE IN HIGH VOLTAGE SUBSTATIONS

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Abstract: Ground Potential Rise (GPR) is a concern in the design of substation grounding grid. This paper will present Ground Potential Rise (GPR) causes, effects, variations in the values GPR in high voltage substations. The purpose of this paper is provide knowledge about the GPR, substation grounding grid and step and touch potentials.
Keywords: Ground Potential Rise (GPR), Grounding, Resistivity, Step and Touch Potential

I. INTRODUCTION

High voltage substations are very important for the electric power system stability. Any malfunction can cause blackout. The blackout results in loss which will be crucial for electricity generating companies, boards and for ultimate consumer also. Where high and low voltage earthing system exists in proximity, part of the GPR (Ground Potential Rise) from HV system is impressed on the LV system. High voltage substations are very often placed in the open area. They consist of many high metallic components such as overhead transmission towers, busbars, bridges etc. and are exposed to direct lightning strike. Malfunction of the electric system feeding-points can be catastrophic for national economy.

It can cause electric power system break-up. During strike, grounding system will transfer lighting current to earth. Parameters of this system are changing dynamically during the lightning current flow. This effect causes a ground potential rise (GPR) during the lightning with respect to remote earth or other substation grounding system. When a large amount of energy is rapidly deposited in to the ground by a cloud-to–ground lightning strike or by an electrical fault on a utility power system, the ground potential at this junction point rises to a higher level with respect to the more distant. Direct lightning strike to the earthed components of HV substation can cause severe interference problems in electronic equipment and systems.

Electrical and electronic devices, as a part of high voltage substations are susceptible to disturbances or destruction by direct lightning strokes. A lightning discharge current can cause disturbances to 1-3km from strike centre, depending on impedance factors, soil structure and other variables. Lightning protection specialist should consider all situations in overvoltage analysis [1].

The severity of the ground voltage rise and associated hazards are directly influenced by the effectiveness of the grounding grid. A key performance indicator is the grounding system impedance. High overall impedance relates to a greater ground grid voltage rise and

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subsequently higher touch and step voltages. The effect of fault-produced ground potential rise can directly result in mistaking operation, damaging of equipment or human safety [2].Ground grid is mostly done at the beginning stage of substation design and, firstly, its design purpose is considered well for both human safety and equipment protection [3-5].

II. PURPOSE OF GROUNDING SYSTEM

The purpose of a grounding system at a substation includes the following:

1.To provide the ground connection for the grounded neutral for transformers, reactors and capacitors.

2.To provide the discharge path for lightning rods, surge arrestors, spark gaps and other similar devices.

3.To ensure safety to operating personnel by limiting potential differences that can exist in a substation.

4.To provide a means of discharging and de- energizing equipment to proceed with maintenance on the equipment.

5.To provide a sufficiently low resistance path to ground to minimize rise in ground potential with respect to remote ground. The substation grounding system is connected to every individual equipment, structure and installation in the substation so that it can provide the means by which grounding currents are conducted to remote areas.

III. CAUSES OF GROUND POTENTIAL RISE

Earth Potential Rise (EPR) also called Ground Potential Rise (GPR) occurs when a large current flows to earth through earth grid impedance. The potential relative to a distant point on the Earth is highest at the point where current enters the ground, and declines with distance from the source. Ground potential rise is a concern in the design of electrical substation because the high potential may be a hazard to people or equipment. The

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potential gradient (drop of voltage with distance) may be so high that a person could be injured due to the voltage developed between two feet, or between the ground on which the person is standing and a metal object. Any conducting object connected to the substation earth ground, such as telephone wires, rails, fences, or metallic piping, may also be energized at the ground potential in the substation. This transferred potential is a hazard to people and equipment outside the substation.

Ground Potential Rise is caused by electrical substation, power plants or high voltage transmission lines or when lightning strikes, Ground Potential Rise occurs, which can damage equipment and injure personnel working on the equipment unless proper isolation or protection is provided. The GPR produces a dangerous potential difference between the power station and a remote ground connection located at a telephone company control office, remote terminal, distant manufacturing building or other sites. Telecommunication cable damage can occur if grounding takes place across the potential difference caused by a power fault or lightning strike.

Short circuit current flows through the plant structure and equipment and in to the grounding electrode station .The resistance of Earth is finite, so current injected in to the earth at the grounding electrode produces a potential a potential rise with respect to a distant reference point. The resulting potential rise can cause hazardous voltage, many hundreds of yards (meters) away from the actual fault location. Many factors determine the level of hazard ,including: available fault current,, soil type, soil structure, temperature, underlying rock layers, and clearing time to interrupt a fault.

The ground potential rise (GPR) arising from real power system ground faults is also of particular importance to telecommunication companies. If high enough, the rise in potential

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of the ground can cause insulation breakdown and other damage to nearby telecommunication cabling and equipment. In addition to this, the GPR can create hazards for technicians working on the affected circuits. The GPR traverse measurements can be used to gauge the severity of the GPR encountered during a real power system ground fault.

IV. STEP AND TOUCH POTENTIALS

The flow of electric current through the human body is a source of danger. Standards define limits on body currents that can be caused by touching grounding structure under adverse conditions. Consequently, grounding system should be designed so that the possible electric body current in an operator or by stander should not exceed these limits.

Abnormal operations includes on the level of the potential difference between earth points and grounded hazardous condition may be generated for human beings. This condition may result from two distinct possibilities [6-8].

"Step potential" is the voltage between the feet of a person standing near an energized grounded object. It is equal to the difference in voltage, given by the voltage distribution curve, between two points at different distances from the "electrode". A person could be at risk of injury during a fault simply by standing near the grounding point.

"Touch potential" is the voltage between the energized object and the feet of a person in contact with the object. It is equal to the difference in voltage between the object and a point some distance away. The touch potential could be nearly the full voltage across the grounded object if that object is grounded at a point remote from the place where the person

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is in contact with it. For example, a crane that was grounded to the system neutral and that contacted an energized line would expose any person in contact with the crane or its uninsulated load line to a touch potential nearly equal to the full fault voltage.

"Mesh potential" is a factor calculated when a grid of grounding conductors is installed. Mesh potential is the difference between the metallic object connected to the grid, and the potential of the soil within the grid. It is significant because a person may be standing inside the grid at a point with a large potential relative to the grid itself.

V. SAFETY

Earth potential rise is a safety issue in the coordination of power and telecommunications services. An EPR (Earth potential Rise) event at a site such as an electrical distribution substation may expose personnel, users or structures to hazardous voltages. Safety of personnel can be achieved through education, proper facility design, and approved and tested insulated safety equipment Personnel should use approved and tested rubber gloves and/or insulating blankets when working on the high voltage interference (HVI) equipment.

Proper personal protection equipment, procedures and tools can help job safety and efficiency. All safety equipments (rubber gloves, leather protectors and cotton liners) have to meet safety standards established by organizations like the American National Standards Institute (ANS) and the American Society for Testing and Materials (ASTM).

VI. MITIGATION

Analysis of the power system under fault conditions can be used to determine whether or not hazardous step and touch voltages will develop. The result of this analysis can show the need for protective measures and can guide the selection of appropriate precautions.

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Several methods may be used to protect employees from hazardous ground-potential gradients, including equipotential zones, insulating equipment, and restricted work areas.

1. The creation of an equipotential zone will protect a worker standing within it from hazardous step and touch potentials. Such a zone can be produced through the use of a metal mat connected to the grounded object. In some cases, a grounding grid can be used to equalize the voltage within the grid. Equipotential zones will not, however, protect employees who are either wholly or partially outside the protected area. Bonding conductive objects in the immediate work area can also be used to minimize the potential between the objects and between each object and ground. Bonding an object outside the work area can increase the touch potential of that object in some cases, however.
2. The use of insulating equipment, such as rubber gloves, can protect employees handling grounded equipment and conductors from hazardous touch potentials. The insulating equipment must be rated for the highest voltage that can be impressed on the grounded objects under fault conditions (rather than for the full system voltage).
3. Restricting employees from areas where hazardous step or touch potentials could arise can protect employees not directly involved in the operation being performed. Employees on the ground in the vicinity of transmission structures should be kept at a distance where step voltages would be insufficient to cause injury. Employees should not handle grounded conductors or equipment likely to become energized to hazardous voltages unless the employees are within an equipotential zone or are protected by insulating equipment.

In cases such as an electrical substation, it is common practice to cover the surface with a high resistivity layer of crushed stone or asphalt. The surface layer provides a high resistance between feet and ground grid and is an effective method to reduce the step and touch potential hazard.

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VII. GROUND POTENTIAL RISE CALCULATIONS

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 grounding 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 1-5Ω, 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.

The ground potential rise is equal to the product of the station grid impedance and the total fault current that flows through it. When a ground fault occurs, fault current will divide among all circuit paths back to the source including metallic, earth return paths include overhead ground wires, multi-grounded neutrals, bonding conductors, station ground grids, messenger wires, metallic cable shields and other conducting materials. The calculated values of GPR may also be used in estimation of step and touch voltages. However, if the calculated GPR is higher than the safety margin for step and touch potential then further evaluations and investigations should be conducted. The ground potential rise (GPR) at the substation is given by equation given below:

$GPR = I_G R_G$

Where, I_G = current flowing between the ground and the surrounding earth, R_G = resistance of the station grounding system.

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VIII. FACTORS AFFECTING THE VALUE OF GPR

The burial depth of the grid affects the Ground Potential Rise (GPR) to some extent as well as the ground rod, connected with the grid, and also plays an important role in GPR reduction. In case that the top soil-layer resistivity is more than the bottom-layer, the ground grid with and without ground rod will greatly reduce the value of GPR. On the contrary, in case that the top soil-layer resistivity is less than the bottom-layer resistivity, the ground grid with and without ground rod will slightly reduce the value of GPR. This indicates that the current density over the grid affects directly to the current distribution to the soil layer. Therefore, the design and construction of grounding grid in the area which the top soil-layer resistivity is less than the bottom-layer resistivity, can lessen the number of ground rod used in the grid because the value of GPR is insignificantly different. Finally, the deeper the grid buries in the layer, the lesser is the value GPR.

Due to the different in soil characteristics at each substation, ground grid design must carefully be done to gain acceptable safety as well as optimal investment. From the past, ground grid design without rods and with rods was carried out. A vertical rod is more effective electrode than a horizontal rod [9-10].The rod length is varied to determine the influence of rod length on GPR, furthermore, when the soil structure is two-layer structure, the optimum ground layer depth and rod length for ground grid must be determined to gain safety and proper investment [11].Therefore, the study of ground grid buried in each layer depth is done to determine the effect of GPR.

Table 1

Basic Factors affect the value of GPR [3]

Factors	The values of Reflection Coefficient

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	Positive values of K $\rho_1 < \rho_2$	Negative values of K $\rho_1 > \rho_2$
Grid only	-A larger portion of the grid is discharged in to low resistivity soil layer. -A periphery grid conductor discharges a larger portion of the current in to earth than to the centre conductors.	-Most of the grid current discharged from the grid downward in to low resistivity soil layer. -As the first layer depth increases the higher current density in the outer grid conductors become more dominant.
Rod Only	-For rods that are mainly in the low resistivity first layer most of the grid current can be well discharged in this layer. So the rod length is not necessary to reach the high resistivity deep layer. -Higher current density in the outer rods as compared to rods near the centre design.	-For rods that are mainly in the high resistivity first layer most of the grid current can be discharged at the small level. Most of the grid current discharged in to the high conductor layer. So the rods have to reach deep layer in order to discharge the current in this layer. -The current density of the outer rods is higher than the current density of the rods in the centre design.
Combination of Grid	-Current density for the portion of the ground rods in the low first layer is still higher than the grid conductors. -The ground rods become largely dependent on h or on the length of rod in the more conductive	-The majority of the current is discharged through the rods in to the lower resistivity layer. -The current density is higher in the ground rods than in the grid rods.

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and Rod	layer. The rod lengths are effectively shortened so that they may not contribute significantly to the control step and touch voltages.	

IX. CONCLUSIONS

Direct lightning strike to the earthed components of high voltage substation can cause severe interference problems in electronic equipment and systems. It is possible to approximate ground potential rise during the lightning by the numerical calculations. Proper cable arrangement could minimize lightning over voltages level with respect to air-termination rods and other high structures.

Substation grounding grid design can be designed by lessen the number of ground rod in case of which the top layer soil resistivity is lesser than the bottom layer resistivity. Because the ground rod can slightly reduce the GPR value. The deeper the grid buried in the layer, the lesser is the value of GPR.

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