Design of Grounding System for Tehri Hydro Power Project

M.M. Babu Narayanan, B.N Sarkar, C. Prabhakar and S.C. Mishra

Abstract – This paper highlights some of the most important design features of the grounding system proposed for the Tehri Hydro Power Project (HPP) in Uttaranchal. Design of grounding system for the Tehri HPP has been carried out at Central Power Research Institute (CPRI), Bangalore after extensive survey and measurements of soil characteristics at the project site. Grounding systems were designed for the machine hall, GIS transformer hall, overhead interface facility, Gas insulated bus (GIB) tunnel, turbine hall and various other utilities in the power station with proper interconnections in order to achieve an overall reduction in grounding system resistance. Of these, design aspects of certain critical installations like GIB and interface facility are explained in the paper. Design has been carried out using the GMAT software developed at CPRI.

Index terms – Ground resistance, Gas insulated switch gear, Adits, Interface facility

I. INTRODUCTION

For meeting the peak load requirements of northern region of India, Tehri hydro power project (HPP), presently under construction envisages 4 x 250 MW conventional generators to be installed in the underground power house. In stage-II, pumped storage units of 4 x 250 MW in another underground power house and a surface power house of 4 x 100 MW at Koteswar are also envisaged. The Tehri HPP will generate 1000 MW of power at 15.75 kV that will be stepped up to 400 kV. The evacuation of power from generator transformer in the underground transformer hall to the surface interface facility will be through gas insulated switchgear (GIS) and gas insulated bus duct (GIB).

Grounding systems were designed for installation under the machine hall, GIS transformer hall, overhead interface facility, GIB, turbine hall and other utilities with the interconnection between various ground mats derived through bus ducts, adits (access tunnels) etc.

A. Proposed Earthing system

The proposed earthing system for the Tehri HPP consists of the following:

i) ground conductor system at the surface of the rock (on the side walls) of the transformer hall cavity, GIS bus duct gallery, medium voltage bus duct etc.

ii) ground conductor system through the tail race tunnels, Draft tubes and the Access tunnels (adits)

iii) ground mat under the transformer hall area

iv) ground mat at the outdoor interface facility

v) ground mat under the turbine area

vi) steel liners of the penstocks connected to the grounding system and

vii) ground conductor system at butterfly valve chamber, draft expansion chambers etc

All the above grounding systems are to be inter-connected in order to achieve an overall reduction in grounding system resistance. The lay out plan of the above mentioned locations at Tehri HPP together with the interconnections is shown in fig.1.

II. DESIGN CONSIDERATIONS

A. Fault current

As per the system study, the maximum ground fault current at Tehri HPP was calculated as 25 kA. Considering the future system growth also, a value of 40 kA was chosen for grounding system design.

B. Fault duration

For determining the maximum step & touch potentials from the point of view of maximum permissible body currents, the fault clearing time of back-up protection relays was taken. This value is 0.5 second as per [1]. Earth conductor once placed in the ground is not normally inspected. It is prudent to make it suitable for the maximum possible time for which the fault current may flow in the system. Therefore, for determining the earth conductor size, fault duration of 1 second is adopted as per [2].

C. Earth conductor material & size

Mild steel is considered as the earthing conductor material as it is the common earthing practice in India. Calculation of the earthing conductor size is based on the equation for minimum conductor size as given in [3] wherein the values for mild steel is considered for obtaining the cross sectional area.
III. DESIGN OF GROUNDING SYSTEM

A. Penstock Steel Liner

The steel liners of all the penstocks are used as part of the grounding system and are connected to the ground conductors of the valve house chamber, machine hall etc. through welded joints. In Tehri HPP, the four penstocks are of different lengths ranging from 230-350 m emanating from a common outlet.

The penstock liner is considered as a 4-arm ground electrode with certain average length to determine its ground resistance. The analytical expression for ground resistance of such a configuration is [4]:

\[ R = \rho \left[ \log\left(\frac{2l}{a}\right) - 1 + N(n) \right]/(n \pi l) \]  

(1)

where

\[ N(n) = \sum_{m=1}^{n-1} \log\left(1 + \sin(\pi m/n) / \sin(\pi m/n)\right) \]

R: resistance of ground electrode, ohms
\( \rho \): resistivity of soil, ohm-m
l: average length of steel liner; m
n: no. of arms of the electrode
a: radius of the electrode. m

B. Outdoor Interface Facility

Grounding system for outdoor interface facility is designed as per [3] wherein the dangerous potential gradients within the outdoor yard are to be controlled besides achieving a low value of ground resistance. For this purpose, the grounding system shall consist of a combination of horizontal (grid) conductors and vertical ground rods placed at suitable locations within the grid.

It was assumed that the outdoor yard is spread with a layer of gravel (crushed rock) at the surface, the thickness of gravel layer being determined as part of safe design. The dimensions of the ground mat to be laid at the interface facility is 147 m x 39 m out of which an area of 20 m x 147 m was available for laying the ground mat in the natural soil. The remaining area was identified at a lower level in view of the peculiar nature of the terrain at the interface facility.

C. Grounding grid in GIS bus duct

The GIS bus duct extends from the transformer hall to the outdoor interface facility. A special grounding arrangement is proposed to be laid in the entire length of the bus duct which has an overall length of 670 m and width of 6.5 m. This being a GIS facility, the design is carried out according to the requirements specified for GIS in [3] which are briefly explained in the following section.

1) Grounding system for GIS

 Typically, the GIS installation necessitates 10-25% of the area required for conventional air-insulated switchgear (AIS) installations. Due to this and other unique characteristics, it is difficult to obtain an adequate grounding solely by conventional means. In so far as the design of ground mat for the GIS at Tehri HPP bus duct is concerned, the requirements of a safe design are derived from the two basic faults as follows:

i) an internal fault within the gas insulated bus system such as a flash over between the bus conductor and the inner wall of the conductor
ii) a fault external to the GIS, in which fault current flows through the GIS bus and induces currents in the enclosures. In both the above cases, a person touching the outer sheath of the GIS might be exposed to dangerous voltages which are to be controlled by proper grounding system.

Since a person may stand on a grounded metal platform and the accidental circuit may involve both hand-to-hand or hand-to-feet current path, the analysis of grounding necessitates considerations of an additional problem: that of permissible touch voltage for a metal-to-metal contact. The equation for permissible touch voltage for a metal-to-metal contact can be obtained by substituting for soil resistivity \( \rho = 0 \) in the expression for permissible touch voltage for conventional AIS as [3]:

\[
E_{\text{touch}}' = \frac{155}{\sqrt{t}}
\]

where, 
\( t = \) shock duration, seconds.

For a hand-to-feet contact made by a person standing on a non-metallic surface (concrete slab or a soil layer above the ground), only a minor modification of the formula for touch voltage is required in order to take into account the maximum inductive voltage drop occurring within the GIS assembly. The touch voltage criterion for the GIS is [3]:

\[
\sqrt{E_m^2 + E_{\text{touch}}'}^2 \leq E_{\text{touch}}
\]

Where,
\( E_m = \) computed value of mesh (touch) voltage and 
\( E_{\text{touch}} = \) Tolerable value of touch voltage for GIS
\( E_{\text{touch}}' \) has been defined in (2).

IV. RESULTS & DISCUSSION

Design of ground mats at various locations in Tehri HPP has been carried out using the GMAT computer program developed at CPRI. The software carries out economic design of the grounding grids at the same time achieving safe potential gradients under fault conditions within the grid so designed. Of the various grounding systems designed for the Tehri power station as indicated in I. A above, results of two cases namely, the ground mats at outdoor interface facility and GIS bus duct are discussed here since these designs are considered to be very critical.

A. Grounding grid for outdoor interface facility

With the input parameters that have been broadly explained in section II, an initial design of the ground mat was achieved when the depth of burial of the grid is 0.25 m and grid conductor spacing of 0.50 m. In order to optimize the grid conductor spacing, the program was re-run with increased depth of burial starting from 0.30 m which results in an increased grid conductor spacing of 2.25 m corresponding to depth of burial of 0.50 m. As a consequence, the total length of grid conductors is drastically reduced from 25,350 m to 5,910 m. Further increase in depth of burial did not result in any such advantage and therefore not considered.

The ground mat as designed is presented in fig. 2. It can be seen that besides the horizontal grid, there are in all 168 nos. of vertical ground rods (each 3 m long) that are proposed at the periphery of the grid in order to mitigate the mesh potentials in the peripheral meshes of the grid. The maximum mesh potential occurring inside the peripheral meshes of the grid is 1373 volts as against the permissible value of 1629 volts. Rest of the grid parameters are available in fig. 2.

B. Ground mat in GIS bus duct

As mentioned in earlier sections, the GIS bus duct extends from the transformer hall to the outdoor interface facility. The area considered for laying the ground mat is 670 m x 6.5 m.
In the design procedure, gradients due to metal-to-metal contact are also checked besides those for conventional AIS by including the inductive voltage term in the touch voltage equation. According to the final calculations, the grounding grid is to be laid 0.20m below the finished surface of the GIS bus duct. The size of the mesh is 1.5m x 1.5m. In this case, the maximum mesh potential is 357 volts as against the permissible value of 602 volts. Sectional view of the grounding grid proposed in the GIS bus duct is shown in fig. 3.

Fig.3 . Sectional view of Grounding grid at GIS Bus duct

C. Computed values of ground resistance

As part of the design, analytical expressions as explained in earlier sections and also in [5] were employed to compute the ground resistances of individual grounding systems based on the configuration of the electrodes proposed at different locations in Tehri HPP. In cases where ground mat is designed (as for outdoor interface facility, GIS bus duct etc.), the computed values include elemental conductance of the horizontal grid and vertical ground rods (where ever ground rods are employed). The values of ground resistances of individual grounding systems of Tehri HPP are presented in Table I. From this, the overall grounding system resistance is computed as 0.2885 ohm [5].

It may be mentioned that as far as possible, design of ground conductor system for individual location/facility ensured that mutual resistances between various ground conductors have been made negligible by proper placement of conductors. Nonetheless, total elimination of mutual resistances is not feasible in an extensive grounding arrangement as that of the Tehri HPP. In view of this, the actual grounding system resistance at the Tehri HPP may be slightly more than 0.2885 ohm, which has to be assessed only by field measurements after laying the complete grounding system.

However, the grounding system resistance of 0.2885 ohm is quite acceptable as this value is below 1.0 ohm which is recommended for large power stations as per [2].

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Description of Grounding system</th>
<th>Resistance (Ohms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Tail race tunnels (TR #1 &amp; #2)</td>
<td>3.9093</td>
</tr>
<tr>
<td>2</td>
<td>GIS Bus duct ground mat</td>
<td>1.1599</td>
</tr>
<tr>
<td>3</td>
<td>Adits</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Ground mat under transformer hall area</td>
<td>9.6550</td>
</tr>
<tr>
<td>5</td>
<td>Ground mat under M/c Hall &amp; turbines</td>
<td>9.0440</td>
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<tr>
<td>6</td>
<td>Ground mat at outdoor interface facility</td>
<td>2.9510</td>
</tr>
<tr>
<td>7</td>
<td>Ventilation tunnel</td>
<td>3.5533</td>
</tr>
<tr>
<td>8</td>
<td>Upper expansion chamber</td>
<td>9.5329</td>
</tr>
<tr>
<td>9</td>
<td>OVERALL GROUNDING SYSTEM</td>
<td>0.2885</td>
</tr>
</tbody>
</table>

TABLE I
GROUND RESISTANCE OF INDIVIDUAL GROUNDING ARRANGEMENT

VI. CONCLUSION

Design of grounding system for hydro power stations is a very complex task in view of the high value of soil resistivity prevalent in such rocky areas. In case of Tehri HPP also, the high soil resistivity at site necessitated design of extensive grounding grids at several locations. When inter-connected, they provide a low value of resistance. Special design methods were employed for GIS ground mat to take care of the metal-to-metal contact. The overall grounding system resistance at Tehri HPP is calculated as 0.2885 ohm, which is quite acceptable for major power stations.

VII. ACKNOWLEDGMENT

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VIII. REFERENCES