# TECHNIQUES TO OBTAIN THE PERMISSIBLE GROUNDING RESISTANCE OF HYDROELECTRIC POWER PLANT IN HIGHLY RESISTIVE SOILS

**Eitazaz ul haq[1], Tahir Izhar[2]**
[1]Department of Electrical Engineering, University of Engineering & Technology, Lahore.
eitazazulhaq@gmail.com, Ph # 0345 4148151
[2] Department of Electrical Engineering, University of Engineering & Technology, Lahore.

***ABSTRACT:*** *The main emphasis in the design phase of grounding system of power plant is to obtain grounding resistance within the permissible limits. The lower the value of the rounding resistance, safer is the grounding system. As the grounding resistance is directly proportional to the soil resistivity, so for the power plants built on the highly resistive soils, desired grounding resistance cannot be achieved using traditional approaches. In the paper, different design techniques to calculate the grounding resistance is analysed along with the approaches to lower the grounding resistance. The ground resistance values obtained from these techniques is compared with the values of grounding resistance computed via engineering software ETAP.*

**Keywords:** Decreases Grounding Resistance, Interconnected Grounding Grid

## 1. INTRODUCTION

A power plant or substation with a properly designed grounding system is the key to its safe operation. In order to ensure the safety of personnel, power apparatus and secondary devices in the substation, the grounding resistance of the substation should be lowered to a permissible value. Decreasing the grounding resistance decreases the maximum GPR, and hence, the maximum transfer potential. The most effective way to decrease the grounding resistance is by increasing the area occupied by the grounding grid. Another method is to effectively decrease the resistivity of the soil region neighbouring the grounding grid, because the soil resistance of this region provides a large part of the grounding resistance of the substation [1]. If a deep low-resistivity soil layer exists, the grounding resistance can be effectively decreased by arranging long vertical ground rods or ground wells to penetrate into it. This technique may help in decreasing the ground resistance but this also helps in reducing the maximum ground potential rise and maximum transfer potential.

Different techniques have been utilized to decrease the grounding resistance of a grounding system. Some of the conventional techniques include increasing the area of the grounding grid, interconnection of main grounding grid to an additional external grounding grid, increasing the burial depth of the grounding grid, utilizing natural grounding objects such as the steel foundations of structures, addition of vertical grounding rods and exchanging the soils around the grounding grid for low resistivity materials. These methods are suitable for different geological situations but that does not mean they should be taken up independently. In fact, in a specific soil environment, two or more methods should be taken up to decrease the grounding resistance effectively. Adding deep vertical ground rods to the grounding grid is very effective if the low resistivity layer is present in the depth. This method can utilize the low resistivity soil layer and eliminate seasonal influences. In order to decrease the grounding resistance, a special method was proposed for decreasing the grounding resistance of grounding grids in a high resistivity area, called the explosive grounding technique [2]. This method has proved quite effective, but the shortcoming of the explosive grounding technique is the high engineering cost.

In the power plants located in the highly resistive soils particularly in the hilly areas, it is often difficult to attain a low value of grounding resistance by employing the conventional techniques. In this scenario, this paper gives initial design procedure and techniques in calculation of grounding resistance of the power plant and the substation at proposed Dasu dam site. The site is located on river Indus in KPK province of Pakistan. The project will have an underground powerhouse housing 12 Francis turbines, each of which will be capable to produce 360 MW power, and a final maximum capacity to produce 4320 MW, along with 500KV substation. It will have an intake structure having four power tunnels, with three turbines installed in each power tunnel, underground 12 penstock, 4 number surge chambers, 4 number tailrace tunnels, a GIL Tunnel and main access tunnel. Geophysical survey shows that the resistivity of the region is relatively high up to 30000 Ω.m.

## 2. GROUNDING GRID DESIGN

In design of the grounding system of a substation or power plant, the estimation of grounding resistance is key in determining the geometry of the grounding system. Resistance to ground calculation method for a uniform soil covered by a grounding grid region used to be studied by many researchers.

### 2.1 IEEE Methods

IEEE 80-2000 [4] includes and defines some methods. Commonly used methods are Laurent-Niemann Method, Sverak Method, Schwarz Method, Dwight Method and Thapar-Gerez Method.

#### a. Laurent-Niemann Method

Laurent & Niemann develops formula for the calculation of ground resistance that is a function of the area covered by the region and the soil resistivity in that region. The soil resistivity has a non-uniform nature. It is a well-known fact that soil resistivity may vary both vertically and horizontally in an earth region. Soil resistivity has direct relation with the resistance. Varying soil resistivity causes varying resistance. So the designer try to estimate the minimum value of ground resistance at a certain depth h from the ground surface [5]. Laurent-Niemann Method expressed Eq. (1) to estimate the ground resistance [6].

$$R = \frac{\rho}{4r} + \frac{\rho}{L} \qquad (1)$$

- ρ is the resistivity of the region.
- L is the total length of the buried conductor.

- r is the radius of a circular plate occupying the same area as the grid.

**b. Schwarz Method**

Schwarz developed set of equations in order to determine the grounding resistance in uniform soil conditions. Ground resistance of a grid formed by straight horizontal wires is represented by equation (2) as follows [4]:

$$R = \frac{\rho}{\pi L}\left[loge\frac{2L}{a'} + \frac{K1L}{\sqrt{A}} - k2\right] \qquad (2)$$

- Z is the depth of mesh
- a is the Radius of conductor
- A is the area of the mesh in meters²
- L is the length of total conductor in meters
- a'=√2az
- K1 and K2 have been taken from a graph that has been provided in IEEE Guide 80 manual.

Schwarz also develop equation for calculation of ground resistance of vertical rod bed as given in equation (3) as follows [4]:

$$R = \frac{\rho}{2\pi n L_1}\left[ln\frac{4L_1}{b} - 1 + \frac{2k_1L_1}{\sqrt{A}}\left(\sqrt{n} - 1\right)^2\right] \qquad (3)$$

- ρ represents resistivity of the region
- L1 is the length of each rod
- N is the number of rock bolts
- $k_1$ - function of L/W given by graph in IEEE guide 80 manual
- A(m²) is the area covered by rods

**c. Dwight Method**

Dwight develops set of expressions for calculating the value of Ground resistance. For the grounding grid composed of horizontal wires, dwight expression can be employed by considering the grid as a ring of wire with equivalent diameter "D" calculated from the area of the grid. The expression for calculating the resistance of ground is found by (4) as given in [8]:

$$R = \frac{\rho}{2\pi 2D}\left[loge\frac{8D}{d} + loge\frac{4D}{S}\right] \qquad (4)$$

- d is the Diameter of wire in meter
- D is the diameter of the ring in meter
- S = Depth of conductor * 2

## 2.2 Finite Element Grounding Methods

The recent studies on grounding analysis are mostly based on Finite Element Methods (FEM). This method is used to determine grounding resistance of a grounded region. This method gives more accurate results compared to conventional grounding methods discussed above.

Old FEM techniques are based on current flow analysis that uses grid potential set. In this technique, once the current is calculated, dividing voltage by current results in ground resistance. Major drawback of this technique is selecting the size of the model that is the distance of the earth is taken such that it starts from the grounding grid. Since analysis of each potential in the soil for a selected point is considered from grounding grid to the point.

In the new FEM technique, drawbacks in the old FEM technique have been addressed. First assumption in the new method is that grounding resistance does not depend on potential or current in the grounding grid except frequency cases other than power frequencies (50Hz or 60Hz). Second assumption is that the region is an infinite flat surface. ([9] give sample results and derivations). Model structure for this solution is given in Figure1.

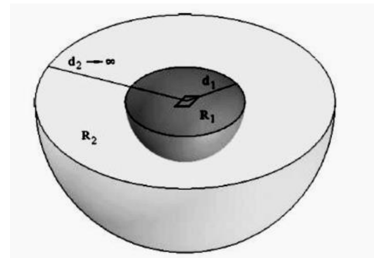


**Fig 1.New Finite Element Model of soil**

R1, R2, d1 and d2 are the variables for the model. d1 is the distance from grid to the points where semi-spherical model of equipotent surface disturbs, d2 is the distance from grid to the points where electrical potential goes to zero. Technically, this point is at infinity. R1 is the resistance inside the semi-spherical surface and R2 is the resistance outside the semi-spherical surface. From tests of various designs, researchers found that Eq.5 can be used to determine d1 [9].

$$d1 = \frac{D}{2} + 30 \qquad (5)$$

where D is the diagonal distance of grounding grid.

$$R = R1 + R2 \qquad (6)$$

In [9], R2 is computed from Eq. (7)

$$R2 = \frac{\rho}{2\pi d1} \qquad (7)$$

Determination of R1 is not as simple as R2. This is where finite element analysis exactly takes its place. In general, R1 can be calculated from dissipated power given in Eq. (8)

$$R_1 = \frac{(Voltage)^2}{DissipatedPower} \qquad (8)$$

R1 can be detailed by replacing the terms as in Eq. (9)

$$R_1 = \frac{(V_G - V_B)^2}{\int_V \frac{E^2}{\rho} dV} \qquad (9)$$

Where VG is the potential in the grid, VB is the potential in the boundary d1.

From Eq. (7) and (9), one can compute the grid resistance by Eq. (6).

## 3. METHODOLOGY

The proposed power plant is built on the rock of high resistivity, so the resistance to ground of the power plant and substation would result into several ohms. In order to achieve a desired resistance to ground which is less than 1Ω for the high head power plants [6], interconnection of grounding grids of different power plant components is required.

In this paper, effect of different components of the power plant in reducing the grounding resistance is investigated. The individual resistance to ground of these components i.e. power house, Transformer Room, Surge chamber, Access Tunnel, GIL Tunnel, Draft tube, Tailrace Tunnel and substation would result into several ohms. Reinforcing steel used in building these structures contributes to control the step and touch potential but they contributes very little in reducing the resistance to ground to a desired level due to high resistivity [7]. The desired grounding resistance can only be obtained by designing the grounding grid that interconnects the grounding grid of above mentioned structures through copper conductors. As the resistivity of the rock is high, the low resistive path to the remote earth is through the water in the penstock to the power tunnel.

Further, as the power tunnel is in direct contact with large volumes of water, so the resistance to ground can be brought to a desired level if a mesh of conductors installed there and interconnects with the power plant grounding conductors. Advantages can also be taken from the reinforced steel laid in the tailrace tunnel and Main Access Tunnel. It would then appear as several electrodes to ground connected in parallel, and the overall ground resistance is the equivalent resistance of the entire network. The ground resistance has been calculated utilizing the IEEE methods i.e: Laurent-Niemann, Schwarz and Dwight. The resistance to ground also computes with the help of Finite Element Method (FEM) of ETAP. The ground resistance values obtained from the IEEE methods will be compared with the ground resistance using FEM and the method which has less percentage error will be taken as the design value.

## 4. CALCULATION OF RESISTANCE TO GROUND

In this present scenario, the resistance to ground calculations has divided into eight major parts. Calculations for each part have been performed in detail and in some cases, more than one method have used. Some of the parts have been divided into smaller parts to achieve a higher degree of accuracy.

### 4.1 Transformer /GIS Grounding Resistance

For ease of evaluation transformer/GIS cavern has been subdivided into two parts namely:

a. Conductors Buried in Concrete
b. Rock Bolts in Arch Roof

**a. Conductors Buried In Concrete**

(Same for transformer and GIS Floor)

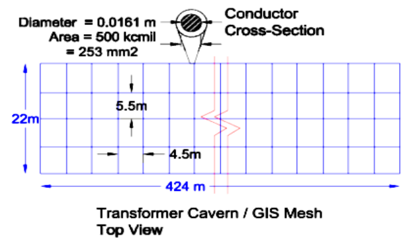


**Fig 2. Transformer Floor / GIS Mesh Top View**

Resistance of conductor buried in concrete has been calculated using three different formulas derived by Laurent, Schwarz and Dwight.

**i. Laurent Method**

Ground Resistance using equation (1) can be calculated with the following details.

- ρ (resistivity of granulite) = 30000 Ω m
- Grid Size= 424m x 22m
- Mesh Size = 4.5m x 5.5m
- Length of the conductor = 4210m.

Putting the values in (1) gives R= 144.8 Ω.

**ii. Schwarz Method**

Ground Resistance using equation (2) can be calculated with the following details.

- Depth of mesh (Z) = 0 .5 meters
- Radius of conductor (a) = 0.00805 meters (500 KCMIL)
- A is the area of the mesh in meters²
- L is the length of total conductor in
- meter.K1=0.89 and K2 = 8.40 have been taken from a graph that has been provided in IEEE Guide 80 manual.
- A (m²) = 9328

Putting the values in (2) gives R= 94.9 Ω.

**iii. Dwight Method**

Ground Resistance using equation (4) can be calculated with the following details.

- Diameter of wire (d) = 0.0161 meter
- S = Depth of conductor * 2 = 1.0 meter
- D= Diameter of the plate=108.98m

Putting the values in (4) gives R= 236.7 Ω.

Now the resistance to ground value obtained from the above three methods are compared with the values obtained through Finite Element Analysis of ETAP and the results are summarized below:

| Grid Size | Laurent Niemann | Schwarz | Dwight | ETAP FEM |
|---|---|---|---|---|
| (m) | R (Ω) | R (Ω) | R (Ω) | R (Ω) |
| 424 x 22 | 144.8 | 94.9 | 236.7 | 92.3 |

Resistance to ground values obtained using the Schwarz Method has chosen for further analysis as the percentage error of this method with the FEM is low.

**b. ROCK BOLTS IN THE ARCH ROOF**

The rock bolts in the roof of the transformer room in order to support the ceiling of the transformer room acts as grounding rods, and resistance of which is given by the Schwarz Equation (3).

- ρ (resistivity of granulite) = 30000 Ω-m
- L1 is the length of each rod = 5.5m.
- b is the radius of bolts considering it as an ground rod=0.015m.
- N is the number of rock bolts =3500
- Width of mesh = 28 m
- K1 is the function of L/W given by the graph in IEEE-80 manual.
- A (m²) - area covered by rods=11872.

Putting the values in (5) gives R= 81 Ω.

As the resistance value of rock bolts is too high, this also shows that by drilling the rods in the rock is not helpful in reducing the resistance.

### 4.2 Power House Calculations

For ease of evaluation, powerhouse has been subdivided into three parts namely:

a. Conductors Buried in Concrete
b. Rock Bolts in Arch Roof
c. Power Tunnel
d. Steel Lining in Contact with Water (Penstock)

#### a. Conductors Buried in Concrete

The top view of the mesh buried in power house has shown below:

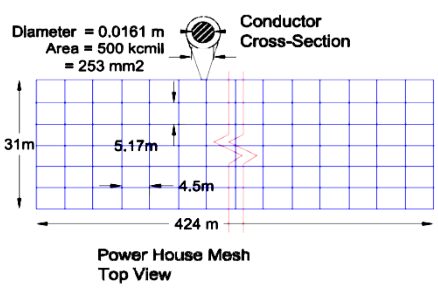


**Fig 3. Power House Mesh Top View**

Resistance of conductor buried in concrete has been calculated in the same way using three different formulas as described by (1), (2) and (4) and the result of each method is summarized below:

##### i. Laurent Method

Ground Resistance using equation (1) can be calculated with the following details.

- ρ (resistivity of granulite) = 30000 Ω m
- Grid Size= 424m x 31m
- Mesh Size = 4.5m x 5.17 m
- Length of the conductor = 5913 m
- Radius of the plate =64.7m.

Putting the values in (1) gives R= 121 Ω.

##### ii. Schwarz Method

Ground Resistance using equation (2) can be calculated with the following details:

- Depth of mesh (Z) = 0 .5 meters
- Radius of conductor (a) = 0.00805 meters (500 KCMIL)
- A is the area of the mesh in meters² =13144
- L is the length of total conductor in meters.
- K1=0.96 and K2 = 7.54 have been taken from a graph that has been provided in IEEE Guide 80 manual.

Putting the values in (2) gives R= 86.7 Ω.

##### iii. Dwight Method

Ground Resistance using equation (4) can be calculated with the following details.

- Diameter of wire (d) = 0.0161 meter.
- Depth of conductor * 2 = 1.0 meter
- D = Diameter of the plate=129.4m

Putting the values in (4) gives R= 203 Ω.

Now the resistance to ground value obtained from the above three methods are compared with the values obtained through Finite Element Analysis of ETAP and the results are summarized below:

| Grid Size | Laurent Niemann | Schwarz | Dwight | ETAP FEM |
|---|---|---|---|---|
| (m) | R (Ω) | R (Ω) | R (Ω) | R (Ω) |
| 424 x 31 | 121 | 86.77 | 203 | 83.97 |

Resistance to ground values obtained using the Schwarz Method has chosen for further analysis as the percentage error of this method with the FEM is low.

#### b. Rock Bolts in the Arch Roof

The rock bolts are considered as ground rods, and resistance of which is given by the same method as given by equation (3) as:

- ρ (resistivity of granulite) = 30000 Ω-m
- L1 is the length of each rod = 5.5m.
- n is the number of rock bolts=3500
- Width of mesh = 31 m
- A is the area covered by rods =16536.

Putting the values in (3) gives R=83.1 Ω.

#### c. Power Tunnel

Resistance of conductor buried in concrete has been calculated in the same way using three different formulas as described by (1), (2) and (4) and the result of each method is summarized below:

Length = 450 m (Average)
Diameter of the tunnel = 6 m
Width of conductor = 2 π r =18.84 m

##### i. Laurent Method

- ρ (resistivity of granulite) = 30000 Ω m
- Grid Size= 400m x 18.8m
- Mesh Size = 10m x 3m
- Length of the conductor = 3557 m
- Radius of the plate =51.94m.

Putting the values in (1) gives R= 152.7 Ω.

##### ii. Schwarz Method

Ground Resistance using equation (2) can be calculated with the following details.

- Depth of mesh (Z) = 0 .5 meters
- Radius of conductor (a) = 0.00805 meters
- (500 KCMIL)
- A is the area of the mesh in meters²=8478
- L is the length of total conductor in meters
- K1=0.88 and K2 = 9.08 have been taken from a graph that has been provided in IEEE Guide 80 manual.

Putting the values in (2) gives R= 97.09 Ω.

**iii. Dwight Method**

Ground Resistance using equation (4) can be calculated with the following details.

- Diameter of wire (d) = 0.0161 meter
- S = Depth of conductor * 2 = 1.0 meter
- D= Diameter of the plate=103.88m

Putting the values in (4) gives R= 246.6 Ω.

Now the resistance to ground value obtained from the above three methods are compared with the values obtained through Finite Element Analysis of ETAP and the results are summarized as:

| Grid Size (m) | Laurent Niemann | Schwarz | Dwight | ETAP FEM |
|---|---|---|---|---|
| | R (Ω) | R (Ω) | R (Ω) | R (Ω) |
| 400 x 18.8 | 152.7 | 97.09 | 246.6 | 100.3 |

Resistance to ground values obtained using the Schwarz Method has chosen for further analysis as the percentage error of this method with the FEM is low.

**d. Steel Lining in Contact with Water (Pen Stock)**

The resistance of the penstock can be calculated by considered it as a rectilinear electrode [10].

$$R = 0.366 * \frac{\rho}{l}\{\text{loge}\left(\frac{3l}{2d}\right) + \text{loge}\left(\frac{3L}{8h}\right)\} \qquad (5)$$

Where:

- Þ = Resistivity of water/Steel =400 Ω-m
- ℓ= length of the penstock (m) =255 m
- ɤ= radius of penstock (m) =3m
- d= diameter of the penstock (m) = 6m
- h= depth of concrete=0.5m

Thus the Resistance of Penstock (R) = 5.51 Ω.

With the twelve Penstock in parallel (three for each Power Tunnel), the ground resistance is calculated as 0.46 Ω.

### 4.3 Surge Chamber

Copper Conductors are buried in the form of grid in the surge chamber. A surge chamber receives water from the draft tubes and directs it to tail race tunnels. The surge chamber is located parallel to the power plant room. The ground resistance of the surge chamber grounding grid is calculated in the same way as for power house and transformer cavern using (1) (2) & (4).

Height of the surge Chamber =56m
Diameter of the tank = 37 m
Width of conductor = 2 π r =116.23 m

**i. Laurent Method**

- ρ (resistivity of granulite) = 30000 Ω m
- Grid Size= 116m x 56m
- Mesh Size = 10m x 3m
- Length of the conductor = 2880 m
- Radius of the plate =45.5m.

Putting the values in (1) gives R= 175 Ω.

**ii. Schwarz Method**

Ground Resistance using equation (2) can be calculated with the following details.

- Depth of mesh (Z) = 0 .5 meters
- Radius of conductor (a) = 0.00805 meters (500 KCMIL)
- A is the area of the mesh in meters² =6508
- L is the length of total conductor in meters
- K1=1.24 and K2 = 6.1 have been taken from a graph that has been provided in IEEE Guide 80 manual.

Putting the values in (2) gives R= 174 Ω.

**iii. Dwight Method**

Ground Resistance using equation (4) can be calculated with the following details.

- Diameter of wire (d) = 0.0161 meter
- S = Depth of conductor * 2 = 1.0 meter
- D= Diameter of the plate=128.74m

Putting the values in (4) gives R= 202.5 Ω.

Now the resistance to ground value obtained from the above three methods are compared with the values obtained through Finite Element Analysis of ETAP and the results are summarized below:

| Grid Size (m) | Laurent Niemann | Schwarz | Dwight | ETAP FEM |
|---|---|---|---|---|
| | R (Ω) | R (Ω) | R (Ω) | R (Ω) |
| 10m x 3m | 175 | 174 | 202.5 | 160.5 |

Resistance to ground values obtained using the Schwarz Method has chosen for further analysis as the percentage error of this method with the FEM is low. With the four surge chambers connected in parallel, the ground resistance is calculated as 43.5Ω.

### 4.4 Draft Tube Gallery

Conductors are embedded in the concrete of each draft tube. The resistance to ground is calculated as follows:

**Schwarz Method**

The resistance to ground of the conductor laid in the concrete of draft tube can be calculated by treating it as a buried straight horizontal wire. Schwarz has derived the ground resistance of buried horizontal wire as:

$$R = \frac{\rho}{\pi L}\left[loge\frac{2L}{a'} - 1\right] \qquad (10)$$

Where:

- ρ (resistivity of granulite) = 30000 Ω m
- Depth of mesh (Z) = 0 .5 meters
- Radius of conductor (a) = 0.00805 meters
- L is the length of total conductor = 400 meters
- a'=√2az=0.0634m

Putting the values in (10), gives R = 193.3Ω.

### 4.5 Access Tunnel

Resistance of conductor buried in concrete of Access Tunnel has been calculated in the same way using three different formulas as described by (1), (2) and (4) and the result of each method is summarized below:

Length of the tunnel = 1000 m (Average)
Width of conductor = 2 π r =29 m.

**i. Laurent Method**

- ρ (resistivity ) = 30000 Ω m
- Grid Size= 1000m x 29m
- Mesh Size = 4.8m x 10m
- Length of the conductor = 8900 m
- Radius of the plate =96.1m.

Putting the values in (1) gives R= 81.4 Ω.

**ii. Schwarz Method**

Ground Resistance using equation (2) can be calculated with the following details.

- Depth of mesh (Z) = 0 .5 meters
- Radius of conductor (a) = 0.00805 meters (500 KCMIL)
- A is the area of the mesh in meters² =29000
- L is the length of total conductor in meters
- K1=0.86 and K2 = 10.73 have been taken from a graph that has been provided in IEEE Guide 80 manual.

Putting the values in (2) gives R= 49.64 Ω.

**iii. Dwight Method**

Ground Resistance using equation (4) can be calculated with the following details.

- Diameter of wire (d) = 0.0161 meter
- S = Depth of conductor * 2 = 1.0 meter
- D= Diameter of the plate=192.2m.

Putting the values in (4) gives R= 143.2 Ω.

Now the resistance to ground value obtained from the above three methods are compared with the values obtained through Finite Element Analysis of ETAP and the results are summarized below:

| Grid Size (m) | Laurent Niemann | Schwarz | Dwight | ETAP FEM |
|---|---|---|---|---|
| | R (Ω) | R (Ω) | R (Ω) | R (Ω) |
| 1000m x 29m | 81.4 | 49.64 | 143.2 | 45.37 |

Resistance to ground values obtained using the Schwarz Method has been chosen for further analysis as the percentage error of this method with the FEM is low.

**4.6 Tailrace Tunnel**

Resistance of conductor buried in concrete of Access Tunnel has been calculated in the same way using three different formulas as described by (1), (2) and (4) and the result of each method is summarized below:

Length = 2025 m

Diameter of the tunnel =11m

Width of conductor = 2 π r =34.54 m.

**i. Laurent Method**

- ρ (resistivity ) = 30000 Ω m
- Grid Size= 800m x 34.54m
- Mesh Size = 6m x 10m
- Length of the conductor = 7563m
- Radius of the plate =93.8m.

Putting the values in (1) gives R= 83.9 Ω.

**ii. Schwarz Method**

Ground Resistance using equation (2) can be calculated with the following details.

- Depth of mesh (Z) = 0 .5 meters
- Radius of conductor (a) = 0.00805 meters (500 KCMIL)
- A is the area of the mesh in meters² =27632
- L is the length of total conductor in meters
- K1=0.87 and K2 = 8.97 have been taken from a graph that has been provided in IEEE Guide 80 manual.

Putting the values in (2) gives R= 53.6 Ω.

**iii. Dwight Method**

Ground Resistance using equation (4) can be calculated with the following details.

- Diameter of wire (d) = 0.0161 meter
- S = Depth of conductor * 2 = 1.0 meter
- D= Diameter of the plate=187.56m

Putting the values in (4) gives R= 146.3 Ω.

Now the resistance to ground value obtained from the above three methods are compared with the values obtained through Finite Element Analysis of ETAP and the results are summarized below:

| Grid Size (m) | Laurent Niemann | Schwarz | Dwight | ETAP FEM |
|---|---|---|---|---|
| | R (Ω) | R (Ω) | R (Ω) | R (Ω) |
| 800 x 34.54 | 83.9 | 53.6 | 146.3 | 52.02 |

Resistance to ground values obtained using the Schwarz Method has been chosen for further analysis as the percentage error of this method with the FEM is low.

**4.7 Substation**

Substation of the Power House has dimensions of 200 X 220 m. Resistance of grid in the switchyard has been calculated in the same way using three different formulas as described by (1), (2) and (4) and the result of each method is summarized below:

Length of the switchyard = 200 m

Width of the switchyard = 220 m

ρ (resistivity of granulite) = 3000 Ω -m.

**i. Laurent Method**

- ρ (resistivity ) = 3000 Ω m
- Grid Size= 220m x 200m
- Mesh Size = 5m x 5m
- Length of the conductor = 17600 m
- Radius of the plate =118.34m.

Putting the values in (1) gives R= 6.50 Ω.

**ii. Schwarz Method**

Ground Resistance using equation (2) can be calculated with the following details.

- Depth of mesh (Z) = 0 .5 meters
- Radius of conductor (a) = 0.00805 meters
- (500 KCMIL)
- A is the area of the mesh in meters² =44000
- L is the length of total conductor in meters.
- K1=1.36 and K2 = 5.6 have been taken from a graph that has been provided in IEEE Guide 80 manual.

Putting the values in (2) gives R= 6.58 Ω.

**iii. Dwight Method**

Ground Resistance using equation (4) can be calculated with the following details.

- Diameter of wire (d) = 0.0161 meter
- S = Depth of conductor * 2 = 1.0 meter
- D= Diameter of the plate=236.68m

Putting the values in (5) gives R= 11.89 Ω.

Now the resistance to ground value obtained from the above three methods are compared with the values obtained through Finite Element Analysis of ETAP and the results are summarized below:

| Grid Size (m) | Laurent Niemann | Schwarz | Dwight | ETAP FEM |
|---|---|---|---|---|
| | R (Ω) | R (Ω) | R (Ω) | R (Ω) |
| 220 x 200m | 6.50 | 6.58 | 11.89 | 6.32 |

As the shape of the grid is close to square shape, percentage error for the ground resistance calculated using Laurent Niemann method is less as compared to FEM. However, ground resistance value using Schwarz method has chosen for further analysis as the percentage error of this method with the FEM method is in positive and less.

### 4.8 GIL Tunnel

Resistance of conductor buried in concrete of GIL Tunnel has been calculated in the same way using three different formulas as described by (1), (2) and (4) and the result of each method is summarized below:

Length of GIL Tunnel = 750 m (Average)

Width of conductor = 2 π r =30.75 m.

Mesh Size=5mx10m

Radius of plate=84.98

Length of buried conductor=6768 m.

K1=0.87 and K2=9.2.

Area ($m^2$) = 22687

Diameter of the plate =170m

| Grid Size (m) | Laurent Niemann | Schwarz | Dwight | ETAP FEM |
|---|---|---|---|---|
| | R (Ω) | R (Ω) | R (Ω) | R (Ω) |
| 750 x 30.75 | 92.7 | 58.8 | 159.7 | 56.26 |

Resistance to ground values obtained using the Schwarz Method has chosen for further analysis as the percentage error of this method with the FEM is low.

## 5. RESULTS

The desired grounding resistance of the power plant built in highly resistive soils can be obtained by interconnecting grounding grids of different components of power plant. In this paper, the ground resistance for the different components have been calculated employing techniques as described in Section 3. The simplified interconnected grounding grid structure showing the grounding resistance of each component is shown in the fig 4.

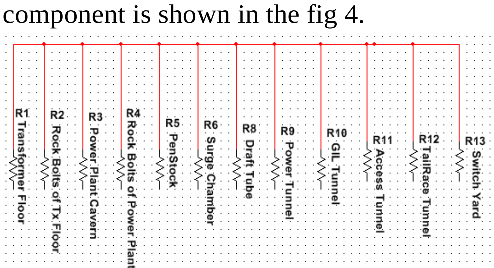


**Fig 4. Equivalent Network of Grounding System**

Summary of the results of resistance calculated in each component is shown in the table1 below. The equivalent resistance of the entire network is 0.41 Ω.

**Table 1: Ground Resistance of each component**

| Component Name | Resistance R (Ω) |
|---|---|
| Transformer Cavern | 94.9 |
| Rock Bolts in Arc Roof | 81 |
| Power Plant Cavern | 86.77 |
| Rock Bolts in Arc Roof | 83.1 |
| Power Tunnel | 24.3 |
| Pen Stock | 0.46 |
| Surge Chamber | 43.5 |
| Draft Tube | 193.3 |
| GIL Tunnel | 58.8 |
| Access Tunnel | 49.64 |
| Tailrace Tunnel | 43.5 |
| Switch Yard | 6.58 |
| **Overall Resistance** | **0.40** |

## 6. CONCLUSIONS

The proper designing of the grounding system plays important role in safe operation of any power plant. Designing a safe grounding system in highly resistive soils is a major challenge. This is because for hydroelectric power plants built in the hilly areas with high soil resistivity, the ground resistance cannot be achieved to the desired value of less than 1Ω.

The interconnection of different ground grids is the most important intervention in achieving the desired grounding resistance and safety of the personnel and plant. The interconnection of grounding grids of different components acts like several electrodes connected in parallel and the overall ground resistance is the parallel combination of the entire network. Some useful elements, like steel lining of penstock that is in contact with water prove to be effective in reducing the overall ground resistance. Thus the interconnected grounding grid structure helps to achieve the overall grounding resistance to the desired level.

In the initial design of the grounding system, designers try to adopt design values that fulfil their requirement efficiently. Different methods have been utilized to calculate the grounding resistance of underground power plant and some other elements like substation. These methods are general and can be applied to other types of plants as well. The design value of grounding resistance chosen for the analysis is that value which has less percentage error with ground resistance value calculated using Finite Element Analysis (FEM) of ETAP. The ground resistance value calculated using Schwarz method has less percentage error with the FEM. So this value is adopted as the design value.

## REFERENCES:


1. Jinliang He, Rong Zeng, Bo Zhang, “Methodology and Technology for Power System Grounding” 1st Ed, John Wiley & Sons Singapore Pte. Ltd 2013.
2. Zeng, R., He, J.L., Gao, Y.Q. et al. (2000) Test probe arrangement for grounding resistance measurement of grounding system in vertical-layered soil. Proceedings of IEEE Powercon, Perth, Australia, pp. 1469–1474.
3. “Environment Management Action Plan, Vol-8”, DASU Hydro Power Project, General Manager (Hydro) Planning, Water & Power Development Authority (WAPDA), June 2013.
4. IEEE Guide for Safety in AC Substation Grounding, IEEE Std. 80, USA, 2000

5. Mustafa Güçlü Aydiner, "GROUNDING DESIGN ANALYSIS", MSc thesis submitted to the Graduate School of Natural and Applied Sciences of Middle East Technical University, February 2009.
6. R. Verma, P. Barbeau, "Design of a Low Resistance Grounding System for a Hydro-Electric Plant Located on Highly Resistive Soils", IEEE Transactions on Power Apparatus and Systems, Vol. PAS-97, No. 5, Sept/Oct 1978.
7. "IEEE guide for Generating Station grounding" IEEE Std 665™-1995 (R2001)
8. H.B Dwight, "Calculation of Resistance to Ground", AIEE Transactions, Vol. 55, Dec. 1936, pp. 1319-1328.
9. J.A. Güemes, F.E. Hernando, F. Rodrigez, J.M. Ruiz, ―A Practical Approach of Determining the Ground Resistance of Grounding Grids‖, IEEE Transactions on Power Delivery, Vol. 21 No.3, July 2006
10. Anup Kumar, Prasanna D. Bharadwaj, Sanjai Kumar Yadav, "Grounding System Design for a Small Hydropower Station", International Journal of Emerging Engineering Research and Technology, Volume 3, Issue 4, April 2015, PP 22-29