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# Grounding System Design for a Small Hydropower Station

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## ABSTRACT

Safety, stability and economic operation of power system have become essential for today modern power systems. A sound grounding system for substation play a vital role to guarantee the safe and reliable operation of power systems and also ensure the safety of human being in case of any disturbance or fault in the power system. This paper presents the design of grounding system for power house and switchyard of a small hydro electric power plant (1 x 1.8 MW) as per IEEE standard 80-2000. The area available for grounding system design of this hydropower station is small. The required data for earth mat design are obtained from field test and the required parameters are computed using MATLAB tool.

**Keywords:** Earthing mat, grounding grid conductors, ground potential rise, safety, mesh potential, touch voltage

## INTRODUCTION

It is necessary to design an effective grounding grid for substation which play an important role from the people safety point of view. The main objective of the grounding system for safe and effective operation is to provide a path for high fault current due to lightning or electrical disturbance to ground and for that the resistance of the grounding system should be low in order to prevent voltage build up along the current flow path which can cause electrical shock to people or the damage of electrical equipment [16]. When these fault current circulate in the ground then produce voltages between different points of the earth that may be dangerous to people. A person who is exposed to such a gradient potential should not cause ventricular fibrillation for the purpose of safety requirements. The step and touch voltage at any point in the grid area should not exceed the safe tolerance limit values. Horizontal parallel conductors are buried by utilizing standard procedures and vertical rods are connected to horizontal conductors. Adding vertical ground rods to grounding grid reduces grid resistance as well as ground potential rise.

The parameter which affect grounding mat design are: fault current magnitude and duration, soil resistivity, resistivity of surface material, shock duration, material of earthing mat conductor, earthing mat geometry [11]. The duration and magnitude of the fault decides the type and size of the conductors chosen. Type and size of the conductors also affect the cost of the grounding system.

The major difference between generating station and substation is that generating stations usually have numerous large buried structures and foundations which have a significant impact in lowering the overall grid resistance of the station [6]. In addition many generating stations are located close to a source of water which may be useful as a low resistance reference point [6].

In this paper section II describes the Wenner’s four pin method for soil resistivity measurement. While section III describes the design methodology. The grounding grid design for power house and switchyard of hydro electric power plant are done as per IEEE standard 80-2000 using MATLAB program which is described in section IV. Section V gives symbols definition and section VI include conclusion.

## MEASUREMENT OF SOIL RESISTIVITY

Wenner’s four pin is the most commonly used method in the industry for soil resistivity measurement.

In this method four electrodes are drived into the earth along a straight line at equal intervals ‘x’ such

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that depth 'Y' of electrode is usually less than 1/20th of the distance between two adjacent electrodes [2]. Minimum eight test directions should be chosen from the centre of the site location. The test results show variations in soil formation. In this method a low frequency current (I) is injected through current electrode C1 and C2 into the soil and the earth voltage drop (V) observed between two inner voltage electrodes P1 and P2.

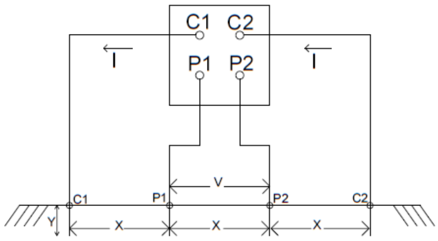


**Figure1.** *Wenner's four-pin method*

The ratio of V/I gives the apparent average resistance R (in ohms) of the soil. The apparent soil resistivity in ohm meters of the soil is given by the equation (1).

$$\rho = \frac{4\pi x R}{1 + \frac{2x}{\sqrt{(x^2 + 4y^2)}} - \frac{x}{\sqrt{(x^2 + y^2)}}} \tag{1}$$

Since probe depth 'Y' is small compared to 'x'. So above equation reduced to

$$\rho = 2\pi x R \tag{2}$$

Average weighted apparent resistivity of the soil up to the depth 'x' can be found by equation (2) [2, 15]. Soil resistivity can varies vertically as well as horizontally. However, if the soil resistivity variations are within 20 to 30 percent of the average value, it is assumed to be uniform soil [11].

## GROUNDING GRID DESIGN PROCEDURE [1]

**Step 1-** It includes required grounding grid area of site and electrical resistance of soil profiles obtain through measurement.

**Step 2-** Grounding grid conductor sizing require the maximum expected future fault current (3 $I_0$) that will be conducted by any conductor in the grounding system and fault clearing time $t_c$ [1]. Required conductor cross section is calculated by given formula (3).

$$A_{mm^2} = I_f \sqrt{\frac{\left( t_c \alpha_r \rho_r \times 10^4 / TCAP \right)}{\ln\left( \frac{K_0 + T_m}{K_0 + T_a} \right)}} \tag{3}$$

**Step 3-** Because of any fault the maximum driving voltage should not exceed the safe limit. The safe tolerable step and touch voltage is calculated by given formula (4) - (8).

$$E_{step\ 50} = (1000 + 6C_s\rho_s)\frac{0.116}{\sqrt{t_s}} \tag{4}$$

$$E_{step\ 70} = (1000 + 6C_s\rho_s)\frac{0.157}{\sqrt{t_s}} \tag{5}$$

$$E_{touch\ 50} = (1000 + 1.5C_s\rho_s)\frac{0.116}{\sqrt{t_s}} \tag{6}$$

$$E_{touch\ 70} = (1000 + 1.5C_s\rho_s)\frac{0.157}{\sqrt{t_s}} \tag{7}$$

$$C_s = 1 - \frac{0.09\left(1 - \frac{\rho}{\rho_s}\right)}{2h_s + 0.09} \tag{8}$$

**Step 4 –** Preliminary design include initial estimate of horizontal conductors spacing, ground grid conductors depth, total length of grid conductors including ground rods length also.

**Step 5 –** Resistance of grounding system is given by equation (9).

$$R_g = \rho\left[\frac{1}{L_T} + \frac{1}{\sqrt{20A}}\left(1 + \frac{1}{1 + h\sqrt{\frac{20}{A}}}\right)\right] \tag{9}$$

**Step 6 –** Maximum injected grid current as given by equation (11) is determined by proper selection of decrement factor and current division factor according to fault clearing time.

$$S_f = \frac{I_g}{3I_0} \tag{10}$$

$$I_G = C_p \cdot D_f \cdot I_g = C_p \cdot D_f \cdot 3I_0 \cdot S_f \tag{11}$$

**Step 7-** Ground potential rise is determined by equation (12).

$$GPR = I_G \cdot R_g \tag{12}$$

If calculated GPR is more than the tolerable touch voltage then further design evaluation are necessary.

**Step 8-** The actual mesh and step potential is calculated by given formula (13) and (14) respectively.

$$E_m = \frac{\rho \cdot K_m \cdot K_i \cdot I_G}{L_M} \tag{13}$$

$$E_s = \frac{\rho \cdot K_s \cdot K_i \cdot I_G}{L_s} \tag{14}$$

In equation (13), $L_M$ for grid with no ground rods or with only a few ground rods is given as in (15)

$$L_M = L_C + L_R \tag{15}$$

For grids with ground rods in the corners as well as along perimeter and throughout the grid, $L_M$ is given by (16).

$$L_M = L_C + \left[1.55 + 1.22\left(\frac{L_r}{\sqrt{L_x^2 + L_y^2}}\right)\right]L_R \tag{16}$$

In equation (13) $K_m$ and $K_i$ is given as

$$K_m = \frac{1}{2\pi}\left[\ln\left(\frac{D^2}{16hd} + \frac{(D+2h)^2}{8Dd} - \frac{h}{4d}\right) + \frac{K_{ii}}{K_h}\ln\frac{8}{\pi(2n-1)}\right] \tag{17}$$

$$K_i = 0.644 + (0.148 \times n) \tag{18}$$

Where

$$n = n_a \cdot n_b \cdot n_c \cdot n_d \tag{19}$$

$$n_a = \frac{2L_C}{L_P}, \; n_b = \sqrt{\frac{L_P}{4\sqrt{A}}}, \; n_c = \left(\frac{L_x \cdot L_y}{A}\right)^{\frac{0.7A}{L_x \cdot L_y}}, \; n_d = 1$$

In equation (14) $K_S$ and $L_S$ is given by

$$K_S = \frac{1}{\pi}\left[\frac{1}{2h} + \frac{1}{D+h} + \frac{1}{D}\left(1 - 0.5^{n-2}\right)\right] \tag{20}$$

$$L_S = 0.75 \cdot L_C + 0.85 \cdot L_R \tag{21}$$

**Step 9-** If the calculated actual mesh potential is below the tolerable touch voltage then proceed to step 10 otherwise modify the design.

**Step 10-** If the calculated actual step voltage is below the tolerable step voltage then go for detailed design otherwise modify the design

**Step 11-** If either the calculated actual step or touch voltage exceeded the tolerable limits, revision of the grid design is required. These revisions may include smaller conductor spacings, additional ground rods, etc.

**Step 12-** After satisfying the step and touch voltage requirements, detail grounding grid design such as 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. Additional ground rods may be required at the base of surge arresters, transformer neutrals, etc.

The flow chart for designing grounding grid is shown below:

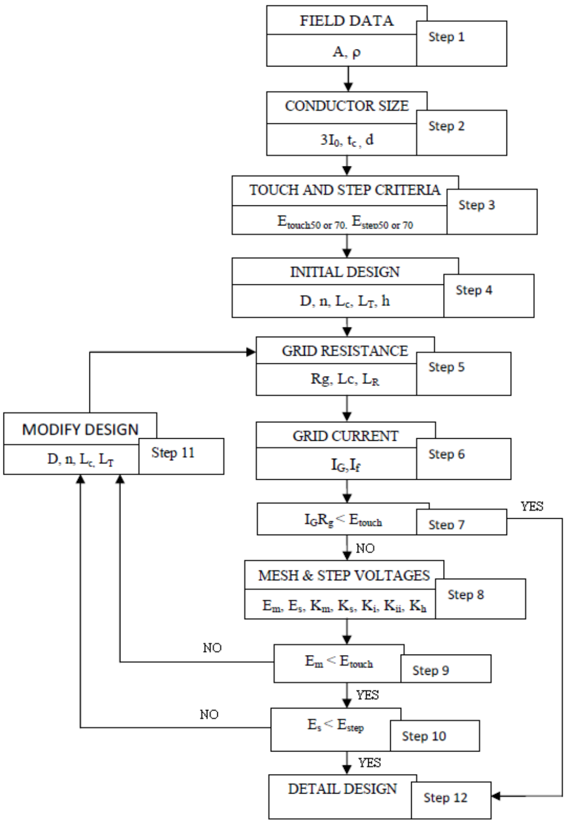


**Figure2.** *Design procedure block diagram [1]*

## GROUNDING SYSTEM FOR (1×1.8 MW) SMALL HYDROPOWER STATION USING MATLAB.

Grounding system for a (1×1.8 MW) small hydropower plant in Kolhapur district of Maharashtra state consists of two parts:

1) Grounding system for Power House (PH)

2) Grounding system for Switchyard (SY)

Grounding system is designed to limit the value of step voltage, mesh voltages and GPR within tolerable limit. Required input parameters for earth grid design are shown in Table 1. Table 2 shows standard material constant values of used grid material. The calculated parameters of grid design have been shown in Table 3. Table 4 shows the results of designed grounding grid. Parameters required in calculating overall grid resistance are shown by Table 5. While Table 6 shows the result after connecting the earth grid of Power house and switchyard with penstock.

**Table1.** *Required input design parameters*

| Parameters | Power house | Switch-yard |
|---|---|---|
| Length of earth grid | 16 m | 15 m |
| Width of earth grid | 11 m | 13 m |
| Area of earth grid (A) | 176 $m^2$ | 195 $m^2$ |
| Soil resistivity (Uniform soil) | 120 Ω.m | 120 Ω.m |
| System voltage | 3.3 kV | 33 kV |
| Fault current | 10 kA | 17.5 kA |
| Fault duration | 0.5 s | 0.5 s |
| Fault current division factor ($S_f$) | 0.5 | 0.5 |
| Surface layer resistivity | 5000 Ω.m | 5000 Ω.m |

**Table2.** *Material constants for mild steel used as earth grid conductor.*

| Grid conductor material (Mild Steel) constants | Values |
|---|---|
| Maximum allowable Temperature ($T_m$) | 620 $^0C$ |
| Ambient Temperature ($T_a$) | 45 $^0C$ |
| Thermal Co-eff. of resistivity at reference temperature ($\alpha_r$) | 0.0016 1/$^0C$ |
| Resistivity of ground conductor at ref. temperature ($\rho_r$) | 15.9 μΩ-cm |
| Thermal capacity per unit volume(TCAP) | 3.28 J/($cm^3$. $^0C$ ) |
| $K_0$=(1/$\alpha_0$) or (1/$\alpha_r$) at 0 $^0C$ | 605 |

**Table3.** *Design details of earth grid.*

| Grid Parameters obtained by MATLAB | Power house | Switchyard |
|---|---|---|
| Conductor cross section - M.S. Flat | (50mm) x (8mm) | (50mm) x (8mm) |
| Depth of grid conductor burial (h) | 0.6 m | 0.6 m |
| Surface layer thickness ($h_s$) | 0.3 m | 0.3 m |
| Number of conductor along lengthwise | 10 | 12 |
| Number of conductor along widthwise | 8 | 11 |
| Spacing between parallel conductors (D) | 1.8 m | 1.4 m |
| Total number of ground rod | 8 | 14 |
| Length of each rod | 3 m | 3 m |
| Total length of buried conductors ($L_T$) | 262 m | 363 m |
| Effective buried length for mesh voltage ($L_M$) | 279.72 m | 393.84 m |
| Effective buried length for step voltage ($L_S$) | 198.9 m | 276.4 m |
| Spacing factor for mesh voltage ($K_m$) | 0.333 | 0.265 |
| Correction factor for grid geometry($K_i$) | 1.96 | 2.34 |
| Corrective weighting factor for the effect of burial depth ($K_h$) | 1.26 | 1.26 |
| Corrective weighting factor ($K_{ii}$) | 1 | 1 |
| Spacing factor for step voltage ($K_s$) | 0.573 | 0.651 |
| Reflection factor (K) | - 0.953 | -0.953 |

**Table4.** *Earth grid design results*

| Results obtain by MATLAB | Power house | Switchyard |
|---|---|---|
| Grounding grid resistance ($R_g$) | 4.16 Ω | 3.86 Ω |
| Ground potential rise (GPR) | 20814.73 V | 33809.4 V |
| Tolerable touch voltage ($E_{touch50\ or\ 70}$) | 1675.27 V | 1675.27 V |
| Calculated mesh voltage ($E_m$) | 1400.33 V | 1659.25 V |
| Tolerable step voltage ($E_{step\ 50\ or\ 70}$) | 6035.01 V | 6035.01 V |
| Calculated step voltage ($E_s$) | 3389.32 V | 5797.09 V |

Earth grid resistance of Power house and Switchyard are 4.16 Ω and 3.86 Ω respectively which are more than one ohm. Hence grounding grid of power house and switchyard are connected together to reduce the overall grid resistance. Earth grid of both power house and switchyard are also interconnected with penstock to achieve the overall earth grid resistance less than one ohm.

Penstock can be considered as a rectilinear electrode with a length 'L' and a diameter 'd' buried at a depth 'h' whose resistance can be expressed by equation (22).

$$R_{Penstock} = \frac{0.366 \times \rho}{L}\left(\log\left(\frac{3L}{2d}\right) + \log\left(\frac{3L}{8h}\right)\right) \quad (22)$$

Equivalent earth grid resistance ($R_{eq}$) with interconnection of power house earth grid and switchyard with penstock is calculated by using equation (23).

$$\frac{1}{R_{eq}} = \frac{1}{R_{g1}} + \frac{1}{R_{g2}} + \frac{1}{R_{penstock}} \quad (23)$$

**Table5.** *Parameters required in calculating overall grid resistance*

| Parameters | Value |
|---|---|
| Grounding grid resistance of Power house ($Rg_1$) obtains from table IV. | 4.16 Ω |
| Grounding grid resistance of Switchyard ($Rg_2$) obtains from table IV. | 3.86 Ω |
| Length of penstock (L) | 50 m |
| Diameter of penstock (d) | 1.45 m |
| Depth of the concrete (h) | 0.300 m |
| Resistivity of water discharged by penstock (ρ) | 50 Ω.m |

**Table6.** *Result after connecting the earth grids of Power house and switchyard with penstock.*

| Parameter obtained | Value |
|---|---|
| Overall grounding system resistance ($R_{eq}$) | 0.782Ω |

## SYMBOLS DEFINITION

**Table7.** *Used symbols and their description*

| Symbol | Description |
|---|---|
| $\rho$ | Soil resistivity in Ω.m |
| $\rho_s$ | Surface layer resistivity in Ω.m |
| $3I_0$ | Symmetrical fault current in amperes |
| A | Total surface area enclosed by earth grid in $m^2$ |
| $C_s$ | Surface layer derating factor |
| d | Earth grid conductor diameter in meters |
| D | Distance between parallel conductors in meters |
| $D_f$ | Decrement factor |
| $C_p$ | Corrective projection factor by considering future growth |
| $t_c$ | Duration of clearing fault current in seconds |
| $E_m$ | Mesh voltage in volts at the centre of the corner mesh |
| $E_s$ | Step voltage in volts |

| | |
|---|---|
| $E_{step50\ or\ 70}$ | Tolerable step voltage for 50 kg or 70 kg weight human in volts |
| $E_{touch50\ or\ 70}$ | Tolerable touch voltage for 50 kg or 70 kg weight human in volts |
| h | Earth grid burial depth in meters |
| $t_s$ | Shock duration |
| $h_s$ | Surface layer thickness in meters |
| $I_G$ | Maximum grid current in amperes |
| $I_g$ | Symmetrical grid current in amperes |
| $S_f$ | Current division factor or split factor |
| $R_g$ | Resistance of grounding system in ohms |
| K | Reflection factor |
| $K_h$ | Effect of burial depth correction factor |
| $K_i$ | Grid geometry correction factor |
| $K_{ii}$ | Corrective weighting factor that adjusts for the effects of inner conductors on the corner mesh |
| $K_m$ | Spacing factor for finding mesh voltage |
| $K_s$ | Spacing factor for finding step voltage |
| $L_c$ | Total length of earth grid conductor in meters |
| $L_M$ | Effective length of $L_c$+$L_R$ for determining mesh voltage in meters |
| $L_R$ | Total length of ground rods in meters |
| $L_r$ | Length of each ground rod in meters |
| $L_s$ | Effective length of $L_c$+$L_R$ for determining step voltage in meters |
| $L_T$ | Total effective length of earth grid conductor in meters |

## CONCLUSION

This paper has discussed the grounding system design of Power house and Switchyard of small hydro power station (1×1.8 MW) as per IEEE std.80-2000 using MATLAB tool. It can be seen from Table IV that the calculated actual mesh voltage and step voltage are within tolerable limit. So the designed grounding grid should be safe. But the grounding resistance of Power house and switchyard has been calculated 4.16 Ω and 3.86 Ω respectively which should be lower than one ohm from safety point of view. So both the grounding grids are tied by multiple conductors to reduce overall resistance which is calculated 2 ohm after tiding both grids. The overall grid resistance can further be reduced by designing auxiliary mat nearby and tiding it to grounding grid of power house and switchyard. More effective method to reduce overall grid resistance is to tie earth mat to Penstock. Thus reduction in overall grid resistance helps to restrict touch and step potential within tolerable limit during heavy fault and lightning condition.

## REFERENCES

[1] ANSI/IEEE Std. 80-2000,”Guide for Safety in AC Substation Grounding”,IEEE, New York.

[2] IEEE std 81-1983," IEEE guide for Measuring earth Resistivity, Ground impedance, and earth surface potentials for a ground system"

[3] ANSI/IEEE Std 81.1-1983, IEEE Guide for Measuring Earth Resistivity, Ground Impedance, and Earth Surface Potentials of a Ground System, 1983.

[4] ANSI/IEEE Std 81.2-1991, IEEE Guide for Measurement of Impedance and Safety Characteristics of Large, Extended or Interconnected Grounding Systems.

[5] F. Wenner, "A Method of Measuring Resistivity", National Bureau of Standards, Scientific Paper 12, No. S-258, 1916.

[6] IEEE Std 665-1987,” IEEE Guide for Generating Station Grounding”, Institute of electrical and electronic engineers,Inc. New York

[7] I.S.3043-1987,Indian Standard Code of Practice for Earthing.

[8] B.Thapar, V. Gerez, Balakrishnan, Donald A. Blank, “Simplified Equations For Mesh And Step Voltages In An Ac Substation”, IEEE Transactions On Power Delivery Vol. 6, No. 2. April 1991 pp 601-607

[9] Ashwani Kumar, Member, IEEE, and Hans R. Seedhar, Senior Member, IEEE, " Grounding System for High Resistivity Limited Area Substations in Hilly Region of Himachal Pradesh "16th National Power Systems Conference, Dec.2010, pp.516-522.

[10] F. Dawalibi, D. Mukhedkar, "Influence of Ground Rods on Grounding Grids", IEEE Transactions on PAS, Vol. PAS-98,No. 6, November/December 1979, pp. 2089-2098.

[11] Manual on," Earthing of A C Power Systems," Publication No 302, C.B.I.P. New Delhi, Oct. 2007.

[12] B. Thapar, V. Gerez, Arm Balakrishnan,Donald A.Blank, "Simplified equations for mesh and step voltages in an ac substation", IEEE Transactions on Power Delivery Vol. 6, No. 2. April 1991, pp. 601- 607.

[13] B. Thapar, V. Gerez, R. Balakrishnan, "Ground resistance of the foot in substation yards", IEEE Transactions on Power Delivery, Vol. 8, No. 1, January 1993 pp. 1-7.

[14] B. Thapar, V. Gerez, V. Singh, "Effective ground resistance of the human feet in high voltage switch yards", IEEE Transactions on Power Delivery, Vol. 8, No. 1. January 1993, pp. 7-12.

[15] M.G. Unde, B.E. Kushare, "Cost Effective Design of Grounding Grid using Ground Rods-a case study", in Proc. IEEE Fifth Power India Conference 2012,Delhi, India,pp.1-6.

[16] Gary Gilbert, "High Voltage grounding Systems", Doctorate thesis at the department of Electrical and Computer Engineering, university of Waterloo, Ontario, Canada, 2011.


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