Earthing System Design for Small Hydropower (SHP) Station – A Review

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***Abstract*—Grounding is critically important to achieve equipment and personnel protection in Small Hydropower (SHP) station. Moreover, the performance of any electrical or electronic system is greatly affected by the state of earthing. The paper includes the purpose of grounding, basic knowledge regarding the objective, review of various research works useful for designing a safe grounding system and recent trends which can be employed in designing a sound as well as an economic earthing system. The aim of the paper is to carry out the review of the techniques and developments in Earthing System and suggest the loop holes if any.**

***Index Terms*—Earthing mat, step potential, touch potential, ufer grounding**

I. Introduction

A. General

With the development of modern power system to the direction of extra-high voltage, large capacity, far distance transmission and applications of advanced technologies, the demands on the safety, stability and economic operation of power system becomes higher. A good grounding system is the fundamental insurance to keep the safe operation of power system. Before now the design and the subsequent implementation of substation earthing was a trial and error procedure. The recent years has shown the development of computer-based tools for the design and performance analysis of substation earthing grid systems.

B. Purpose [1]

The function of a grounding electrode system and a ground terminal is to provide a system of conductors which ensures electrical contact with the earth. The grounding system serves the following functions.

1) Personnel safety
2) Equipment and building protection
3) Electrical noise reduction
4) To establish a reference

C. Grounding Principles [1]

The grounding systems of generating stations should meet the following principles.

1) All metallic enclosures on equipment and exposed noncurrent-carrying conductive materials capable of becoming energized due to either insulation failure, inadvertent contact with an energized conductor, or building up of a static or induced voltage should be grounded.
2) The grounding arrangement should ensure a deliberate ground fault current return path, so that the (over current or ground fault) protection system will sense the fault and either trip the faulty circuit or provide an alarm to the station operator.
3) The grounding should limit the step and touch voltage to acceptable limits under all climatic conditions and also during faults.
4) The grounding conductors and connections should withstand the ground fault current for the duration of the fault, without being damaged by thermal, thermomechanical or electromechanical stresses.
5) The grounding conductors should be continuous, i.e no switching device should be inserted in the grounding conductors (except where the operation of the switching device will also automatically disconnect all power sources from the equipment grounded by that conductor).
6) The grounding conductors should be mechanically reliable or protected in order to withstand any possible mechanical stress imposed on them.
7) The grounding system should be designed to minimize corrosion to adjacent structures, equipment and enclosures.To minimize the effect of lightning strikes on personnel, equipment and structures

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II. Basics of Earthing

A. General

The electrical properties of earthing depend essentially on two parameters.

1) Configuration of Earthing electrodes
2) Soil resistivity

B. Electrical Electrode

Earthing electrodes maintain ground potential on all the connected conductors. This is used to dissipate currents into the ground conducted by these electrodes.

1) Components of Earthing Electrode [2]: Earthing electrodes basically consist of 3 components as shown in Fig. 1 namely:
   - Ground Conductor
   - Connection/Bonding of ground conductor to earthing electrode
   - Earthing electrode

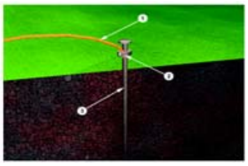

Fig. 1. Components of earthing electrode [2].

2) Location of Resistance [3]: The resistance of earthing electrode has 3 basic components

- The ground electrode and its connections
- The contact resistance of the earth to the electrode
- The resistance of the surrounding body of earth

The ground resistance due to first two reasons is negligible with respect to the resistance of the surrounding body of earth.

3) Parameters for Earthing Electrode resistance: The parameters which affect the ground system resistance are as follows:

a) Length/Depth of the ground electrode: One very effective way of lowering ground resistance is to drive ground electrodes deeper. The variation in soil resistivity with length/depth of earthing electrode can be shown by Fig. 2. [3].

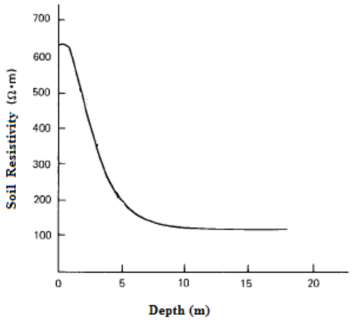

Fig. 2. Graph of Soil resistivity vs. Depth of earthing electrode [4].

b) Diameter of the ground electrode: Increasing the diameter of the ground electrode has very little effect in lowering the resistance. For example, you could double the diameter of a ground electrode and your resistance would only decrease by 10 % [3].

c) Number of ground electrodes: In this design, more than one electrode is driven into the ground and connected in parallel to lower the resistance as shown in Fig. 3. For additional electrodes to be effective, the spacing of additional rods needs to be at least equal to the depth of the driven rod and care needs to be taken because without proper spacing of the ground electrodes, their spheres of influence will intersect and the resistance will not be lowered. Fig. 4 shows the zone of influence or the sphere of influence.

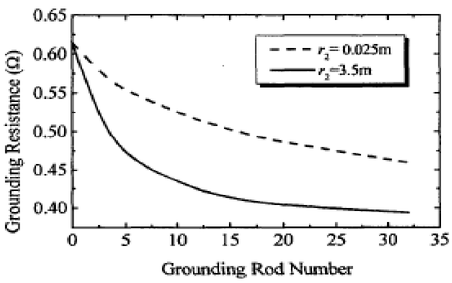

Fig. 3. Graph of grounding resistance vs. No. of earthing rods [5].

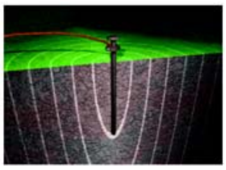

Fig. 4. Sphere of influence.

d) Ground system design: Different ground systems have different ground resistivity calculations. Various types of ground systems are shown in Fig. 5 to Fig. 8.

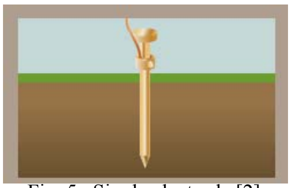

Fig. 5. Single electrode [2].

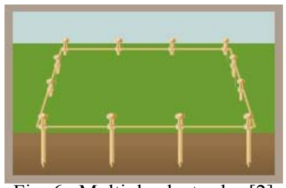

Fig. 6. Multiple electrodes [2].

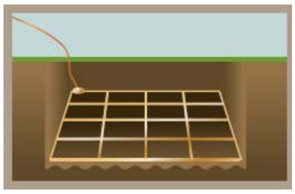

Fig. 7. Mesh network [2].

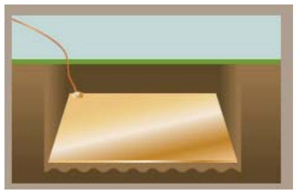

Fig. 8. Earth plate [2].

4) Types of Earth Electrode [6]: The earth electrodes generally used are as follow:

a) Rod Electrode: These electrodes can consist of rod, pipe etc. and are driven or buried to depth usually from 3 m to 30 m.

b) Strip Electrode: These are generally used for interconnection of electrodes and equipment. Cable with exposed metal sheath or armour behaves similar to a strip-type earth electrode.

c) Ground Plate: These electrodes are in form of plates generally of copper or aluminium.

d) Chemical-type Electrode: It consists of a copper tube filled with a salt. Holes in the tube allow moisture to enter, dissolve the salts, and allow the salt solution to leach into the ground. These electrodes are installed in an augured hole and typically back-filled with soil treatment.

e) Foundation Earth Electrode: These electrodes are formed from conductive structural parts embedded in concrete foundation providing a large area contact with the earth.

C. *Soil Resistivity*

One of the most important parameter in designing the station grounding system is the resistivity of the soil in the station area. The reason for measuring soil resistivity is to find a location that has the lowest possible resistance.

1) Soil Resistivity Variables [7]: Soil resistivity is not constant as there are number of factors affecting it. Principle factors affecting soil resistivity are:

a) Type of soil: The soil composition can be of clay, gravel, loam, rock, sand, shale, silt, stones, etc. In many locations, soil can be quite homogenous, while other locations may be mixtures of these soil types in varying proportions, thereby having different ground resistance.

b) Seasonal Conditions: The effects of heat, moisture, drought and frost can introduce wide variations in "normal" soil resistivity. Soil resistivity usually decreases with depth, and an increase of only a few percent of moisture content in a normally dry soil will markedly decrease soil resistivity. The effect of seasonal variables on soil resistivity is shown in Fig. 9 and Fig. 10.

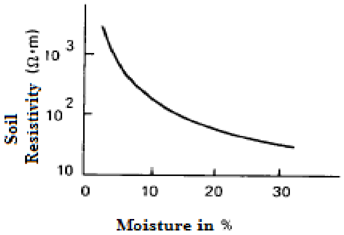

Fig. 9. Effect of moisture on soil resistivity [4].

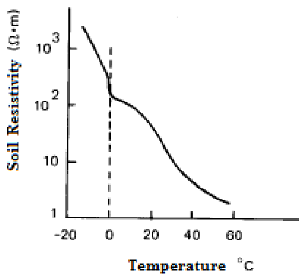

Fig. 10. Effect of temperature on soil resistivity [4].

c) Other factors: Other soil properties conducive to low resistivity are chemical composition, soil ionization, homogeneous grain size and even grain distribution - all of which have much to do with retention of soil moisture, as well as providing good conditions for a closely packed soil in good contact with the earth rod. Variation of soil resistivity with salt content is as shown in Fig. 11.

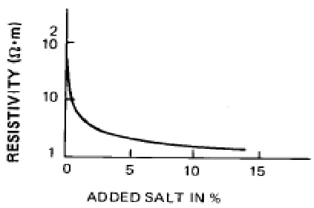

Fig. 11. Effect of added salts on soil resistivity.

2) Soil Resistivity Measurement Technique [8]: The techniques for measuring soil resistivity are essentially the same whatever the purpose of the measurement. Complexity caused by non uniform soils is common, and in only a few cases are the soil resistivities constant with increasing depth. Some of the techniques for measuring soil resistivity are

a) Wenner Array Method (4-pole equally spaced method)

b) Schlimberger Arrangement (4-pole unequally spaced method)

c) Fall of Potential (3-point method)

III. Designing an Earthing System

A. Criteria for Safety

The maximum allowable touch and step voltages are the criteria that should be met to insure a safe design. If the touch and step voltages of the grid design are below the maximum values, then the design is considered adequate [8]. Lower the maximum allowable touch and step voltages more difficult it is to produce an adequate grid design. The permissible touch and step potential are given by following expression presented in Table I.

TABLE I: Touch and Step Potential [9].

Particulars	For body weight of 50 kg.	For body weight of 70 kg.
Touch Potential	$E_{touch} = (1000 + 1.5C_s\rho_s)\frac{0.116}{\sqrt{t_s}}$	$E_{touch} = (1000 + 1.5C_s\rho_s)\frac{0.157}{\sqrt{t_s}}$
Step Potential	$E_{step} = (1000 + 6C_s\rho_s)\frac{0.116}{\sqrt{t_s}}$	$E_{step} = (1000 + 6C_s\rho_s)\frac{0.157}{\sqrt{t_s}}$

Here,

t_s = duration of shock current (in second)

ρ_s = soil resistivity of ground (in Ωm)

C_s = reduction factor for derating the nominal value of surface layer resistivity ρ_s with a thickness of h_s laid on a native soil of resistivity ρ_{soil} and could be assigned [8] as

$$C_s = 1 - \frac{0.09(1 - \frac{\rho_{soil}}{\rho_s})}{2h_s + 0.09} \quad (1)$$

B. Sizing of Earthing Electrode

In sizing the earthing electrodes, three considerations must be borne in mind [1]:

- All grounding conductors should be suitable for the expected mechanical stresses.
- The impedance of the grounding system should be low enough for the current to reach the value for actuating the protective schemes.
- Current carrying capacity of the conductors should be sufficient to carry the maximum current for a fault to ground for a minimum period of 5 sec without damage to the conductor from overheating [10].

C. Designing

The earth electrode resistance should be 1Ω or less [10]. The formulae for calculating earthing system resistance for various types of earthing system can be presented as in a Table II.

TABLE II: Resistance of Various Earthing System [10], [11].

Sr. No	Type of Earthing System	Earthing System Resistance	Terms involved
1	Single Earth Electrode	$R = \frac{100\rho}{2\pi l}\ln\left(\frac{4l}{d}\right)$	ρ = Soil Resistivity (Ωm) l = Length of the strip (cm) d = Diameter of rod (cm)
2	Multiple Earth Electrode	$a = \frac{\rho}{2\pi R_1 S}$ $R = R_1\left(\frac{1+\lambda a}{n}\right)$	R_1 = Resistance of one rod in isolation (Ω) ρ = Soil Resistivity(Ωm) n = No. of rods S = Distance between rods (m) λ= Factor as per Table III
3	Strip Conductor Earthing	$R = \frac{100\rho}{2\pi}\ln\left(\frac{2l^2}{wt}\right)$	ρ = Soil Resistivity(Ωm) l = Length of the strip (cm) w = Depth of burial of electrode (cm) t = Width (cm)
4	Earthing Plate	$R = \frac{\rho}{4}\sqrt{\frac{\pi}{A}}$	ρ = Soil Resistivity(Ωm) A = Area of both sides of plates (in m^2)
5	Earthing Mat	$R = \rho\left[\frac{1}{L} + \frac{1}{\sqrt{20A}}\left(1 + \frac{1}{1 + h\sqrt{\frac{20}{A}}}\right)\right]$	ρ = Soil Resistivity(Ωm) A = Area of earth grid(m^2) h = Depth of grid (m) l = Total length of the conductor (m)

TABLE III: FACTOR FOR PARALLEL ELECTRODES [11].

Number of Electrodes	Factor λ
2	1.00
3	1.66
4	2.15
5	2.54
6	2.87
7	3.15
8	3.39
9	3.61
10	3.81

The basic flow chart for designing an earthing system can be given as shown in Fig. 12.

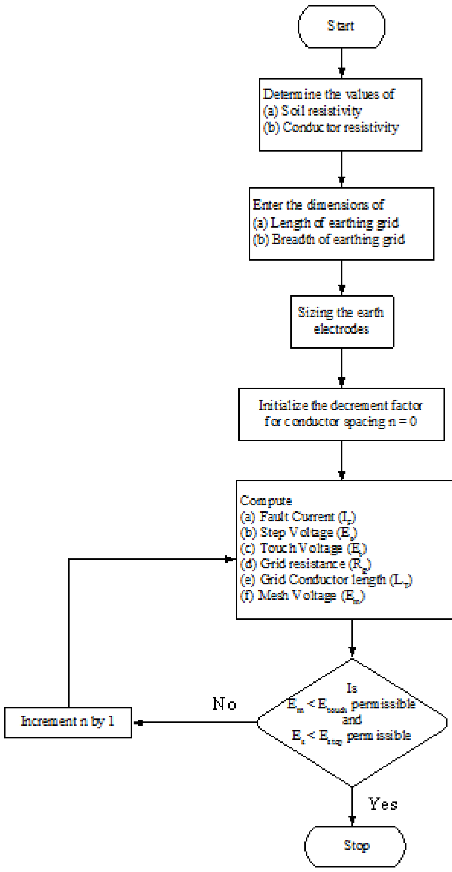

Fig. 12. Flow chart for designing a grounding grid [12].

IV. REVIEW OF DESIGN OF EARTHING SYSTEM

The findings of Ufer that concrete-encased metal objects were effective in providing improved grounding under adverse soil conditions suggests that the reinforcing framework of footings for the columns of structural steel buildings would provide effective grounding function. In addition, the much larger number of column footings required for structural reasons does, when used, provide much more effective grounding under all soil conditions than previously used systems. The steel framework of such buildings, if electrically connected at each column base to an inherent grounding electrode, then can function as a very efficient grounding network for system, lightning, and static grounding [13].

Also, steel in the foundations is not insulated from the metallic superstructures and the installed grounding systems. It therefore acts as a ground element. Hence the concrete foundations may carry substantial amount of leakage and fault current. Therefore, steel embedded in the concrete foundations forms a ground element which gets connected in parallel with the installed grounding system [14]. Currently the part of the grid which lies embedded in concrete and also reinforcement connected to the grounding system which do lower the grid resistance are not taken into account while designing the grounding grid. But, once the ground resistance of a foundation is determined, the rebars in the foundation can then be represented by a simple equivalent conductor for further analysis of the grounding system formed by the foundations

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