Design of Charts for Ground Resistance Calculations of Driven Rods System in Uniform and Non-Uniform Soils

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Abstract: Grounding of electrical substations for safety and neutral point by ground rods provides the lowest economical feasible ground resistance in the path of the expected fault current to ground. Grounding by rods incase of non-uniform soil could be more efficient than any other grounding system or it helps in reducing the ground resistance of other systems like grounding grids.

In this paper charts are designed to choose ground rods number and dimensions for the predetermined grounding resistance value and soil resistivity without any need of calculations. These charts helps the practical engineer to select the optimum dimensions and number of grounding rods required for obtaining satisfactory ground resistance in case of uniform and non-uniform soils, the design flowcharts takes into consideration the weight of the copper of grounding system as indication of the cost of the grounding system. The effect of rods in reducing the grid resistance is discussed also the step and touch potential.

Key Words: Grounding; rods; multi-layer; uniform; non-uniform; charts

INTRODUCTION

The essential characteristics of any system of protection should be almost foolproof, must be cheap and must also require a minimum of attention once installed, as it is unlikely to be examined before being called upon to act and so prevent loss of life or serious damage to property[1-3].

In recent years along with the trend towards smaller, more compact electric facilities, grounding sites have been limited, resulting in more complexes and trouble some grounding design. Moreover, in consideration of the need for shock presentation for electric, electronic and communication facilities and devices, high quality grounding has been essential for insuring safe and stable operations. From the above, a configuration in which grounding electrodes are placed perpendicular to the earth becomes inevitable. In particular, the driven rod method is employed in which a deep-driven rod is used as a grounding electrode. In this method, boring is first performed through the earth to form a hole in which a rod is then buried; this can be a large-scale operation. Accordingly, estimation of earth resistance becomes of prime concern during the grounding design phase[4].

Ground rods are frequently used in-groups connected in parallel and maybe with grids when the ground resistivity is too high to be satisfactory. of course, current following through any member of such a group will raise the potential of all other members; consequently, the apparent average ground resistance for the individual members of such a group will always be higher than the ground resistance of a similar rod when it is applied alone. This effect is a function of the number of rods and their spacing. Also the grid dimension increase of using grid in connection with rods.

To design most economical grounding systems, it is necessary to obtain accurate value of the resistivity on the site. The soil at the most sites is non-uniform. In this paper, different soil structures are characterized by the following:

1. Uniform soil.
2. Double layers soil characterized by first layer of resistivity (ρ_1) has a thickness (d_1) and second layer resistivity of (ρ_2) with infinite thickness.
3. Multi-layer soil structure (three layers structures is taken as example) is characterized by first layer resistivity of (ρ_1) with thickness (d_1), second layer of resistivity (ρ_2) has a thickness of (d_2) and third layer of resistivity (ρ_3) with infinite thickness.

Different methods are used to compute the apparent resistivity of multi-layer soil structure and compared to the actual measurement

DESIGN OF CHARTS FOR EARTHING SYSTEM

I. Design of Charts of Driven Rods Earthing System

The aim of such these calculation and measurements is to obtain the apparent soil resistivity to the design of earthing system by rods.

In practice, it is desirable to drive ground rods deep into the ground to reach more conductive soil. The following equation could be used to calculate the equivalent resistance for n electrode according to IEEE[5-6]

$$R_n = (\frac{\rho_a}{2n\pi l_2})\cdot(\ln(\frac{8l_2}{d_2}) - 1 + 2k_1(\frac{l_2}{\sqrt{A}})\cdot(\sqrt{n} - 1)^2) \qquad (1)$$

Where ρ_a is the apparent soil resistivity as seen by the ground rod, in case of uniform soil equal ρ_l Ω-m, n=number of ground rods placed in parallel area A, l_2 and d_2 are the length and diameter of the driven rods in meter respectively, K_1= constants related to the geometry of the system could be obtain from the equation

$$K1 = 1.41 - (0.04)\cdot X \qquad (2)$$

X is length to width ratio

As indication to the cost, the weight of the earthing system copper is calculated based on the length and diameter according to the relation.

$$w = [(n.\frac{\pi}{4}.d^2.L) + (m.L_x.a) + (z.L_y.a)].\rho_c \qquad (3)$$

a is the cross section area of conductors forming the grid, w is the copper weight, d is the conductor diameter, L is electrode length, n=number of electrodes, ρ_c is the copper density, L_x, L_y are length and width of the grid respectively and m, z are the number of conductor system

Fig.1 gives charts for earthing system design by using rods connected together. In case of non-uniform soil the apparent soil resistivity can be calculated for double layer soil by the relation[7-10] which is in agreement with the experimental measurements.

$$\rho_a = 2(\rho 2-(\rho 2-\rho 1)\cdot e^{-js}) - (\rho 2-(\rho 2-\rho 1)\cdot e^{-2js}) \quad (4)$$

Where $J = \delta / 2(d\,1)$, $\delta = \dfrac{\ln(\rho 1/\rho 2)-\ln(0.0176)}{3.5}$

d_1 is the depth of the first layer in meter and s is the distance between two adjacent rods

For example Table 1 shows apparent soil resistivity for double layer soil, the depth of first soil layer 3 meter and the distance between electrodes is 6 meter

Table1 apparent soil resistivity for double layer soil

$\rho 1$	60	150	300	400
$\rho 2$	30	90	130	250
ρ_a	43.5	118.2	203.9	321.3
Measured value	48	126	218	332

The flowcharts can be modified to be used in non-uniform case as given in fig.(1) by calculating the apparent soil resistivity using equation (4).

To obtain earthing resistance of 3Ω as example driven in non-uniform soil with ρ_1=150Ω.m and ρ_2=90Ω.m then ρ_a=120Ω.m this charts could be used to obtain 12 driven rods of 6.5m with total weight 1044 kg or 20 driven rods of 4.2m with total weight 1060 kg

II. Design of Charts of Driven Rods and Grid Earthing System

In such these charts, the earthing system resistivity of combination of rods resistance, grid conductors resistance and mutual resistance between the grid conductors and rods. The total resistance of the earthing system could be obtained by the equation

$$R_g = \frac{R_1 R_2 - R^2_{12}}{R_1 + R_2 - 2R_{12}} \quad (5)$$

Where R_1 and R_2 are resistance of all ground rods and grid conductors respectively and R_{12} is the mutual resistance between the group of grid conductors and group of ground rods[5]

Fig.2 gives charts of grounding system contains rods with 50mX50m grid earthing system placed in uniform soil with 3 parallel grid conductors at each direction.

The number and depth of driven rods has little effect in earthing system resistance

STEP AND MESH POTENTIAL OF THE EARTHING SYSTEM CONTAINS RODS

Step, touch and mesh potential are very important values for earthing system design. In IEEE standard it is concluded for earthing system design that[11]

$$K_m . K_i . \rho . \frac{i_G}{L_m} < (1000 + 1.5C(h_s, k)\rho_s)\cdot\frac{0.116}{\sqrt{t}} \quad (6)$$

L_m is the effective length of conductors and grids, ρ is soil resistivity in Ω.m, i_G is the maximum grid current that flows between ground grid and surrounding earth in A, t is the duration of shock for determining allowable body current in second, ρ_s is crushed rock resistivity in Ω.m of thickness h_s in meter, C is surface layer resistivity derating factor, k_m and k_i are constant obtained by the relation[11].

$$K_m = \frac{1}{2\pi}\cdot\left[\ln\left(\frac{D^2}{16\cdot h\cdot d} + \frac{(D+2h)^2}{8\cdot D\cdot d} - \frac{h}{4\cdot d}\right) + \frac{K_{ii}}{K_h}\ln\frac{8}{\pi(2n-1)}\right] \quad (7)$$

D spacing between parallel conductors in m, K_{ii}=1 for grids with ground rods along the perimeter, $K_h = \sqrt{1+h}$,

$$K_i = 0.644 + 0.148n \quad (8)$$

The effective length of conductors and rods used in mesh voltage calculation L_m is defined by[11]

$$L_m = L_c + \left[1.55 + 1.22\left(\frac{L_r}{\sqrt{L_x^{\ 2} + L_y^{\ 2}}}\right)\right]\cdot L_R \quad (9)$$

L_c=total length of grid conductors, in m
L_R= total length of all ground rods, in m
L_r=length of each ground rod, in m

The Mesh voltage of the grounding system could be calculated by the following relation[11,12]

$$E_m = \frac{\rho . K_m . K_i . I_G}{L_m} \quad (10)$$

The step potential of the grounding system could be calculated by the relation[11,12]

$$E_s = \frac{\rho . K_s . K_i . I_G}{L_s} \quad (11)$$

Where $L_s = 0.75L_c + 0.85L_r$,

$$K_s = \frac{1}{\pi}\left[\frac{1}{2h} + \frac{1}{D+h} + \frac{1}{D}\left(1 - 0.5^{n-2}\right)\right] \quad (12)$$

Fig.(3) gives the relation between touch potential of the grounding system and total length of rods and grid conductors also Fig.(4) shows relation between step potential of the grounding system and total length of rods and grid conductors. Grid dimension 50m.50m with 11 parallel grid conductors at each direction and rods located at perimeter, buried at 0.5 meter depth, crushed rock of 3500 Ω.m resistivity and thickness 10 cm used, grid current assumed to be 1kA for 1 second fault clearance duration. The calculations are done tacking three values of soil resistivity 100,500 and 1000 Ω.m. The safety values (step and touch) are shown also in the figures. The safety design length decrease with decreasing the earth resistivity

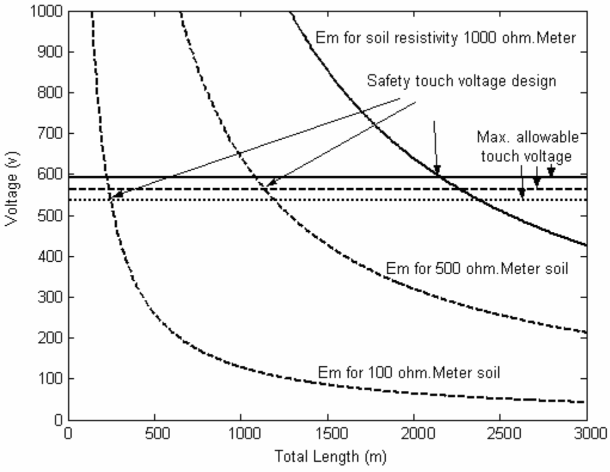

Fig.3 touch potential of the grounding system

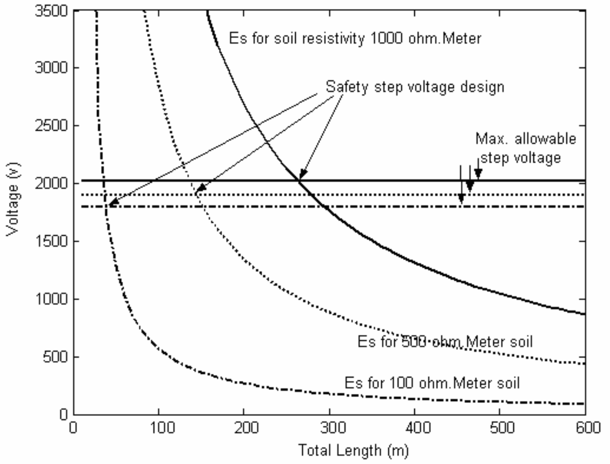

Fig.4 step potential of the grounding system

In case of step and mesh potential are very high than the tolerable step and touch potential and the ground system design must be modified, it is possible to increase crushed rock thickness or resistivity as it will affect the maximum allowable step and touch potential.

Fig.(5) shows the relation between step voltage and maximum allowable step voltage for different crushed rock resistivity.

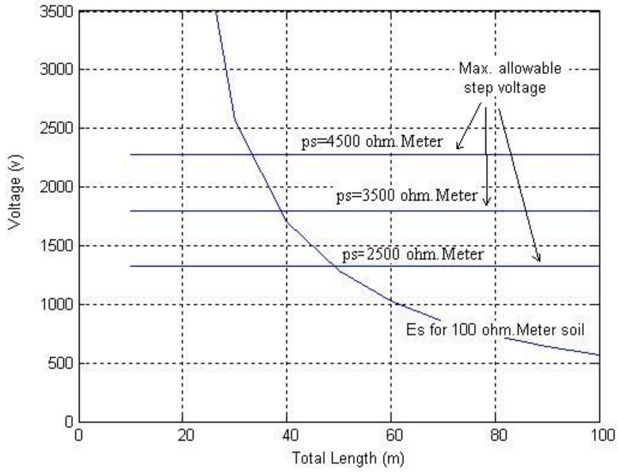

Fig.5 step potential of the grounding system for different crushed rock resistivity (h_s=0.1m).

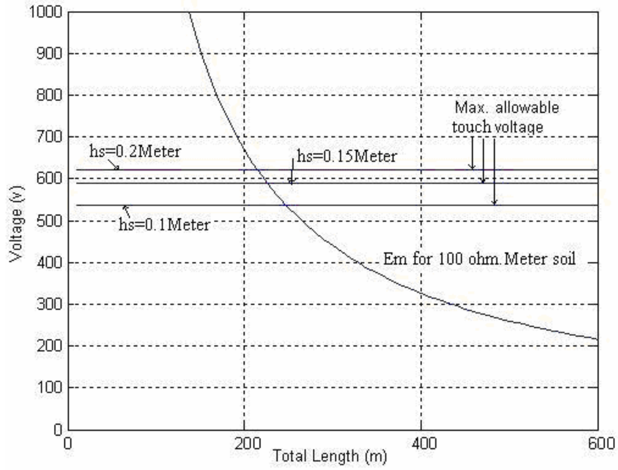

Fig.6 touch potential of the grounding system for different crushed rock thickness (ρ_s =3500 Ω.m).

Fig.(6) shows the relation between mesh potential and maximum allowable touch voltage for different crushed rock thickness (0.1,0.15 and 0.2 meter).

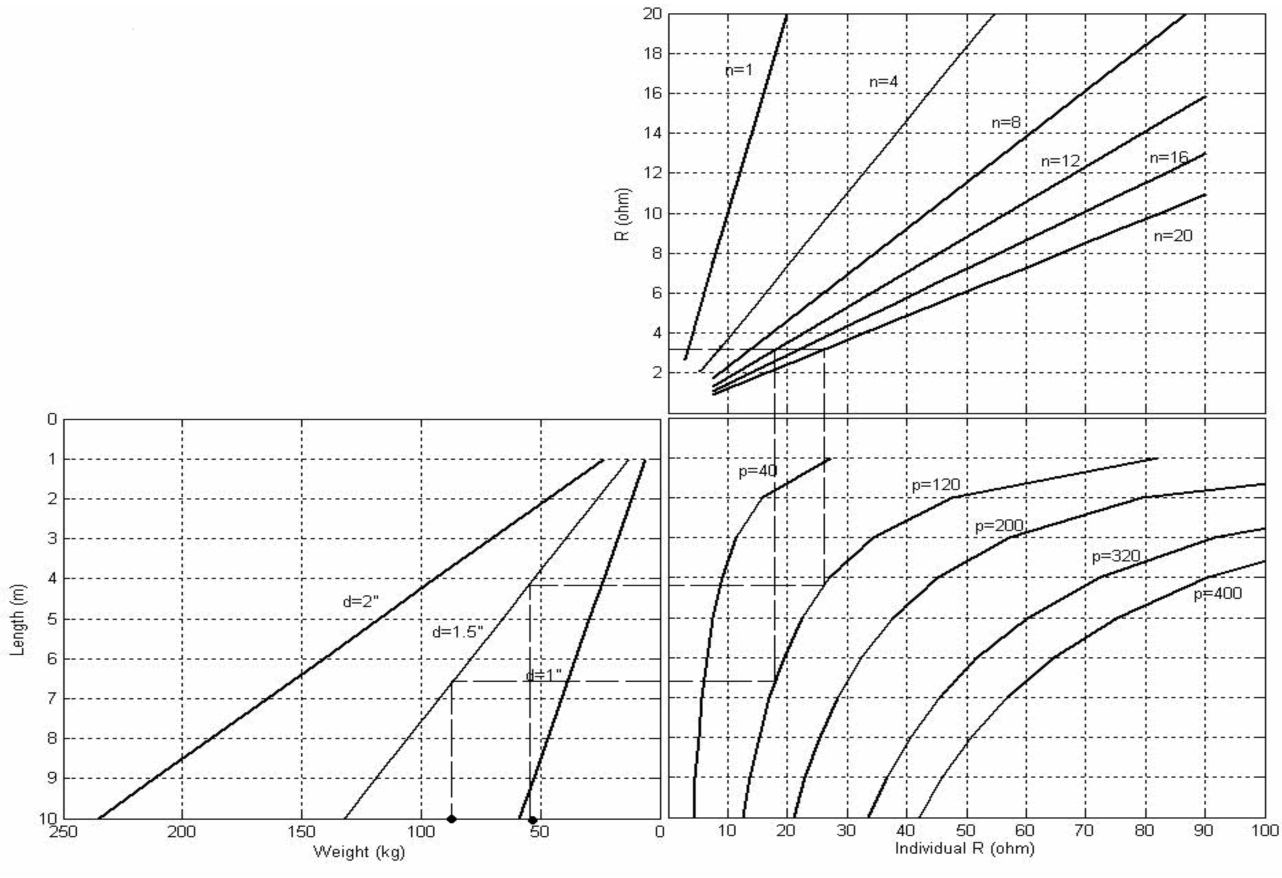

Fig.1 charts for earthing system design by using rods connected together

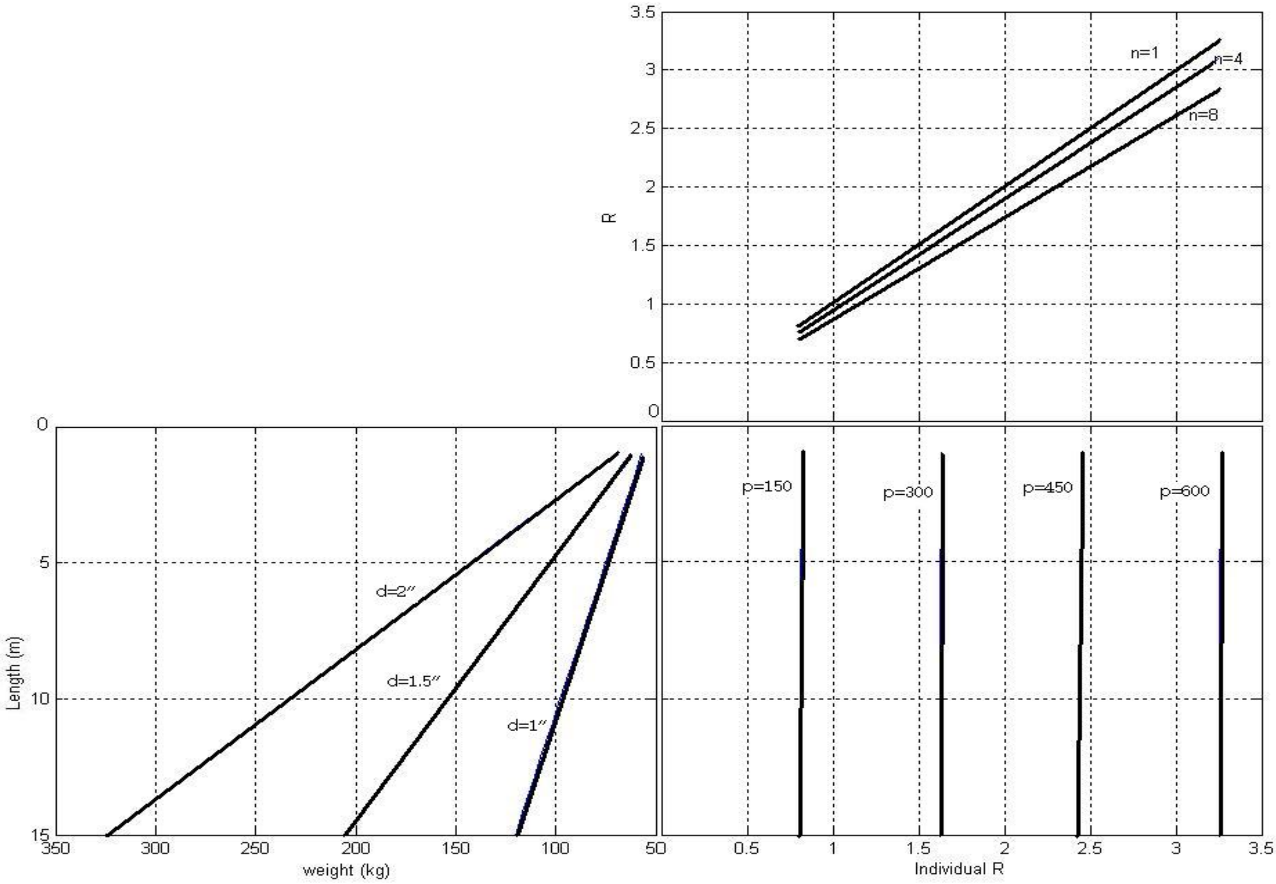

Fig.2 charts for earthing system design by using rods with 50mX50m grid earthing system connected together

CONCLUSIONS

(1) Charts have been designed to calculate the earthing system resistance in case of uniform and non-uniform soil. The charts have the advantage that the practical engineer can estimate the cost of the earthing system based on the weight of the copper used in the earthing system.
(2) Step and touch voltage decrease with adding more driven rods to the grid design. Safety step and touch voltage charts developed to permit a preliminary determination of buried grid conductor and driven rods length necessary to keep the maximum step and touch voltage within the grounded area below the safe limits.

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