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Unequally Spaced Grounding Grid Designed from Equally Spaced Grounding Grid for 220/132 kV Substation

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Abstract - **In unequally spaced grounding grid the buried horizontal interconnected conductors are placed at unequal space in such a manner that denser and closely spaced grid conductors placed near periphery of the grid than center of the earth grid. So grounding grid design in unequally spaced manner may be more safe than equally spaced in which there are greater space between horizontal conductors at the center of grid and distance between adjacent horizontal conductors are gradually decreased from center to the periphery of grid. This paper describes the method to design safe and economic unequally spaced grounding grid from equally spaced grounding grid for 220/132 kV substation without using ground rods in uniform soil to overcome the drawback of equally spaced grounding grid. By designing grounding grid in unequally spaced manner may save grounding grid materials also.**

Keywords- Touch voltage, earth grid resistance, safety, equally spaced and unequally spaced grounding grid.

I. INTRODUCTION

In equally spaced grounding grid, it has been observed that more current emanates from the peripheral conductors which cause earth surface potential to be higher near the periphery of the grid than the center of the earth grid. Hence earth surface potential is not uniform throughout the equally spaced earth grid which makes earth grid unsafe near the periphery under heavy fault condition. This drawback of equally spaced grounding grid can be overcome by placing denser and closely spaced grid conductors near periphery of the grid than center of the earth grid.

In this paper, section II describes the method applied for designing unequally spaced earth grid from equally spaced earth grid and formula required for calculating earth grid resistance and maximum touch voltage for unequally spaced grounding grid. While section III give details about designed unequally spaced grounding grid from the equally spaced grounding grid for 220/132 kV substation in uniform soil without using ground rods.

II. DESIGN METHODOLOGY

A. Step 1

Grounding grid of 220/132 kV substation is designed in equally spaced manner without using ground rods as per IEEE Std.80-2000.

B. Step 2

The total number of horizontal grid conductors used in equally spaced ground grid design can be determined as follows:

$$n = n_1 + n_2 \tag{1}$$

Where,
n = total number of grid conductors
n_1= number of grid conductors used along widthwise
n_2= number of grid conductors used along lengthwise

C. Step 3

Percentage of grid conductors saved using unequal spacing can be determined using given formula as follows:

$$\lambda = \frac{\alpha \cdot \frac{\beta}{100}}{1 + \alpha \cdot \frac{\beta}{100}} \times 100\ \% \tag{2}$$

The values of empirical coefficients α and β varies with the total number, n, of conductors used in equally spaced grid. α and β can be found using following formula as follows:

$$\alpha = 121.2e^{-0.4n} + 1.4864 \quad \text{For } 8 \le n \le 20 \tag{3}$$

$$\alpha = 121.2e^{-0.3n} + 1.2664 \quad \text{For } 20 \le n \le 30 \tag{4}$$

$$\alpha = 121.2e^{-0.4n} + 1.1400 \quad \text{For } n > 30 \tag{5}$$

$$\beta = -92.6e^{-0.07n} + 66.337 \tag{6}$$

D. Step 4

The total number of grid conductors used in unequally spaced grid can be calculated as follows:

$$n_1' = n_1(1-\lambda) \tag{7}$$

$$n_2' = n_2(1-\lambda) \tag{8}$$

$$n' = n_1' + n_2' \tag{9}$$

Where,

n_1' = number of grid conductor used along widthwise in unequally spaced grid

n_2' = number of grid conductor used along lengthwise in unequally spaced grid

n' = total number of grid conductor used in unequally spaced grid

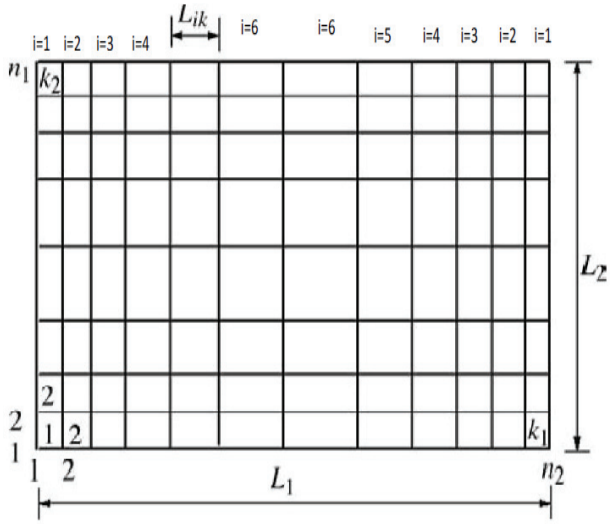

Fig. 1. Unequal-spacing rectangular grounding grid [2]

E. Step 5

The conductor spacing between adjacent horizontal conductors can be calculated as follows:

If a conductor is divided into k segment, the ith segment length, L_{ik} is expressed in percent of the total length, L, of the conductor, as follows:

$$S_{ik} = \frac{L_{ik}}{L} \times 100\ \% \tag{10}$$

$$k_1 = n_2' - 1 \tag{11}$$

$$k_2 = n_1' - 1 \tag{12}$$

$$i = \frac{k+1}{2} \quad \text{For k is odd} \tag{13}$$

$$i = \frac{k}{2} \quad \text{For k is even} \tag{14}$$

The formula to calculate S_{ik} is given as follows:

$$S_{ik} = b_1 \times e^{-b_2 i} + b_3 \tag{15}$$

Therefore ith segment length, L_{ik} can be calculated by:

$$L_{ik} = S_{ik} \times L_i \tag{16}$$

Where b_1, b_2, b_3 are constant related to the segment number k as follows:

a) When $7 \le k \le 14$

$$b_1 = -1.8066 + 2.6681 \lg k - 1.0719 \lg^2 k \tag{17}$$

$$b_2 = -0.7649 + 2.6992 \lg k - 1.6188 \lg^2 k \tag{18}$$

$$b_3 = 1.8520 - 2.8568 \lg k + 1.1948 \lg^2 k \tag{19}$$

b) When $14 \le k \le 25$

$$b_1 = -0.00064 - \frac{2.50923}{k+1} \tag{20}$$

$$b_2 = -0.03083 + \frac{3.17003}{k+1} \tag{21}$$

$$b_3 = 0.00967 + \frac{2.21653}{k+1} \tag{22}$$

c) When $25 \le k \le 40$

$$b_1 = -0.0006 - \frac{2.50923}{k+1} \tag{23}$$

$$b_2 = -0.03083 + \frac{3.17003}{k+1} \tag{24}$$

$$b_3 = 0.00969 + \frac{2.2105}{k+1} \tag{25}$$

The formula used for grid resistance calculation can be expressed as follows:

$$R = k_{Rh} \cdot k_{RL} \cdot k_{Rm} \cdot k_{Rn} \cdot k_{Rd} \left(1.068 \times 10^{-4} + \frac{0.445}{\sqrt{S}} \right) \rho \quad \text{ohm} \tag{26}$$

Where,

k_{Rh}, k_{RL}, k_{Rm}, k_{Rn} and k_{Rd} are respectively the influential coefficients of the burial depth, the shape, the number of meshes, the number of conductors and the diameter of the conductors:

ρ = soil resistivity

S = grid area

h = burial depth

L_1 = length of earth grid

L_2 = width of earth grid

n_1 = number of grid conductors along widthwise

n_2 = number of grid conductors along lengthwise

m = total mesh number of grounding grid

= $(n_1-1)(n_2-1)$

d = diameter of grid conductors

The formula used for maximum touch voltage calculation for unequally spaced grid is as follows:

$$U_{TM} = k_{TL} \cdot k_{Th} \cdot k_{Td} \cdot k_{TS} \cdot k_{Tn} \cdot k_{Tm} \cdot V_{GM} \tag{27}$$

Where,

U_{TM} = Maximum touch voltage

V_{GM} = GPR= Maximum ground potential rise

k_{TL}, k_{Th}, k_{Td}, k_{TS}, k_{Tn} and k_{Tm} are respectively the influential coefficients of the shape, burial depth, diameter of the grounding conductors, area of the grounding grid, number of grounding conductors and mesh number of the grounding grid.

III. UNEQUALLY SPACED GROUNDING SYSTEM DESIGN

Unequally spaced grounding grid is designed from equally spaced grounding grid for 220/132 kV substation in uniform soil without using ground rods as per procedure described in above section II. The design details are given below in the form of table as follows:

TABLE I. Available input design parameters for designing equally spaced grounding grid.

Input design parameters	Values
Length of earth grid	215.27 m
Width of earth grid	187 m
Soil resistivity (uniform soil)	44 ohm-m
Surface layer resistivity	3000 ohm-m
Surface layer thickness	0.15 m
Grid burial depth	0.6 m
Fault current	40000 Ampere
Fault duration	1 second
Fault current division factor	0.6
Horizontal grid conductor spacing	10 m
Used grid conductor material	M.S Flat- 75 mm × 10 mm

TABLE II. Available design details of equally spaced grounding grid.

Designed Grid Parameters	Values
Number of conductor along lengthwise (n_2)	23
Number of conductor along widthwise (n_1)	20
Total number of horizontal conductors used (n)	43
Number of ground rods	0
Grid resistance (R)	0.10254 ohm
Tolerable touch voltage	702.85 V
Actual touch voltage	278.209 V
Tolerable step voltage	2340.41 V
Actual step voltage	204.128 V

TABLE III. Details of unequally spaced grounding grid designed from equally spaced grounding grid.

Calculated parameters	Unequally spaced ground grid
Number of grid conductor along lengthwise (n_2')	14
Number of grid conductor along widthwise (n_1')	12
Total number of grid conductor used (n')	26
Grounding grid resistance (R)	0.101235 ohm
Tolerable touch voltage	702.85 V
Actual maximum touch voltage attained	182.569 V

TABLE IV. Horizontal conductor spacing calculated for unequally spaced grounding grid

Conductor spacing calculated along lengthwise	Conductor spacing calculated along widthwise
L_{1k1} = 4.671 m	L_{1k2} = 5.58 m
L_{2k1} = 10.49 m	L_{2k2} = 12.27 m
L_{3k1} = 15.12 m	L_{3k2} = 17.27 m
L_{4k1} = 18.77 m	L_{4k2} = 21.02 m
L_{5k1} = 21.67 m	L_{5k2} = 23.83 m
L_{6k1} = 23.97 m	L_{6k2} = 25.93 m
L_{7k1} = 25.78 m	

IV. CONCLUSION

Unequally spaced grounding grid has been designed from equally spaced grounding grid for 220/132 kV substation in uniform soil without using ground rods in which horizontal grid conductors are placed closely near periphery of the grid than center of the grid to achieve the safe and economic design. It is found that the grid resistance computed i.e. 0.1012 ohm for unequally spaced ground grid is almost same as that of equally spaced grid which is 0.1025 ohm. The computed maximum touch voltage in unequally spaced ground grid is 182.57 Volts which is well below the maximum tolerable touch voltage limit i.e. 702.85 Volts and also below the actual mesh voltage i.e. 278.21 Volts of equally spaced grounding grid. Hence the designed unequally spaced ground grid from equally spaced designed ground grid is safe. In the designed unequally spaced grounding grid, 40% grid conductors have been also saved and hence it is cost effective also.

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