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A New Method of Grounding Grid Design

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Abstract. In order to equalize the electric potential distribution of the grounding grid surface, and improve the safety level of the grounding grid, method for optimal arrangement of conducts in the grounding grid is proposed in this paper. The calculation results about maximum touch voltages and mesh potentials show that the method can reduce touch voltage and equilibrium surface potential. It is shown that the design of the grounding grid is related to not only the soil environment, but also the rectangular shape. Comparing with other methods, the method proposed in the paper can reduce maximum touch voltage about 12%. This method also can be applied in a uniform and non-uniform soil, rectangular and square grounding grids. The optimize effect meets the related standards of the power industry.

1 Introduction

Grounding grid is an important guarantee of the safe operation in substation. Grounding grid performance has been the hot spot research for a long time. Ground grid can provide a common reference point for various electrical equipment. When lightning strike or malfunction occur in power system, the grounding grid can reduce the substation ground potential rising and discharge fault current rapidly. The performance of grounding grid is directly related to the personal safety and electrical equipment operating normally.

The earliest research is the theory of the arrangement grounding grid of the non - uniform soil which was put forward by Sverak [1]. Dawalibi had made some researches about optimal placement of the ring conductor in the grounding grid [2-3]. In 1986, Professor Chen Xianlu of Chongqing University proposed a optimization method of grounding grid in uniform soil. Professor Zeng Rong and He Jinliang researched on grounding grid performance in the high frequency situation. Professor Sima Wenxia, Wen Xishan arranged grounding grid ring conductor non-uniformly in uniform soil situation by means of Genetic Algorithm (GA). Professor Gao Yanqing studied on the optimum compression ratio of grounding grid in non-uniform soil situation. Cao Xiaobin, Hu Jinsong took the lead on the optimization design of the rectangular grounding grid [4-10].

The research shows that the index arrangement of the grounding grid is not the optimal layout scheme. Due to the rapid attenuation of the exponential function, it will lead to dense edge mesh when the grounding grid is optimized. In this paper, a new optimize method can be applied in the uniform and non-uniform soil condition, and it is suitable for the square and rectangular grounding grid.

There are many electrical parameters to evaluate the performance about substation grounding grid. The touch voltage is the most difficult to meet the requirements, so it is selected as the optimization goal to reach the safety requirements in this paper.

2 The establishment of simulation model

Firstly, it is considered that the square grounding grid optimization, assuming that a=b=100m, the square length divided into n-1 parts by N ring conductors, each part being numbered from left to right, defining Mi (i=1， 2…..， n-1) for the No.i segment accounted for the proportion of total length.

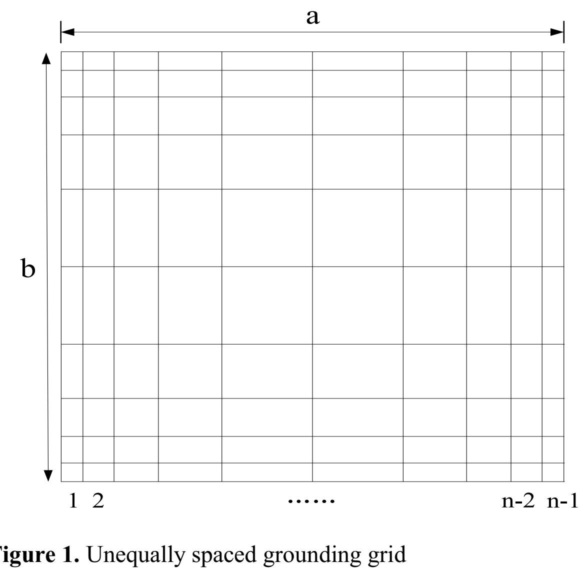

Figure 1. Unequally spaced grounding grid

When the maximum touch voltage of each mesh is equal, the percentage of each segment is as shown in

Table I. Of which, the percentage of the No.i segment is Mi. With the least square method, the fitting formula is shown in formula 1.

$$M_i = e^{-(\frac{i-n/2}{2})^2} \quad n=1, 2, \ldots, n-1 \tag{1}$$

In this formula, only the denominator of the exponent is change, when the area of grounding grid and the number of ring conductors are changed. Therefore, the optimal fitting formula is shown in formula 2.

$$M_i = e^{-(\frac{i-n/2}{b})^2} \; ; \; n=1, 2, \ldots, n-1 \tag{2}$$

Table 1. Optimal ground in different segment

n	i=1	i=2	i=3	i=4	i=5	i=6	i=7	i=8	i=9	i=10
1	1									
2	0.5	0.5								
3	0.3125	0.3751	0.3125							
4	0.2048	0.2952	0.2952	0.2048						
5	0.1327	0.2295	0.2755	0.2295	0.1327					
6	0.0824	0.1711	0.2465	0.2465	0.1711	0.0824				
7	0.0481	0.1199	0.2074	0.249	0.2074	0.1199	0.0481			
8	0.0261	0.0781	0.1622	0.2336	0.2336	0.1622	0.0781	0.0261		
9	0.0131	0.0469	0.1168	0.202	0.2425	0.202	0.1168	0.0469	0.0131	
10	0.006	0.0258	0.0772	0.1602	0.2308	0.2308	0.1602	0.0772	0.0258	0.006

In the fitting function b can been considered as a parameter. As long as the optimal value of b is obtained, the optimal layout scheme of the grounding grid can be received.

3 The influence of various factors on the optimal coefficient

3.1 The upper soil thickness

The relationship between the optimal parameter value b and the upper soil thickness h and the reflectional coefficient k is shown in figure 2.

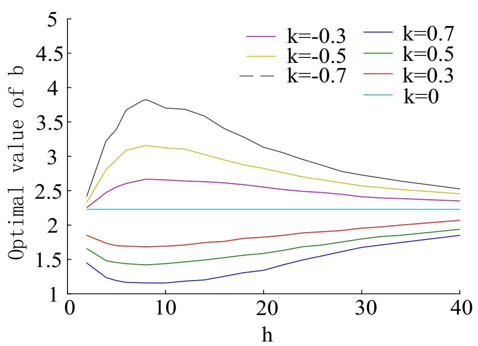

Figure 2. L=100 b-h curves

This paper makes a calculation from two situations: the reflectional coefficient k which is a fixed value and greater than zero and less than zero. In the situation of k<0, b increases with the increase of h. When h reaches a certain value (about 9 m), b reaches a maximum value, and then decreases with the increase of h. In the case of k>0, b decreases with the increase of h. When h reaches a certain value (about 7 m), b reaches a minimum value, and then increases with the increase of h.

3.2 Reflectional coefficient

Figure 3 shows that relationship between b and reflectional coefficient of double soil. When the upper soil thickness h is a constant coefficient, b decreases with the increase of k. That means the lower soil resistivity is larger and ground grid is more uniform, when the upper layer soil thickness is constant value.

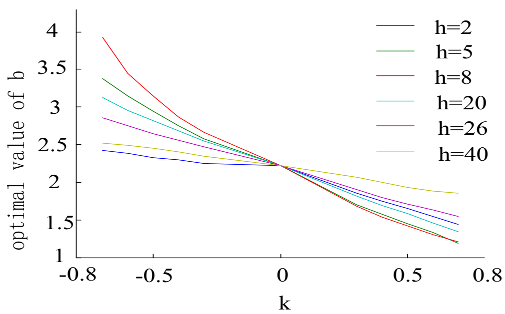

Figure 3. L=100m b-k curves

3.3 Grounding grid area

With k=-0.3, the relationship between b and side length of grounding grid L is shown in figure 4.

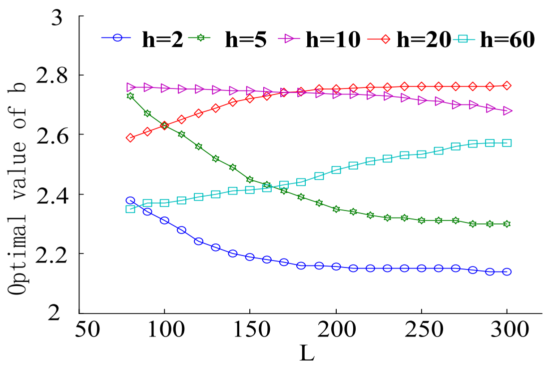

Figure 4. k= - 0.3 b-L curves

The upper layer soil in more than or less than 10m b-L curve shows different trends.

If the h<10m, the value of b decreases as the length increases. If the h>10m, the value of b increases as the length increases. When the length increased to 180m, the optimal b value tends to be stable.

According to the above results, the optimal fitting formula of b value should be divided into two situations: h⩾10m and h<10m.

3.4 Fitting formula for computing the optimal value of b

Due to the optimization parameters is related to soil thickness, reflectional coefficient and the area of the grounding grid, three parameters are set as independent variables with the neural network fitting method, and each data is considered as a three-dimensional coordinate point. Let b=f(h,k,L), and the expression is shown in formula 3.

$$b = a + c \times h + d \times L + e \times k \tag{3}$$

The corresponding coefficients of soil thickness of different grounding grids are shown in the following table 2.

Table 2. Coefficient values of fitting formula

h	a	c	d	e
$h < 10m$	2.1492	0.0526	-0.0015	-1.1351
$h \geq 10m$	2.4067	-0.0053	0.0007	-1.0298

3.5 The optimization effect inspection in non-uniform soil situation

The enclosed station grounding grid is 100×100m2. There are seven ring conductors in horizontal and vertical directions. Grounding depth is 0.5m. The ring conductor radius is 0.08m. The upper soil resistivity is 185.714Ω•m, and the thickness is 2 meters. The lower soil resistivity is 100Ω•m. The current is 1kA. The grounding grid is arranged respectively with the optimal compression ratio optimization method (method I) and the fitting function method (method II which is the method of this paper)

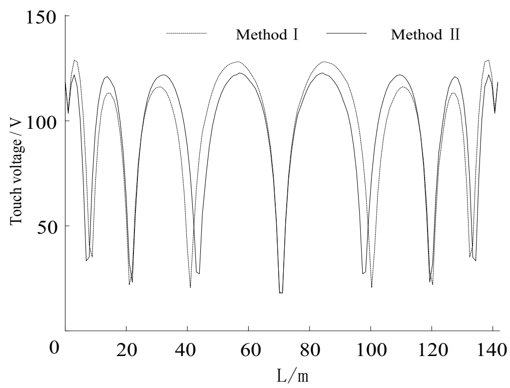

Figure 5. Touch voltage distribution on diagonal in non-uniform area

In the Figure 5, the touch voltage of edge mesh increases with method II, but the touch voltage of middle mesh reduces. And the peak touch voltage of the whole network is basically the same relative to the method I. Finally, it is balanced mesh touch voltage in grounding grid with method II.

4 To optimize the formula in the application of the rectangular grounding grid

4.1 Ensure each side of the rectangle section number

Ring conductor layout of rectangular grounding grid which is 100×60m is obtained by the fitting formula. The number of long segments is 8. The number of wide segments starts from 1 to 8 as shown Figure 6. The touch voltages with the different widths are shown in table 3.

Table 3. Max value, min value and D-value in rectangle

The segmentation number of width	The maximum value / V	The minimum value / V	The difference value / V
1	205.098	70.168	134.930
2	179.139	66.220	112.919
3	156.484	57.622	98.861
4	132.232	52.192	80.04
5	113.678	46.748	66.930
6	104.897	37.293	67.603
7	101.374	27.399	73.976
8	97.163	19.048	78.115

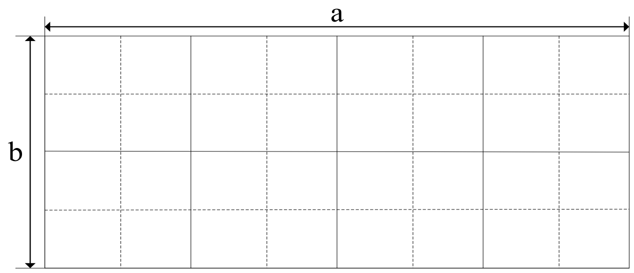

Figure 6. Rectangle grounding grid for simulation

When the maximum touch voltage is close to the minimum touch voltage , the optimization is the best.

The Table III shows that when the segmentation number of width is 5, maximum and minimum difference is minimal. When the aspect ratio is close to the ratio of segments, the optimization effect is best.

Table 4. Divided method of width in different rectangle

The length of the side a /m	The length of the side b /m	The segmentation number of length	The segmentation number of width
100	50	8	4
100	60	8	5
100	70	8	6
100	80	8	7
100	90	8	8

4.2 The optimization effect inspection in non-uniform soil

In a rectangular grounding grid, rectangular length is 120m and the width is 80m.The soil situation is same to III.

With the optimal compression ratio method(method I) and the fitting function method (method II which is the method of this paper), the touch voltage distribution on diagonal is shown in Figure 7. The touch voltage distribution of the total station with method II is shown in Figure 8. As shown in Figure 9, the touch voltage distribution of the total station with method I.

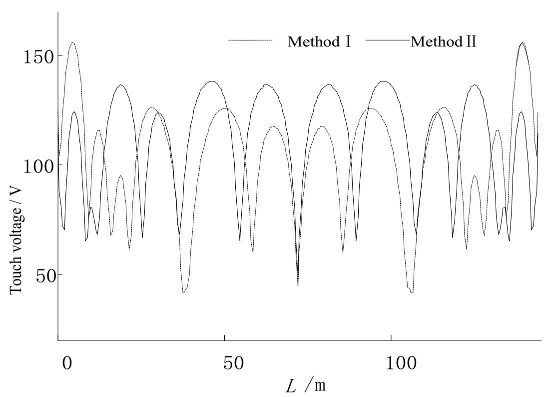

Figure 7. Diagonal touch voltage distribution in homogeneous soil with the method I and II

The method II reduces the marginal mesh size, and increase the middle mesh size relative to the method I. This arrangement can balance mesh touch voltage and reduce the maximum touch voltage .

After fitting, the maximum touch voltage is 155V with the method I. The maximum touch voltage is 138V with the method II. It is reduced by 12.1%.

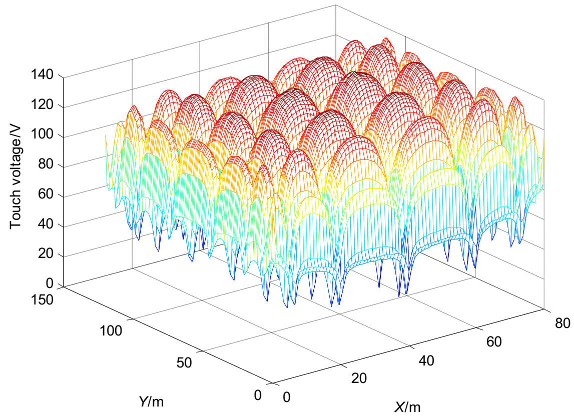

Figure 8. Touch voltage distribution of the total station with method II

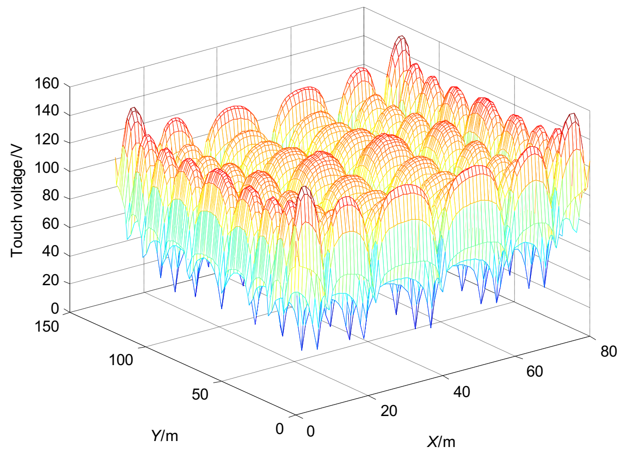

Figure 9. Touch voltage distribution of the total station with method I

5 Conclusion

By analyzing the influence of different reflectional coefficient, the area of grounding grid and the thickness of the upper soil on the optimal coefficient, this paper obtains the optimal formula of the optimal coefficient, and applies it to the optimization of the rectangular grounding grid in the non-uniform soil. The calculation results show that:

In view of the different reflectional coefficient, the upper layer soil thickness and the area of the grounding grid, the calculation formula of the optimal layout is obtained.

In the rectangular grounding grid, when the aspect ratio is close to the ratio of segments, the optimization effect is best.

Through the above results, this formula is also applicable for rectangular grounding grids and non-uniform soils. The maximum contact voltage is reduced by about 12%.

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