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## **POWER STATION GROUNDING GRID DESIGN USING FIELD METHODS**

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*The paper presents the methodology of designing grounding grids by means of a field model. The model has been created and implemented in ANSYS. The results have been compared with those obtained by analytical calculations or measurement.*

### **1. INTRODUCTION**

The primary aim of creating a grounding grid model is the possibility of examining different variations of its construction before making the investment decision, with the main criterion being the admissible values of shock voltages. The methods of modelling of power station grounding grids have been described in literature for many years. First models of grounding grids were based on calculations using physical models due to the lack of calculating equipment. Then, the analogue models were replaced by more advanced models based on more sophisticated calculation techniques.

### **2. INTRODUCTION TO GROUNDING GRIDS DESIGN**

In order to systematize the knowledge about grounding grids, it is necessary to define basic terms.

Grounding grids are non-insulated metal parts (rods, bands, etc.) buried in soil used for grounding.

Remote earth is the place on soil surface that lies beyond the zone of electric current impact in the ground. For simple grounding grids, the point farther than 20 m from the grounding grid is called the potential of remote earth.

Grounding voltage  $U_E$  is the voltage occurring during grounding between a grounding grid and remote earth.

Grounding current  $I_E$  is the current going to the ground through the grounding system impedance.

Resistivity of a grounding grid is the ratio of the grounding voltage to the grounding current (1).

$$R_E = \frac{U_E}{I_E} \quad (1)$$

Step voltage  $U_k$  is the difference of potentials between points that are 1m away from one another (the approximate step).

From the point of view of a grounding grids designer, the most fundamental issue is to ensure that the shock voltage values on the soil surface are appropriate. The shock voltage values directly result from the electric field of the soil surface. In order to calculate them, it is essential to know the equation of Laplace (2) in a given zone:

$$\nabla^2 V = 0 \quad (2)$$

It is possible to acquire a proper analytical result of the equation for simple shapes of fields in question. However, for more complicated shapes that are very common, it is necessary to use an approximate method, for example:

- Method of moments [2],
- Method of design by long line [1].

In order to find the solution to equation 2, it is necessary to define the input data, such as geometrical shapes, parameters and, first and foremost, the resistivity of soil, which has the biggest influence on the grounding grid resistance.

### 3. ANALYTICAL METHODS IN DESIGNING OF GROUNDING GRIDS

Analytical methods used for grounding grid designing are a frequent subject in national and foreign norms. Therefore when designing a grounding grid, the following data should be assumed in the first place:

- resistivity of soil  $\rho_e$  [ $\Omega\text{m}$ ],
- ground current value  $I_E$  [A],
- the time of ground current flow  $t_f$  [s],
- the geometrical shape of the ground to be used by a grounding grid,
- the depth of the grounding grid  $h$  [m],
- construction material used for the construction of the grounding grid,
- the kind and thickness of surface material.

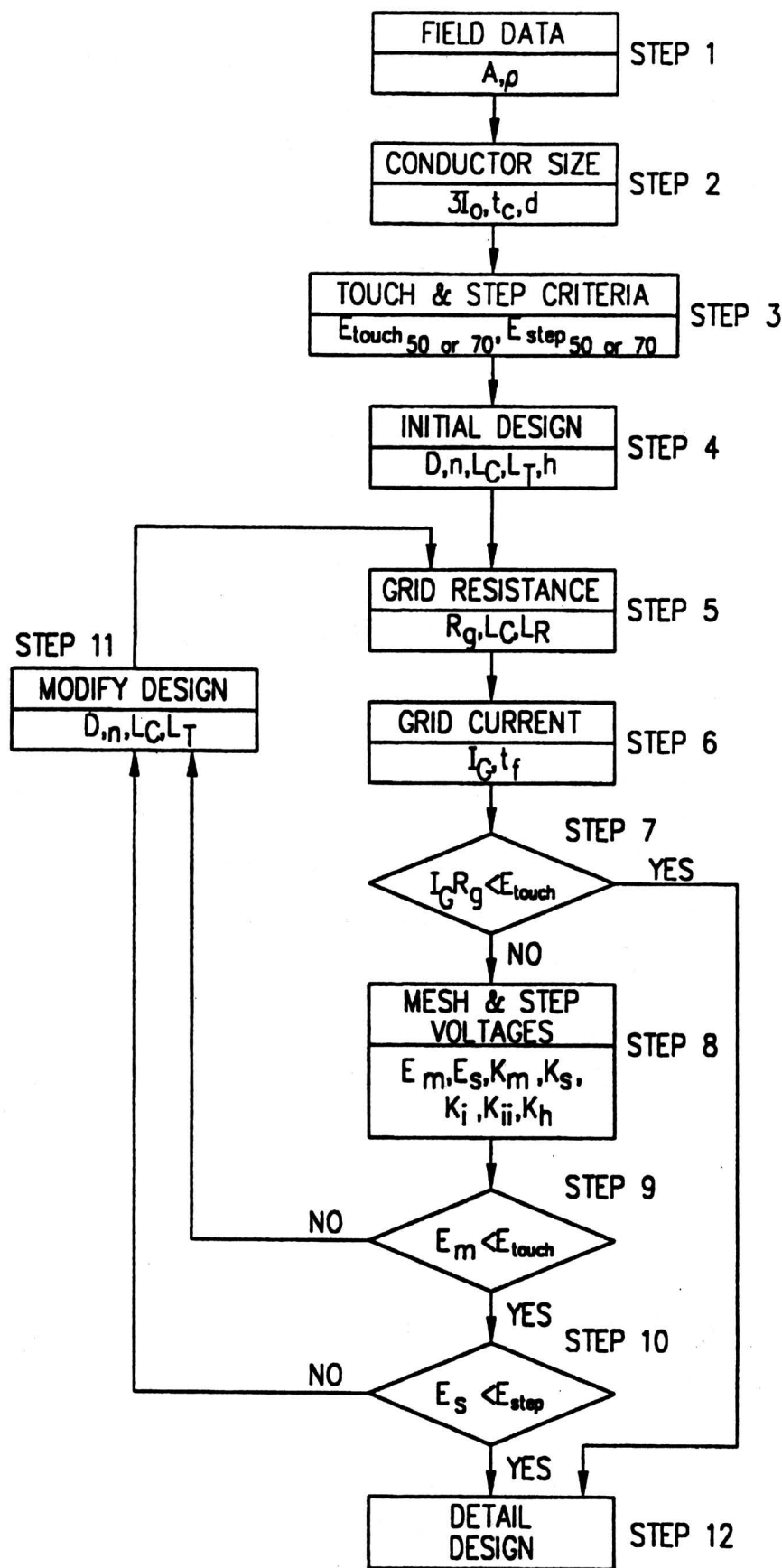


Fig. 1. The algorithm of the grounding grid design presented in [5]

The most reliable method of calculating the soil resistivity is making measurements on the spot or, if there is no possibility of doing so, using tables in norms. The value of  $I_E$  and the time of the ground current flow  $t_f$  depend on the structure of electric mesh and the safety devices. The depth of the grounding grid  $h$  is usually between 0.5 to 1m. The admissible shock voltage values result from the time of the ground current flow, and they are presented in a graphic form [4] or analytical equation. In accordance with the guidelines presented in, for example [5], the values amount to:

$$E_{step50} = [1000 + 6C_s(h_s, K)\rho_s] \frac{0.116}{\sqrt{t_s}} \quad (3)$$

$$E_{touch50} = [1000 + 1.5C_s(h_s, K)\rho_s] \frac{0.116}{\sqrt{t_s}} \quad (4)$$

where  $E_{step50}$  – step voltage [V],  $E_{touch50}$  – touch voltage [V], 1000 – resistivity of human body [ $\Omega$ ], 1.5 – parallel resistivity of two feet walking [ $\Omega$ ], 6 – series resistivity of two feet walking [ $\Omega$ ],  $C_s$  – coefficient taking account of surface material,  $\rho_s$  – resistivity of surface material [ $\Omega m$ ],  $t_s$  – shock duration [s], 0.116 – parameter of body weight of 50 kg.

The algorithm of the following activity depends on the calculating method chosen. For the methodology presented in [5] in a graphic form it is shown in Fig. 1.

Regardless of the chosen methodology, in each case the design accuracy is verified by the fact that the admissible shock voltage values are not exceeded.

#### 4. THE CHOICE OF PARAMETERS OF A GROUNDING GRID MODEL

A grounding grid model consists of two basic parts: the underground metal construction and the surrounding soil. The underground construction is made of steel, copper or aluminium. Its dimensions are limited by a given power station zone and electric appliances installed in the power station. The model of the surrounding soil is a cuboids whose dimensions are proportional to the size of the grounding grid model. The soil has the same physical and chemical

parameters as the construction materials of the grounding grid. The size of the soil model is calculated as a multiple of the grounding grid size and is closely dependent on the accuracy of calculations. To create the methodology for calculating the minimum dimensions of the soil model, parameters  $w_1$ ,  $w_2$  and  $w_3$  were introduced:

$w_1$  – the parameter of the soil model length,  
 $w_2$  – the parameter of the potential gradient,  
 $w_3$  – the parameter of the soil model depth.

The parameter  $w_1$  is a non-dimensional value and is defined as the ratio between characteristic dimensions of the soil and grounding grid model. The characteristic dimension is the biggest of the three dimensions: the length, width or depth of the soil and grounding grid model. The value of the parameter  $w_1$  is calculated on the basis of the following equation:

$$w_1 = \frac{a}{d_w} \quad (5)$$

where  $a$  – characteristic dimension of the soil model [m],  $d_w$  – characteristic dimension of the grounding grid model [m].

The projection of the electric field pattern can be regarded reliable if the soil model contains remote earth. The soil surface zone can be regarded with some accuracy as remote earth if the value of the potential gradient near the edge of the soil model is relatively low. Taking this into account, considering only the geometrical parameter  $w_1$  is insufficient. That is why the parameter of the potential gradient  $w_2$  defined by equation (6) has been introduced.

$$w_2 = \min \left( \frac{dV_2}{dr} \right) \quad (6)$$

where  $r$  – distance along axis  $r$ .

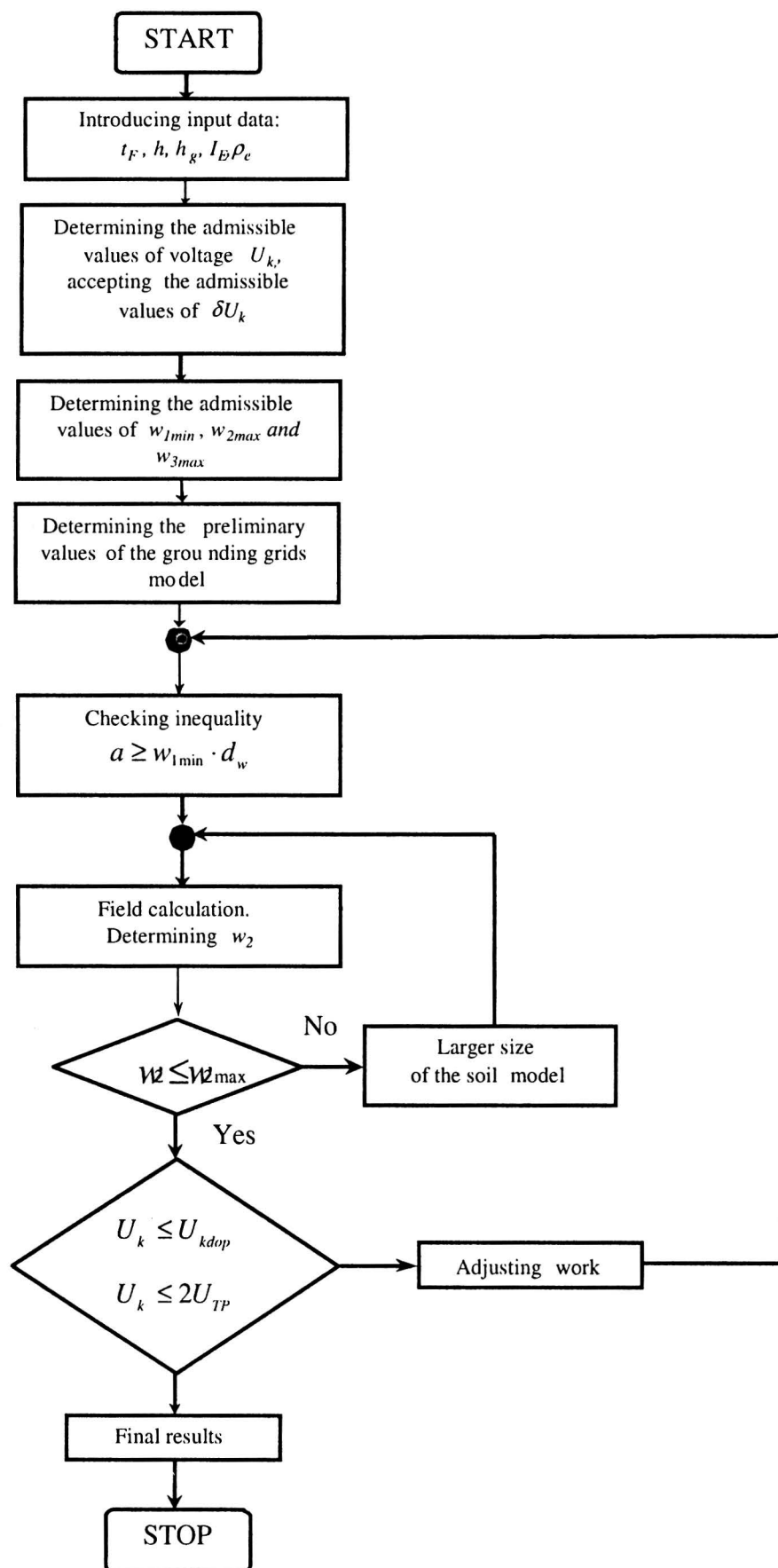


Fig. 2. The algorithm of a grounding grid design with the usage of its field model

The parameter  $w_2$  was defined as the minimum value of the potential gradient on the surface of the soil model along the axis  $r$ .

The third parameter used in the methodology for calculating the minimum size of the soil model is  $w_3$ , the model depth parameter, which is a non-dimensional value and is defined as the ratio between the soil model depth  $h_g$  and the characteristic dimension of the soil model, defined by the equation:

$$w_3 = \frac{h_g}{a} \quad (7)$$

The suggested algorithm of a grounding grid design is presented in a graphic form in Fig. 2. The algorithm is based on the assumed error value of the step voltage. The admissible parameters used in the algorithm have been calculated by comparing the results obtained by means of the field method and the accurate analytical method for the selected shapes of grounding grids.

## 5. VERIFICATION OF THE OBTAINED RESULTS

The verification of the results obtained from the electric field pattern for simple shapes was carried out by means of comparison calculations, using the accurate results achieved analytically. In other cases, norm method results and published results were used for analysis. The comparative analysis results are presented in Table 1. Mesh voltage is the difference between the grounding voltage and the soil surface voltage in the middle part of the grounding grid.

The step voltage values obtained by means of the field method are higher than those obtained by means of the methods described in standards and the difference is a systematic error. Hence the grounding grid designed by means of the latter method type is 25% bigger than that designed by means of the field method.

**Table 1.** Comparison of maximum values of step voltage and parameter  $w_2$

| Parameters<br>of the grounding grid<br>model  | $U_{kmax}$ by<br>analytical<br>method<br>[5][6][V] | $U_{kmax}$ by<br>field<br>method<br>[V] | The<br>difference<br>of step<br>voltage<br>calculation<br>[%] | $w_2$ [V/m]                |
|---|--|---|---|----------------------------|
| Dimensions 6.3 x 6.3 m, n = 4 (mesh number in a grounding grid) buried at h = 0.8 m, soil model with dimensions 60x60x30    | 12.64  | 15.87                                   | 25.6  | 0.2<br>( $w_{2max} = 4$ )  |
| Dimensions 6.3 x 6.3 m, n = 4 (mesh number in a grounding grid ) buried at h = 0.8 m, soil model with dimensions 30x30x15 m | 12.64  | 16.22                                   | 28.3  | 0.9<br>( $w_{2max} = 16$ ) |

6. CONCLUSIONS

The following conclusions can be drawn from the analyses conducted to calculate the minimum dimensions of the soil model surrounding the grounding grid (for which the accuracy of step voltage is 10%):

- The step voltage values obtained by the field method are higher than those obtained by the methods described in standards.
- The parameter of the soil model length  $w_1$  should be 9.5 or higher.
- The parameter of the soil model depth  $w_3$  should be 0.5 or higher.
- For lower values of the two parameters mentioned above (a soil model of smaller values) there is a sharp increase in the maximum value of the step voltage error.
- The parameter of the potential gradient  $w_2$  should be approximately 4.3 V/m or lower.
- The algorithm of a grounding grid design by means of the field method and calculating the dimensions of the soil model in accordance with the parameters mentioned above is shown in Fig. 2. This algorithm shows the cases when the dimensions of the soil model should be increased and the necessary calculations should be redone, when the grid meshes should be



increased (a thicker grid) and/or when additional vertical rod electrodes should be used.

- Obtaining the value of the step voltage error lower than 10% requires increased calculations, which may not always be profitable and justified. The relationship between the model dimensions and the accuracy is clearly nonlinear.
- In order to compare the electric field pattern obtained by means of the field method with the calculations obtained by means of an analogue model, the following calculations have been carried out:
  - The measurement uncertainty calculations of the analogue method using the ProNP 1.2 program.
  - When comparing the results obtained by means of the field method and the analogue model [3] (with the assumed accuracy of both methods: 10% for the field method and 5% for the analogue model calculations), it may be assumed that the results obtained by means of the field method are reliable.

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# **MODELOWANIE UZIOMU STACJI ELEKTROENERGETYCZNEJ Z WYKORZYSTANIEM METOD POLOWYCH**

## **Streszczenie**

W referacie została przedstawiona metodologia projektowania uziomu w wykorzystaniem jego modelu polowego. Stworzony model został zaimplementowany do środowiska ANSYS. Uzyskane wyniki zostały porównane z uzyskanymi z obliczeń analitycznych lub pomiarów.

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