New way in design of a power station earthing system

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***Abstract*— This article discusses the design of a power station earthing system using two methods that are compared to each other. The design was based on the software method using CYMGRID and the mathematical method based on IEEE 80-2000. The process in both methods is aimed at creating a grounding model, determining the overall resistance, overloading the cross-sections of the earthing switches and adhering to the limit values for the touch and step potential. The work compares these analyses and evaluates the differences in design and possible shortcomings, such as the possibility of over-dimensioning or underestimating the grounding system.**

***Keywords*— earthing system, earthing, step and touch potential; CYMGRD, earthing resistance**

I. Introduction

When designing earthing systems projects, it is possible to design these systems using various program tools. Nowadays, there are several programs that we can create and analyse grounding systems. The individual programs differ from each other in particular by the procedures and possibilities of designing a grounding system design. But there are also inaccuracies between the various programming tools in the process of designing the system. The aim of this work was to process and compare the process of creating a functional grounding system meeting all requirements using two program tools. One program tool was CYMGRD and the other was a mathematical calculation. The reason for dealing with this issue is to identify the inaccuracies that may arise in these proposals. These inaccuracies can affect both economic and functional requirements. From an economic point of view, this can affect the unnecessary overcharge of the grounding system due to system overdimension. Otherwise, undersize the system may cause problems in future expansion and system requirement

II. Protection against dangerous step and touch potential

A. Step and touch potential

For touch potential, we consider the voltage difference between the potential at the surface of the ground where the person is in contact with the feet and at the same time the potential increase in the grounded area it is touched. If the magnitude of the voltage of the touch of these parts does not expose the person to an electric shock or expose, but with a very low probability, it is referred to as permitted touch voltage. The step potential is generated on the ground around the point where the fault has touched the conductor under tension or on the earthing system at which time the current flows and disperses into the soil. In the case of a fallen conductor or touching a live part of the ground, tension circles with different voltage levels are formed around this contact. With increasing distance from this point, the value of these voltages decreases. Comparably, when the current is dispersed into the soil through a grounding mesh, layers are formed in the soil with different voltage levels. In these cases, a person may cross two different voltage levels and expose to different voltages. A point of view of the study of these step potentionals, the distance between the feet is 1 meter, which is roughly one step distance. After bending two levels and exposure to different potential, the body current flows between the feet. Therefore, this voltage also has its allowed maximum limit, which is called the permitted step potential [1].

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B. Ways of protection against dangerous voltage

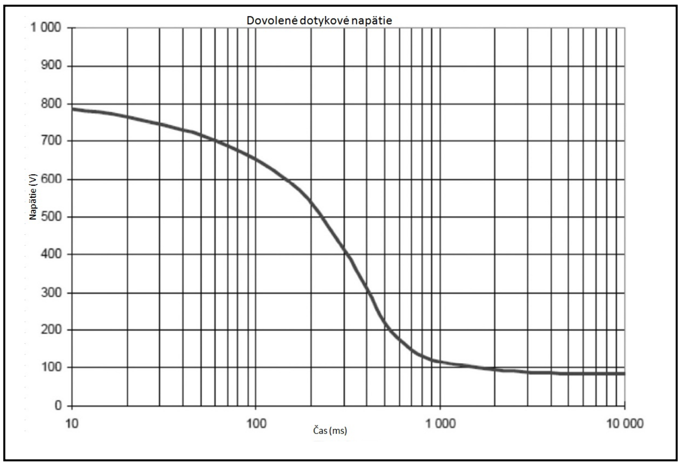
An important task is to investigate an area with the possibility of high voltage values. This includes exploration of the grounding of fences, which delimit stations, pipelines, cable jackets, shafts for control, switches, etc., in the case of nearby rails. Problems related to people subjected to touch or step potentional are more or less the same for people within the area of the station that is fenced as well as for persons outside of the area. A service area may occur if there is a fence installed around station, but it will encircle a much larger area thanit is used in the station and the grounding system will only be created around the grounded object and along the fence. Requirements for grounding of power stations [2].

From a safety point of view, grounding has to meet the following two objectives: It must be able to conduct and distribute the fault current to the ground during both normal and fault conditions and must take care to avoid exceeding the operating or limiting limits. It must be ensured that people who can move within an object are not exposed to critical currents that an electric shock could cause. The created grouding may consist of deliberate grounding and accidental grounding. The earthing system must have a low overall resistance but also a careful design to make the fault current evenly dispersed in the soil and not to create areas with stresses that endanger the safety of persons. Therefore, this current flowing through the system is further analyzed to plan the grounding within the system. Danger that people are threatening is created by a current that can flow through the human body. The IEEE 80-

2000 standard specifies the current relationship from which maximum permitted touch and step potentional are determined [3].

In the analysis of the grounding model, several parameters are considered, such as: maximum grid current, duration of failure, soil resistance, surface material and geometric distribution of earthing devices. Geometric layout of the earthing switches is described by some parameters, but among the most important ones that affect the results are the area on which the lattice system extends, the depth of the laying of this grid and the layout of the earthing devices in the grid, the distances between the parallel conductors that form the squares. While the diameter of the earthing devices or the thickness of the surface material have less influence. So, we can say that the grounding area has the greatest impact. In order to achieve a voltage reduction, it is necessary to reduce the resistance of the system and reduce it by increasing the area on which the earthing system is to be extended. In EN 50522, the currents for calculating the heat load and currents for calculating the earthing system voltage are shown, depending on the type of operation of the power station. Safety considerations mean a danger to humans that can arise by passing the current across the heart region of sufficient size, causing ventricular fibrillation. The cut-off value for this network current is determined in accordance with IEC / TX 60479-1. Using this current, we set the safe voltages to compare the calculated step and touch voltages in the object. Therefore, this standard addresses compliance with the requirements for the allowable contact voltage, which also provides for the step-wise requirements. Limit values of the permitted contact voltage are determined according to Fig. 1. In this figure, the curve of the permitted contact voltage is displayed depending on the duration of the fault. Podľa EN 50522 [4]

Fig. 1. Example of a figure caption.



After determining these permitted contact voltage values, the earthing system design shall be checked for these allowable contact voltages.

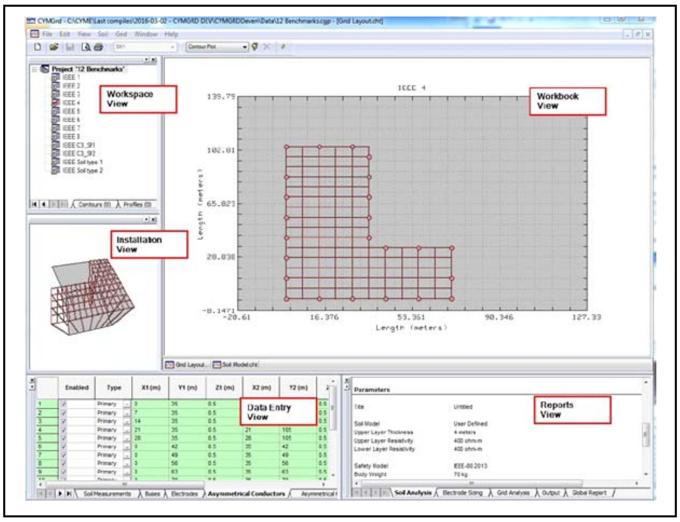
All parts of the earthing system shall be capable of distributing the fault current to the surrounding soil without causing thermal and mechanical damage until the protection is switched off..

III. Design of the Grounding System with a CYMGRD and Mathematical Calculation Program

A. *Design of grounding system using CYMGRD*

CYMGRD serves to create and analyze earthing systems of various shapes and sizes for power stations and buildings to meet safety and operational requirements. The program is based on American standards from IEEE [2].

Fig. 2. Preview of the program CYMGRD



When creating a project, it´s nessesary to define the type of project. Then a soil model can be created. Next is the dimensioning of the wires. The next step is to create the first grounding model. Afterwards,the viewing and evaluating of conditions for touch voltage at individual points could be done. In the case, when these conditions are not achieved, the network configuration has to be changed to meet the conditions. Optional surface material may also be altered and so the soil model can be modified. If we want to create a soil model, we must have results from soil resistance measurements at the point where we want to create a new system or at the site of the existing system that we want to assess. There are several methods suitable for performing this measurement, such as the Wenner Four-Contact Method or the Schlumburger-Palmer Method. Choose a model type that can be single layer, two-layer, or user-defined [5].

Entering the soil resistivity values that were found during the measurement, the maximum allowable contact voltages, the duration of the fault, the weight of the human body and the ambient temperature are selected. The last setting is the determination of the surface material. Ω

We have chosen a single-layer model with a resistivity of 30 Ωm first without surface material. By way of comparison, alternatively we have chosen a surface material with a thickness of 0.2 m. A stone, which has been selected, has a resistivity of 10000 Ωm and a crushed stone has a resistivity of 2500 Ωm. In both cases, the soil model is the same. Only the safety parameters will be different and therefore the maximum allowable touch and step voltage values listed in table I.

TABLE I. VALUES OF ALLOWED TOUCH AND STEP POTENTIONALS FROM THE CYMGRD

Parametres	Soil properties		
	Without surface material	***Cracked stone***	***Stone***
Thickness of the top layer	200	200	200
Resistance of the upper layer	30	30	30
Per - unit resistance of the lower layer	30	30	30
Factor CS	1	0,818531	0,816878
Maximum expected touch potentional	164,07	638,91	2080,75
Maximum expected step potentional	185,26	2084,64	7851,99

a. Sample of a Table footnote. (*Table footnote*)

It results from the above table that the high-resistive surface material greatly affects the allowable touch and step potentionals.

After the soil model is created, the modeling of the earthing system itself follows. The total resistance of the grounding system, the dispersion of currents into the soil through the individual parts of the grounding system, as well as the potential increase in the earthing system [6].

In our case, we are designing a grounding system for a power station with two voltage levels of 150 kV and 33 kV with these parameters:

Duration of failure tf = 1s

Factor of current distribution SF = 1

Depth of mesh storage h = 0.5 m

Maximum lattice current for 150 kV, IG = 1468 A

and X / R = 3.3

Maximum grid current for 33 kV, IG = 3180 A

and X / R = 16.2

Both voltage levels are operated without grounding the transformer node and therefore the fault current does not return to the grid through the transformer node but flows through the earthing system into the ground. Therefore both contribute to the rise of potential on the grounding system.

On the 33 kV side, we have a larger fault current than the 150 kV side, this current will cause higher potential gains when crossing the grounding system to the soil. In other analyzes we will therefore consider a fault current IG = 3180 A.

When dimensioning the cross section, it is necessary to determine the minimum cross-section of the earthing switches in order to avoid their damage due to the flow of currents and other fault factors.

The choice of suitable material and size should meet the following criteria: electrical conductivity, corrosion resistance, current load and mechanical strength.

In the CYMGRD program a grounding model was developed, with three types of electrodes being used (Primary, Return, Distinct). It is possible to choose six types of grounding devices: symmetrically arranged wires, asymmetrically arranged wires, symmetrically arranged rods, asymmetrically arranged rods, arcuate conductors, asymmetric empty wires (ducts / pipes).

In our case, we formed a rectangular symmetrical mesh with dimensions in the x-axis direction of 24 m and in the y axis direction of 38 m. Depth of mesh storage h = 0.5 m. The size of each square of the grid has been chosen 5 m x 5 m. So, in order to reach this parameter, we have calculated that the number of conductors in the direction of the axis X = 9 and in the direction of the axis Y = 6. We have created this grid design to be used in two different ways, with the surface material but also for the non-surface design.

When designing without surface material, we have to use additional earthing devices because the touch potentional limits have been exceeded. One wire perpendicular to the X axis was added at a distance of 1.25 m from 0 on the X axis. And also on the opposite side at a distance of 22.5 m from 0 on the X axis.

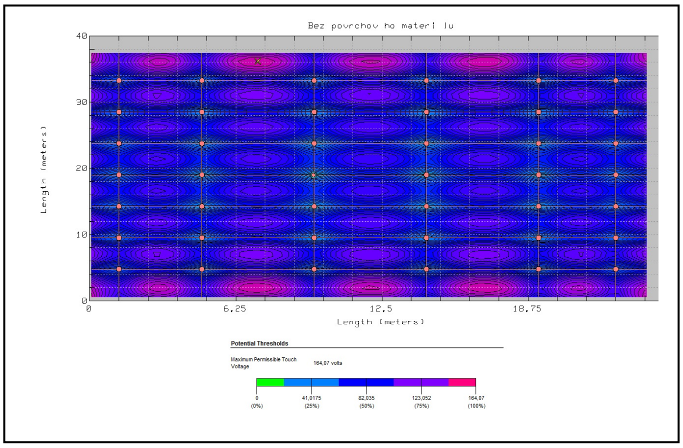
When simulating symmetrical rods are being modeled, as with symmetrical earthing switches, two opposite surface points are placed on which the bars are disposed. We have entered the number of rows of rods 9 that are parallel to the X axis and the number of rods in one row 6. Depth of the h = 0.5 m, the length of the rods L = 2 m apply to all rods so spaced. This also applies to the material we have chosen for the dimensioning and cross section of the bars [7].

Using asymmetric rods, we can deploy one bar or a whole row. Coordinates are set as for asymmetric conductors. Parameters are valid for the given bar or given row. In this setting, the number of elements of a given bar or row, how many are contained in the top and how many in the lower layer of the soil, is also entered. Asymmetric rods were used in both designs.

After modeling the grounding system, we evaluated the surface tensions at the ground station of the power station. In this way, it is possible to detect dangerous points at various surface locations in the power station and using 2D or 3D graphs to plot silos of tension that are graphically differentiated for better visualization. These voltage analyzes can be triggered if soil and mesh analysis has already been performed. The tension plotting module allows you to draw two types of graphs.

The first possibility of evaluating the results is to plot the voltage lines in the marked section. By selecting the desktop and running the analysis, the program calculates and displays the color graph with voltages. It is possible to draw either touch or surface tension. Subsequent to this analysis, we are able to view the mapped silos and locate the places with the values exceeded [7].

Fig. 3. Example of a figure caption.



The resulting outputs contain the evaluation or the voltage conditions and the coordinate of the places with the least and the highest voltage of the given system calculated. It is possible to generate a graph that contains equipotential layers and shows changes in touch and step tensions.

B. Design of grounding system by mathematical calculation

This proposal includes a modeling of the earthing system. Furthermore, the cross-sectional dimensions of the wires are reduced to avoid damage due to the thermal effects of the fault currents. Calculation of earthing resistance and determination of maximum allowances and actual touch and step potentionals [8].

We have selected annealed copper for earthing material. A minimum cross sectional area was calculated for this material [3].

According to IEEE 80-2000

$$A = \frac{1}{\sqrt{\frac{TCAP * 0{,}0001}{tc * \alpha r * \rho r} * \ln(\frac{K_O + T_m}{K_O + T_a})}}$$

The closest cross section is 120 mm2.

When creating a system model, we created a grid that spans the entire building where the power station is built. This station will be spread over an area of 25 m x 39 m. So we created a mesh of the same size, the size of each square being 5m x 5m. After analyzing this grid, we found that the voltage values did not match, so we had to add the earthing rods. It was necessary to add 54 earthing rods.

On the basis of the input parameters, the resistance of the grounding system was calculated with a value of 0.464 Ω [3].

According to IEEE 80-2000

$$R_g = \rho * \left[\frac{1}{L_T} + \frac{1}{\sqrt{20 + A}} * (1 + \frac{1}{1 + h * \sqrt{20 * A}} \right]$$

Allowed touch and step potentional values were calculated for 50 kg and 70 kg for body weight.

These allowances are linked to the resistance of the human body and weight. The heavier the larger the figure, the greater the current passing through the body, and thus the higher the value of the allowed voltages. In most cases, however, we consider 70kg body weight calculations [3]. Podľa IEEE 80-2000

$$E_{S70} = (1000 + 6 * C_S * p_S * \frac{0{,}157}{\sqrt{t_S}} [V]$$

$$E_{T70} = (1000 + 1{,}5 * C_S * p_S * \frac{0{,}157}{\sqrt{t_S}} [V]$$

We did not consider the surface material in the design. The permitted stepping voltage is 185.3 V and the permitted contact voltage is 164.1 V. For the geometric parameters of the earthing system the maximum value of the stepping voltage is 145.8 V and the maximum value of the contact voltage is 148.6 V.

IV. Discusion

The design of the grounding system deals with four main areas. These areas are: ground, cross-section dimensioning, grounding model and ground resistance calculation, safety voltages.

Both methods of solving earthing systems are dedicated to soil analysis, which in CYMGRD means to create a curve of the course of the resistance, depending on the depth. This curve determines the program by entering the measurement values. For mathematical computations, we need to process these values forward, and we have a direct unit resistance already entered into the calculation. Thanks to the program, we are able to create a more faithful model to achieve more accurate results when calculating earthing resistances. Surface material that increases the allowable stresses is taken into account in both calculation methods.

When dimensioning the cross-section of the earthing system, there are differences between the two methods. The CYMGRD calculates these cross sections from the grid currents that flow through the earthing switches during the fault to the ground and generate voltage thereon. Lattice currents are smaller than total fault currents because a portion of the total fault current can be returned back to the system, and the current at the input to the earthing system is divided between the individual earthing switches. The mathematical calculation calculates cross-sections based on a total failure current that does not affect lattice currents and allowed stresses, but can mechanically and thermally load the upper parts and damage them. Therefore, if the mathematical calculation overrides earthing switches to total fault currents, we will prevent damage to any part with a system that might be exposed to a higher current. From this point of view, it is possible to underestimate some parts of the system when determining the minimum cross-section in CYMGRD and then the selected cross-section. Similarly, in the minimum cross-section, the possibility of future growth should also be taken into account as it is less costly to take this fact into account and use larger cross-sections than to subsequently modify the system.

Using mathematical calculation, we can calculate the values of the maximum real values that can be generated on a given model. However, we do not know in which parts these maximum values may occur. CYMGRD knows exactly how to calculate the voltage across all parts of the grounding system. Using graphical rendering, we can accurately determine locations from increased stresses. With such an analysis after identifying dangerous sites, we can modify the system in a given location to meet the voltage conditions. We can draw a 2D plot of stress, pitch, and surface tension between two arbitrary points in the system in different directions.

V. Conclusion

In the paper we have devoted two methods of calculating the earthing system. The first method was the calculation using CYMGRD, which is specially designed to solve grounding systems. The second method was a mathematical calculation.

In soil analysis, the program can create a single-layer or two-layer soil model after inputting values from soil resistivity measurements. Mathematical calculation is based on uniform soil resistivity. With the program, we can create a more faithful model to achieve more accurate results when calculating earthing resistances.

The dimensioning of the cross-section of the earth conductors according to both methods is different. The minimum cross sections calculated by the program are unrealistic, there is a risk of underdimensioning of the grounding system. Mathematical calculation is more appropriate for this purpose.

When analyzing touch and step potentionals, the program offers better possibilities than mathematical calculation. CYMGRD allows you to accurately determine the points of contact overvoltage, which allows us to modify the configuration of the grounding system only in the given locations and to unnecessarily redesign it.

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