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Assessment of Overvoltage Level and Grounding bar Impedance Value by Finite Difference Method

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ABSTRACT: Overvoltage phenomenon in the grounding system has a direct impact on the power grid and electrical equipment. Therefore, when designing the grounding system, the issue of concern is that the grounding rod and grid must respond to overvoltage caused by lightning or load switching. Because the overvoltage phenomenon caused by lightning on the power system must be transmitted and dissipated on the grounding system to ensure the safety of the line, transformer station and ensure the normal operation of electrical equipment. To calculate and design the grounding system to meet the requirements on resistance value and ensure that there is no overvoltage phenomenon on the grounding system, we need to find the best method for calculation. There are many approaches to calculate overvoltage on the grounding system such as: the approach to the electric circuit, electromagnetic field, according to the transmission line model or using numerical methods such as the finite element method... In this article, we use the finite difference method and apply matlab software to calculate overvoltage on the top of the grounding rod. Our results are a calculation program, which can be shown graphically and analyzed specifically when changing the input parameter values such as length (l), radius (r) and resistivity (ρ) of the soil.

KEYWORDS: Finite difference method of overvoltage on grounding system, grounding system.

I. INTRODUCTION

Grounding is an indispensable task in the power system. There are 3 forms of grounding: working grounding, safety grounding and lightning protection grounding. Each form of grounding will have its own role and task in the power system. However, for the lightning protection grounding system (atmospheric overvoltage), it is one of the important tasks in the power system, because it ensures the safety of the power system to operate even when there is atmospheric overvoltage (lightning voltage) on the line and transformer station. The grounding system has the task of conducting lightning current when there is overvoltage on the lightning protection system and dissipating it through the grounding system. Currently, there are many research projects on lightning protection grounding and overvoltage phenomena on the grounding system.

Related research works such as [1], by author Nguyen Quoc Van have studied and proposed solutions to use chemicals to improve soil for the grounding grid system at high voltage transformer stations in Ho Chi Minh City. This research aims to help reduce the contact resistance value between the soil and the grounding grid system to achieve the required value, which will limit the phenomenon of overvoltage on the grounding system due to lightning. The group of authors, Vu Phan Tu, Nguyen Nhat Nam, Huynh Van Van, Huynh Quoc Viet [2], published their research in the Journal of Science and Technology K1 2010, with the results achieved as follows: "Simulating lightning transient voltages in grounding systems using the finite element method. Using the finite difference method,the group of authors Phan Tu-Vu and colleagues [3], introduced an advanced application of Radial Basis Function–Finite-Difference Time-Domain (RBF-FDTD), to calculate lightning transient voltages in grounding systems at two horizontal grounding electrodes and three standard grounding grids. This method modeled grounding structures as heterogeneous transmission lines, controlled by mathematical equations with parameters varying in space and time—inductance L(x, t), conductance G(x, t) and capacitance C(x, t) on complex grounding configurations. Although the differential time-

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domain method finite difference method (FDTD) to solve Maxwell's equations is very difficult to calculate the rising ground potential (EPR) and instantaneous ground resistance (TGR), but this method is used [4], to calculate EPR and TGR for different configurations of the grounding system in wind power system (WT) because the FDTD method can effectively handle the three-dimensional geometric configurations of a studied structure.

After studying the above published works, we see that the authors only investigated overvoltage when changing the length of the rod in the grounding grid. Based on the IEE Std.80-2000 standard [5], [6], the calculation of the voltage value and grounding resistance of the system also depends on many other parameters. Therefore, our group decided to study the overvoltage phenomenon in the grounding system with changes in parameters such as length (l) and resistivity (ρ) of the soil, using the finite difference method and showing the results through simulation by matlab software.

The difference diagram of this system of equations is described as follows:

$$i_1^{n+1/2} \quad i_2^{n+1/2} \quad i_{m-2}^{n+1/2} \quad i_{m-1}^{n+1/2} \quad i_m^{n+1/2}$$

II. PROPOSED SOLUTION

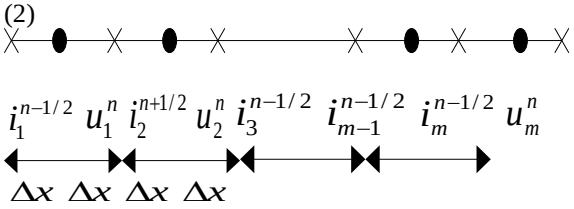
The grounding grid is a system of interconnected rods and piles. Therefore, we can completely predict the propagation of overvoltage and current on the grounding grid when we know the transient process occurring on a single ground rod or pile. Therefore, we must examine the process of voltage and current wave propagation on the grounding rod, the system of equations describing this propagation process has the following form.

$$\begin{aligned} -\frac{\partial u}{\partial x} &= Ri + L\frac{\partial i}{\partial t} \\ -\frac{\partial i}{\partial x} &= Gu + C\frac{\partial u}{\partial t} \end{aligned} \quad (1)$$

With R, L, G and C being the resistance, inductance, conductance and capacitance per unit length of the conductor respectively.To calculate the parameters on the underground conductor by the finite difference method, the system of equations (1) is developed by the central difference scheme and rewritten for the relationships in the m segment as follows:

$$\begin{cases} \dfrac{u_m^n - u_{m+1}^n}{\Delta x} = \dfrac{R}{2}(i_m^{n+1/2} + i_m^{n-1/2}) + L\dfrac{i_m^{n+1/2} - i_m^{n-1/2}}{\Delta t} \\ \dfrac{i_{m-1}^{n+1/2} - i_m^{n-1/2}}{\Delta t} = \dfrac{G}{2}(u_m^n - u_m^{n+1}) + C\dfrac{u_m^{n+1} - u_m^n}{\Delta t} \end{cases}$$

(2)



Simplify the system of equations (2):

$$\begin{cases} i_m^{n+1} = \dfrac{1 - \dfrac{R_m^n \Delta t}{2L_m^n}}{1 + \dfrac{R\Delta t}{2L_m^n}} i_m^n + \dfrac{1}{(\dfrac{R_m^n}{2} + \dfrac{L_m^n}{\Delta t})\Delta x}(u_m^n - u_{m+1}^n) \\ u_m^{n+1} = \dfrac{1 - \dfrac{G_m^n \Delta t}{2C_m^n}}{1 + \dfrac{G_m^n \Delta t}{2C_m^n}} u_m^n + \dfrac{1}{(\dfrac{G_m^n}{2} + \dfrac{C_m^n}{\Delta t})\Delta x}(i_{m-1}^{n+1} - i_m^{n+1}) \end{cases} \quad (3)$$

Or in the form:(4)

$$\begin{aligned} i_m^{n+1} &= A_m^n i_m^n + B_m^n (u_m^n - u_{m+1}^n) \\ u_m^{n+1} &= C_m^n u_m^n + D_m^n (i_{m-1}^{n+1} - i_m^{n+1}) \end{aligned}$$

(4)

Regarding the boundary conditions, we base on the equivalent model of the grounding rod at the two ends, atthe input position of the lightning current, the rod head has voltage (5), the rod end has voltage (6) and the pulse dissipation resistance of the grounding system is calculated according to formula (7)

$$U_1^{n+1} = \left(G + \frac{C}{2\Delta t}\right)^{-1}\left[\left(\frac{C}{\Delta t} - \frac{G}{2}\right)U_1^n - 2\frac{i_s(n\Delta t) - I_1^{n+\frac{1}{2}}}{\Delta x}\right] \quad (5)$$

$$U_M^{n+1} = \left(G + \frac{C}{2\Delta t}\right)^{-1}\left[\left(\frac{C}{\Delta t} - \frac{G}{2}\right)U_1^n - 2I_N^{n+\frac{1}{2}}\right]$$

(6)

$$Z(t) = \left(\frac{U(t)}{I_m(t)}\right) \quad (7)$$

In this paper, we use formulas (5), (6) and (7) to calculate the voltage at the grounding bar end and determine the input parameters for the

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simulation of overvoltage and impulse impedance on the grounding bar using Matlab software.

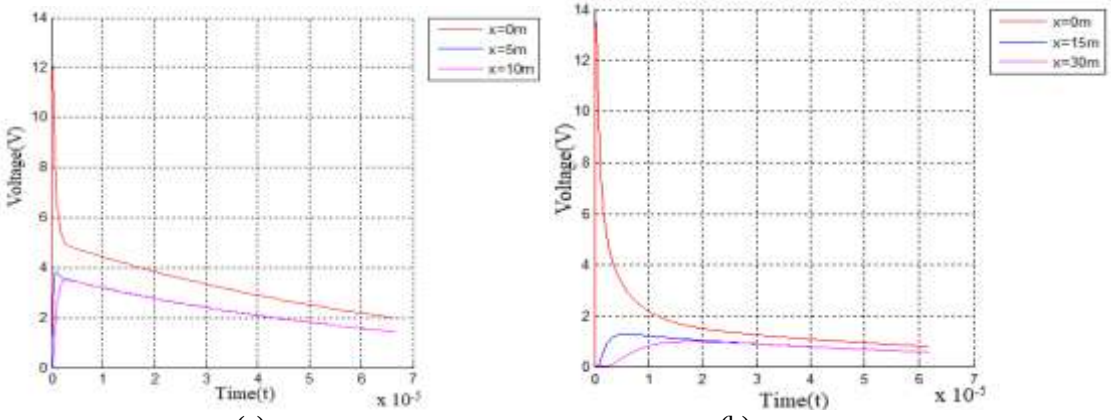
III. DISCUSSION RESULTS

To investigate the overvoltage on the grounding rods, we choose the lightning current $i_s(t) = 1.0.(e^{-14203.84*t} – e^{-4880435*t})$ kA; with the rod length l = 10m, impulse voltage form 1.2/50 with current $I_m(I_{imp} – I_{mpulse}$ current) also known as the maximum current, charge and energy of the impulse. The parameter I_{imp} is used to classify the tests of level 1 lightning protection devices, choose I_m = 1.0kA, this is the minimum maximum test current for level 1 lightning protection devices (according to standard IEC 61643-1). The 1,2/50 µs impulse voltage (voltage impulse) also known as the impulse voltage has a front value of 0 – 1.2 µs peak and decreases to 1/2 peak value within 50 µs. In this discussion results section, we examine 3 cases (cases): Case_1 examines overvoltage at the beginning, middle and end of the bar when the length of the bar changes. Case_2 examines overvoltage at the end of the bar when the soil resistivity value changes. Case_3 examines the impulse impedance at the end of the bar when the length of the bar and the soil resistivity change. The input parameters to write the program for all three cases are given in table [1] and the lightning current form $i_s(t) = 1.0.(e^{-14203.84*t} – e^{-4880435*t})$ kA compared to the standard waveform 1.2/50µs:

Table 1: Input parameter table for all three cases:

Length of grounding bar l(m)	Time to survey the transition process (t_{max})	Radius of grounding bar: r(m)	Burial depth of grounding bar from ground d(m)	Relative soil conductivity (e_r)	Soil resistivity ρ_d (Ωm)	Resistivity of the bar ρ_t (Ωm)
Case 1	**Investigation of bar overvoltage when changing bar length**					
10	15e-6s	$1.5*10^{-3}$	0.8	20	20	$0.25*10^{-6}$
30	15e-6s	$1.5*10^{-3}$	0.8	20	20	$0.25*10^{-6}$
Case 2	**Investigation of overvoltage of the bar when changing the resistivity of the soil**					
10	60e-6s	$15*10^{-3}$	0.8	20	50; 100; 200; 300; 400; 500	$0.25*10^{-6}$
Case 3	**Investigation of the impulse impedance of the rod when changing the length of the rod and the resistivity of the soil**					
10	30e-6s	$15*10^{-3}$	0.8	20	50; 100; 200; 300; 400; 500	$0.25*10^{-6}$
30	30e-6s	$15*10^{-3}$	0.8	0	50; 100; 200; 300; 400; 500	$0.25*10^{-6}$

Case 1. Survey results and analysis of overvoltage of bars with length: l = 10m and 30m



(a) (b)

Figure 1. Overvoltage levels at the beginning, middle and end of the grounding bar when length l = 10m(a); l = 30m(b)

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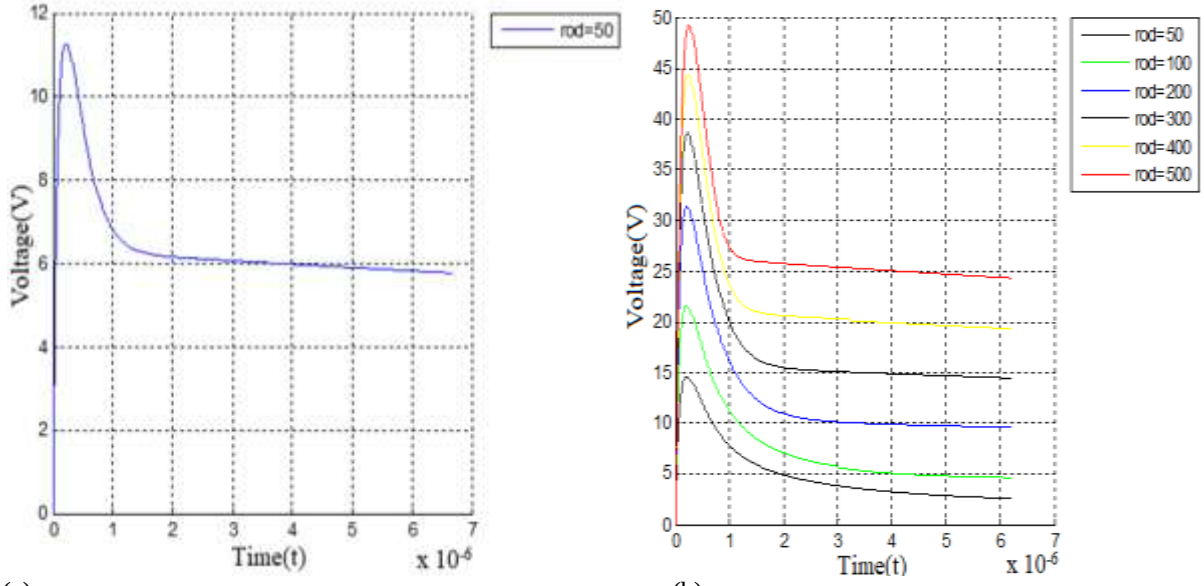
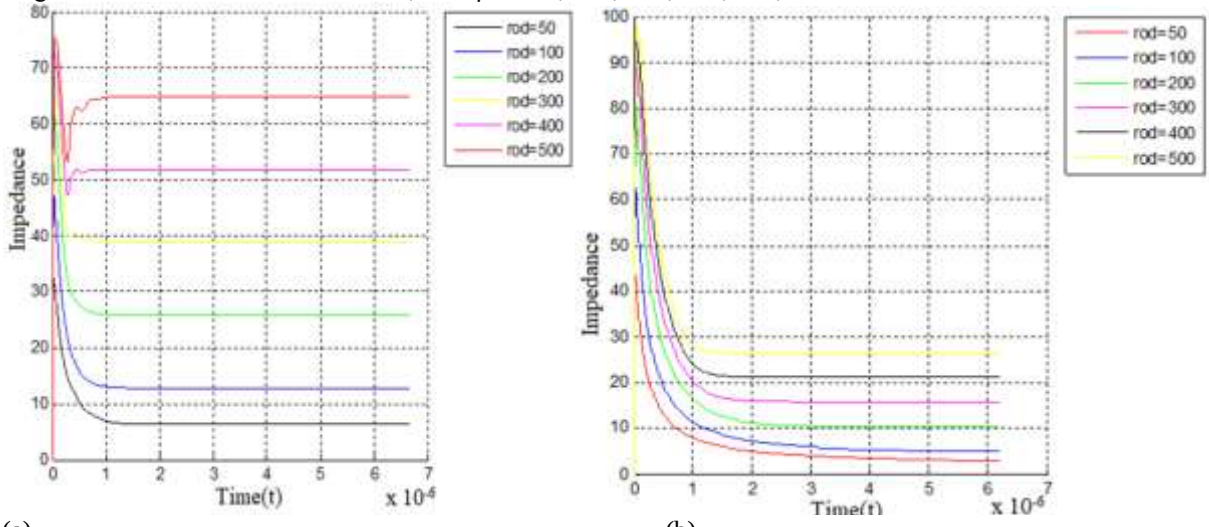
Case 2. Results of survey and analysis of overvoltage at the end of the grounding conductor with length l = 10m when changing the soil resistivity value ρđ = 50; 100; 200; 300; 400; 500 Ωm:



(a) (b)

Figure 2. Overvoltage of grounding bar with length l = 10m, ρđ = 50 and l = 10m with ρđ = 50; 100; 200; 300; 400; 500 Ωm

Case 3. Results of survey and analysis of the total impedance at the end of the grounding bar when changing the length of the bar: l = 10m and l = 30m, with ρđ = 50; 100; 200; 300; 400; 500Ωm



(a) (b)

Figure 3: Impedance at the end of the grounding conductor with length l = 10m(a) l= 30m(b) with ρđ = 50; 100; 200; 300; 400 Ωm

We see the survey results of the 10m long bar, Figure 1(a), the overvoltage pulse at the end of the bar is 12kV, the amplitude stabilization time is about 0.15μs and the voltage is 4kV. The 30m long bar, Figure 1(b) has a voltage amplitude of approximately 14kV and the voltage stabilization amplitude is approximately 1kV.

With the survey results in Figure 2(a) and Figure 2(b), we see that when the soil resistivity increases, the overvoltage pulse and the stable voltage increase. This proves that when grounding the lightning protection system, the resistivity factor affects the resistance value of the grounding system. The higher the soil resistivity, the higher thegrounding resistance, and the overvoltage when lightning occurs also increases.

In the survey of transient impulse impedance on the grounding rod, the parameters for

surveying impulse impedance are exactly the same as for surveying overvoltage on rods of different lengths. Therefore, we only survey the change in soil resistivity at the 10m rod.

From figure 3(a) we see that the amplitude of the impulse impedance increases as the resistivity increases and the stability amplitude also increases. In figure 3(b) with the bar l=30m, the result is similar to that in the survey of the bar 10m because in both cases, when ρ_d=50 Ωm, the decrease in the stability amplitude has a small value and when the resistivity increases to 100 Ωm; 200 Ωm; 300 Ωm; 400 Ωm; 500 Ωm, the decrease in the stability amplitude has a significant increase. However, the decrease in the amplitude between the amplitude of the stable impedance and the impulse impedance is different, for the bar 10m, the decrease fluctuates with a large value compared to the bar with length l=30m.

IV. CONCLUSION

On the same conductor, the overvoltage pulse value will change and decrease from the beginning of the rod to the end of the rod. A large voltage at the beginning of the rod will cause overvoltage to the grounding system, affecting the stability of the electrical system and electrical loads. The soil resistivity parameter is a parameter that indicates the characteristics of the land area where the lightning protection system is located. When the soil resistivity increases, the overvoltage pulse and stable voltage increase. To keep the resistivity stable, we need to install the grounding system at a sufficient depth or use chemicals to improve the soil resistivity. The total impulse impedance depends on the length and resistivity of the soil. Through the survey, we see that with the same resistivity, but the grounding rod has a large length, the impulse voltage will decrease when the resistivity is large, but for the rod with a small length, the opposite is true.

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