DESIGN AND OPTIMISATION OF THE THROUGH WALL BUSHING FOR THE CLIMATE CHAMBER

Teboho Lekeno (110992)

School of Electrical & Information Engineering, University of the Witwatersrand, Private Bag 3, 2050, Johannesburg, South Africa

Abstract: The purpose of his report is to design ~~the~~ a through-wall high voltage bushing for the climate chamber. The bushing is used to safely deliver 132kV AC and 132kV DC into the climate chamber. Numerous bushing tests are performed to assure that the bushing design comply with the IEC and SANS standards. The insulator to prevent the flash over a the opening was found to be Porcelain. Lightning impulse test was perfumed and the Porcelain bushing failed to withstand the impulse voltage of 500kV.

give summary of design procedure and results

Key words:

1. INTRODUCTION

Too brief an introduction

In transmission lines, it is important to prevent the occurrence of the flash-overs as they may cause serious problems and damages [1]. The design of the high voltage bushing needs an in-depth understanding of the electrical field distribution since the design will highly depend on it.

2. BACKGROUND

The climate chamber the bushing is designed for has the height o 1370mm, the length of 300mm, the height of 240mm. The diameter of the wall opening is specified to be 158mm.

2.1 Requirements

The design of the high voltage bushing has to comply with the following requirements.

- The final design should be capable of delivering 132kV AC, 132kV DC and 500kV peak lighting impulse inside the chamber safely.
- The bushing designed should allow all specified testing including the test for lighting impulse discharge.
- The design should be financial, economic, and environmental attainable.

Success Criteria The project is deemed successful if the design delivers 132kV DC, 132kV AC and the impulse at 500kV into the climate chamber.

2.2 Literature Review

This really can't be all for literature review

Reference [2] shows several factors a ect the insulation by increasing the build-up of pollution on the insulator of which electric field in the major contributing factor, especially under DC conditions. This study will be applied in the design to limit the electric field strength on the surface of the insulator.

The research carried out by [2] further shows that the less insulation flashover is obtained in DC compared to AC whereby the leakage current follows the contour path in AC and propagate through the air under the DC conditions.

2.3 Constraints and Assumptions

To limit the scope of the design, the following assumptions are imposed on the design of the bushing.

- All the walls of the climate chamber are grounded.
- The conductor material will be selected based on its strength due to the smaller current in the conductor.
- The dimensions of the climate chamber are fixed, they cannot change.
- Since the flashover occurs mostly in AC compared to DC under the same voltage [2], preventing flashover for AC will subsequently prevent the DC flashover.

3. DESIGN OF THE HIGH VOLTAGE BUSHING

To simplify the design, it is broken into WWW main sections. These sections are conductor diameter selection, determination of the insulation material and electric field strength, Determining the creepage distance and calculation of clearance for the lightning.

3.1 Conductor Diameter Selection

Yes, but why?

The current flowing through the bushing is small, thus this allows the selection of the conductor diameter to be based on strength. Since this is a high voltage bushing design with the maximum voltage up to 132kV AC, therefore using the IEC standards, the conductor diameter is calculated with reference to 1250N cantilever load [3], which is a specification for voltages between 123-245kV. The designed bushing is heavy and will experience deflections through the wall. The tilting of the bushing downwards due to gravity may occur. The deflection factor is therefore applied in the selection criteria of the conductor radius, which is required to be less than 5cm [4]. The radius of the conductor is therefore modeled by equation 1 below.

$$r = \sqrt[4]{\frac{4 \cdot P \cdot L^3}{3\pi E_x d}} \quad (1)$$

Where P are characterizes the cantilever load, d is the deflection factor, E_x is Young's modulus of copper at a constant value of 118GPa and L is the length of the bushing chosen to be 2.5m. The radius of the conductor was calculated to be 34.487mm, which gives the diameter of 68.974mm.

3.2 Determining Insulation Material and Electric Field

The insulator diameter was selected such that it does not exceed the diameter of the opening inlet of the climate chamber wall. To satisfy the constraint, the outer diameter of the insulator was selected to be equal to the diameter of the chamber opening, therefore it is equal to 79mm. The bushing at this point will be modeled as a coaxial cable as shown by the figure below.

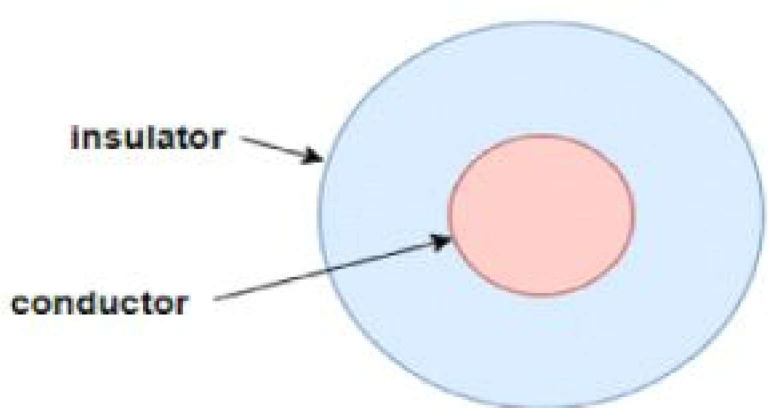

Figure 1: Bushing modelling as a co-axial cable

Di erent insulators such as Epoxy, Mineral oil and Porcelain may be used. Equation 2 below will be applied to calculate the maximum electric field strength, which will be used to determine the insulator material.

$$E = \frac{V}{r \cdot \ln(\frac{R}{r})} \quad (2)$$

Where E characterizes the electric field strength of the required insulator, r symbolizes the radius of the conductor and V is the voltage imposed to the conductor. The specified maximum voltage of 132kV will be used.

The electric field strength is calculated to be 4.6178kV/mm. Using IEC standard [5], it shows that the field strength of the insulation should be 50% more than the operating electric field strength. Therefore the required insulator should have an electric field strength over the value of 9.2356kV/mm. Using the list of insulation materials with their electric field strength [6], it is observed that the Porcelain will be able to meet the requirements with its electric field strength of 15kV/mm. Porcelain is therefore selected as the insulation material and its thickness is calculated by equation 3 below,

$$T = R - r \quad (3)$$

where T is the thickness of the insulation, R is the outer radius of the insulator and r is the radius of the conductor. The thickness is calculated to be 44.513mm.

3.3 Determining the Creepage Distance

Creepage distance is the minimum contour distance on the surface of the insulator. Creepage distance is also known as the leakage distance. IEC60815 standard provides the specific creepage distances and Table 1 below was used to obtain the creepage distance [7], where the minimum specific creepage considered is for the AC since the creepage distance for it is always higher than DC. Since the climate changes conditions, it will be associated with very heavy pollution and the outside of the will associated with the light pollution. The knowledge of the shed spacing and shed thickness was required in order to obtain obtain the number of sheds to be used. The following assumptions were considered:

Table 1: Recommended creepage distances for various pollution levels under AC voltage

Pollution severity class	Minimum specific creepage distance (mm/kV)
Light	28
Medium	35
Heavy	43
Very heavy	54

The total creepage distance required was calculated to be is calculated to be 7128mm inside the climate chamber and 3696mm outside the pollution chamber. It is required to known the parameters of the creepage dimensions before the number of sheds are calculated. The parameters were we changed multiple times using trial and error method to ensure the shed designing meets the IEC standards for shedding. The assumed parameters are shown in the Table below, assuming all the sheds will have the same dimensions.

An equation from the parameters can therefore be derived to calculate the number of sheds for both the internal and the external part of the bushing. The derived equation 4 below will be used.

Table 2: Assumed values of spacing and thickness for shed

Creepage Proerty	Value
Shed spacing	100mm
Shed thickness	30mm
Inner diameter	79mm
Outer diameter	179mm

$$N_s = \frac{L_{creepage}}{2 \cdot (D_o - D_i) + T_s + L_s} \quad (4)$$

Where N_s is the required number of sheds, $L_{creepage}$ is the creepage distance, D_o is the outer diameter of the shed, D_i is the inner diameter of the shedding, T_s is the thickness of the shed and L_s is the shed spacing between two sheds.

The number of sheds required for the bushing side inside the climate chamber is calculated to be 22 and outside is 11 sheds. The IEC standards specify the requirements of the for creepage factor, profile factor and projection factor [8], which necessary to prevent sheds closely packed as it could result create flaws when supplying DC power to the system. Table below shows the IEC standards specified values against the values obtained for the designed bushing.

Table 3: Assumed values of spacing and thickness for shed

Ratio and Factors	IEC recommended	Obtained using Porcelain
Creepage factor (CF)	< 3.5	$= 2.56$
Profile factor (PF)	≥ 0.8	$= 1.12$
projection ratio (s/p)	≥ 0.65	$= 0.947$

The obtained ratios and factors satisfy all the requirements desired by the IEC815 standard.

With knowledge of the creepage distance, the leakage current and the minimum voltage to cause the flashover can be obtained. The leakage current is calculated using equation 5 below.

$$I_{MAX} = \left(\frac{S_{creepage}}{15.32}\right)^2 \quad (5)$$

Where S_{CD} is defined by equation 6 below

$$S_{creepage} = L_{creepage} V_m \quad (6)$$

$L_{creepage}$ characterizes the creepage distance in mm, V_m is the maximum phase voltage in kV. The resistance of the insulator play a major role and is calculated using equation 7 below.

$$R = \frac{\rho \cdot L_{creepage}}{A} \quad (7)$$

Where A is the cross-sectional area and ρ is the resistivity of the Porcelain equal to $10^{13}\Omega/mm$. The minimum voltage to result in the flashover is thus calculated using equation 8, where the constant values of k_1 and k_2 are 7.6 and 0.35 respectively.

$$V_{min} = k_1 \cdot L_{creepage} \cdot \left(\frac{R}{L_{creepage}}\right)^{k_2} \quad (8)$$

So What is the minimum voltage.

3.4 Clearance Base on Lightning Impulse Conditions

The high voltage bushing should be designed such that there will be no flashover occurring from the end of the bushing and the wall of the climate chamber or ground. This requirement will influence the length of the bushing. The calculation of the air clearance to withstand the lightning impulse will be performed using equations provided by [9], for high voltage bushings at higher altitudes.

The recommended equation to calculate the clearance is characterized by equation 9 below.

$$S = \frac{V_{crestph-g}}{CFO_{Gradient}} \quad (9)$$

Where S is the metal-to-metal strike distance using meters. $V_{crestph-g}$ is measured in kilovolts. $CFO_{Gradient}$ characterizes the critical flashover gradient measured in kilovolts/meter. BIL of the lightning is calculated by equation 10 below,

$$BIL = \frac{V_{crestph-g}}{CFO_{1.15}} \quad (10)$$

therefore substituting equation 10 into 9 gives

$$S = \frac{1.15 \cdot BIL}{605} = \frac{BIL}{526} \quad (11)$$

Using this equation 11 the minimum clearance required is calculated to be 950.57mm. The calculated clearance meet the designed bushing specifications as the external length o the bushing is 1000mm.The bushing is also 1610mm from the surface which shows the ground flashover cannot occur as well, as it can be seen on Appendix A, Figure 2.

4. SIMULATIONS O THE HIGH VOLTAGE BUSHING

The simulations of the bushing will be carried out using Finite Element Method Magnetics (FEMM) software.

4.1 The Co-axial Simulation of the Bushing

As aforementioned, the bushing is modeled as a coaxial cable, this all allows modeling and analysis o di erent points. Figure 3 in the Appendix shows the model. It is observed that the field strength is concentrated on the midpoint of the conductor and depreciates as the inner radius of the insulator increases. The maximum electric field strength is found to be 4.616V/mm with reference to figure 3 and 4 in the Appendix. This results tally with the calculated electric field strength on the design.

How about in the region of bushing entry into the wall?

Figure 5 in the Appendix showcases the voltage against the distance within the insulator. It is observed that the voltage depreciate on a linearly manner from the higher potential within the insulator to zero at the surface of the insulator.

4.2 Point Charge Flash Over Test

Since the point at the end of the conductor will be free of insulation, their electric field strength will have at that point which can result in the flashover in the air insulation within the closest wall is broken. This test will therefore be used to determine if the system inside the chamber will withstand lightning impulse without flashover. The model shown in Figure 7 on the Appendix was used.

Figure 7 on the Appendix showcases the results obtained from the simulations. It is observed from the graph that when the length is equivalent to the displacement between the conductor point and the wall, the wall is moved to the potential of 200kV, this results shows that the flashover will occur in the ground.

5. CRITICAL ANALYSIS

The electric field strength on the surface of the conductor was observed to be from the simulation is found to be 2.077 kV/mm. This shows that the flashover will not occur since the air insulation breakdown at the electric field strength of 3.00 kV/mm. The creepage distance for outdoor and indoor bushing were calculate and used to determine the number of sheds necessary for each side. The number of sheds for both indoor and outdoor were calculated to be 22 and 11 respectively. The design was capable of meeting the IEC standards for the projection ratio, creepage factor and profile factor. The clearance using lightning impulse calculated to be 950.57cm, the flashover will also not occur in this stand since the the bushing is 1370mm above the ground. The insulator was not able to withstand the high impulse voltage exerted by the lightning.

6. FUTURE RECOMMENDATIONS

It is was observed in the that the lightning strike at the voltage of 500kV will cause the flashover inside the climate chamber, due to time constraint the mitigation action was not introduce but it is recommended in the future to use method such as application of corona ring. The voltage rating of the bushing can be further increased by minimizing the shed spacing spacing to projection which will eventually increases the creepage distance.

7. CONCLUSION

The design and simulation of the high voltage bushing for the climate chamber is presented. The bushing designed has the outer radius of 79mm and the insulation thickness of 44.513mm. The length of the bushing was selected to be 2.5m, with 1.00m on the outside and 1.50m on the inside of the chamber. The clearance was calculated to be 950.57mm which is satisfied by the bushing since it is 1370mm above the group. Sheds to overcome the leakage current were designed. It was observed that the bushing fails to withstand the impulse voltage of the lightning. Methods such as capacitor grading to reduce the electric field.

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Appendix A

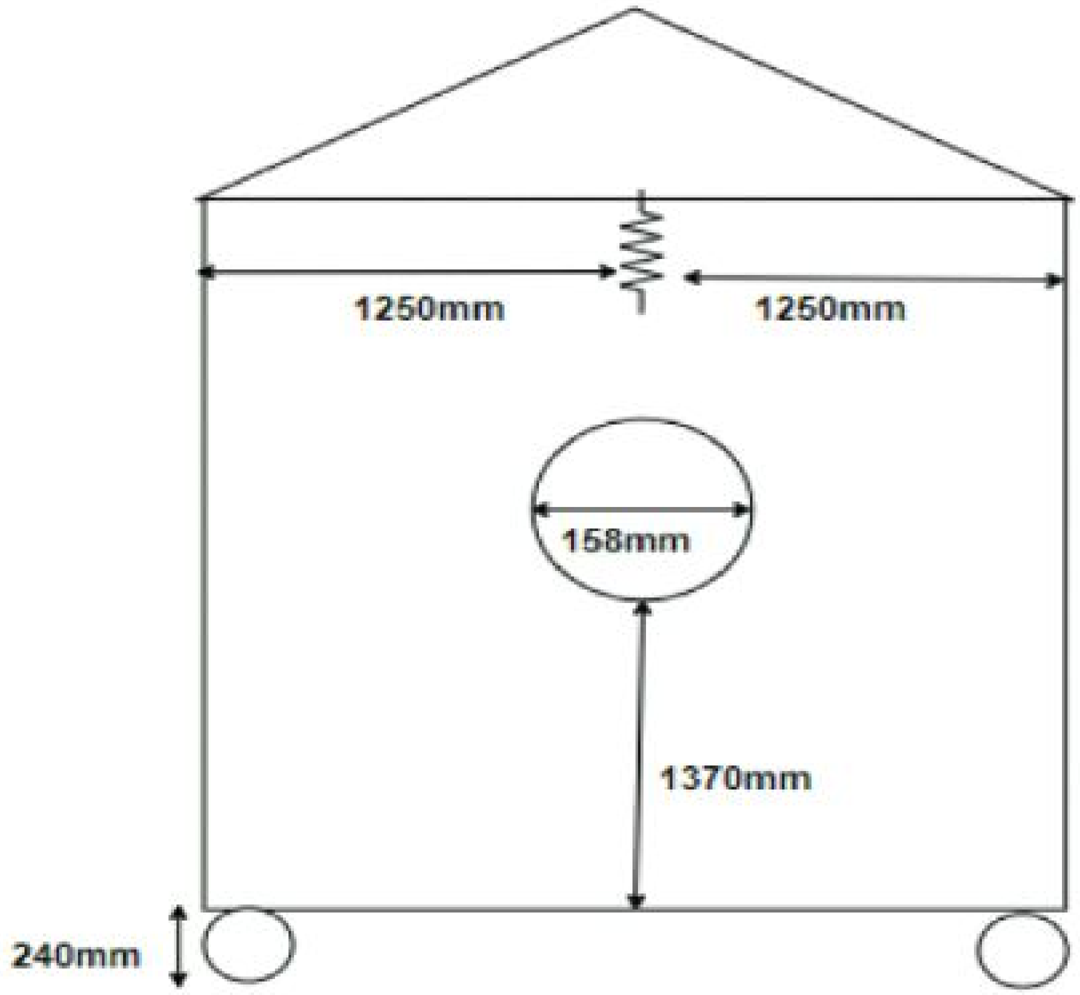

Figure 2: Side view of the climate chamber

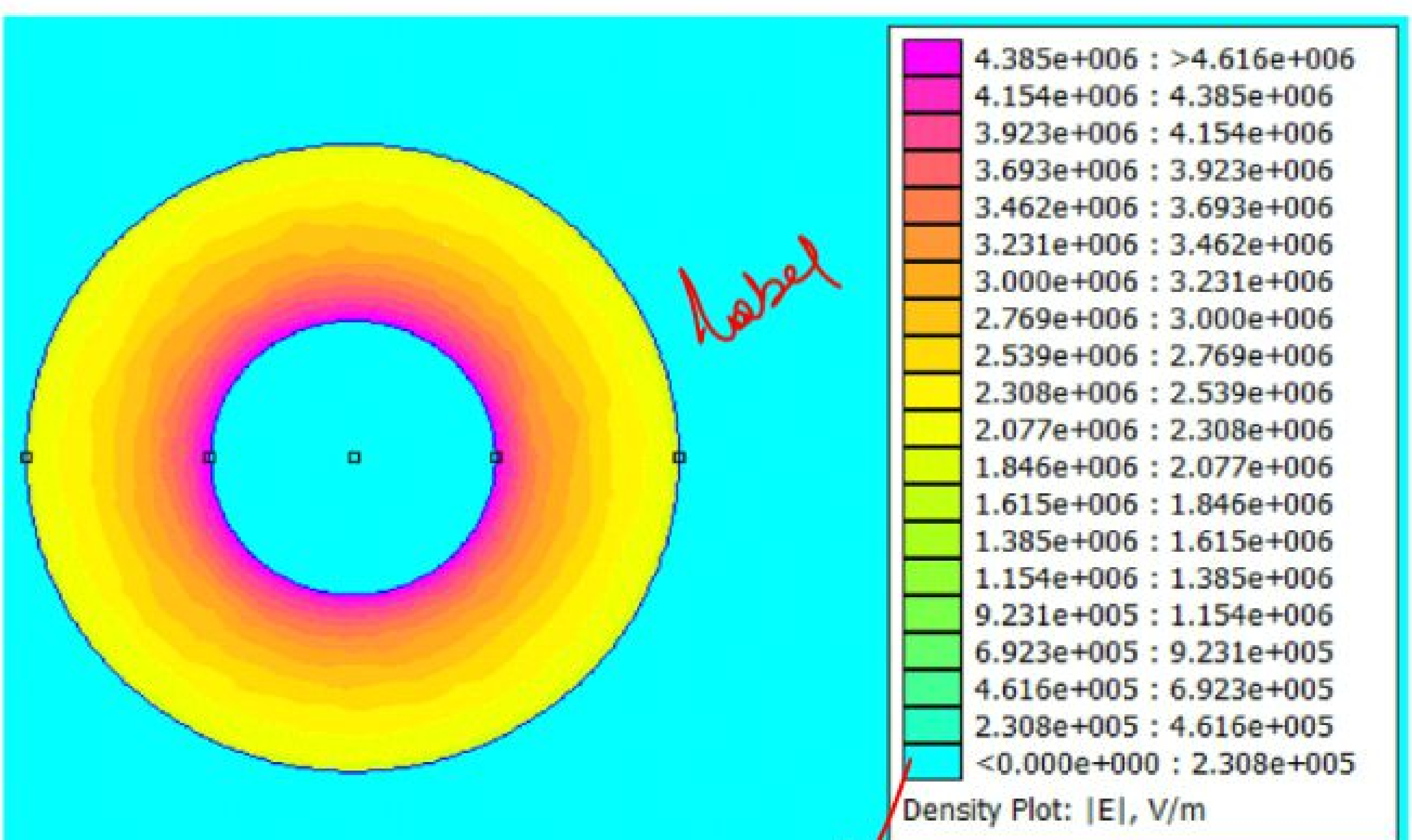

Figure 3: Tested bushing electrical field strength with distance.

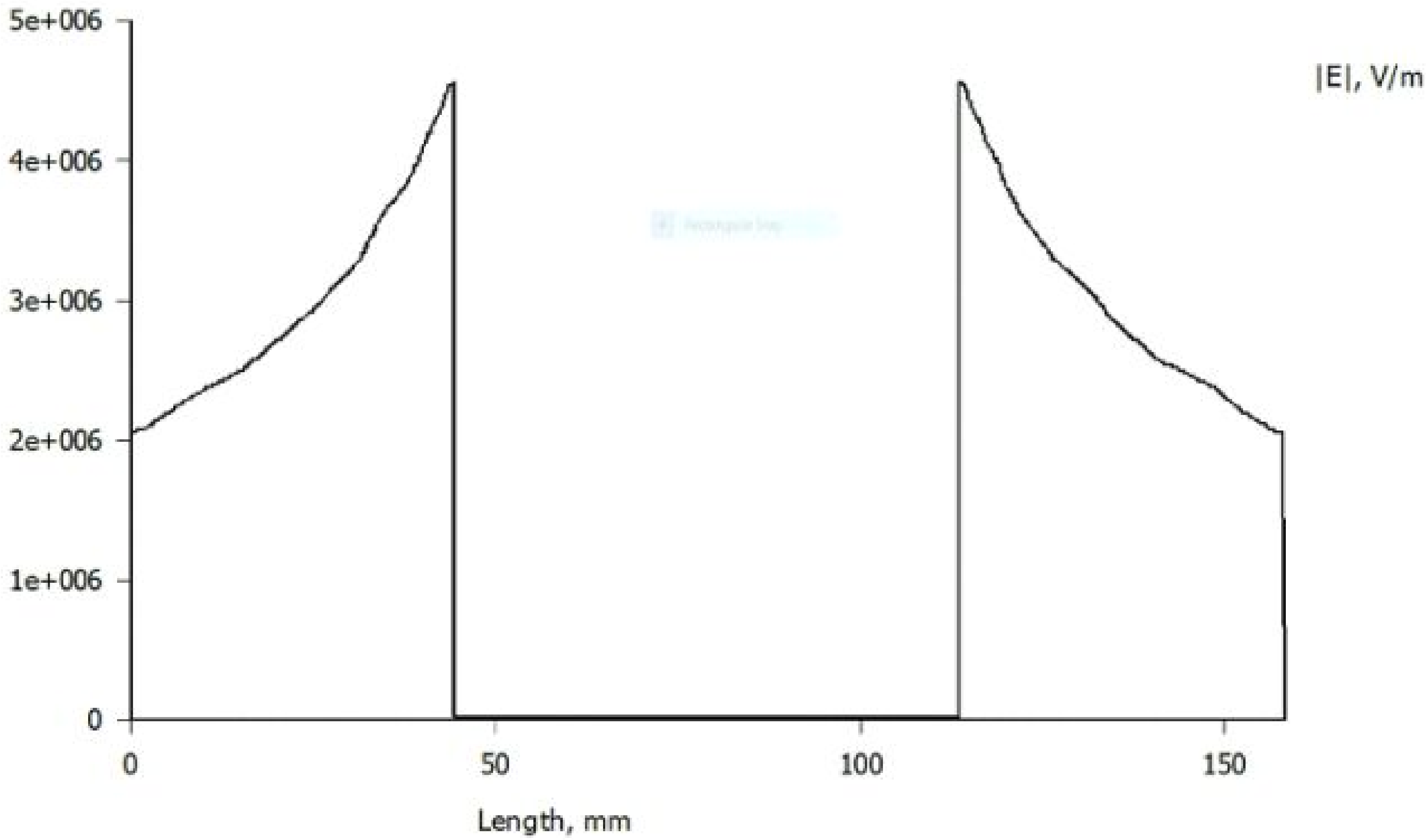

Figure 4: Change in electric field strength with distance change.

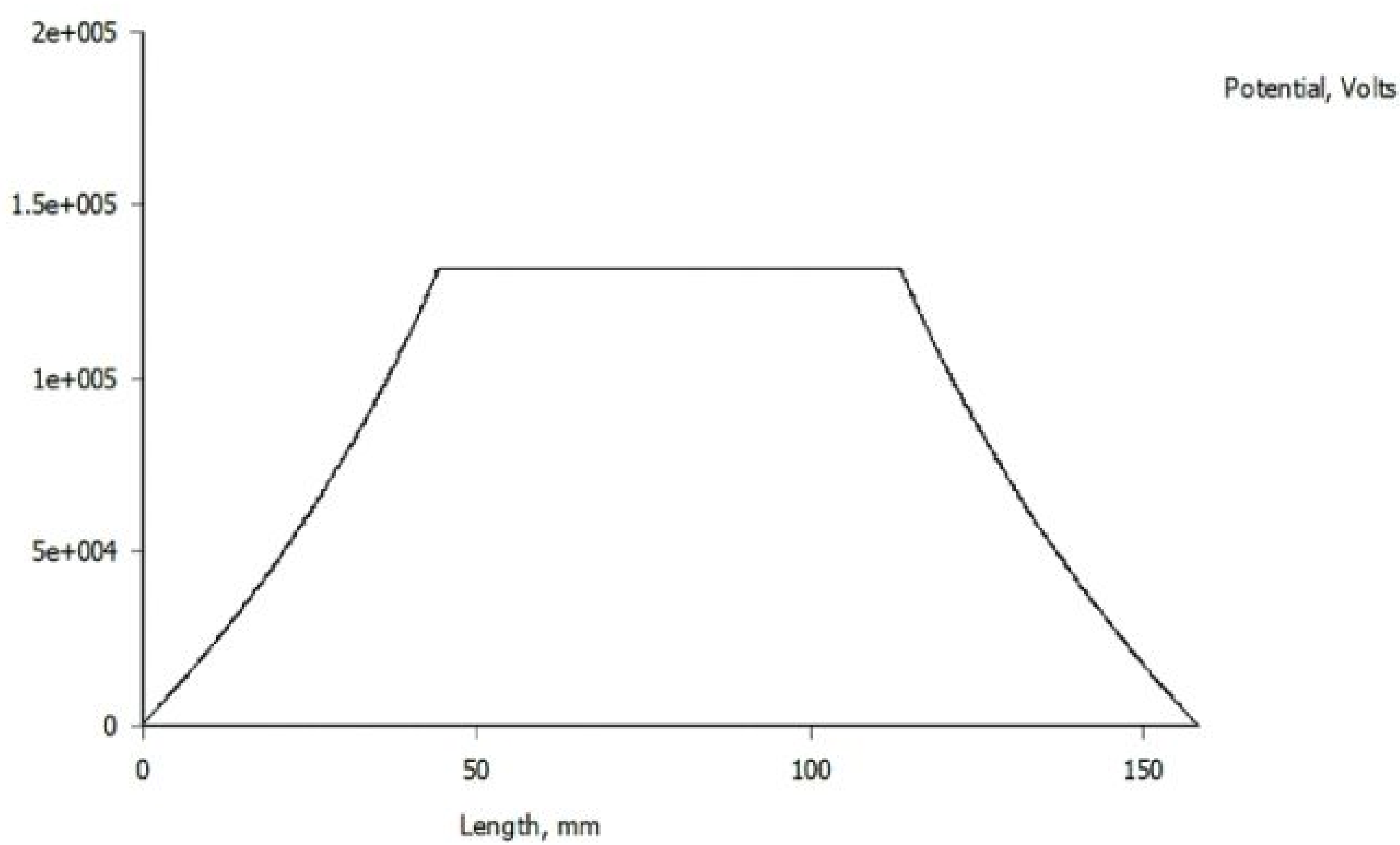

Figure 5: Change in voltage strength with distance change.

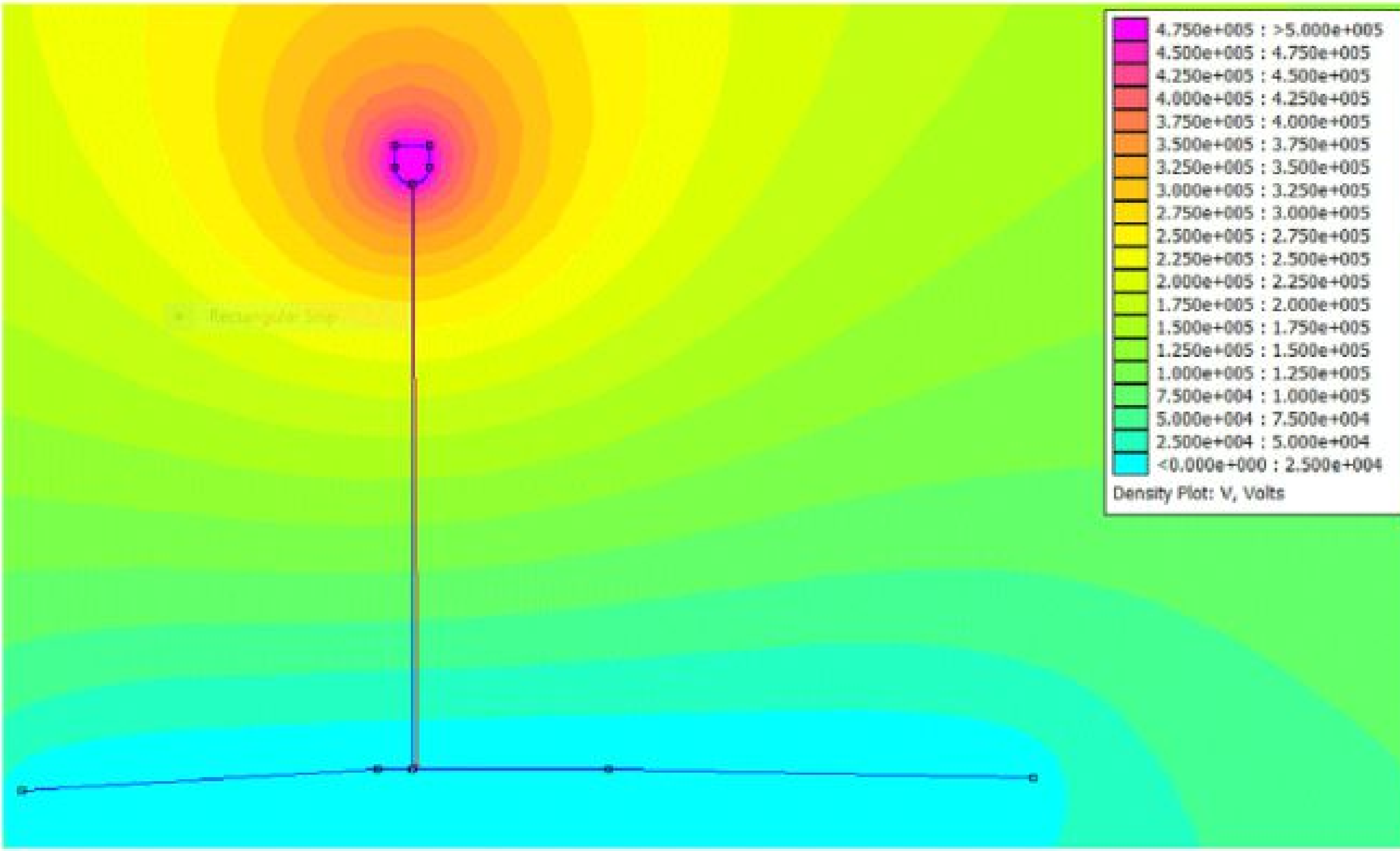

Figure 6: Change in electric field strength as the wall to conductor distance increases.

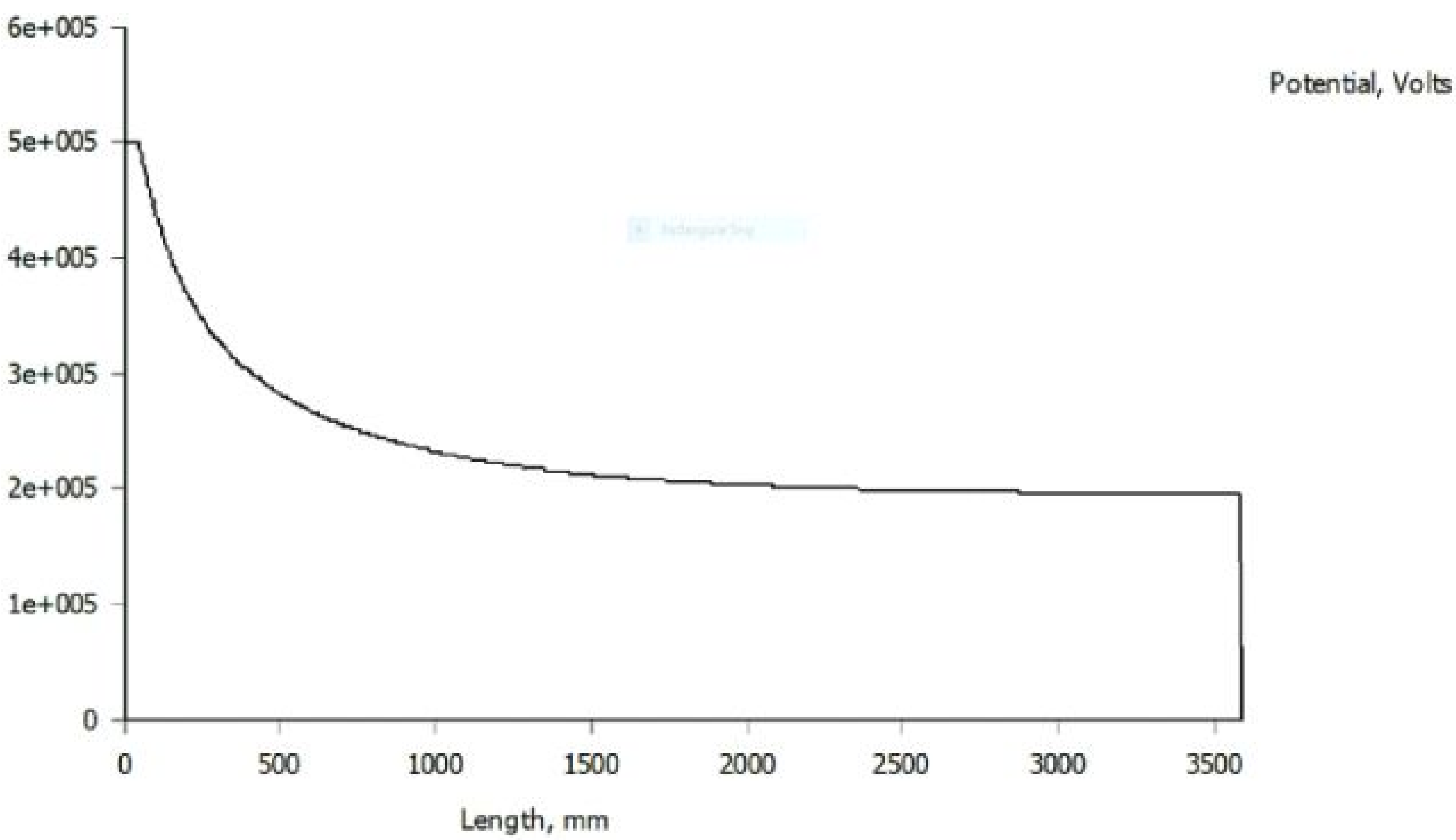

Figure 7: Change in voltage strength with distance change.