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132kV Oil Impregnated Paper Bushing Transformer - Design by CAD, Analysed by FEM

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Abstract The Electric Field and Voltage Distribution (EFVD) are an important parameter for assessing high voltage bushing transformer performance. However, conducting laboratories experiment is dangerous, difficult and expensive due to several aspects. Therefore, Finite Element Method (FEM) software is the best option used as a tool for the assessment of bushing transformer's performance in terms of EFVD. But, before an assessment of analysis could be carried out, an accurate model of bushing transformer must first to be designed. In this research, Computer Aided Design (CAD) software has been employed to design the 145kV bushing transformer based on actual dimension. Upon completion, the design has been exported to FEM software for further analysis. In FEM software, measurement and analysis of electric field and voltage distribution (EFVD) have been carried out. The measurements are performed at various locations of bushing transformer such as of the porcelain surface (both air and oil side), along with aluminum foils, and at oil-impregnated paper (OIP). The results obtained have been compared with other researchers and it is found very satisfactory.

Keywords Bushing Transformer, Oil Impregnated Paper, FEM, CADCAM, Electric Field, Voltage Distribution

1. Introduction

Transformer is the most important and expensive item in electrical power system. The price of transformer depends on its kVA or MVA rated value. The higher kVA or MVA value is, the higher the price of transformer is. Transformer used to step up the value of voltage or vise versa. Stepping up transformer or power transformer normally used at generation station increases the value of voltage before transmitting it to many places. Normally, the values of voltage practices by Tenaga Nasional Berhad (TNB) for their transmission are 132kV, 275kV and 500kV. On the other hand, stepping down transformer or distribution transformer is used to reduce the value of voltage depending on consumer requirement. Normally, the values of voltages are 33kV, 11kV and 415V.

Transformers are categorized according to their insulation methods. There are two categories of insulation method, gas, oil and air [1]. In gas insulated transformer, gas sulfur hexafluoride or notably recognized as SF6 is used as an insulation medium. For oil-filled transformer, oil is used as an insulation medium. However, for dry-type transformer, surrounding air becomes an insulation [2]. The choice of transformer to be employed normally depends on the needs, situation of the installation and the value of the financial investment. All types of transformer have their own advantages. Cast resin type, normally used to step down voltage of 11kV to 415V. But, for transformer at the rated value of 33kV and above mostly an oil type is due to its efficiency, greater overload capability, and longer service life. Meanwhile, gas insulated transformer can be used for voltage 20kV-500kV and reported to have an extra advantages [3].

Transformer 132kV is normally located at Main Intake Substation. It is used to step down the voltage to several values before transmitting it depending on user's requirement. 132kV oil-filled transformer consists of several important parts such as winding core inside transformer, bushings for incoming and outgoing, breather, Buchholz relay and oil tank. All of this part has been shown in Figure 1 [4].

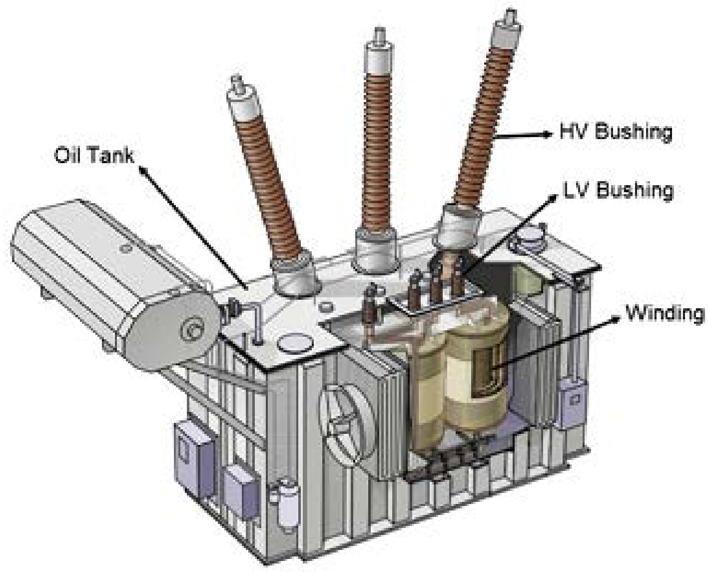

Figure 1. Power transformer

Bushing transformer is one of the fundamental components of high voltage power transformer. **Figure 1** shows the position of bushing transformer. As depicted there, high voltage bushings are the connection between an incoming line and low voltage bushing and the connection for an outgoing to the lower voltage. There are three types of main insulation in bushing transformer [4]; polymer, resin impregnated paper (RIP) and oil impregnated paper (OIP). In this paper, only OIP types of bushing transformer will be discussed. High voltage bushings are an integral part of electrical equipment for carrying one or more high-voltage conductors through a grounded barrier, e.g. a transformer tank or wall [4]. Therefore, bushing must be designed by researcher to have the ability to cater various stresses such as electrical, mechanical, thermal and environment stress [4-7].

Electrical stress is the most important type of stress to be considered compared to other stresses as mentioned above [8]. It is reported that, 25% to 30% failure of bushing transformer contributes to transformer failure [9]. Hence, it is important to study and analyze the effect of Electric Field and Voltage Distribution (EFVD). There are several researches but found very little focusing on bushing transformer [1-6]. Most of the researchers shared their EFVD results to be discussed [1-2,4-8], however most of their analyses are based on their respective country which are the value of voltages that are different compared to Malaysia. Hence, in this paper, the design process of bushing transformers using CAD software will be briefly discussed. It is important to have a proper and accurate bushing model because, with this developed model, many researches or studies on transformer bushing can be done easily in the future [10].

Then, finite element method (FEM) software is employed to evaluate the performance of EFVD for 132kV OIP bushing transformer. The results from simulation show good agreement with several results from [4-7].

2. Methodology

In this, a description of the research method will be described. Detailed dimension for bushing transformer is also given and an important equation for analyzing EFVD using FEM is also discussed.

2.1. Designing of Bushing Transformer using CAD

Computer Aided Design (CAD) software was used to design the bushing transformer model. The dimension for bushing transformer including the arrangement of foils dimension is taken from [4]. It is a modelfrom ABB company ofGOB 145kV OIP type. The structure of bushing transformer and its etails of dimension is shown in **Figure 2**. The construction of bushing transformer consists of these six main parts and it is shown in **Figure 3**. It consists of air, oil, conductor, porcelain, aluminium foils and oil impregnated paper (OIP). On the other hand, **Figure 4** shows the dimension used to design the bushing sheds.

The design in CAD is carried out in 2D drawings. For this reason, EFVD analysis was also performed in 2D using FEM software. However, the bushing transformer design must be done with caution because if something goes wrong for example there are two overlapping lines, it will produce the wrong result.Therefore, the use of the CAD command especially "zoom in" and "zoom out" must be fully utilized. All of these parts must be designed separately. When all is done, they are then integrated into these six sections to form a complete bushing transformer.

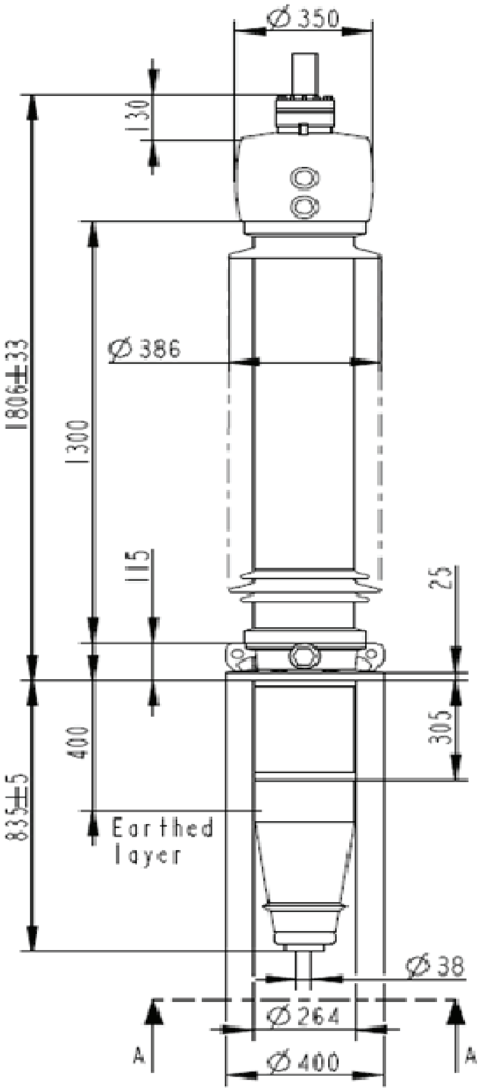

Figure 2. Dimension for bushing transformer [4].

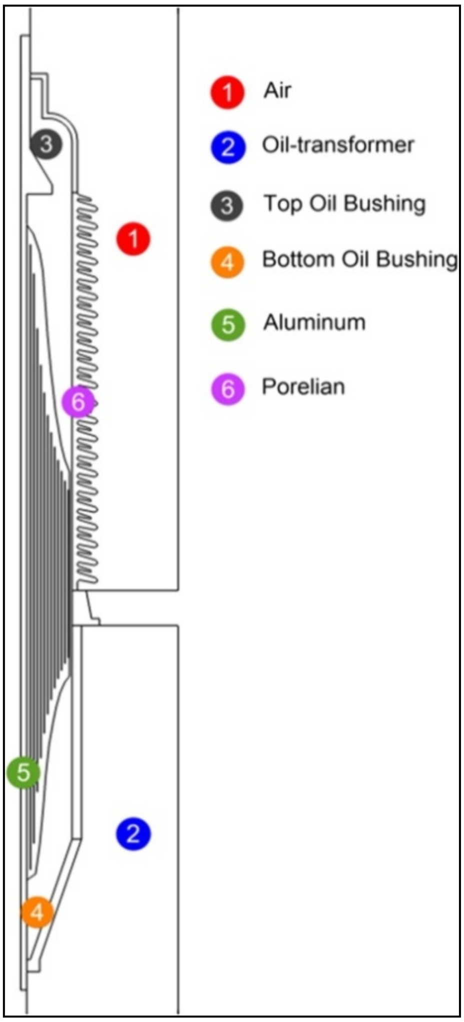

Figure 3. Six main important parts in bushing transformer [7]

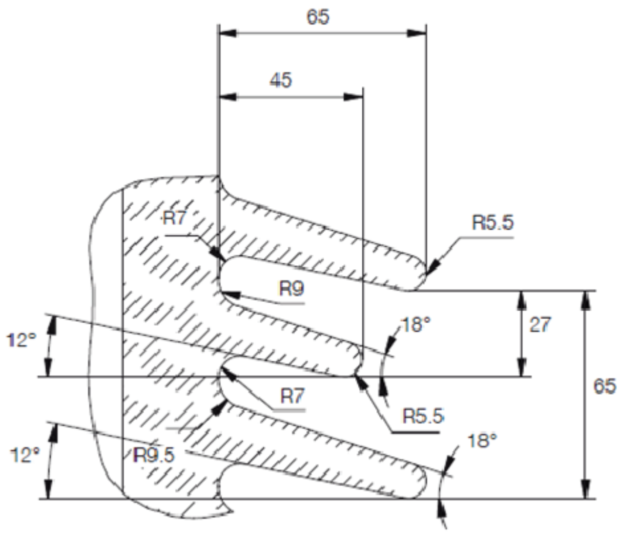

Figure4. Detail dimension for bushing sheds.

The design of the 2D bushing transformer is considered successful if it can be transformed in 3D drawings in CAD software itself. The transformation from 2D to 3D drawing is by using the "rev" command**.**

2.2. Analysis of Bushing Transformer using Finite Element Analysis

Finite Element Method (FEM) software using a numerical method is used to solve problem in engineering and mathemathics. It is useful to solve problems with complicated geometries, loadings, and material properties where analytical solutions can be obtained. The module of FEM used to simulate was AC/DC electrostatic model [11]. Maxwell's equation will be employed to determine the potential and electric field [4,6-7]. Hence, the electric field potential developed by electric field is written as follows;

$$E = -\nabla V \quad (1)$$

From Maxwell's equation;

$$\nabla . E = \frac{\rho}{\varepsilon} \quad (2)$$

where ρ is charge density, ε is permittivity of dielectric material ($\varepsilon = \varepsilon_o \varepsilon_r$), ε_o is air or space permittivity (8.854×10^{-12}) and ε_r is relative permittivity of dielectric material. By substituting equation (1) into (2), the Poisson equation can be obtained as in (3).

$$\nabla^2 V = -\frac{\rho}{\varepsilon} \quad (3)$$

By making the space charge, ρ = 0, the Laplace equation can be obtained.

$$\nabla^2 V = 0 \quad (4)$$

The properties of the materials used in the simulation have been shown in Table 1 [ss].

Table 1. Subdomain material permittivity

Domain	Relative Permittivity, ε_r
Air	1
Oil	2.2
Porcelain	5.5
OIP	4
Foils	10^8

Upon completion, the bushing conductor and the first foil near to conductor are taken as an electric potential. The value for electric potential is 83.7kV (phase to ground) and frequency is 50 Hz. Aluminum foils, OIP boundaries and porcelain sheds are set to continuity because the bushing is exposed to air and oil. Meanwhile, air and oil outer boundaries are set as electric insulation. The last foil and metal flange are grounded. Analysis is carried out by 2D electrostatic FEM.

3. Results and Discussion

In this section, results for electric field and voltage distribution are given. All the results are briefly discussed. For information, arc length is measured in millimeter (mm).

3.1. Electric Field andVoltage Distribution

Figure 3 shows the simulated results for electric field and voltage distribution in the OIP bushing transformer.The length of the first foil which is near the conductor is the longest with 1900 mm. However, the length for subsequent foils keeps decreasing until the last foil is near to the bushing flange. It is important to ensure the voltage distribution almost evenly.

Table 2. Specification of aluminium foils and voltage distributionfor bushing transformer

Foil Number	Length of foils (mm)	Spacing between foils	Voltage (kV) Line to Earth	Voltage difference between two foils(kV)
1	1900	32	73.54	11
2	1728	43	65.62	8
3	1390	54	58.13	7.49
4	1170	65	50.97	7.16
5	1010	76	43.9	7.07
6	880	87	37.36	6.54
7	780	98	30.53	6.83
8	710	109	23.83	6.7
9	645	120	18.06	5.77
10	595	131	12.09	5.97
11	550	142	5.631	6.459
12	510	153	0	5.459

Table 2 shows the result of voltagesat each foil. Since there are 12 foils, it can be seen, the voltage measured each foilreduced form 73.54kV gradually until 0V at foils number 12. The voltage differences between foils also distributed almost equally.

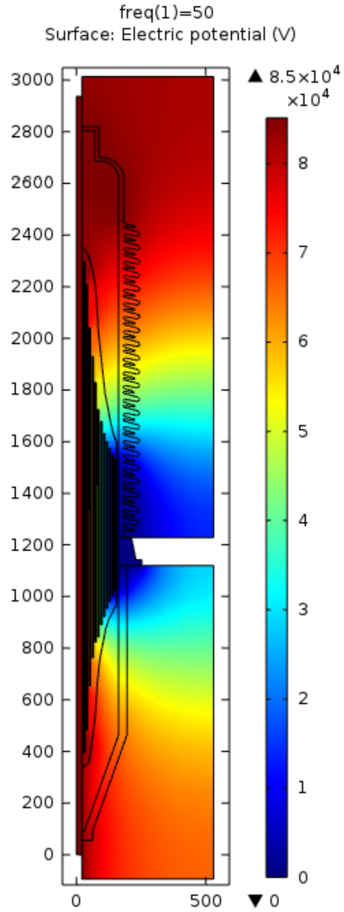

Figure 5. Voltage distribution for bushing transformer in surface plot

Figure 5 shows the voltage distribution in surface plot for voltage distribution for bushing transformer. **Figure 6** shows a surface plot for electric field distribution for bushing transformer. For voltage distribution, the stress is low at the bushing transformer flange. This is because the flange is connected to ground. The voltage distribution also distributed uniformly at each aluminium foil. On the other hand, for electric field, the intensity becomes higher especially at the sharp edge of bushing transformer.

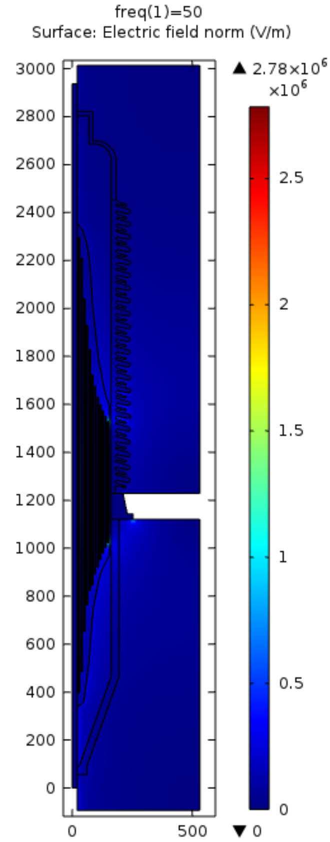

Figure 6. Electric field for bushing transformer in surface plot

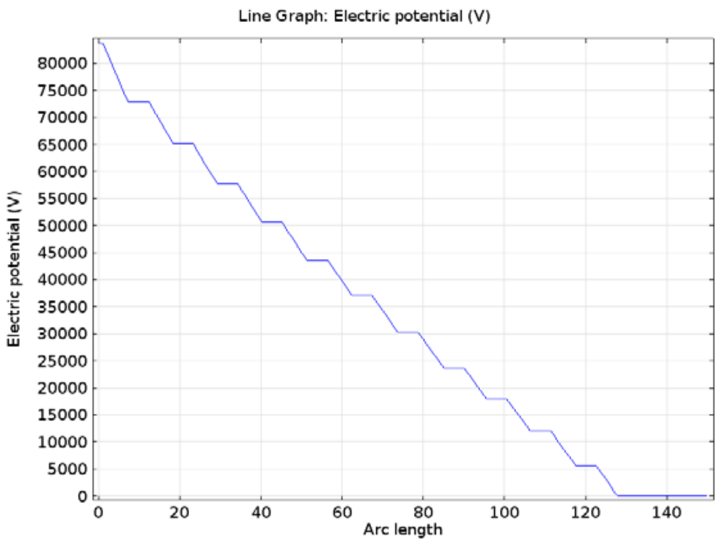

Figure 7. Voltage distribution along aluminium foils

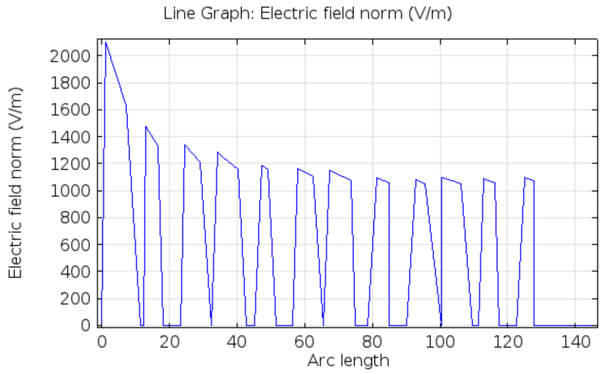

Figure 8. Normalized **e**lectric field along aluminium foils

The graphs plotted in **Figure 7** and **Figure 8**representthe measurement of voltage distribution and electric field respectively. The measurement is taken horizontally along at the aluminium foils and bushing transformer flange (at z=1076). It is shown clearly that the voltage distribution for bushing transformer begins with 83.7kV (phase to earth) at first foil, and decreases to 0V at the last foils.

On the other hand, in **Figure 8**, the electric field also has been distributed uniformly. Electric field is the most important parameter in designing bushing transformer. Hence, the foils are used to distribute the radial electric field inside the insulation so there is no particularly concentrated electric field stress at one point in insulation.

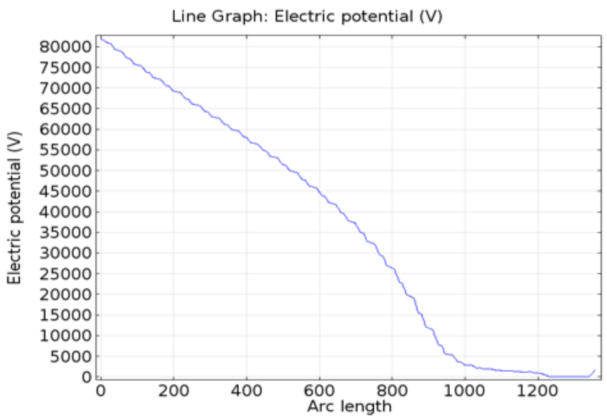

Figure 9. Voltage Distribution for bushing at upper porcelain along r=200.

Figure 9 and **Figure 10** shows voltage distribution and electric field along bushing porcelain at air side. It is measured vertically at r=200. It is important to consider porcelain for the analysis because it can affect the bushing design. In **Figure 9**, the point at which porcelain touches the conductor, gives the value of 83.7kV and the value keeps decreasing until 0V as the porcelain sheds touch the ground. Is is also clear that there is a variation in voltage along the porcelain sheds. **Figure 10** shows the graph for electric field. Electric field is an important parameter to be ascertained and correctly plotted.

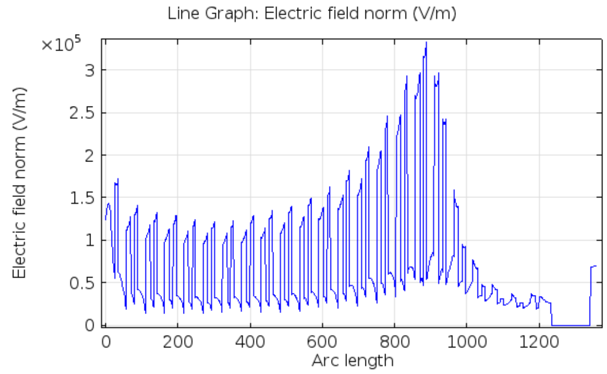

Figure 10. Normalized electric field for bushing along r=200.

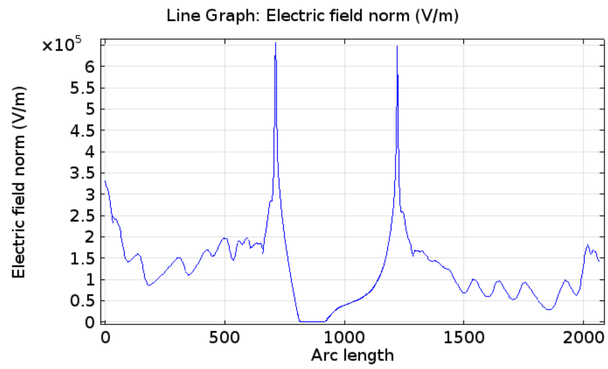

Figure 11. Electric field measured along OIP boundary

Figure 11 shows an electric field measured along OIP parts. But, as the OIP becomes parallel to foils, the electric field is zero. This is because, the parallel parts of OIP are connected to ground at the flange and last foil.

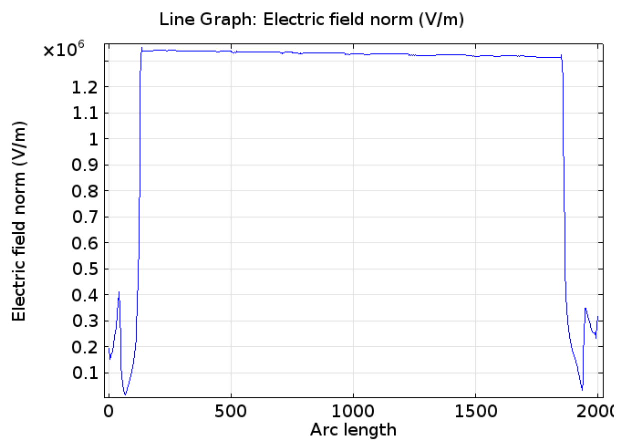

Figure 12. Electric field measured along foils (r=10, z=0)

In **Figure 12** an electric field was plotted vertically parallel to aluminium foils at r=10.

In **Figure 13**, the electric field is measured along foils at r=10. It shows that the axial electric field is zero inside the hyperbolic region of bushing, as it is shown straight line on the graph. However, at the edge of foils, there is an axial electric field stress.

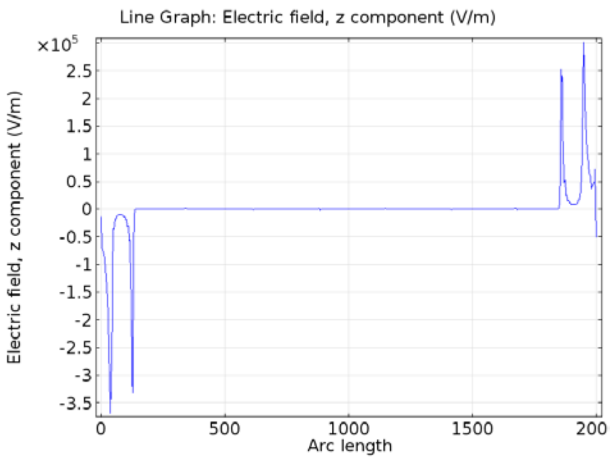

Figure 13. Norm Electric field measured along Z component (r=10, z=0)

4. Conclusions

From the research, we can c make several conclusions which are;

i. In this paper, 2D model of 132kV oil impregnated paper was successfully designed.

ii. The simulation of EFVD has been successfully carried out for 2D axial-symmetry geometry describing OIP bushing transformer.

iii. The results of EFVD show an agreement with other researchers.

iv. The designed 2D model can be used to further research activities in the future.

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