Electric field distribution in 132 kV one piece premolded cable joint structures

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Abstract— **Defect in a cable joint is one of the main reasons of a power system being faulty. A defect can cause the electric field in the cable joint to become higher than the material surrounding the defect. This may result in partial discharge (PD) activity to occur within the defect site. When PD is repeating at the defect site, the material surrounding the defect will be affected, where PD may extend its path in the material. This may result in a breakdown at cable joint and consequently causes breakdown on the whole system. Therefore, the purpose of this research is to study the electric field distribution in 132 kV one piece premolded cable joint with and without the presence of defects. A better understanding of the electric field distribution at a cable joint can be attained by modelling the cable joint structure using finite element analysis (FEA) method. Through modelling and simulation results obtained in this work, an understanding of the electric field distribution in defects within cable joint structure can be enhanced.**

Keywords-electric field, finite element analysis, high voltage cable joint

I. INTRODUCTION

Cable joint is one of the main reasons of a system being faulty due to the undesirable partial discharge (PD) phenomenon. PD occurs at a location where the electric field stress is very high [1, 2]. The structure of a cable joint has a significant influence on the electric field distribution at the cable joint. Therefore, the design of a cable joint structure is crucial to ensure the electric field distribution is not concentrated at certain parts to eliminate PD. This may enhance the performance and reliability of the cable joint.

A better understanding of the electric field distribution at a cable joint can be attained by modelling the cable joint structure using a finite element analysis (FEA) software, which simulates the electric field distribution in the cable joint for various types of defect. Through modelling and simulation, a structure of a cable joint which can improve the electric field distribution in the cable joint can be studied.

A typical type of high voltage power cable insulation used in power system is cross-linked polyethylene (XLPE), due to its technical and economic advantages, such as good electrical properties, simple structure and short manufacturing cycle [3]. This type of cable is used widely and universally in electrical transmission systems. However, the lifetime of XLPE cable is limited. This is mainly due to the degradation and breakdown of the cable, where the major factor which contributes to these events is partial discharge [4].

A cable joint, which connects between two high voltage cables poses two main problems. The outer conducting layers in both cables must be terminated without causing any field concentration and a field-free space should be created to accommodate the cut-down insulation and the connector of two conductors safely.

However, cable joint forms the weakest link in a power system. According to the cable failures and defect statistics of State Grid in 2008, excluding destroyed cables, 70% of cable failures were resulted from cable accessory fault [5]. Several reasons which contribute to cable joint failure are:

i. Inadequate manufacturing, such as internal contaminants or air gap.

ii. Poor installation workmanship, such as installation dimension error, destroyed semi-conductor layer or main insulation, contaminants or metal particles introduced by installation

iii. Interface defect between joint and cable insulations, such as inadequate enclasp forces leading to air-gap.

iv. Ageing of joint insulation, such as multi-stress aging of electric and thermal, moisture and chemical etching.

There are many types of defects at cable joints. Examples of the defect types are high potential metal tip, semi-conductor layer air gap, semiconductor layer tip, insulation incision, mental particle on XLPE insulation and axial direction shift at cable joints [5].

II. MODELLING OF HIGH VOLTAGE CABLE JOINT

A model geometry of 132 kV one piece premolded cable joint has been developed using FEA software. The model geometry was developed in two-dimensional (2D) axial-symmetric due to its symmetrical geometry. Figure 1 shows the cable joint model geometry that has been developed while Table 1 shows the relative permittivity of each component in the model.

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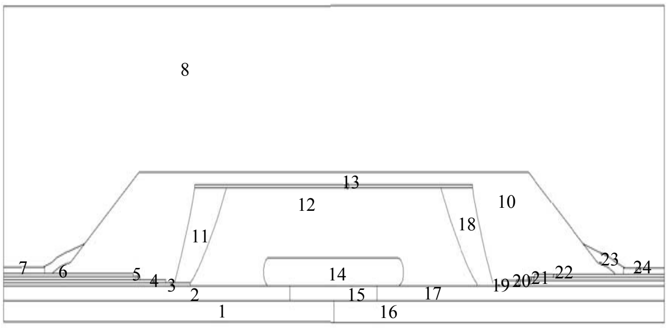


Figure 1. 132 kV one piece premolded cable joint model geometry

TABLE I. RELATIVE PERMITTIVITY OF PARTS IN 132 KV ONE PIECE PREMOLDED CABLE JOINT

Part	Relative permittivity
Copper conductor (1,16)	1
Semiconducting screen (2,4,15,20)	2.26
XLPE insulation (3,19)	2.3
Copper wire screen (5,21)	1
Lead sheath (6,22)	6.9
PE jacket (7,24)	2.25
Air (8)	1
Connector (9,23)	1
Tinsel braid screen (10)	6
Hard rubber insulation (11,18)	4.2
Rubber insulation (12)	3.6
Semiconducting screen (13)	100
Ferrule electrode (14)	1
Ferrule insulation (15)	50

The outer layer of the semiconducting screen is grounded, the ferrule electrode is set as a floating potential, the conductor is assigned with the applied voltage and the rest of the boundaries are continuity.

III. SIMULATION OF ELECTRIC FIELD DISTRIBUTION

In this section, the results of the electric field distributions using the FEA model for different types of cable joint defects are presented. The electric field distributions of cable joints with and without various defects are detailed and discussed.

A. Electric field distribution with defects

The simulation result of the electric field distribution from the FEA model of 132kV one piece premolded joint without any defect is shown in Figure 2. Figure 3 shows the electric field distribution in the cable joint model with various types of defects. Comparisons of the cross section plot of the electric field magnitude in the cable joint between the models with and without defects are illustrated in Figure 4.

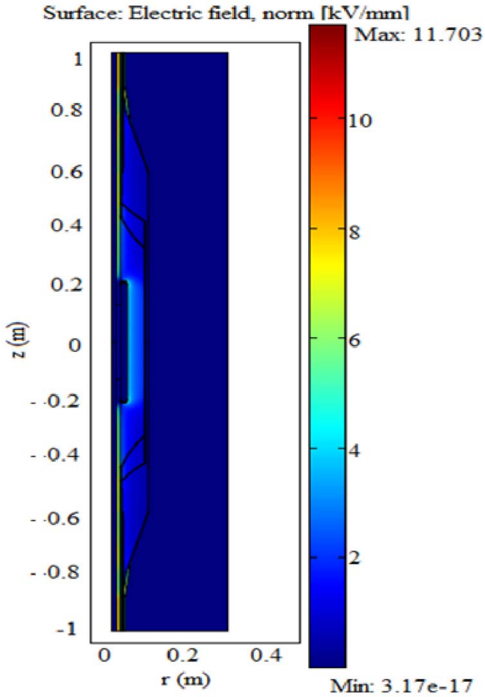
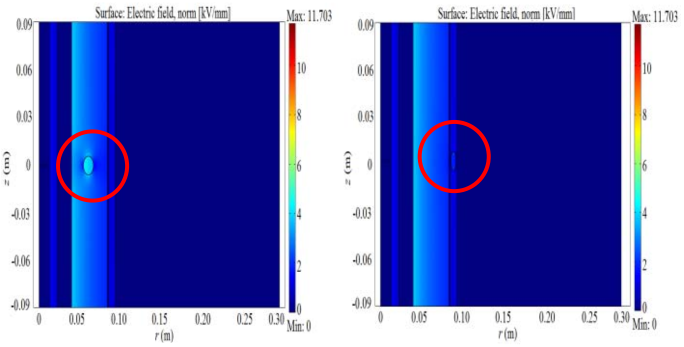


Figure 2. Simulation result of the electric field distribution in the model

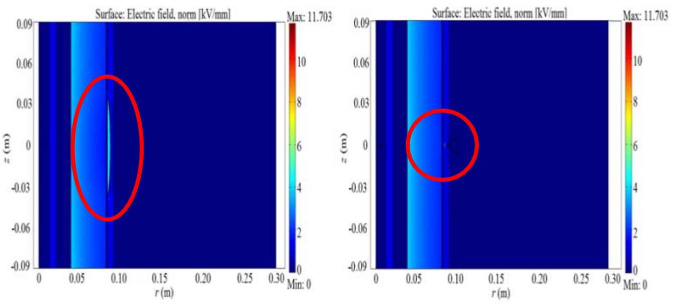
In Figure 2, the electric field at the cable joint (at where the two conductors meet) can be seen to be lower than the other region in XLPE insulation, as shown by the dark blue colour region. This is due to the placement of ferrule insulation and ferrule electrode surrounding the two conductors. A very high permittivity of ferrule insulation compares to XLPE insulation reduces the electric field at that region significantly. In order to insulate the ferrule electrode, a layer of rubber insulation is applied around the ferrule electrode. Therefore, this technique reduces the electric field magnitude around the two conductors at the cable joint.

Referring to Figure 3a, if a cavity exists in the rubber moulding of the cable joint, the magnitude of the electric field in the cavity is higher than the surrounding rubber moulding. This is due to the lower permittivity of air than the surrounding material [6]. For a cavity that exists in the tinsel braid screen, the electric field is higher than the tinsel braid screen, as shown in Figure 3b. A high region of the electric field is obtained when there is a delamination defect between the semiconductor and tinsel braid screen layers (Figure 3c). As shown in Figure 3d, a sharp tip on the outer surface of the cable joint causes the electric field at the sharp tip to become high.

All types of defects mentioned result in a high concentration of the electric field at the defect sites in the cable joint. These high electric field regions may lead to partial discharge (PD) phenomenon to occur. The type of PD depends on the type of defect that exists, such as void, corona and surface discharges. The repetition of PD events at the defect site may cause breakdown of a cable joint insulation when it bridges completely between the high voltage electrode and the grounded layer. This unwanted event may consequently lead to a breakdown of the whole system [7, 8].



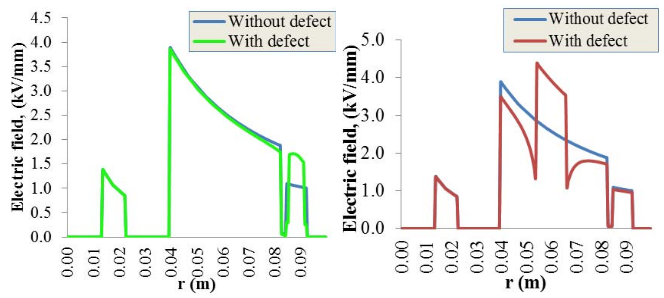
(a) Cavity in rubber molding (b) Cavity in tinsel braid screen



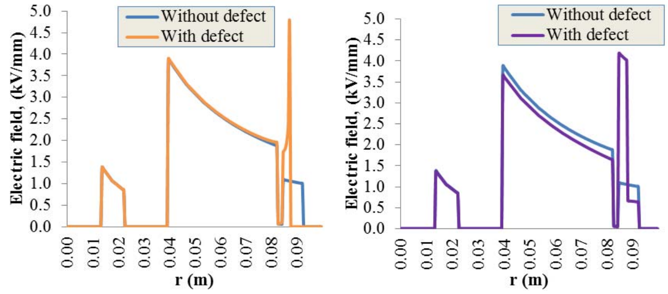
(c) Delamination between 2 layers (d) Sharp pin on surface

Figure 3. Simulation of electric field distribution with various defects from the FEA model

Figure 4 shows the cross section plot of the electric field magnitude in the cable joint between the models with and without defects. In general, the electric field in the model without defects decreases when the distance is further from the conductor. If a cross section plot along the z = 0 line is taken, from r = 0 to 0.013 m, the electric field is zero since this is the conductor region. In ferrule insulation region (r = 0.013 to 0.022 m), the electric field increases sharply at r = 0.013 m but decreases as it is approaching towards r = 0.022 m because of an insulation material. The electric field is zero between r = 0.022 to 0.040 m in the ferrule electrode because it has the similar characteristic with the conductor. Between r = 0.040 to 0.082 m, the electric field decreases gradually but drops to almost zero at r = 0.082 m due to a very high permittivity of the semiconductor screen (permittivity is 100). On the outer surface of the cable joint, where r is larger than 0.09 m, the magnitude of the electric field is zero.



(a) Cavity in rubber moulding (b) Cavity in tinsel braid screen



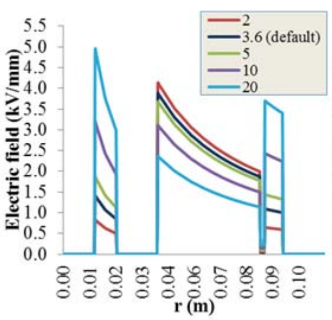
(c) Delamination between semiconducting Screen and tinsel braid screen (d) Sharp tip on the surface

Figure 4. Cross section plot of the electric field magnitude across the cable joint between the models with and without defect along z = 0 line

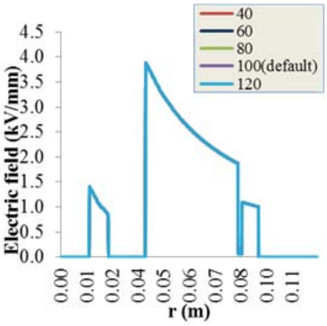
In Figure 4a, the electric field across the cavity (from r = 0.054 to 0.065 m) is higher than the electric field without defects while in Figure 4b, the electric field in the cavity (from r = 0.086 to 0.090 m) is also higher than the electric field without defect. Each cavity in Figures 4a and 4b causes a high concentration of the electric field due to a lower permittivity of air in the cavity, which may lead to void discharges. Delamination between semiconductor screen and tinsel braid screen causes the magnitude of the electric field to increase drastically, as shown in Figure 4c, along r = 0.085 to 0.088 m. This type of defect can be the source of void and surface discharges along the delamination boundary. In Figure 4.3d, a sharp tip introduces a high electric field region along r = 0.085 to 0.088 m. Electrical discharge may occur from the sharp pin in the insulation material if the breakdown strength of the insulation material is exceeded at the sharp pin region.

B. Effect of material permittivity on the electric field

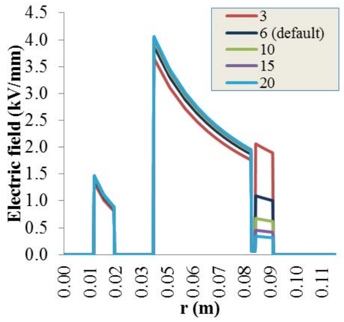
Figure 5 shows the cross section plots of the electric field magnitude across 132 kV one piece premolded cable joint with different values of permittivity of different insulation layers. The cross sectional region from r = 0 to 0.013 m consists of conductor, from r = 0.013 to 0.022 m consists of ferrule insulation, from r = 0.022 to 0.040 m consists of ferrule electrode and from r = 0.040 to 0.082 m consists of insulation layers. In Figure 5a, the permittivity of the rubber moulding layer (from r = 0.035 m to r = 0.082 m) is increased from 2 to 20. It can be seen that the electric field magnitude in the ferrule insulation and tinsel braid screen layer increases but the electric field in the rubber moulding layer decreases as the permittivity of the rubber moulding layer increases. The change in the permittivity of the semiconducting screen does not affect the electric field magnitude in the cable joint. However, when the permittivity of the tinsel braid screen is increased, the electric field magnitude in ferrule insulation and rubber moulding layer increases but decreases in the tinsel braid screen. In general, the change in the permittivity of certain material in the cable joint affects the electric field magnitude in the neighbouring regions of that material.



(a) Variation of rubber moulding layer permittivity



(b) Variation of semiconducting screen permittivity



(c) Variation of tinsel braid screen permittivity

Figure 5. Comparison of different material permittivity values for different insulation layers in 132kV one piece premolded joint model

C. Effects of material permittivity on a cavity's field

To study the effect of the material permittivity on the electric field within a cavity in the cable joint, a cavity with a constant radius and location is introduced in 132kV one piece premolded cable joint model. The magnitude of the electric field in the center of the cavity is obtained by varying the surrounding insulation layer permittivity. Figure 6 shows the plot of the electric field in the center of the cavity when the surrounding insulation material permittivity is increased. From these results, the magnitude of the electric field within the cavity decreases as the material permittivity is higher. A permittivity is a measurement of resistance that is encountered when electric field is formed within the material. With a higher permittivity value, the electric field is harder to be formed. Thus, the electric field within the cavity is smaller when it is surrounded by a higher permittivity of the insulation layer.

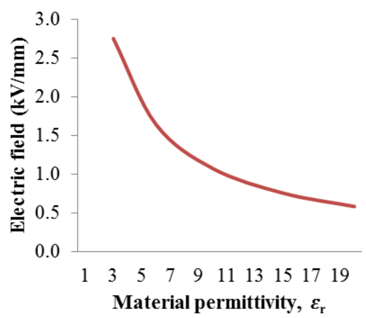


Figure 6. Electric field within the cavity versus material permittivity

IV. Conclusions

In this project, a two-dimensional axial-symmetric model geometry of 132 kV one piece premolded cable joint has been developed using finite element analysis (FEA) software. The model has been used to simulate the electric field and electric potential distributions within the cable joint with and without defects.

From the simulation results, all types of defect distort the electric field distribution in the cable joint. When there are cavity and delamination defects within the insulation material, the electric field becomes higher than the surrounding material due to the lower permittivity of the cavity and delamination defect. A sharp tip increases the electric field at the tip within the material. These defects are the potential sources of partial discharges, which may cause the deterioration of the insulation medium and may lead to breakdown of the cable joint. Thus, reducing the electric field magnitude in the cable joint is crucial in ensuring the reliability of the power system.

The study also shows that material permittivity plays an essential role in determining the electric field distribution within the cavity at the cable joint. A higher insulation material permittivity yields lower electric field magnitude within the cavity in the insulation. Therefore, one of the criteria important for cable joint design in reducing the electric field magnitude is higher insulation material permittivity.

Future work will consider the electric field distribution at the cable joint under transient condition, when a fault occurs in the system.

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