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A MV CABLE JOINT ELECTRIC FIELD REDUCTION

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Abstract: *Improved construction medium voltage XLPE cable joints were explored. In order to reduce maximum electric field inside the joint, some of the construction parameters were examined, such as permittivity and number of layers of the heat shrinkable tubes (HST) forming the joint. Termination angle of the cable insulation and the ferrule insulation permittivity were analyzed too.*

Key Words: *Power cables/ Electric field reduction*

1. INTRODUCTION

Extruded polyethylene (XLPE) cables are in widespread use for many years. Reliability of a long cable line depends mainly on the reliability of the cable joints. Electric field is confined inside the cable and may be very complex inside a joint. Good cable joints reduce power loss and in the same time limit a possible electromagnetic field influence on the environment. Different cable joints are in use, most often with capacitive-geometric, refractive or resistive control of the electric field inside the joint. This work is an effort to combine geometric and a high permittivity regulation of the electric field. Cable joints can be prefabricated [1], cold shrinkable or heat shrinkable, but they are always assembled on sight. Good electrical performances of the cable joints depend strongly on technicians' skills. Often, the termination angle θ of the cable dielectric (See Fig. 1) is made in accordance with their individual experiences. This research gives guidelines on how to cut the cable dielectric in order to reduce the electric field inside the joint. The field was calculated using a finite element method program COMSOL. The calculations explored:

- shape, thickness and permittivity, ε, of the different layers inside the joint and
- boundary angle θ of the cable insulation.

Good electrical parameters prevent overheating of a joint and enable good current caring capacity [2]. Hot spots very often coincide with maximum electric field. In order to optimize the cable joint parameters, two criteria were monitored – total electric field magnitude, E_{max}, and magnitude of the tangential component, E_{tan}. The main goal was to reduce the electric field magnitude, E_{max}, inside the joint. In the same time it was desirable to reduce the tangential component parallel to the dielectric boundary surface, E_{tan}. The area affected by an increased field was also evaluated.

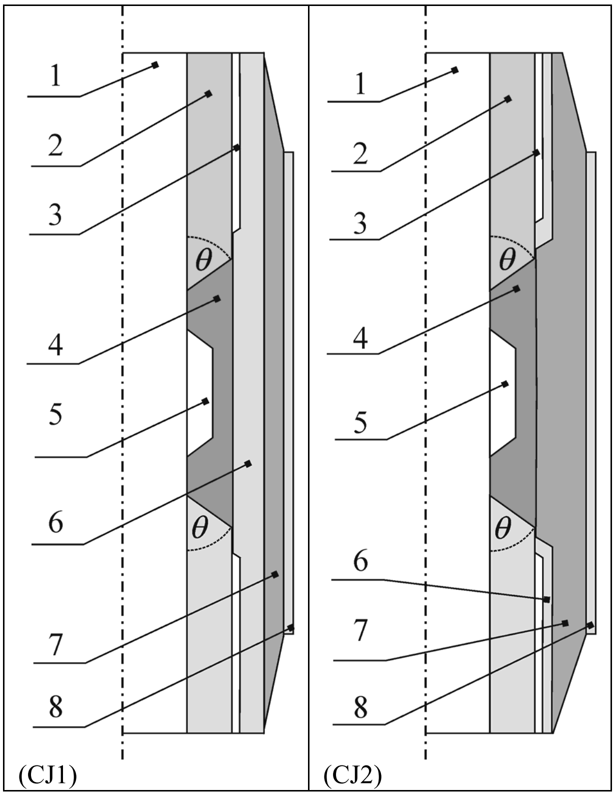

Fig.1. *Medium voltage cable joint constructions: CJ1-left, CJ2-right. Legend: 1-conductor, 2-dielectric, 3-cable screen, 4-ferrule insulation, 5-ferrule, 6-increased permittivity layer, HPW, 7-EP rubber, 8-semiconductive layer. HST1: 6+7+8. HST2: 7+8.*

2. MATERIALS AND METHODS

Fig.1 illustrates the two geometries considered. In order to investigate how some of the parameters affect the electrical performances of the joints, the designs are slightly simplified compared to the real constructions. The Fig.1 is not to scale; please see Tables 1 and 2 for the details. The first type of the joint, labeled CJ1, was designed with three-layer heat shrinkable tube, HST1. The inner layer of the HST1 was made of a high permittivity (ε_{S1}) material. The second type of the joint, labeled CJ2, was designed with a different high permittivity (ε_{S2}) wrap, HPW, covering only the top of the cable screen edge, under the two-layer heat shrinkable tube, HST2. The thickness of the high permittivity material was explored in the range of 1 to 3 mm.

Table 1. *Manufacturing data for the Al/XLPE/PVC cable (1x120mm^2, 12/20kV)*

Conductor	Cross section (mm2)	120
	Material	Aluminum
	Diameter (mm)	15
Conductor screen	Thickness (mm)	0.5
Cable isolation	Material	XLPE
	Thickness (mm)	5.5
Isolation screen	Thickness (mm)	0.5
Metal screen	Cross section (mm2)	16
Outer PVC tubing	Thickness (mm)	2
	Outer diameter (mm)	34

Table 2. *Some data on the joints' parts (See Fig.1)*

Item	Geometry	Relative permittivity, ε_r
Dielectric end (2)	θ = 30°-90° Length 120 mm	2.3
Ferrule (5)	Length 100 mm diameter = 20 mm	1000
Ferrule insulation (4)		1-100
High permittivity layer and HPW (6)	1-3 mm thick	10-40
EP Rubber (7)	3 mm thick	3.4
Semi-conductive layer (8)	2 mm thick	100
Cable joint	Total length 350 mm	

The ferrule insulation was made of a rubber based mass with a good plasticity and a relative permittivity ε_F. The explored values of the ε_F were between 1 and 100, with more interest in the range of 5 to 10. The field was calculated for a different angle θ, ranging from 30° to 90°. The respective high permittivity layers (No 6 from Fig.1) had relative permittivity ε_{S1} or ε_{S2}, ranging between 10 and 40. Their thicknesses were between 1 and 3 mm.

3. CALCULATIONS AND RESULTS

Voltage distributions inside the cable joints were calculated using COMSOL finite element program. The cable conductor was set to 20kV. The cable screen was set to 0V. The voltage distribution was calculated from the Laplace equation in 2D cylindrical coordinates. One example of the voltage distribution of the CJ1 is presented in Fig.2. Once the voltage distribution is known, the data post processing enables calculation of the electric field magnitude.

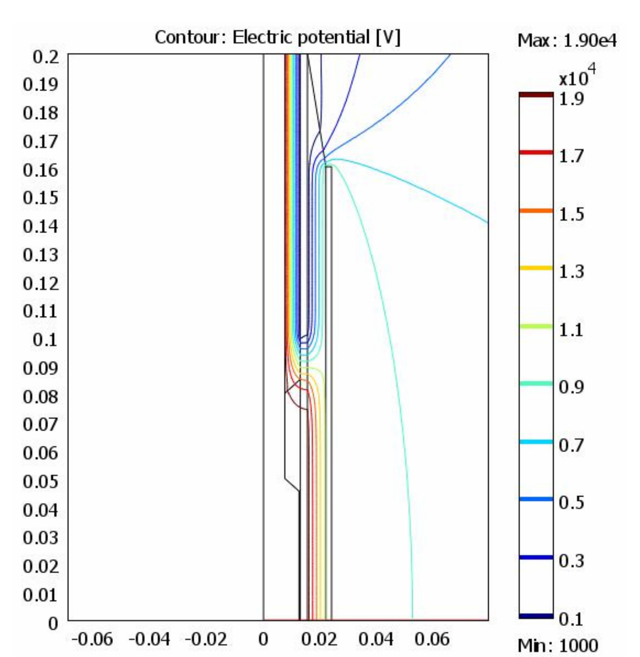

Fig.2. *Voltage distribution of the cable joint ($\theta = 47^o$, $\varepsilon_F = 5$, $\varepsilon_S = 10$)*

Both the CJ1 and the CJ2 were tested. Different geometries were tested with different layer permittivity but gave similar results. Finally, both joints were manufactured using the same high permittivity material for the layer No. 6 ($\varepsilon_{S1} = \varepsilon_{S2} = \varepsilon_S$). The electric fields inside the CJ1 and CJ2 followed similar patterns presented in Figs. 3 and 4. The three-layer HST1 was assumed more convenient for assembling rather than the two-layer HST2 plus an additional HPW on the top of the cable screen edge. The later design prolongs the installation time and introduces more probability for human error.

4. DISCUSION AND CONCLUSIONS

Improved cable joints were designed based on numerical calculations. The ferrule insulation permittivity, ε_F, was found to play an important role in the field regulation. Its increased value may force the electric field out from the ferrule insulation and locate it inside the narrow space below the heat shrinkable tube (HST). On the other side, lower ferrule insulation permittivity tends to reduce the voltage gradient on the top of the ferrule. Consequently, this shifted the main electric stress to the cable dielectric end, closer to the conductor. Larger θ (shorter termination cone in the end of the cable insulation) resulted in the lower total field magnitude. Smaller θ (longer cone) was found to reduce the tangential field component, but made the total field magnitude of the joint higher.

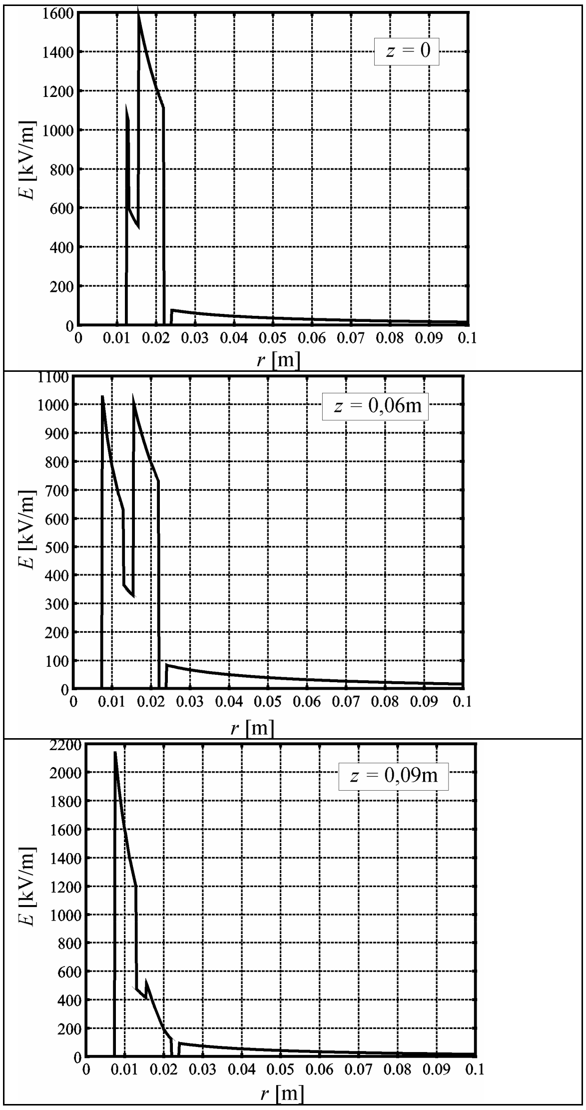

Fig.3 *The electric field magnitude for $\theta = 47^o$, $\varepsilon_F = 5$, $\varepsilon_S = 10$ at different heights, z*

The high permittivity layer (ε_S) was able to mediate the field. The values above 10 were forcing the electric field inside the layer to drop (Compare Figs. 3 and 4, at r=0.015m), but the total field magnitude to rise.

The electric field magnitude at the cable screen end was well enough controlled by only 1 mm thick layer. It was also able to reduce the tangential component of the field to acceptable values. Permittivity greater than 40 would affect the creepage distance and was not included in the study. The idea of the conductive or semi-conductive parts inside the cable joint did not prove right.

The electric field outside the cable joint was small. In the domain of interest it did not exceed the standard limit of 10V/m at 50Hz. Total electric field reduction outside the joint can be achieved by a conductive mesh on the top of the joint.

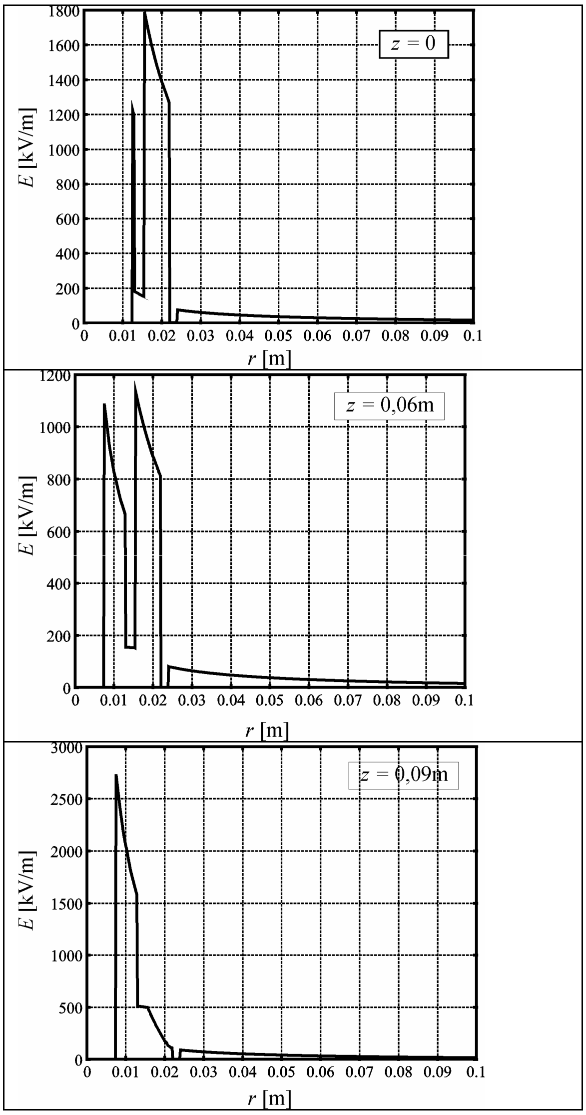

Fig. 4 *The electric field magnitude for $\theta = 47^o$, $\varepsilon_F = 5$, $\varepsilon_S = 40$ at different heights, z*

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5. REFERENCES

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