THERMO-ELECTRICAL MODEL OF A COLD SHRINKABLE JOINT FOR MV CABLES

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INTRODUCTION

Technology for MV cable jointing is changing : pre-molded slip-on or heat-shrink joints are gradually being replaced by cold-shrinkable products. This allows faster and easier installation.
A key point for the succes of this new technology is to ensure the reliability of the components.
We have investigated the long term performance of such a joint by modeling the operating electrical and thermal stresses for each element of the system and by evaluating the maximum stresses that the system can withstand in the long run.

DESCRIPTION OF A COLD SHRINKABLE JOINT

Fig. 1 shows a cross-sectional view of a cold-shrinkable joint installed on a typical MV cable : the area of the conductor connection is covered by a wrap-around semi-conductive plate which acts as a Faraday cage. Over the semi-conductive plate a layer of mastic with high dielectric constant is applied to smoothen the transition between plate and cable insulation. The 3-layer (from inside to outside : high dielectric constant "K", insulation and semi-conductive rubber) co-extruded joint body is shrunk on top of the cable and mastic. The areas of high field strength are indicated by E_1, E_2 and E_t.
Refer to [1] for more detailed description.

MATERIAL PROPERTIES

The electrical field distribution in the joint depends on the dielectric properties of the materials (dielectric constant). For some of the materials, these properties are field and temperature dependent.
On the other hand, the temperature distribution throughout the joint depends on the thermal properties of materials and surroundings and on the heat generation by the conductor (joule effect) and by the insulating and high K materials (dielectric losses).
To analyze such an interdependent system , a coupled dielectric-thermal model is needed. We used the Flux2D software [2].
The model has to be fed with data about the behavior of materials, in particular the high K materials (mastic and rubber layer) show dependency of their properties on temperature and field strength (Fig. 2 and Fig. 4), for the rubber layer also the elongation has some effect on the dielectric constant (Fig. 3) .

MODEL RESULTS

Using the materials data and the joint geometry, we modeled the field and temperature distribution in a cold shrinkable joint, installed on a 150 mm² 20 kV XLPE cable with :

- 12 kV applied on the conductor
- 100 °C and 120°C on the core of the cable
- 3 different thermal surroundings (air, wet or dry sand)

The maximum values of temperature and electrical field strength inside the joint's materials, resulting from the calculations, are given in table 1.

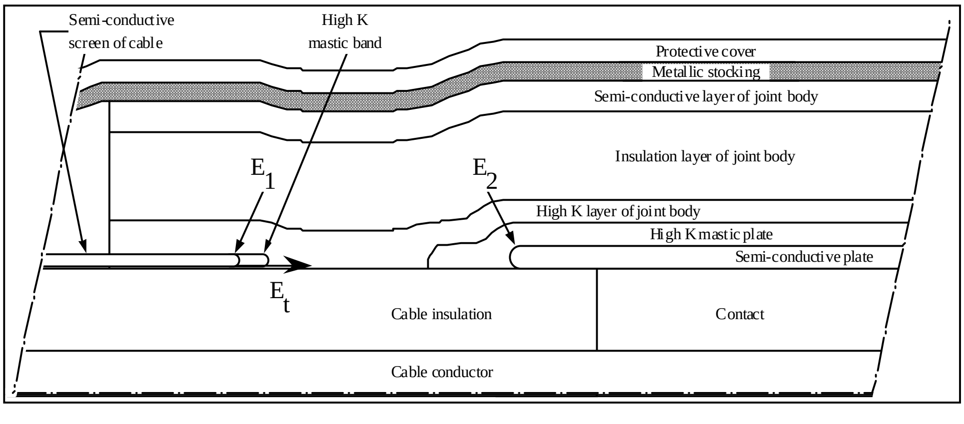

Figure 1 : Longitudinal cross-section through a cold-shrinkable joint

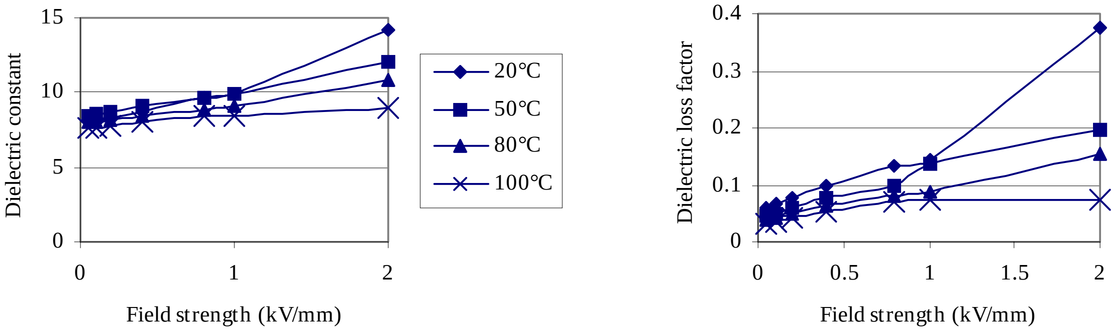

Figure 2 : Dielectric properties of high K layer

LONG TERM BEHAVIOR

Dielectric strength measurements

In order to assess whether the materials used in the joint can withstand these stresses, we measured dielectric strength of each material versus temperature. Data are analyzed with a 2 parameter Weibull statistics and results are given in Table 2.

Evaluation of long term behavior

The conditions of field application during dielectric strength measurement and normal service are obviously different.

To estimate the breakdown probability of a joint during its 40 years life, following assumptions had to be made :

- Thickness effect : breakdown stress (E) decreases with sample thickness (d); the most widely used law is

$$E/E_o = (d/d_o)^{-a} \quad \text{with } a = 0.5 \quad [3]$$

- Aging effect : evolution of breakdown stress versus duration (t) of stress application is assumed to be given by the power law

$$(E / E_o)^{n} = t_o / t$$

With d_o , t_o and E_o values taken from the breakdown experiment on material samples and d, t and E values existing in the real product. The exponent *n* depends on the nature of the defect leading to breakdown. In the sixties a coefficient n = 9 was determined on samples having artificial voids; now the V-t characteristic is considered to be governed by impurities and protrusions rather than voids, and a value n=15 is assumed for the materials used [4].

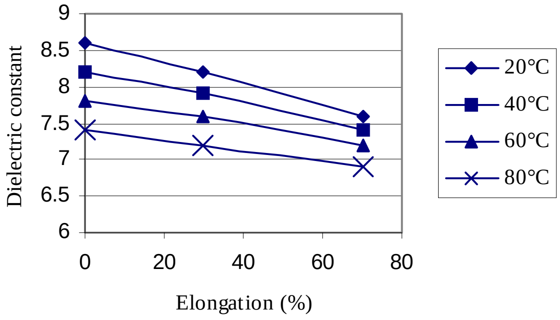

Figure 3 : Dielectric constant of high K layer vs extension

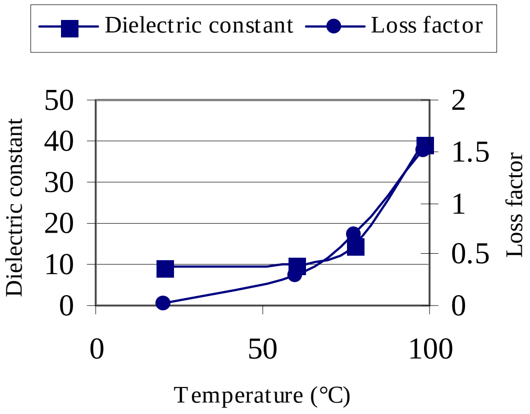

Figure 4 : Dielectric properties of mastic layer

Table 1: Field strength and temperature inside joint materials at 12 kV phase to ground

Core temperature (°C)	Surrounding	Joint insulation		High K layer		Mastic	
		Emax (kV/mm)	Tmax (°C)	Emax (kV/mm)	Tmax (°C)	Emax (kV/mm)	Tmax (°C)
100	air	1.3	79	0.8	85	0.8	97
	dry sand	1.4	83	0.8	88	0.8	97
	wet sand	1.3	73	0.8	82	0.9	96
120	air	1.4	101	0.8	101	0.5	116
	dry sand	1.5	99	0.8	105	0.4	117
	wet sand	1.4	87	0.8	97	0.7	115

Taking these parameters, one can estimate the breakdown probability of the joints corresponding to the conditions used in the model.
We arrive at probabilities in the order of 0.01 % after 40 years service on a 20 kV system.
The possible existence of threshold levels in aging phenomena could even further reduce this value.

Long term qualification tests

In order to support theoretical considerations with laboratory investigations, several joints were installed on cables and submitted to severe testing :

Applied voltage : 36 kV AC phase to ground

Heating cycles : 120 °C on conductor (8 hrs current on, 16 hrs off)

These tests are continuing now since 3 years without any breakdown.

Table 2 : Dielectric strength of joint materials

	Dielectric strength (kV/mm)		
Temperature (°C)	Insulation	High K layer	Mastic
23	55	5.3	20.5
80	57	4.8	23.7
110	64	7.3	8.3

CONCLUSIONS

Using the Flux 2D software, the thermal and electrical stresses in a cold-shrinkable joint were analyzed and found to be within acceptable limits.
An attempt was made to estimate the service reliability, but as long as the exact models are not known, we have to rely on severe long term testing to provide engineering information ; the tests which are continuing since 3 years indicate sufficient service life.

REFERENCES

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