Modeling electromechanical phenomena contributing to cable deterioration

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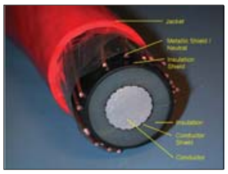
Vision

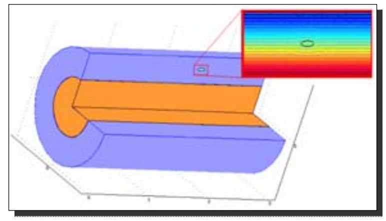
- Understanding the magnitude of electric and magnetic field in and around the cable (now on a larger scale than our previous calculations which were on the scale of a void or inclusion).
- Analyzing the influence of failed concentric neutrals on these quantities.
- Develop diagnostic techniques for identification of cable segments with high probability of failure.
- Improved methods for cable-handling and installation.
- Develop more resistant polymers to Water Treeing.
- Integrating calculations with sensor work.



A modern polyethylene cable for a 25 kV system.

Failed cable after flashover.

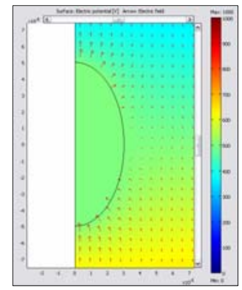
MICROSCOPIC APPROACH: looking at the WATER TREE



A small sample of the dielectric in which an inclusion has been incorporated.

- **Using the finite elements software COMSOL®** we are able to simulate the field distortion around various shapes and sizes of inclusions.

- The lifetime of the cross-linked polyethylene (XLPE) is strongly affected by the electric field it experiences:
  - The central conductor (CC) is at **12kV** and a few millimetres of XLPE providing the insulation, the average field experienced by the XLPE is of the order of 2kV/mm
  - **The presence of defects** (i.e. inclusions, water trees, voids, cracks and de-lamination at the XLPE/semicon interfaces) distorts remarkably the electric field. These distortions are much higher close to the defects or trees.

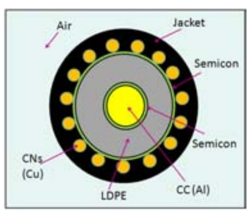


Surface plot representing the electric potential, while the arrow plot represent the electric fields

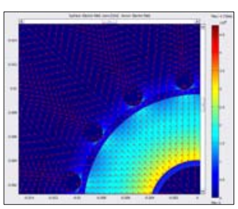
Methods & Findings

MACROSCOPIC APPROACH: Full cable cross section

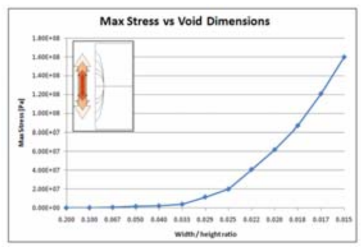
- Implementation of finite element modeling through COMSOL® to understand the mechanisms at work in deterioration of cable.
- Include the presence of SPACE CHARGE in the polymer model
- Allow a better understanding of the electric and magnetic field in the surrounding of the cable.



Full cable cross section simulated in COMSOL® environment



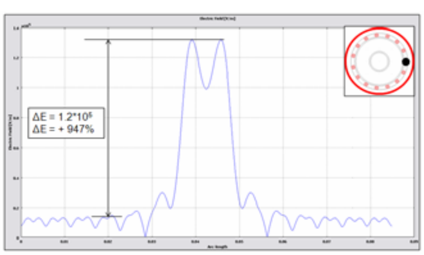
- In the figure: surface plot of the electric field in the CNs region and the arrow plot of the electric field.It's possible to notice the electric **field leakage** among the CNs.



- **Electromechanical forces** play a role in initiation and propagation of the water trees.
- The forces are important in the **vicinity of the inclusions or existing trees.**
- The forces are **dielectrophoretic** and, if space charges occur, **Coulombic**
- The dielectrophoretic forces as well as the ones due to space charge generate a **compression status** on the void.

It is likely these compression forces lead the void to crack in a cyclic environment
→ **FATIGUE = 30 years = 11x10^{10} cycles**

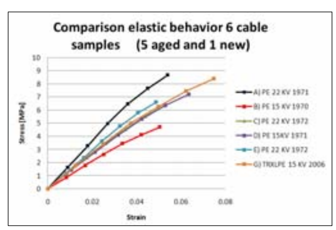
- Simulations showed possibilities in detecting failed CNs looking at the variation of the electric field.
- The previous approach would be even more successfull if it would be possible to keep the CNs into an almost symmetrical distribution along the circumference of the cable.



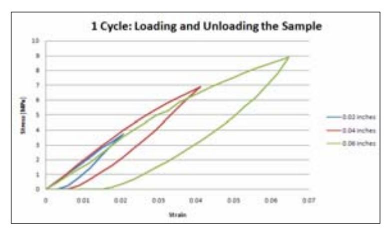
Electric field has been measured along the outer circumference of the cross section of the cable with a failed concentric neutral (see insert). In proximity of the failed wire, the electric field shows a remarkable peak.

MECHANICAL TESTING OF INSULATOR AGED AND NEW SAMPLES

Compression testing with an MTS machine has been carried out. The data gathered are in good agreement with what described in literature.



Investigation of the elastic region for aged and new cable samples.



Loadinga and unloading test showed presence of hysteresis in the polymer that represents a damage in the internal structire.

Future works

- Micro - Fatigue and Creep testing on aged and new samples.
- Carry out Elasto Plastic simulations with COMSOL®.
- Verify the results of the simulations with on field testing.

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