Study Committee D1

Materials and Emerging Test Techniques

Paper D1-PS3-10181

Evaluation of the Electrical Performance of Insulation in HV Equipment Under the Effects of Contaminants Usually Neglected on Ordinary Electric Field Calculations

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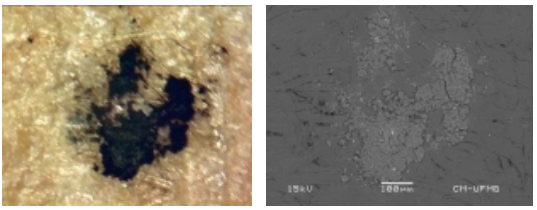
Motivation

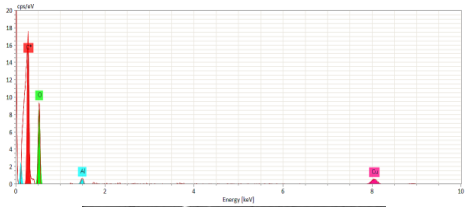
Occurrence of failures at limits below the theoretical value, notably due to changes in materials, the presence of contaminants and dimensional deviations.

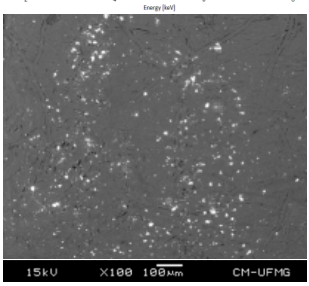
Recently a series of occurrences in a specific equipment were reported in Brazil.

Root cause: Possible design flaw in the layer terminations + **contaminants in OIP**



2nd sample: Optical microscopy (left), SEM (right)

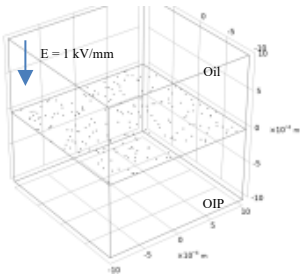




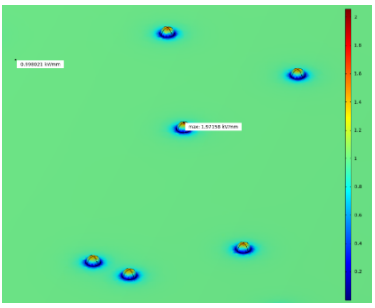
1st sample: EDS analysis (top), SEM (bottom)

Development

- Analyze the effects of contaminants on the electrical performance of insulators
- Survey of contaminants in typical materials found in HV equipment,
- The FEM was used to characterize a representative structure of the paper-oil interface, found in bushings or insulating columns.
- The effects of edges are properly considered.
- The distribution of the contaminants was represented by random functions simulating observed aspects in paper samples, extracted from actual equipment.



Simulation - particle density as in microscopy



Electric field at OIP surface and contaminants

Conclusions

- Evolution of Microscopy techniques → better understanding of contaminants in solid isolation
- Evaluation of the consequences of the possible presence of these contaminants in the equipment insulation system, when in operation, was studied through theoretical models and extracted from experimental observations, thus demonstrating the effect of contaminating particles in the local electric field for OIP insulating systems. This type of phenomenon may not be detectable in routine tests because the level of PD activity, at its onset, may be below the detection limit of the measuring system, but it can progress to a failure.
- Simulations focusing on the local effect of the contaminating particle.
- A complete equipment geometry could provide a better insight. → **equipment reliability**.
- Development is a high-frequency model - particles as dipoles. → inference of defects from PD measurements.

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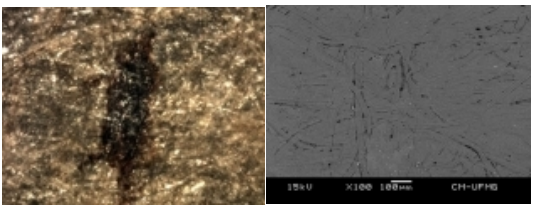
Part I – Experimental investigation

Premises

- Insulating mineral oil under normal conditions regarding its dielectric and physicochemical properties.
- Insulating paper in low-use state, no significant aging due to breakage of the cellulose chains by determining the degree of polymerization (DP);
- Coaxial geometry equipment: ex. high voltage transformer bushing.



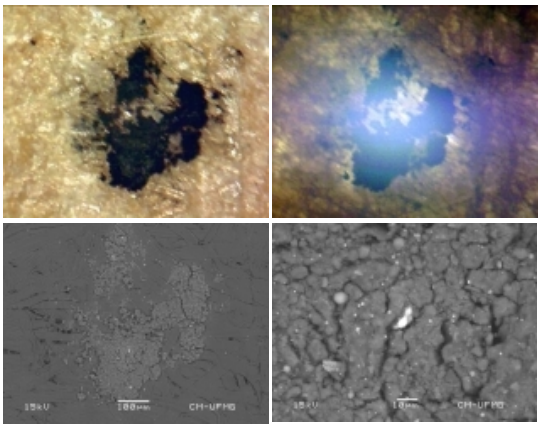
Reference sample: optical microscopy (left), SEM (right)

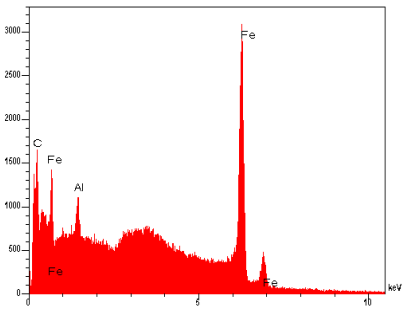
Analysis

- Optical microscopy (transmitted and reflected light);
- SEM, using backscattered electron images to visualize possible chemical contrasts, coupled to an EDS to material identification.
- Samples from (a) reference paper, (b) paper taken from equipment that had never operated and (c) control samples from equipment in operation.
- All paper samples were de-impregnated from the insulating mineral oil, using chloroform in a condenser before analysis.
- Comparison with non-used reference sample (DP≈1200).

Results

- **Reference sample (top) – equipment with no failure history**
- Darkened spot, no chemical contrast, same composition as matrix (cellulose paper)
- **First sample (previous page) – equipment with DP**
- Particles with spherical morphology and sizes ranging from 1 to 10 µm, high chemical contrast.
- EDS – presence of Cu, Al and C.
- Reference for the simulations.
- **Second sample (left and bottom) – equipment with DP**
- EDS - presence of Fe, Al, and C.
- Indication of contamination in the solid due to external factors
- Fourier Transform Infrared Spectrometry – presence of "x-wax" – usual from DP activity





2nd sample: optical microscopy (top left), SEM 50x (bottom left), SEM 350x (bottom center), EDS analysis (right)

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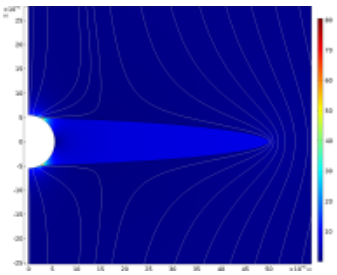
Part II – Simulations

Modeling

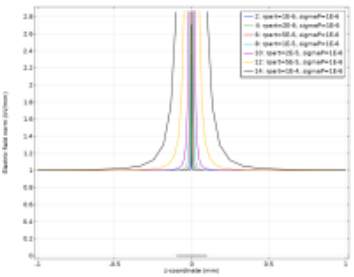
- Finite element method, using COMSOL
- Stationary approximation (DC) and frequency (60 Hz)
- Simulation domains: paper-oil medium + contaminants (dielectric or metallic) – approximation as a sphere
- "Simulation cell" – 2 x 2 x 2 mm



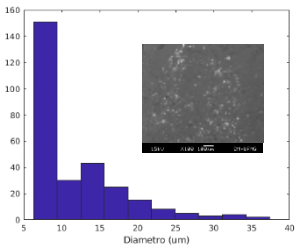
Electric field – contaminant in void

Parametric studies

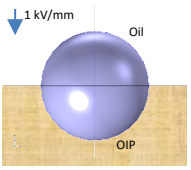
- Single sphere, dielectric or metallic, between media
- Particle (sphere) radius
- Random particle distribution
- Conductive particle inside dielectric gap (ellipsoid)
- Sphere inserted in representative geometry of a HV equipment



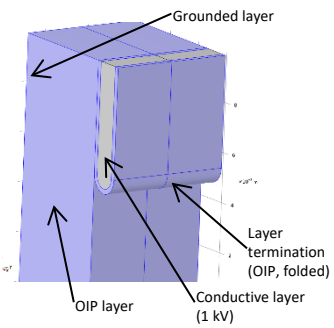
Parametric analysis – particle radius

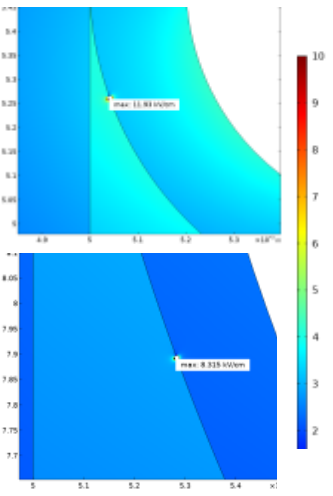


Histogram - particle diameter



Simulation domains





(left) Sample of layer fold (OIP, semiconductive paper, metallic mesh), (center) Geometry of the test cell , (right) Detail of electric field (kV/cm) in the inner side of the fold (contaminant position -70°) – fold radius 0.5 mm (top) and 4.5 mm (bottom)