Aging of Medium Voltage Extruded Dielectric Cables Under Wet Conditions

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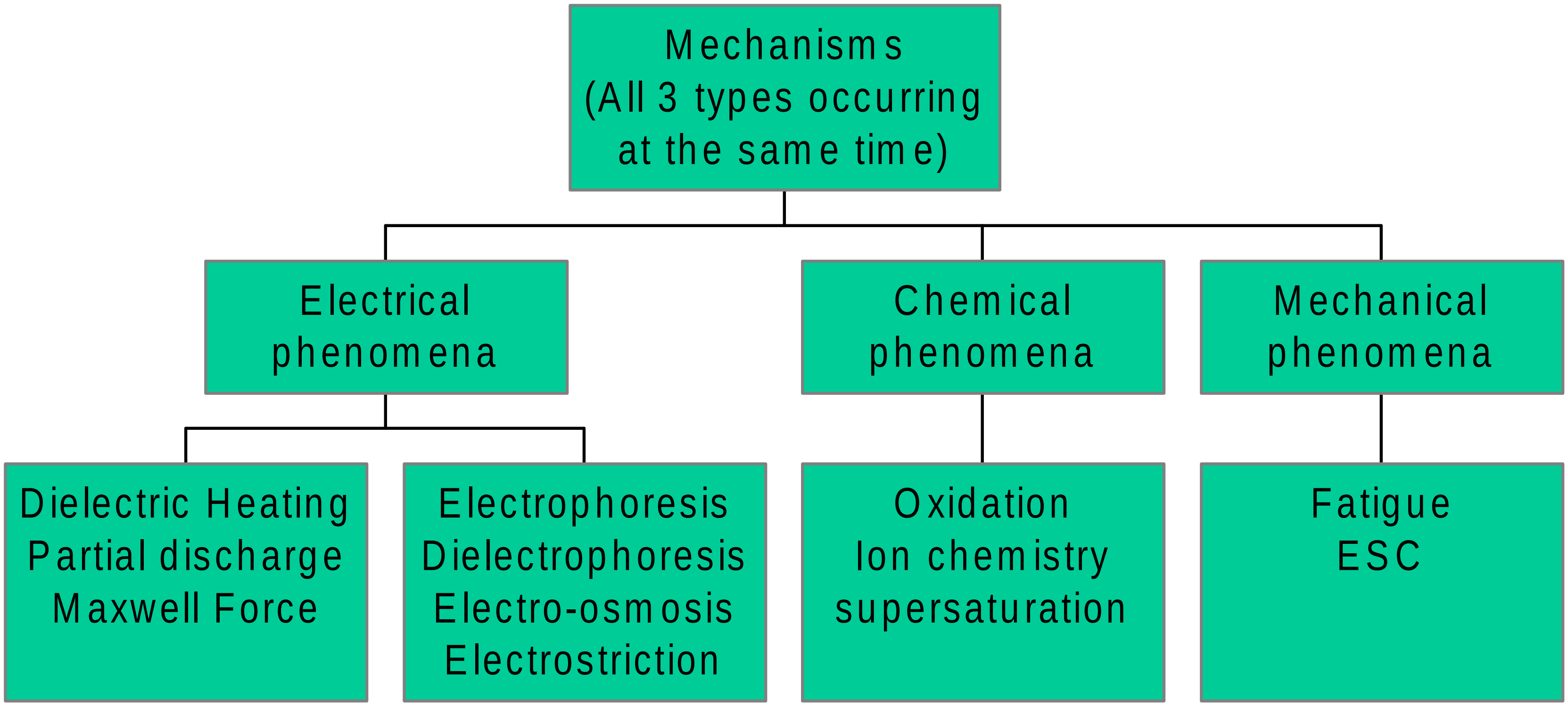
Overview

- Mechanisms of aging
  - Limited to wet conditions
- Influence of test parameters
- Accelerated aging tests

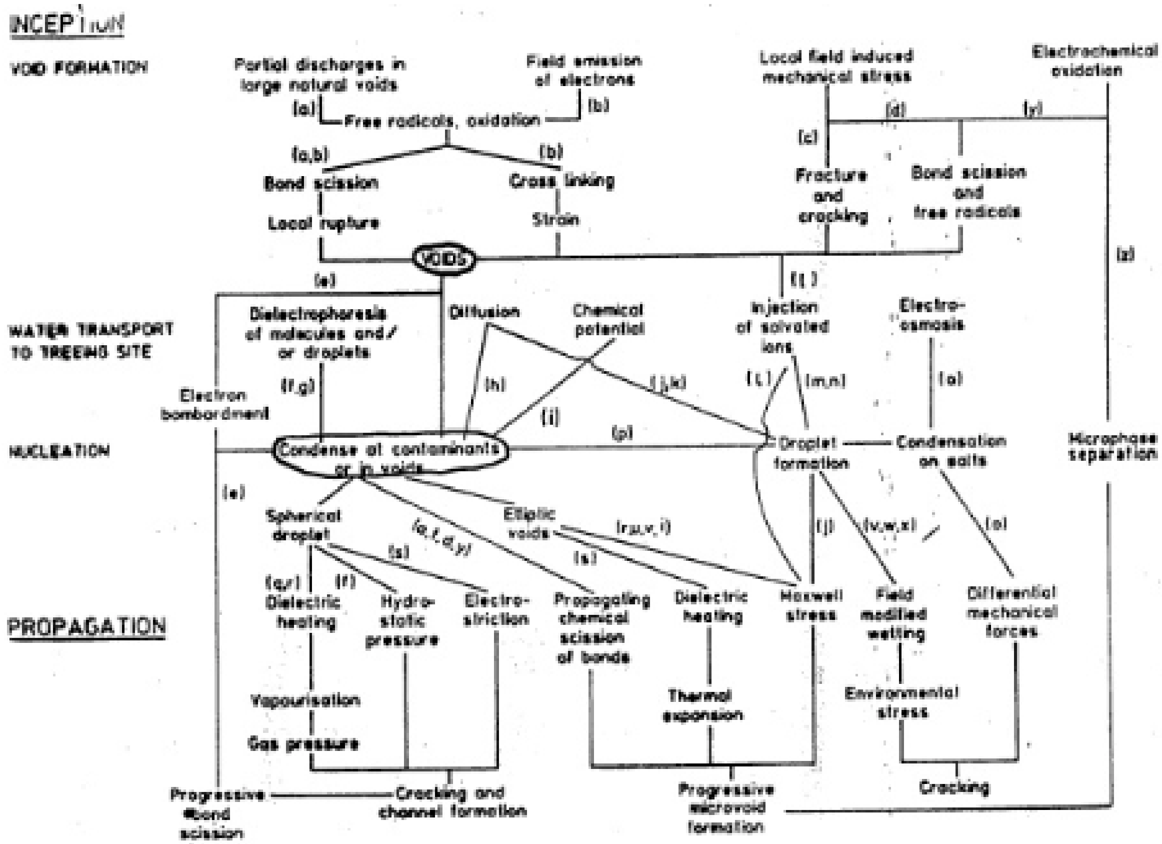
Wet Aging Conditions

- Aging due to water trees
  - Vented and bow tie trees
    - Diffuse tree-like structures up to 4 to 5 mm long - water-filled microcavities
    - 10 nm to ~10 μm dia.
    - $\sim 10^6/\text{mm}^3$
  - Failure either when water tree converts to electrical tree due to surge or thermal runaway if tree bridges insulation

Water Tree Mechanisms



Dissado and Fothergill



Water tree Mechanisms

- No single theory can explain all data
- Several mechanisms occur at same time
- Test conditions determine dominant mechanisms
- permanent changes in insulation
- Voids formed that have hydrophilic surfaces
- Local electrical stress is important
- Aging test needs to choose parameters that will duplicate growth in field

Important Parameters

- Applied Frequency/Time (No. of Cycles)
- Voltage (Local Electrical Stress)
- Water
  – Purity (Concentration and Type of Ions)
  – Location
- Contaminants, Protrusions and Voids
- Temperature
- Temperature Gradient

Effect of Time(t)/Frequency(*f*)

- Inception Time, $t_s \propto f^{-1} E^{-a}$ (3<a<4)
- Growth Rate, $dL/dt \propto (t - t_s)^{-n}$ (n<1)
- Tree Length, $L \propto \exp[N]$ N is No. of cycles

Inception time is field/frequency dependent.

Vented trees continue to grow from soluble contaminants.

Bow-tie trees tend to reach limiting length.

Effect of Voltage/Electrical Stress

- Vented Tree Growth Rate, $dL/dt \propto E^{*2}$
  - E^{*} is local field at tree tip, needle/plane geometry
- Vented Tree Length, $L \propto V^{\sim 1} t^{\sim 1/3}$
  - Needle/plane geometry & miniature cables, relatively short times of ~100s of hours

Most trees grow more slowly with time (E, ions↓) until trees nears opposite electrode.

Reduce growth rate affects ACBDV?

Water

- Most polar liquids will grow trees
- Tree inception will depend on ingress rate
- Ingress rate highly temperature dependent
- Water at both conductors worst case
- Contaminants in water important. Type and concentration of ions affect tree growth
- Soluble contaminants in shields/insulation are worse

Contaminants, Protrusions and Voids

- Soluble contaminants create large osmotic pressures – rapid tree growth, long trees
- Soluble contaminants in shields or in insulation
- Protrusions – high stress regions – trees grow by dielectrophoresis. Trees grade stress
- Unless voids have soluble contaminants inside, they tend to initiate bow tie trees that reach limiting length, thus less harmful

Temperature

- Some tests show increased tree lengths and more trees at higher temperatures while others show the opposite. WHY?
- Affects time for water to reach nucleation sites (diffusion, water on both sides)
- Can grade electrical stress, thus reducing one of the main driving mechanisms
- Affects final failure in life tests. Auto-oxidation of tree increases conductivity → thermal runaway

Temperature Gradient

- Gradient has large effect on supersaturation and precipitation
- Gradient/supersaturation/water in conductor the cause for large numbers of bow-tie trees in aging tests
- Number of BTTs much larger than observed in field-age cables.
- Can these BTTs line up and cause failures at high temperatures?

Accelerated Aging Tests

- Need to duplicate field aging?
- If so:
  - Need to look at test conditions, e.g., temperature/temp. gradient
  - Test at lower temperatures
  - Revisit high frequency testing
  - Apply surges during aging tests
  - Impulse BD rather than AC BD?
  - Water on outside only
  - Specify at least two test conditions

Accelerated Aging Tests

- Need to duplicate field aging?
- If not:
  - Make sure we control temperature/gradient precisely
  - Find ‘Achilles heel’ test condition for different materials
  - Specify at least two test conditions
  - Apply surges during aging tests
  - Impulse BD rather than AC BD?

Accelerated Aging Tests

- Presently use AC BD test to evaluate aged cables
- Are there other tests (non destructive) that we should be considering?
  - Dissipation factor
  - Dielectric spectroscopy
  - Recovery voltage
  - Polarization/depolarization currents