EPRI
ELECTRIC POWER
RESEARCH INSTITUTE

UL Solutions

Water Trees:
Some thoughts for Diagnosticians

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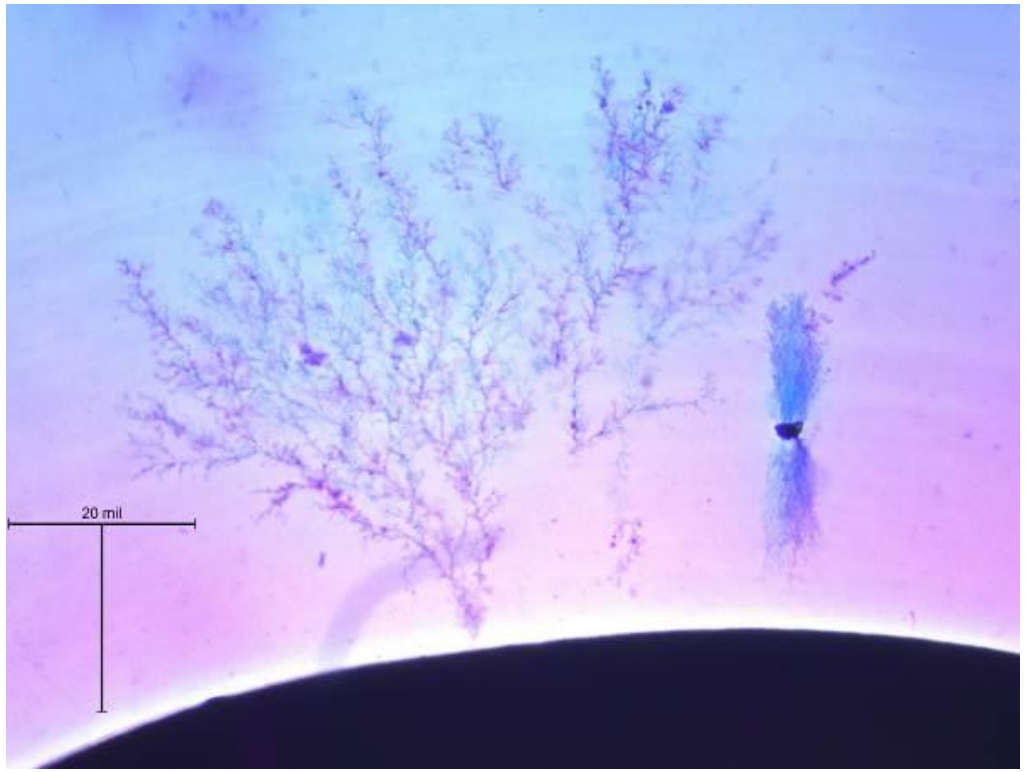
Background

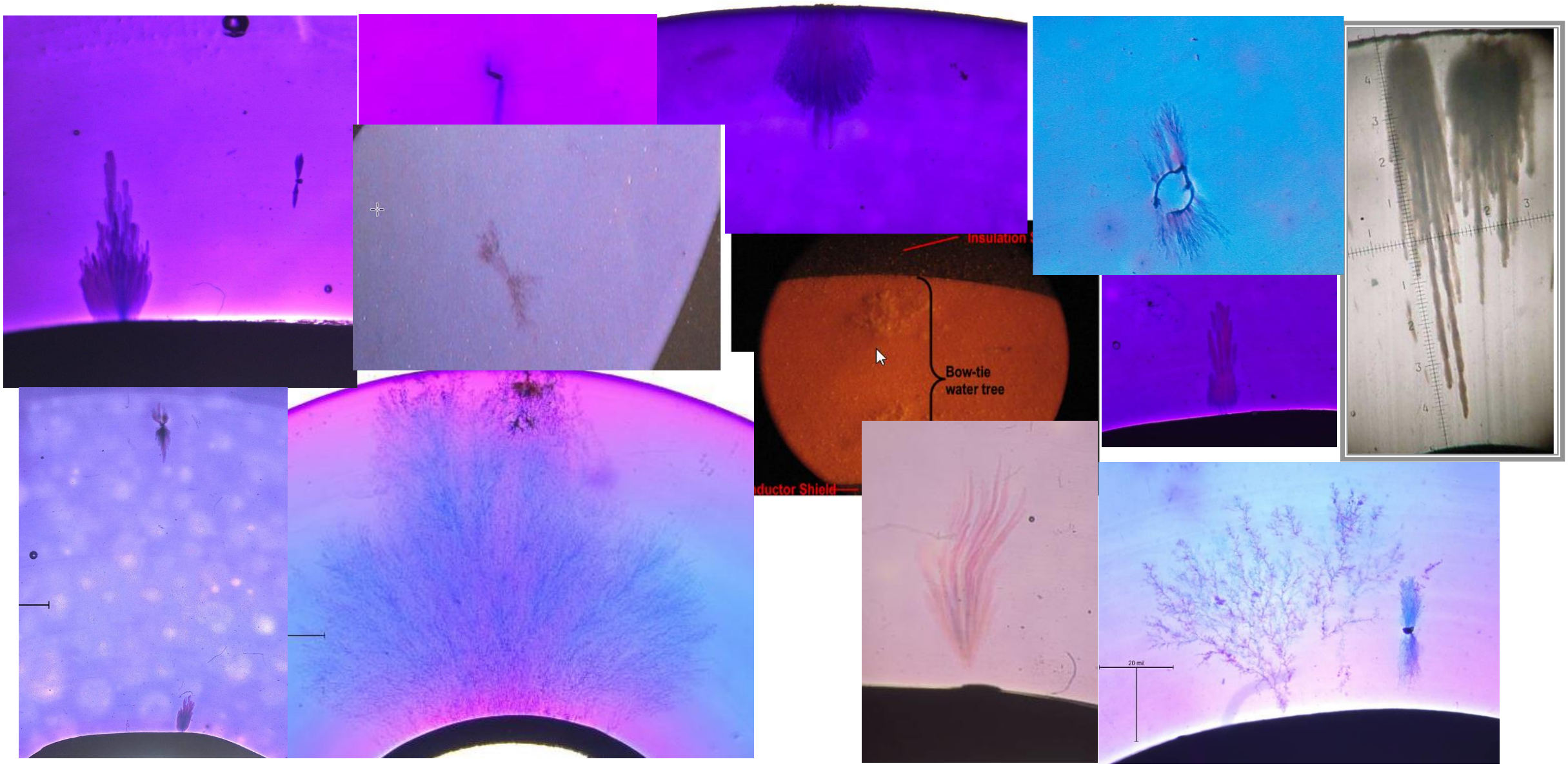
- Expected to perform
  - Better than PILC
  - Reliably for ≈30 yrs.
- Not aware that moisture, voltage stress, imperfections would combine to grow water trees.
- Many cables failed after a few years.



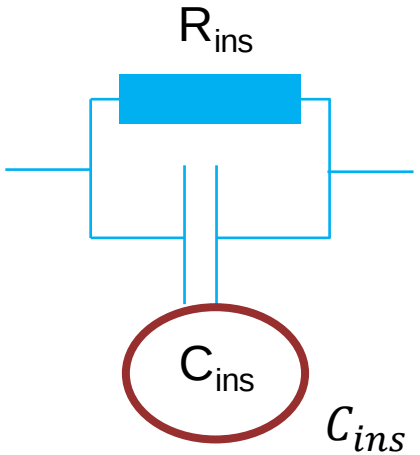
- This impacted operating costs that electric utilities are still dealing with today.

3

Water Trees observed in EPR, HMWPE, WTRXLPE, XLPE



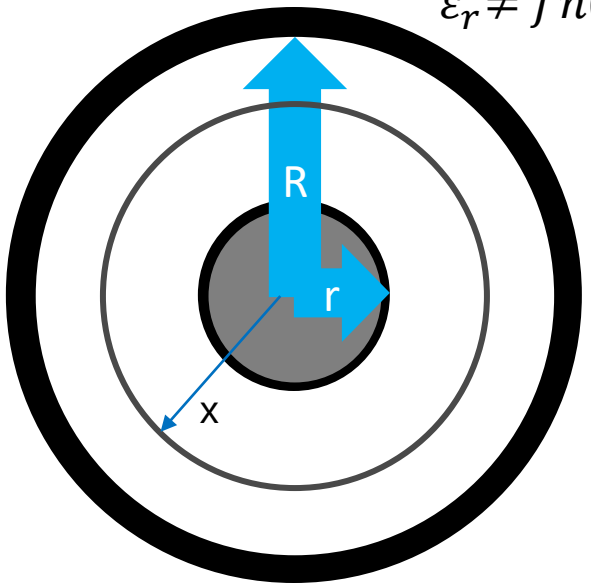
Water Trees & Electrical Stress



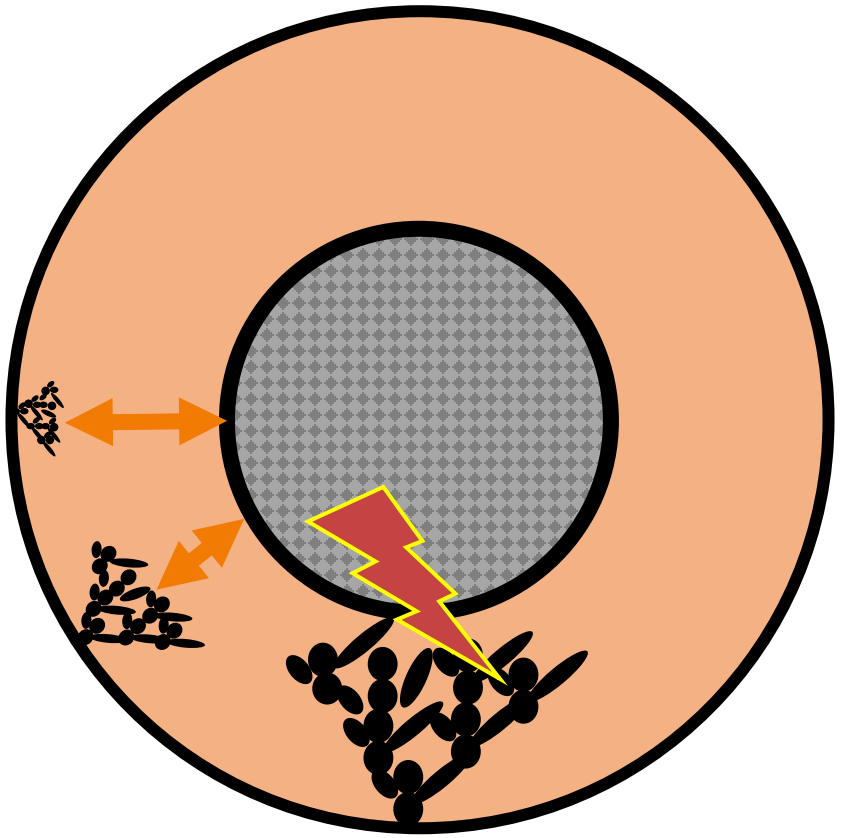
Actual stress at distance x from the center of the cable:

$$V = \int_R^r -E_x dx \qquad V = \frac{-q}{2\pi\varepsilon}\int_R^r \frac{dx}{x}$$

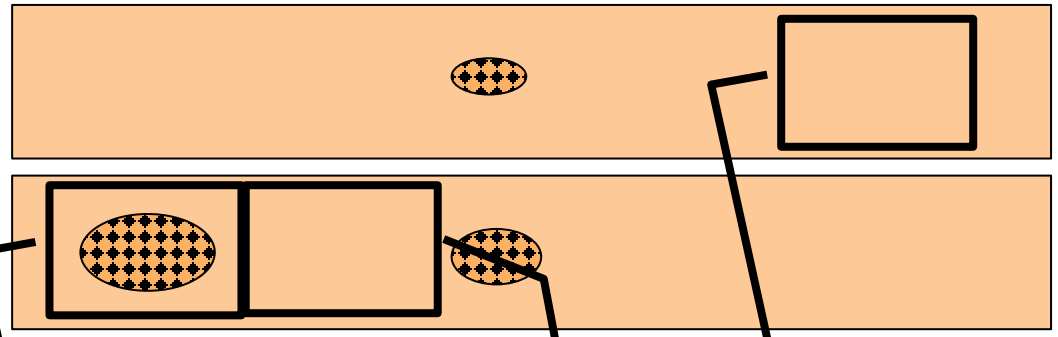
$C_{ins} \propto \varepsilon_r$,
$\varepsilon_r \neq fn(x)$
$\varepsilon_r \neq fn(T)$

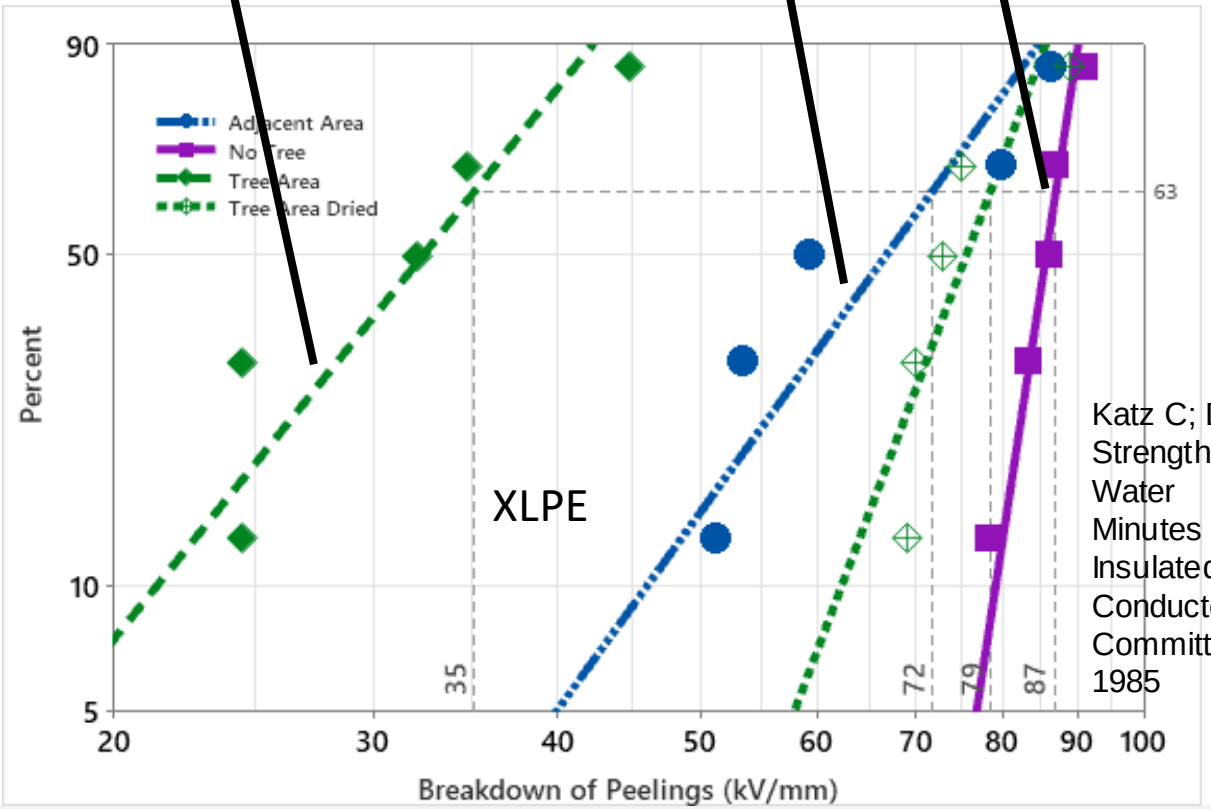


$$E_x = \frac{V}{x ln\frac{R}{r}}$$ kV/mm or V/mil

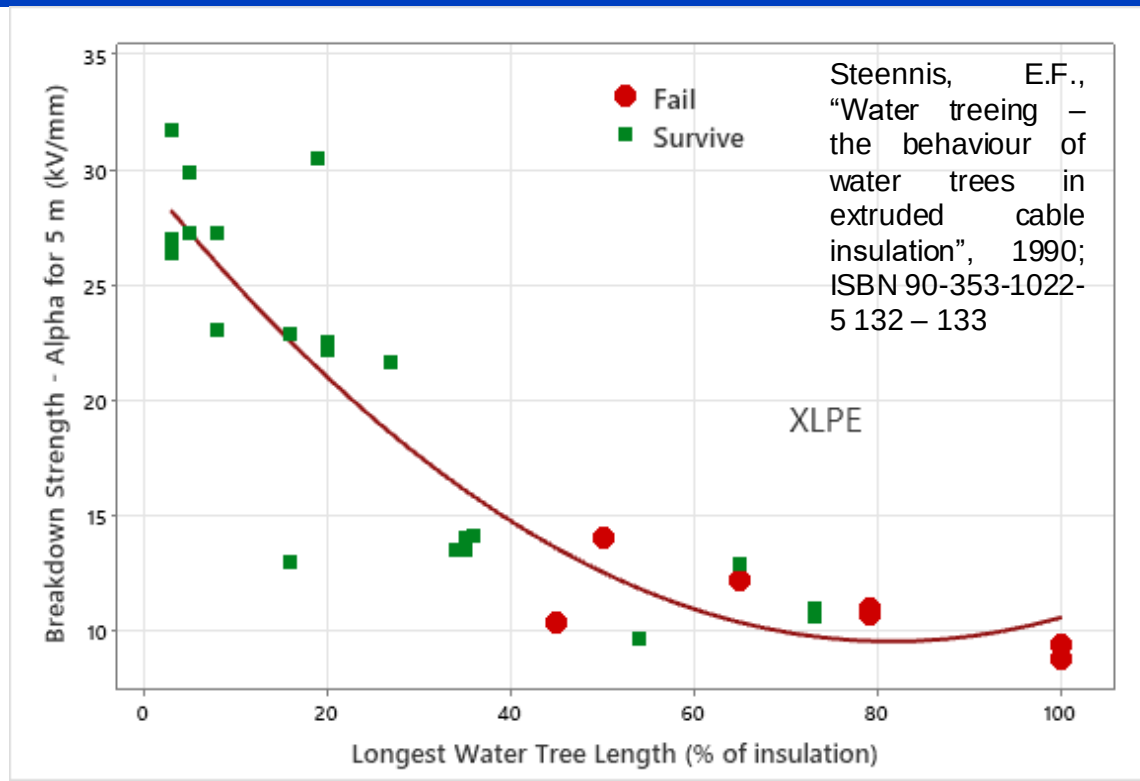


Strength with Water Trees

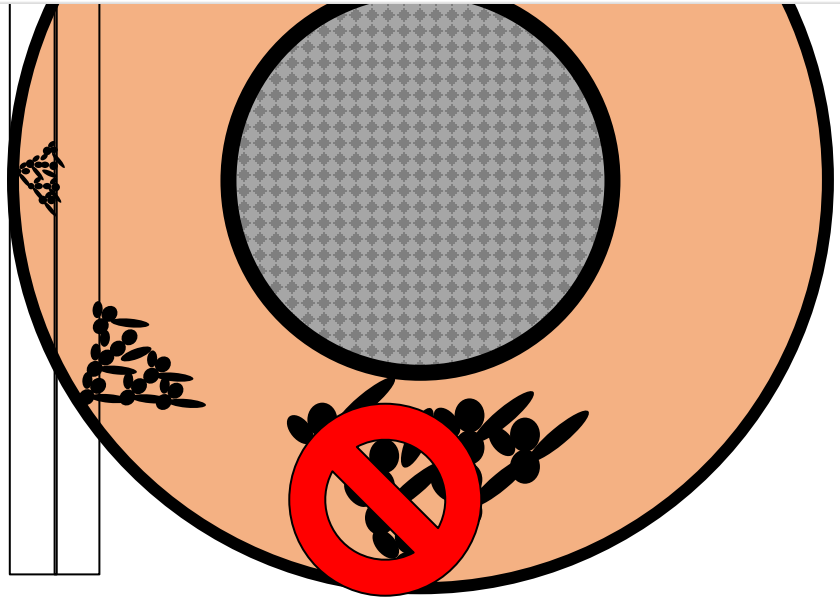




Katz C; Dielectric Strength of Water Trees, Minutes of Insulated Conductors Committee Nov 1985

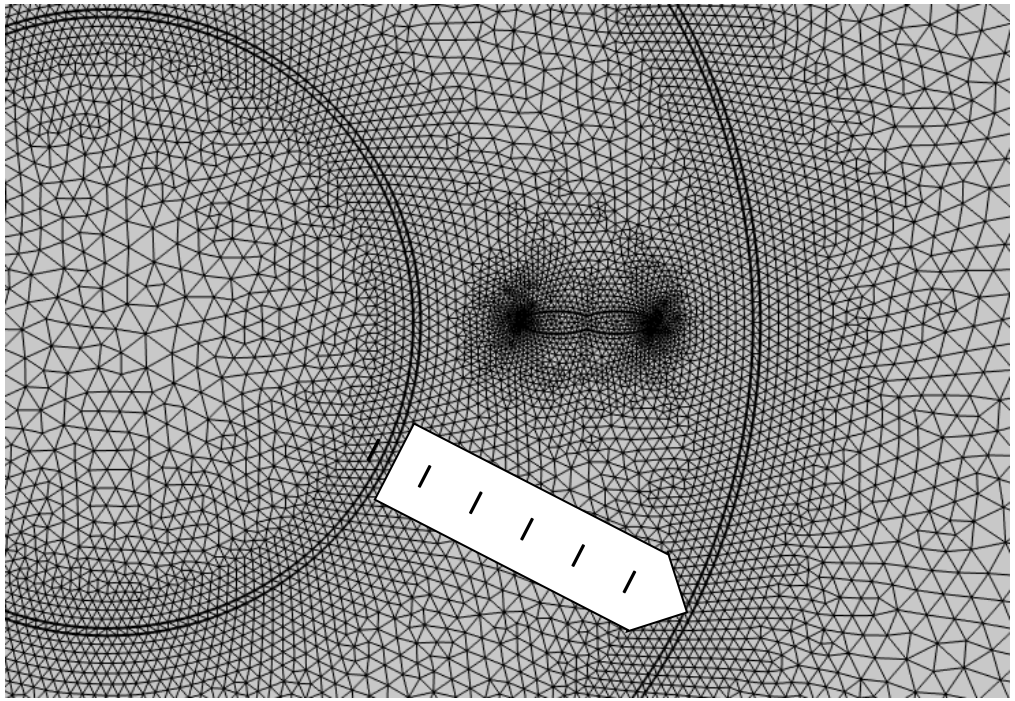


Steennis, E.F., "Water treeing – the behaviour of water trees in extruded cable insulation", 1990; ISBN 90-353-1022-5 132 – 133

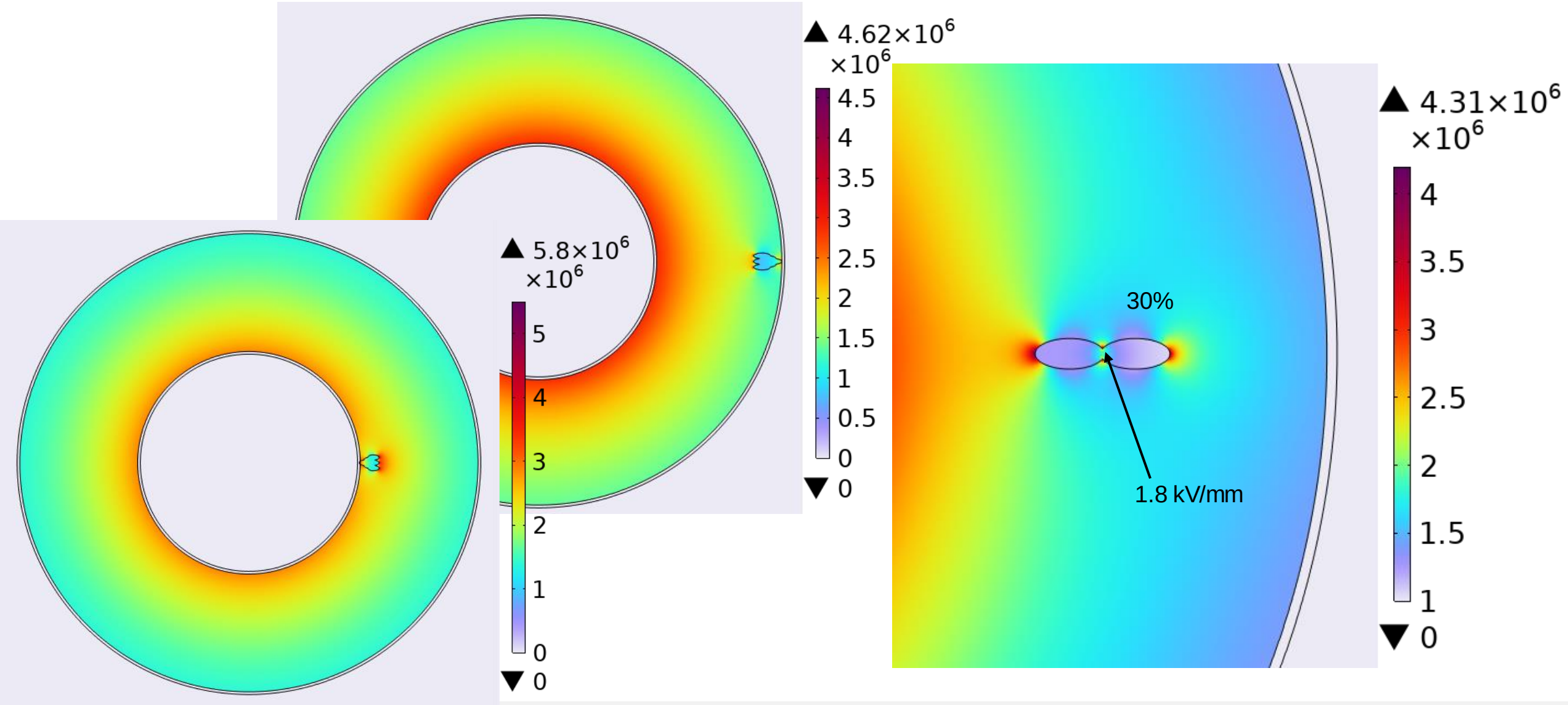


Simulating water treeing in cable

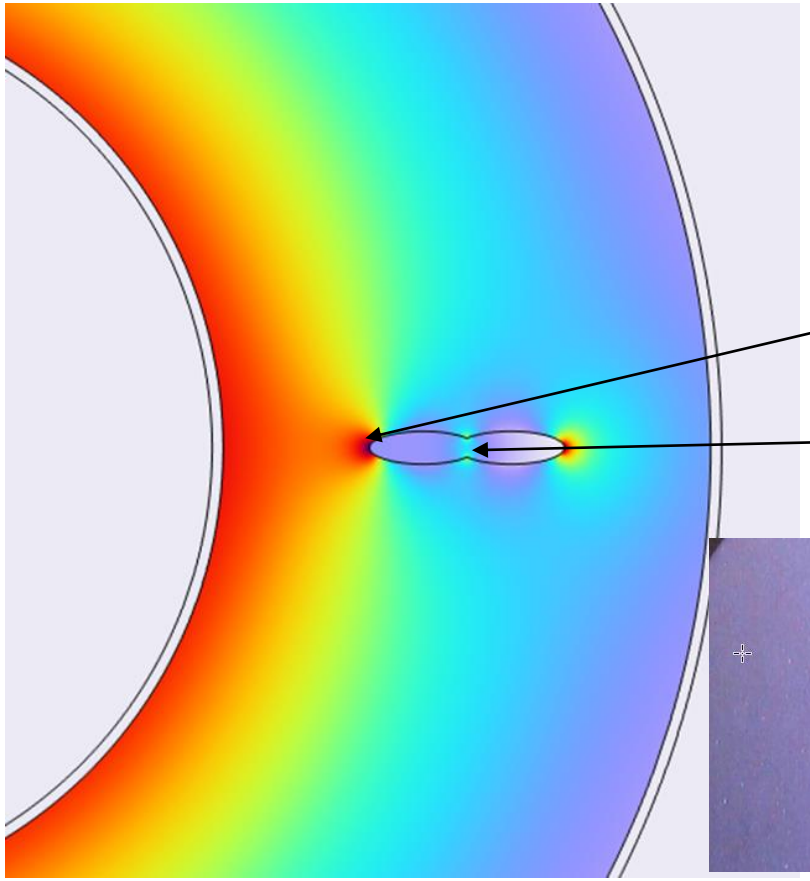
Parameter	Value
Cable Voltage	15/8.7 kV
Insulation thickness	4.45 mm
Conductor cross section	53 mm^2
Insulation conductivity at 25°C [S/m]	10^{-15}
Insulation dielectric constant	2.3
Water treeing area conductivity at 25°C [S/m]	10^{-10}
Water treeing area dielectric constant	8

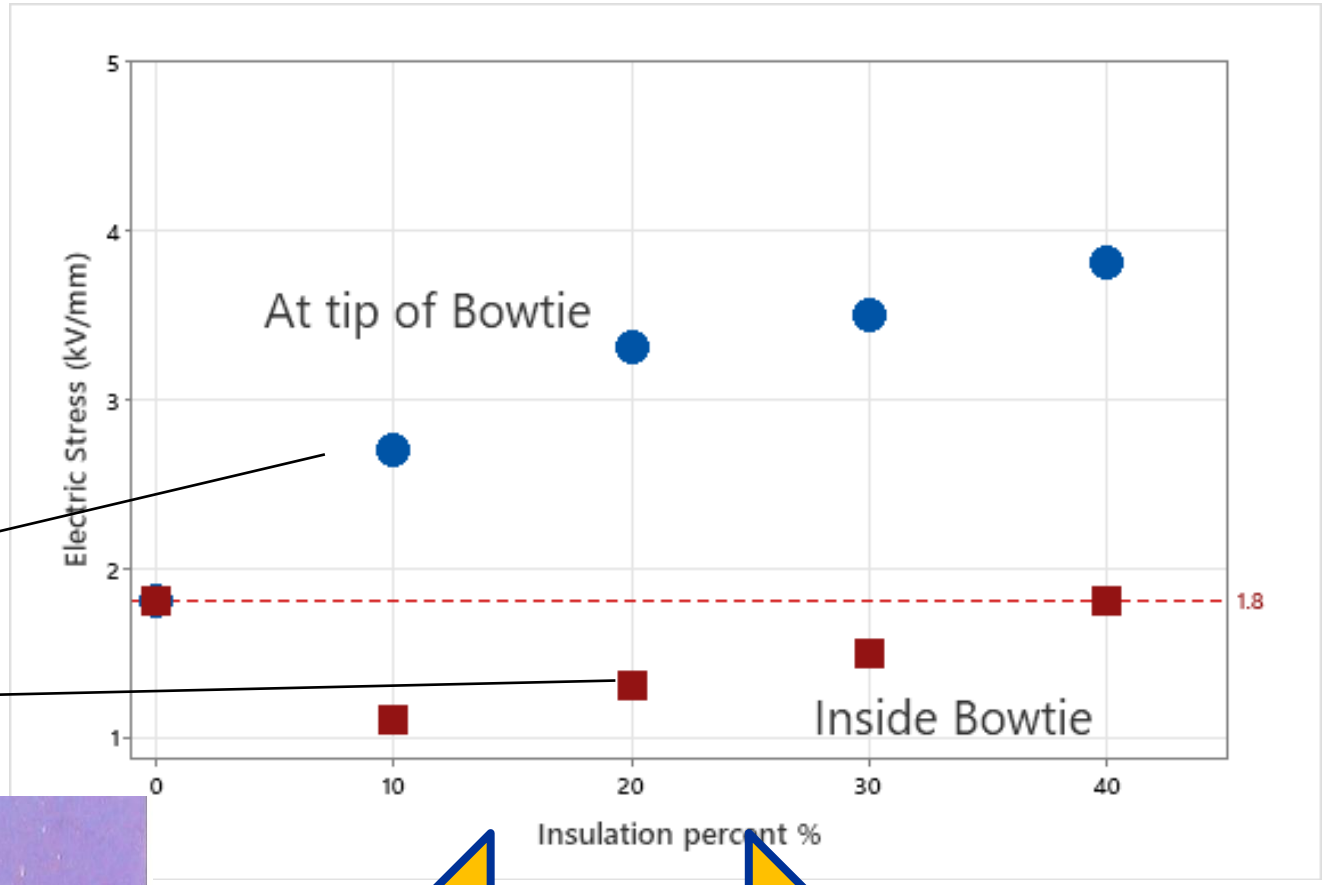


Electric field distribution with water treeing



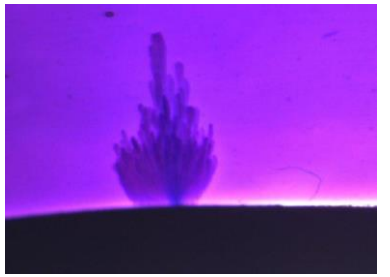
Electrical stresses for bowtie trees

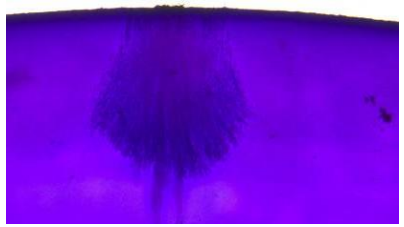




50% of Water Trees

Stress Modifications for Vented Trees





$$E_x = \frac{V}{x \ln \frac{R}{r}}$$

Stress increases locally & moves

35 70 90 α (kV/mm)

5 2.5 ε

Approx Electric Stress (kV/mm)

Distance (% of Ins

Stress increases & does not move

0% IO
4% IO
4% OI
16% IO
16% OI
50% IO
50% OI
80% IO
80% OI

90 70 35

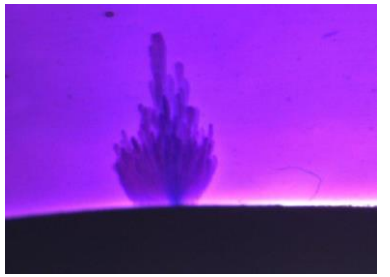
25 5

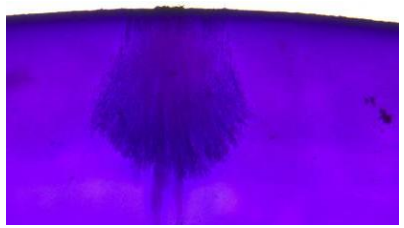
50% of Water Trees

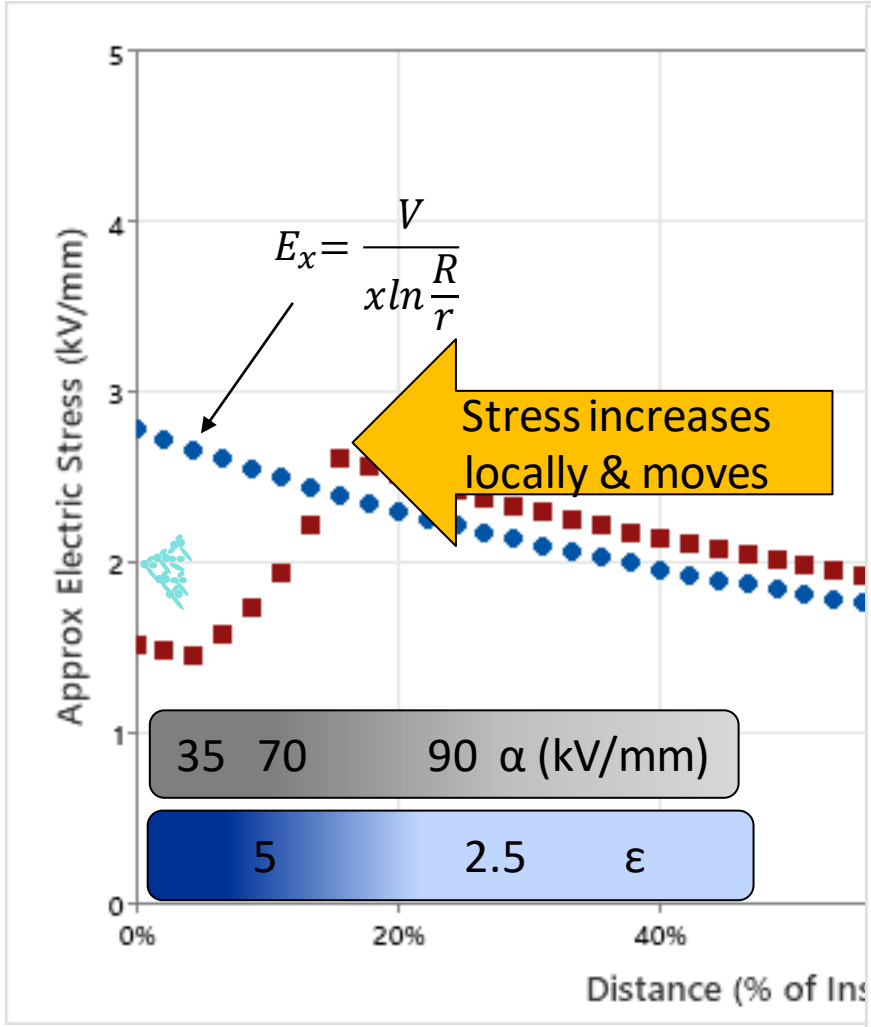
Approx Electric Stress (kV/mm)

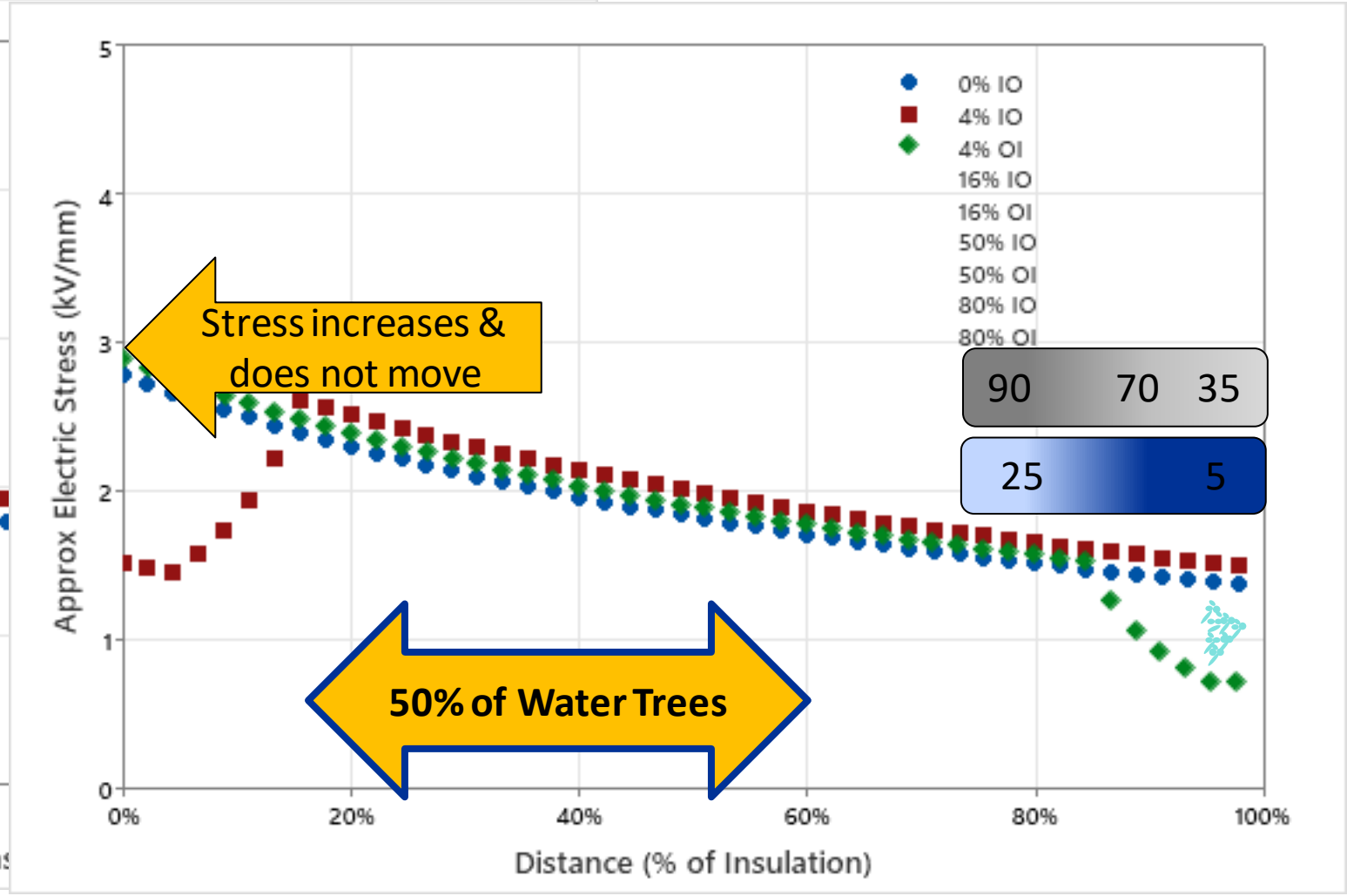
Distance (% of Insulation)

Stress Modifications for Vented Trees

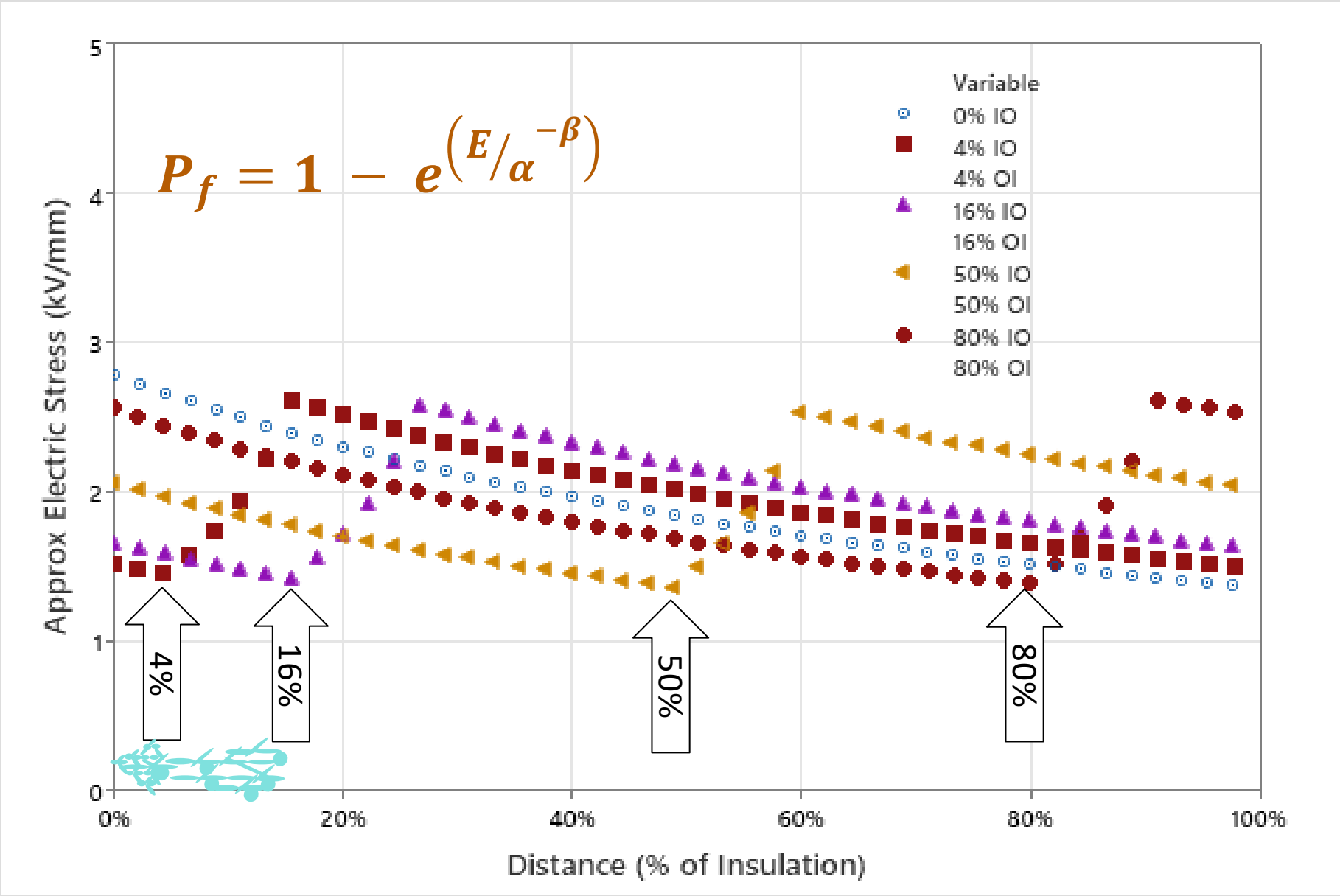








Water Trees Growing Inside Out



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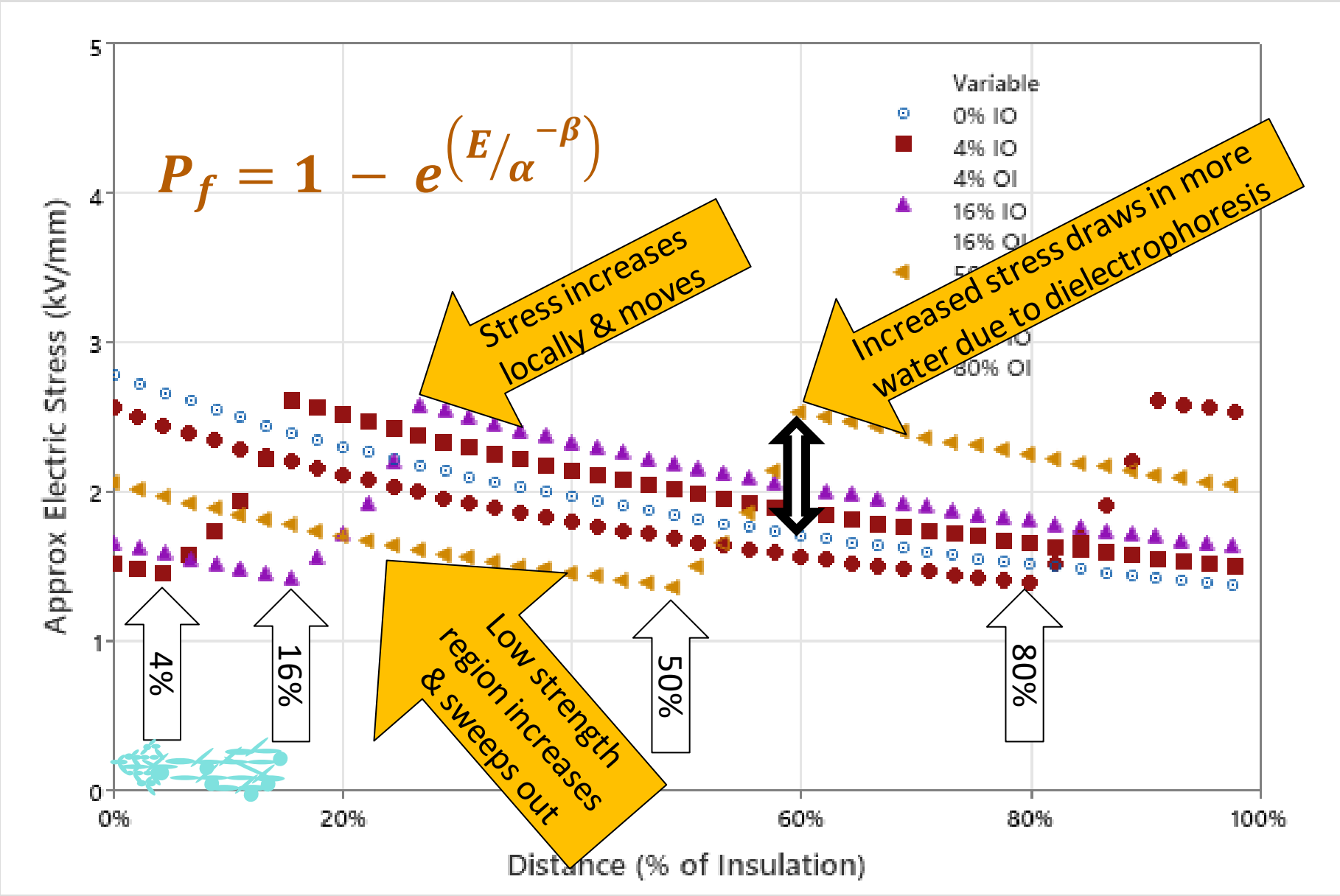
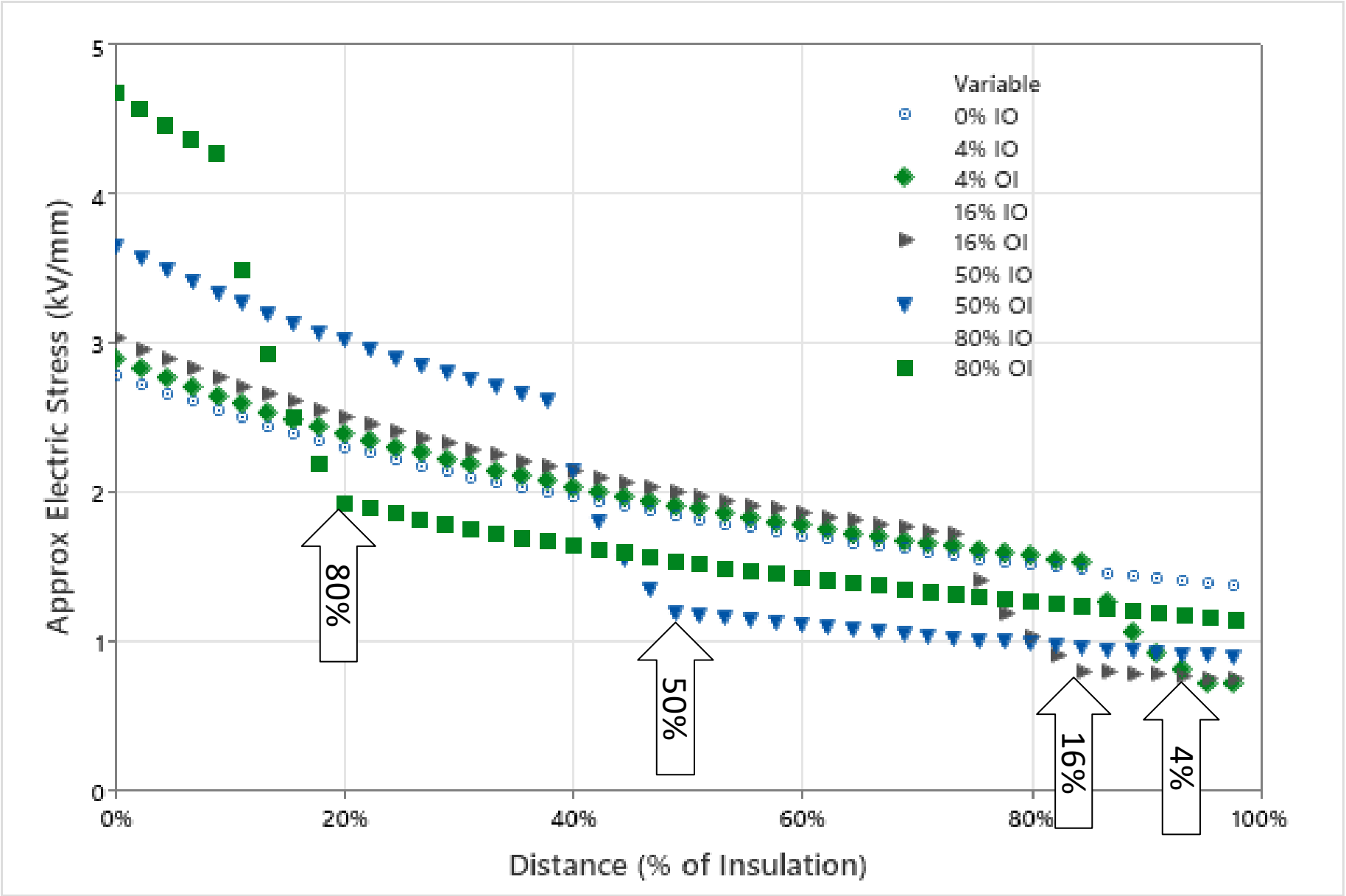
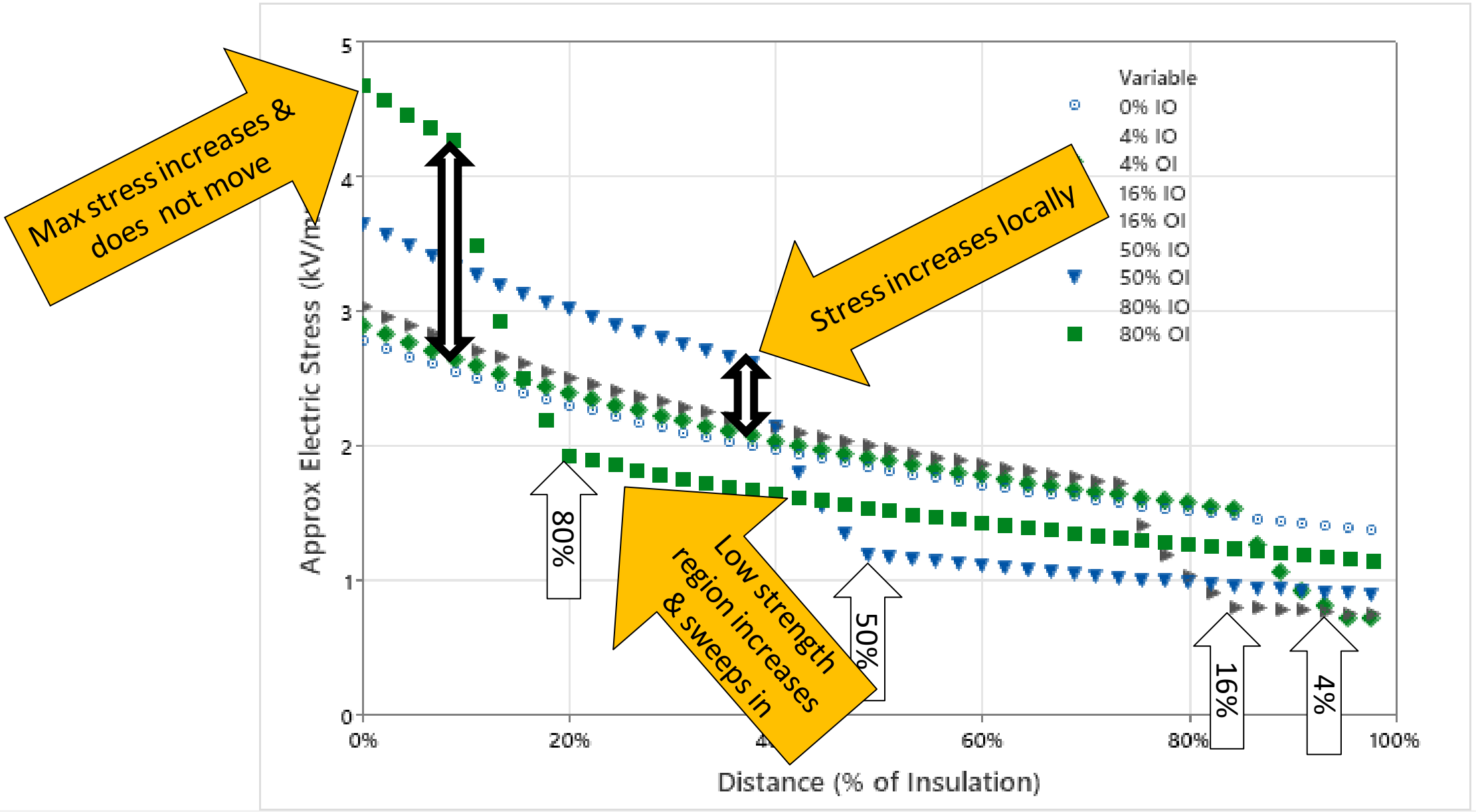


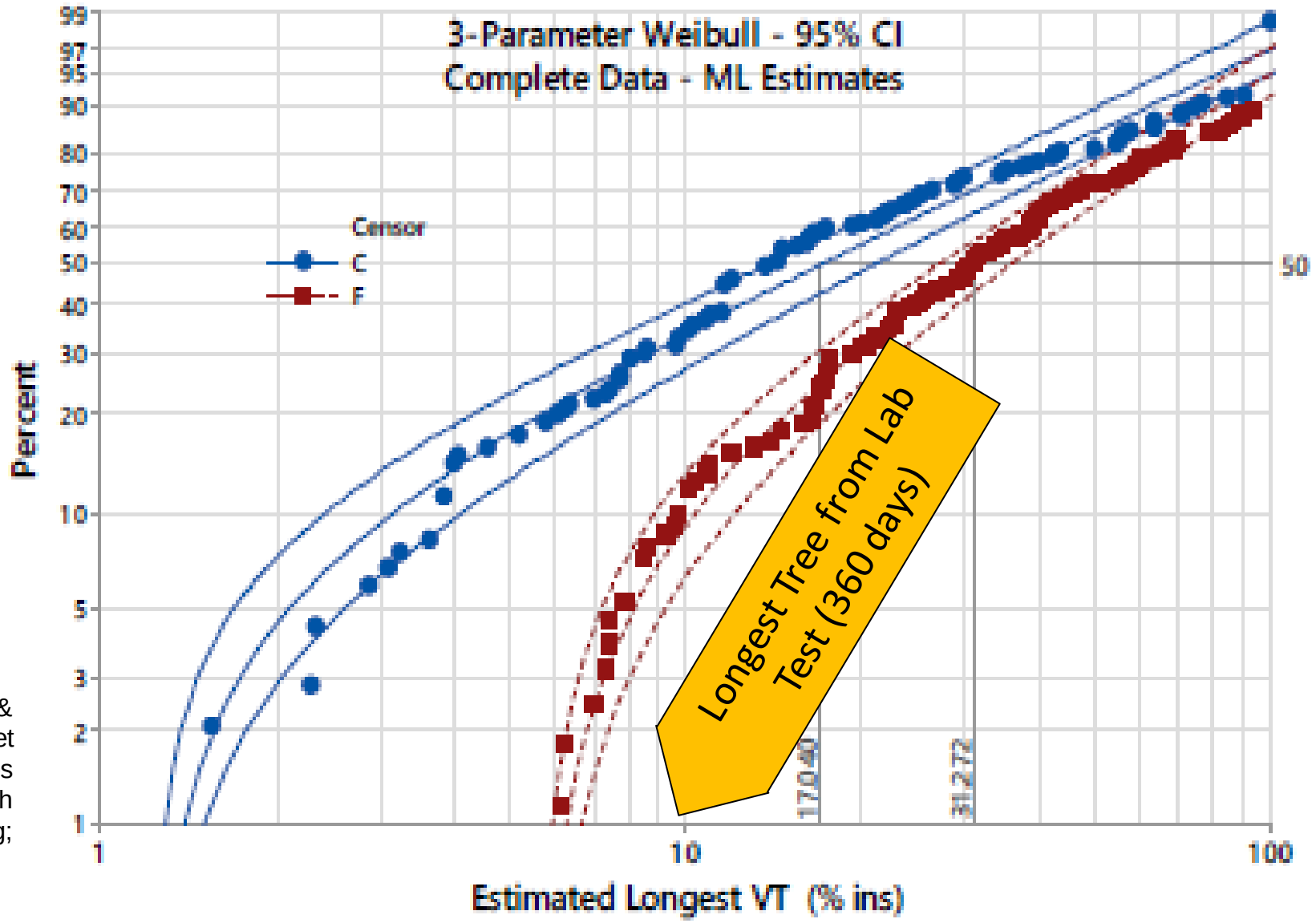
Water Trees Growing Outside In



Water Trees Growing Outside In

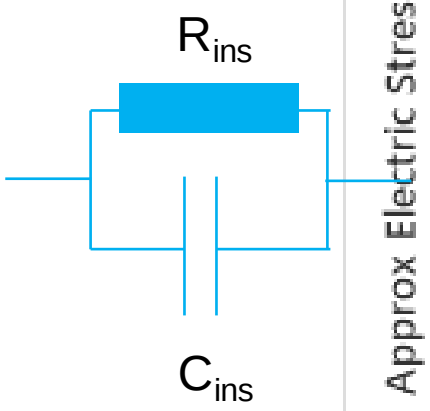


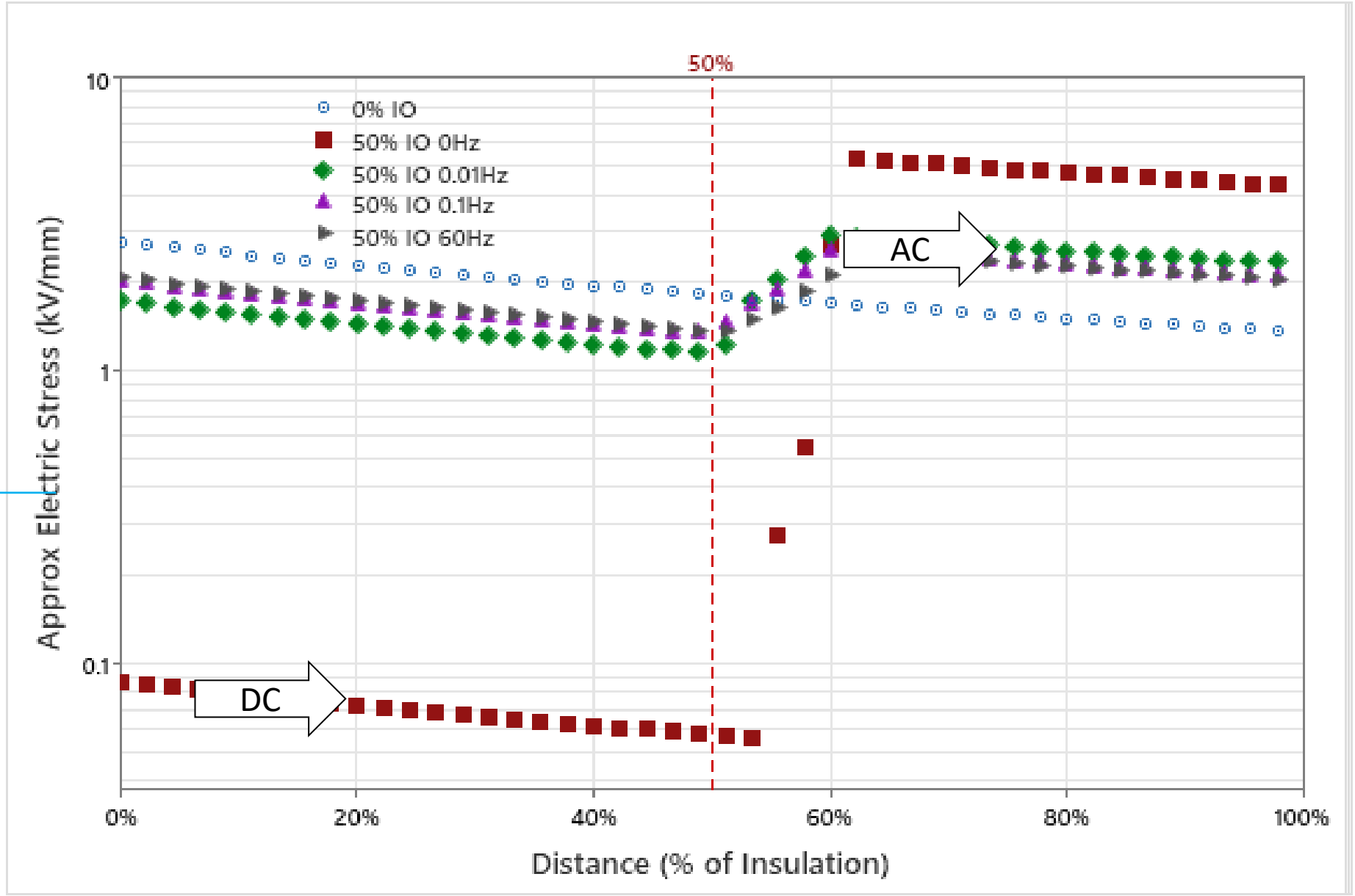
Size of Water Trees



Hampton RN, Perkel J & Williams FD; Asset Management of MV Cables using Data Driven Health Indices for Water Treeing; Jicable19

AC & DC Waveforms





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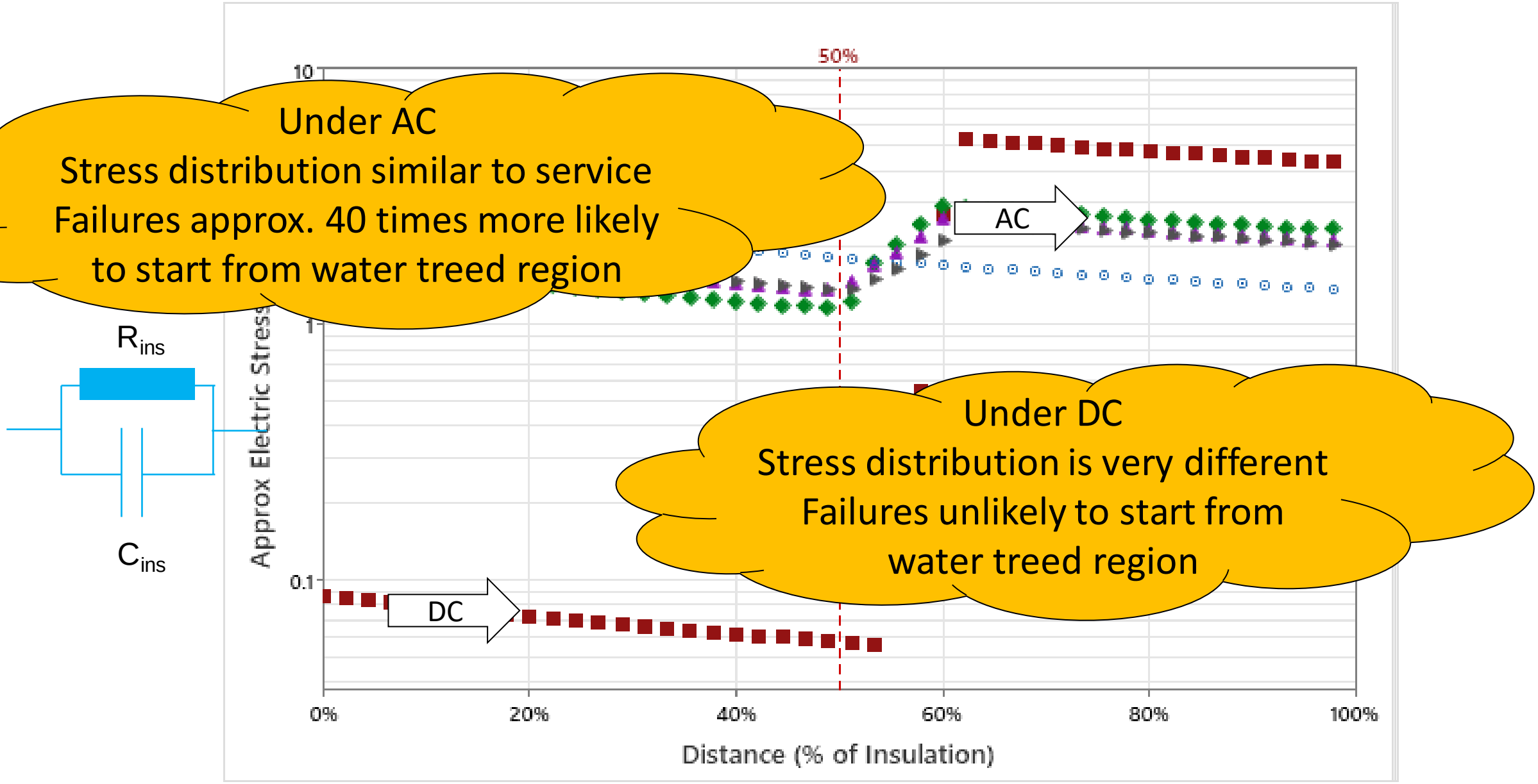

Dielectric Measurements

- The volume of insulation affected and the density of trees impacts the measured Tan Delta
- The Stability and the Tip Up are likely impacted by the local heating within the Water Tree via σ

$$Energy \propto \ \omega * Tan\delta * E^2$$

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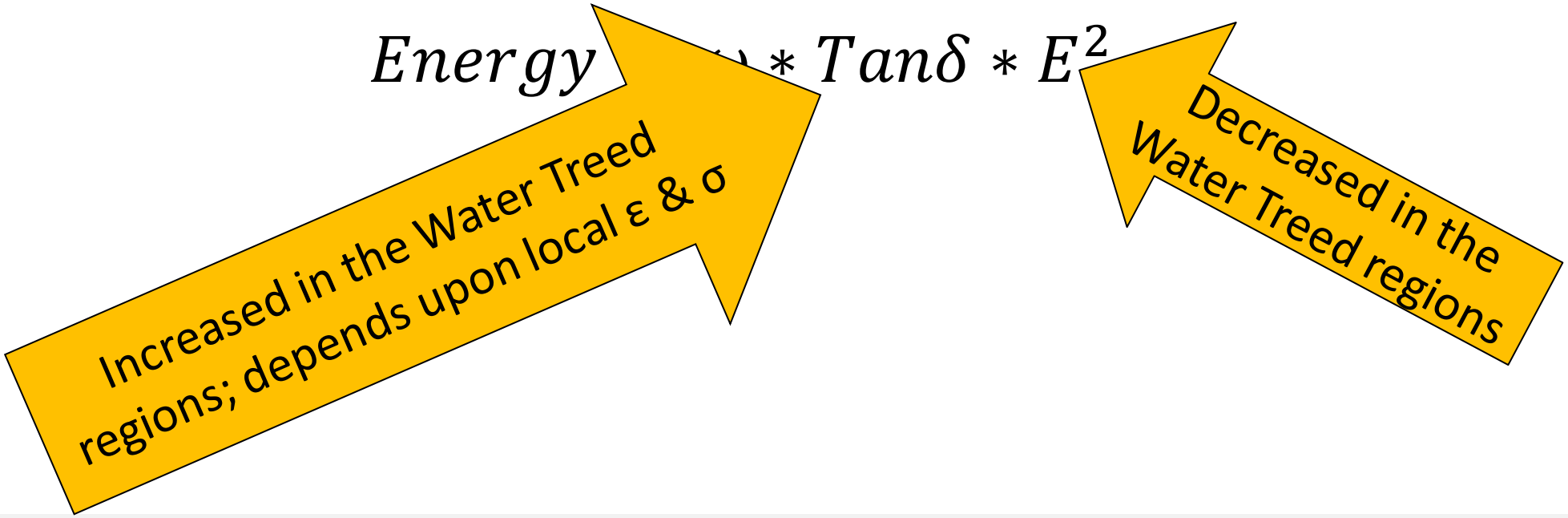
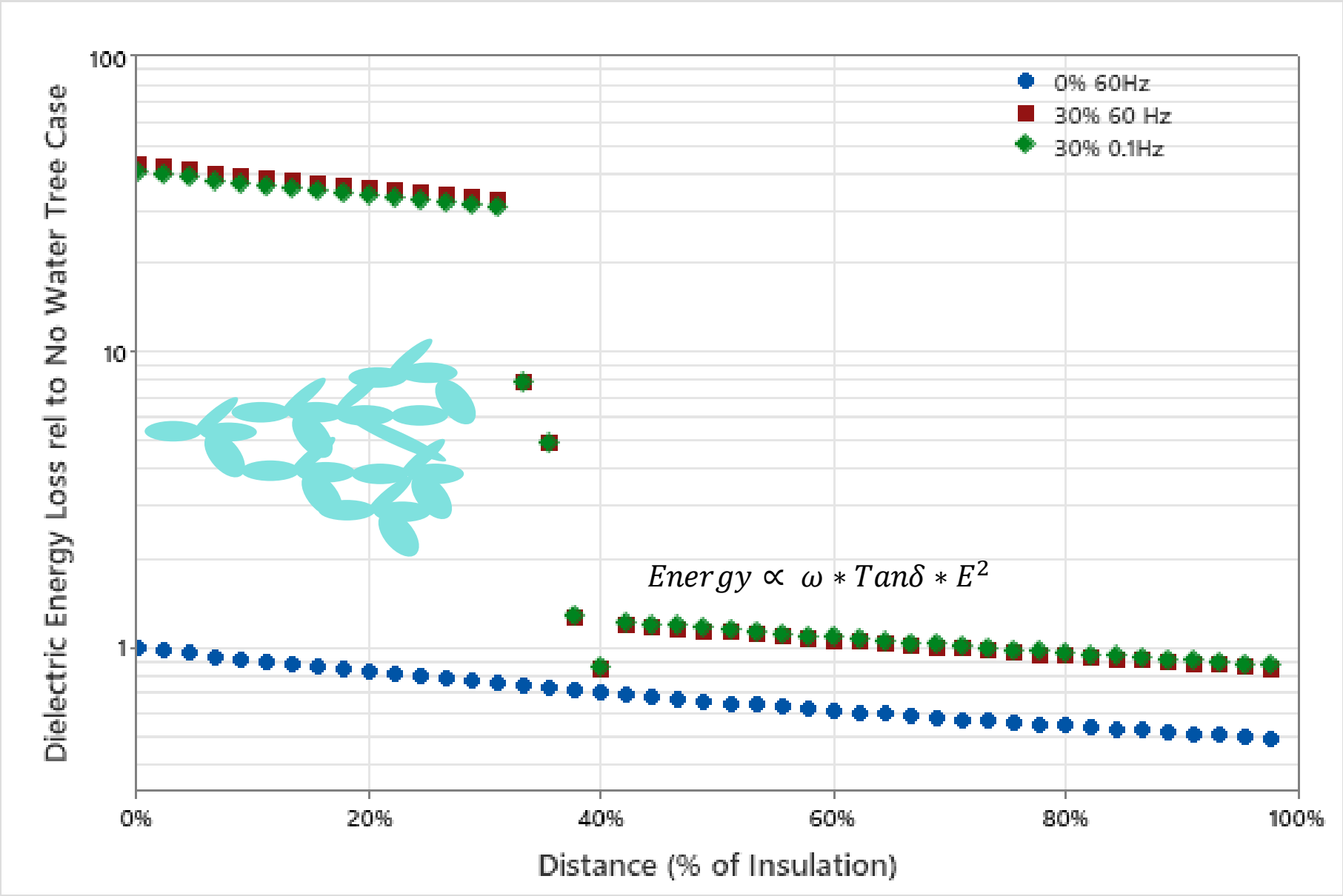


Energy generated in the Dielectric



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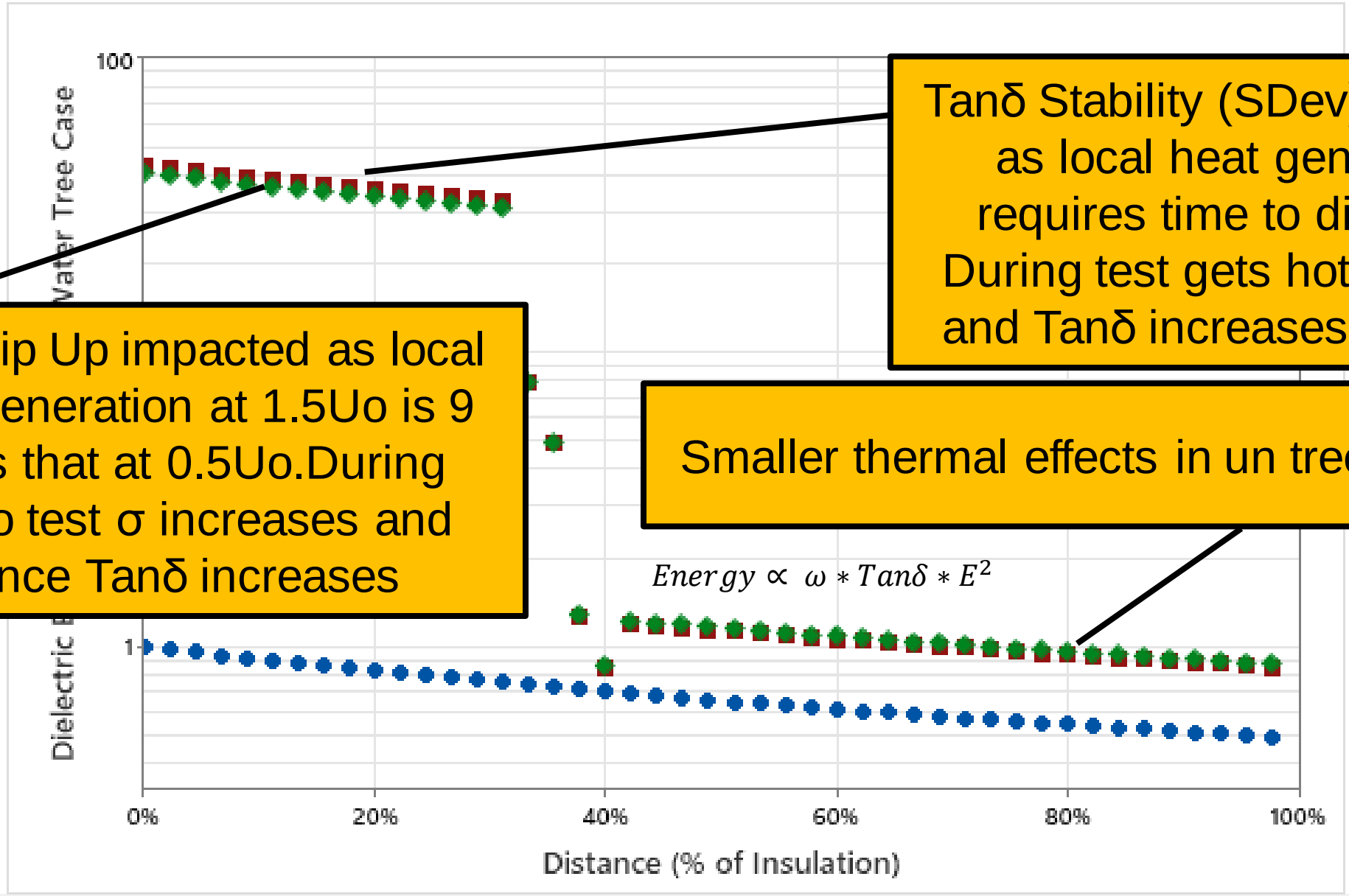

Tanδ Tip Up impacted as local heat generation at 1.5Uo is 9 times that at 0.5Uo.During 1.5Uo test σ increases and hence Tanδ increases

Tanδ Stability (SDev) impacted as local heat generation requires time to dissipate. During test gets hot locally, σ and Tanδ increases with time

Smaller thermal effects in un treed region

To Wrap Up

- Water Trees are not structures that simply form a conducting bridge across the insulation
- They are complex dielectric features that interact with the accessory / cable dielectric
- How and where trees grow impacts our ability to detect them
- Water Trees grown in the lab are different (density & length) to the Trees that grow in service – large lab trees are 6% to 8% of insulation
- Physical basis why Tan δ SDev and Tan δ TU are seen to be powerful diagnostic features