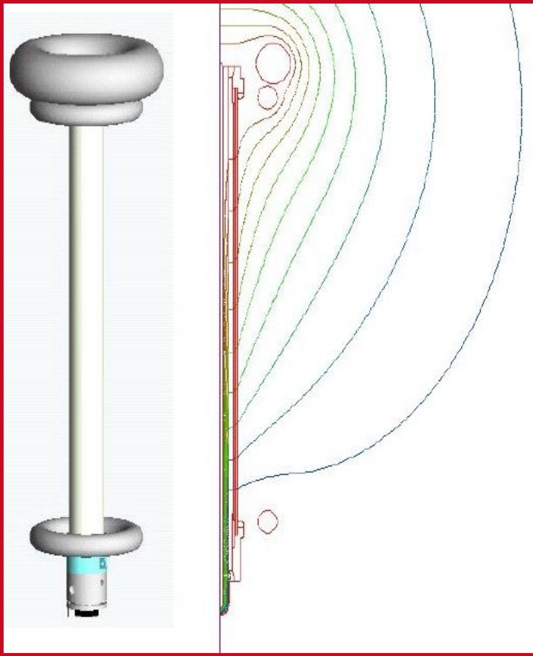
ELECTRIC FIELD CALCULATIONS FOR AC AND DC APPLICATIONS OF WATER CONTROLLED CABLE TERMINATION



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COMSOL CONFERENCE 2014 BANGALORE

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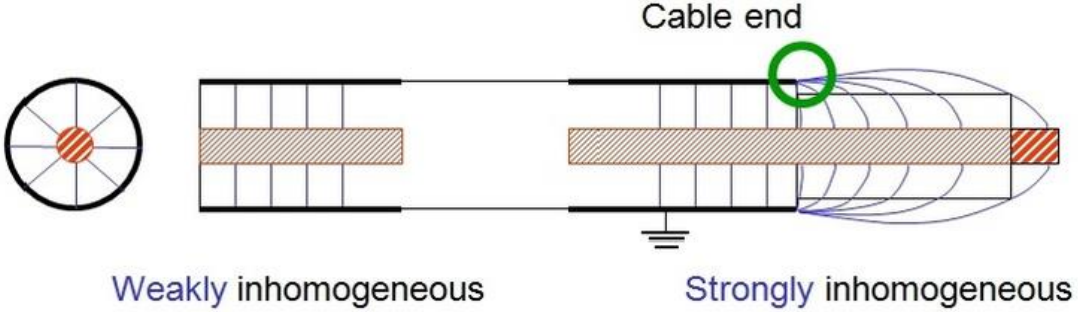
Cable Termination

- Operating Principle
  - Linear electric field control with water of controlled conductivity for performing the routine testing of power cables

- Significance
  - High-voltage tests performed on power cables (75 kV to 800 kV AC and up to 500 kV DC) to check the dielectric integrity of insulation.
  - Cable ends are characterized by strongly inhomogeneous electric field distribution.
  - Electric field distribution is improved at the cable ends by a suitable field control – Cable Termination



- Role of Water
  - Forced resistive control for smoothening the strongly inhomogeneous electric field

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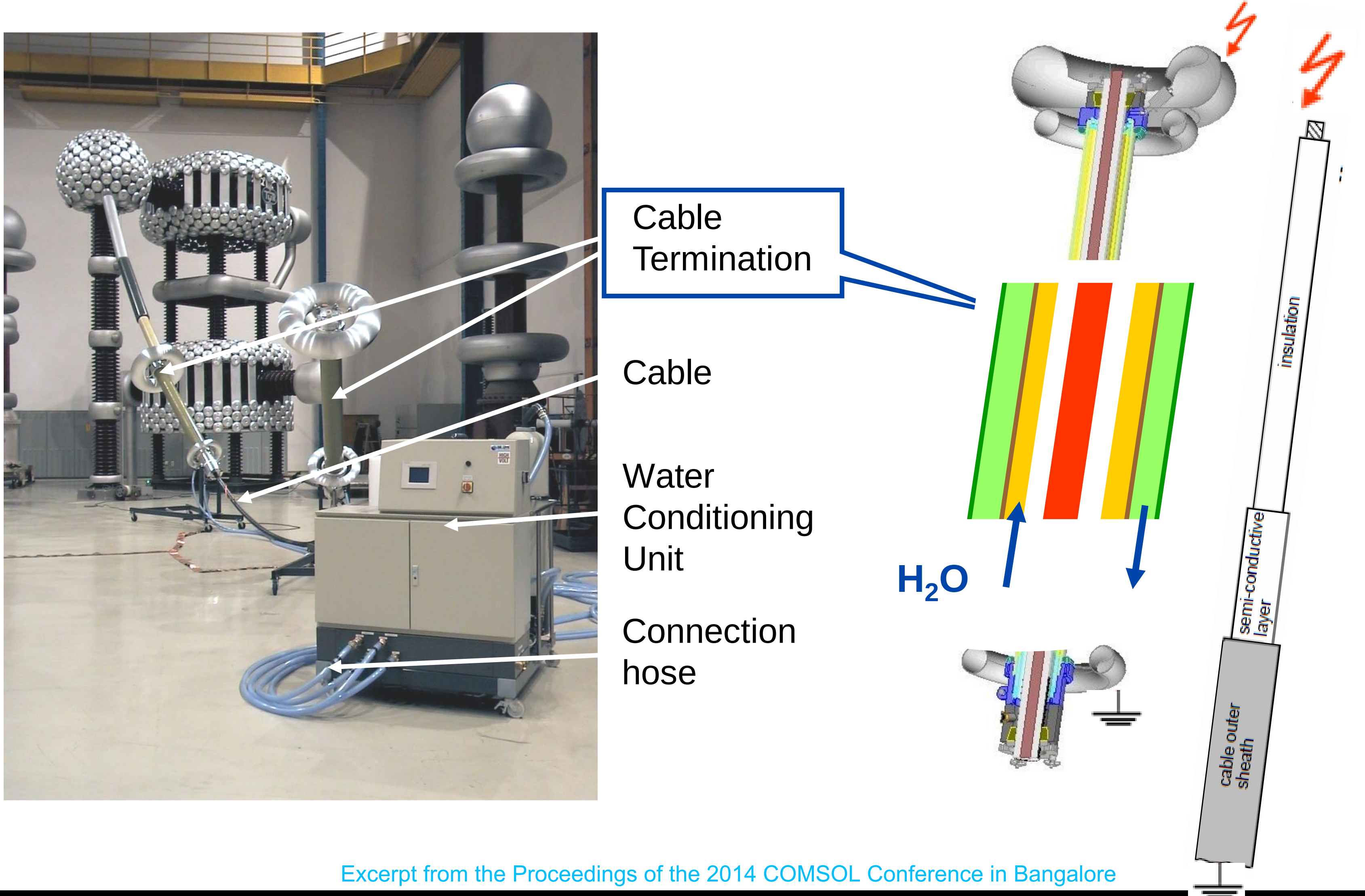
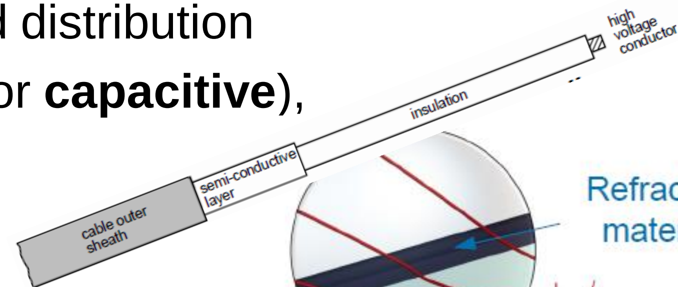
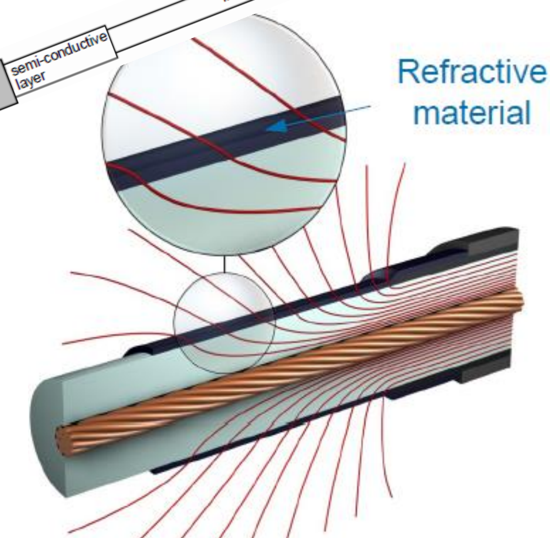
Principle construction of a Cable Termination and its arrangement in a high-voltage test hall



Differences in AC & DC Cable design and concept of Electric field control

- Cable design - strongly influence electric field distribution
- Main differences are: field control (**resistive** or **capacitive**), **sheath resistance** and **material**.





$$\frac{E_1}{E_2} = \frac{\varepsilon_{r2}}{\varepsilon_{r1}}$$

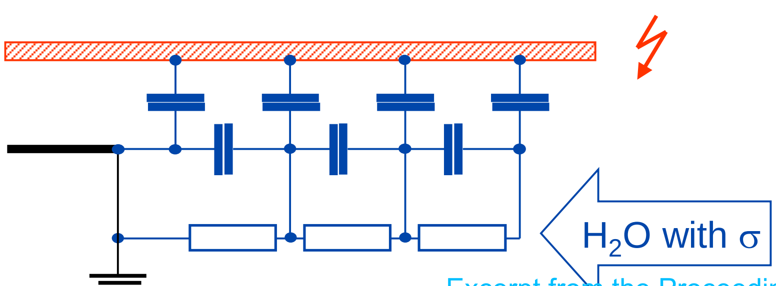
$$\frac{\tan \alpha_1}{\tan \alpha_2} = \frac{\varepsilon_{r1}}{\varepsilon_{r2}}$$

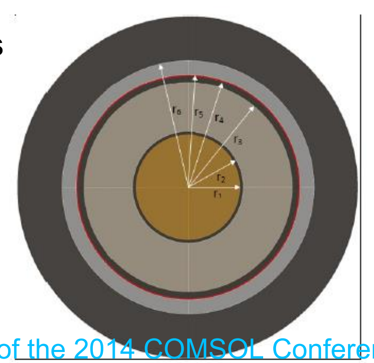
AC cable

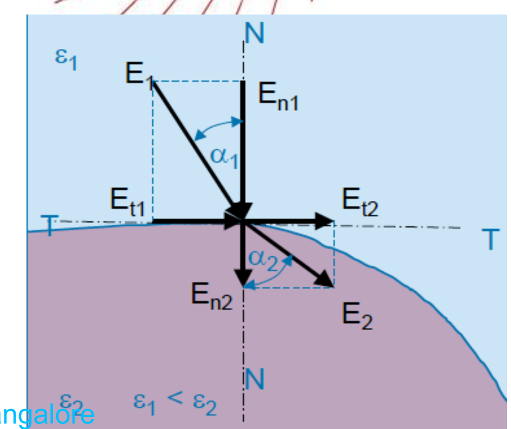
ABB: 400-kV AC XLPE cable, insulation thickness 28 mm

DC cable

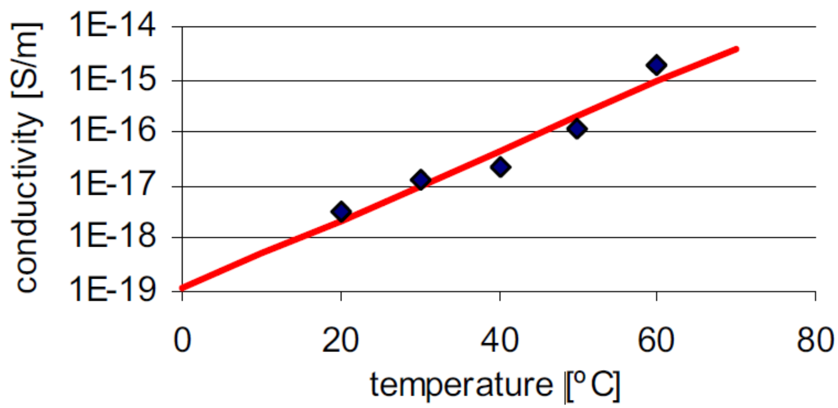
ABB: DC-Cable for Offshore Wind Farms







Strong influence of material conductivity at DC



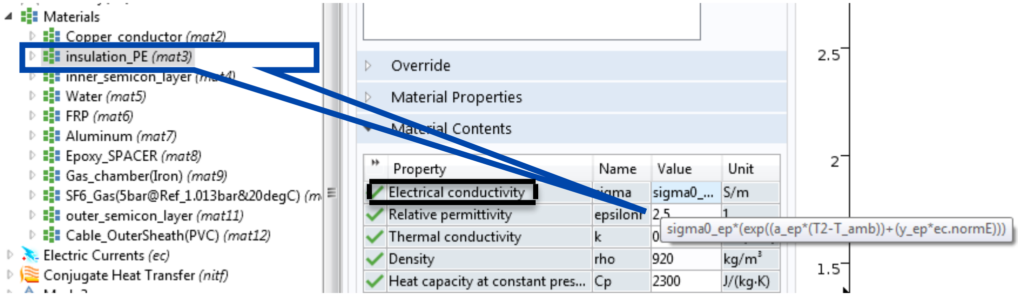
$\sigma\,(T,E) = \sigma_0 * e^{(\alpha T + \beta E)}$

DC conductivity measured on LDPE insulated cable sample as a function of temperature at 20 kV (4 kV/mm);

Reference: Ildstad et al.

Simulation challenge!!!
Incorporation of the nonlinearities to emulate reality

σ = specific DC conductivity in S/m
σ_0 = specific DC conductivity at 0°C and 0 kV/mm
T = temperature in °C
E = electrical field in kV/mm
α = temperature coefficient of specific DC conductivity
β = electric field coefficient of specific DC conductivity



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Simulation requirements for fundamental design optimisation

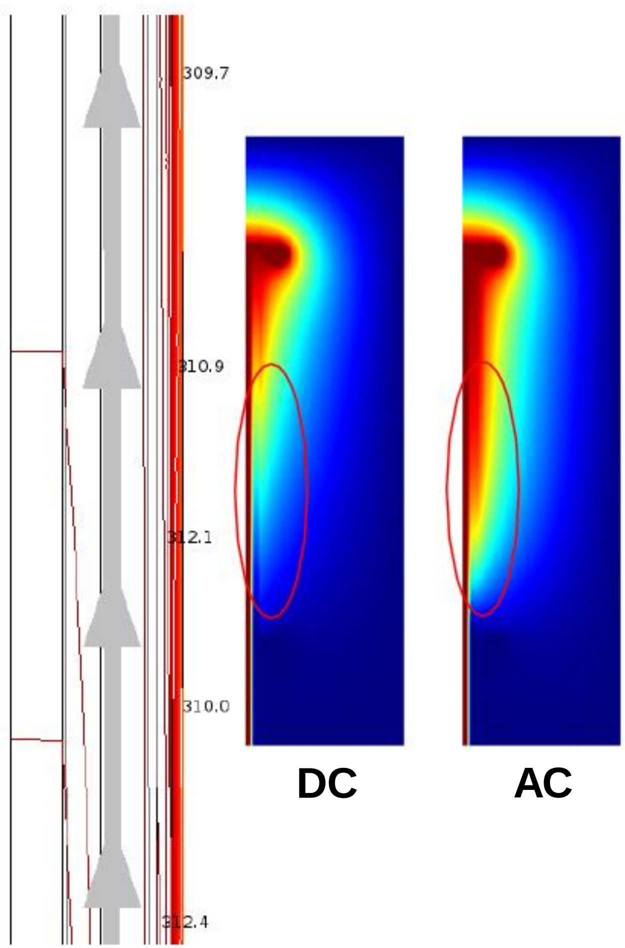
Reasonable computational time and effective resource utilisation

- Influence of various parameters.
- Different test scenarios.

Modelling flexibility

- Solving of bulk PDEs and User-defined nonlinear material equations.
- Interfaces corresponding to material changes.
- Electrical and thermal boundary conditions.
- Coupled behaviour – Multiphysics.

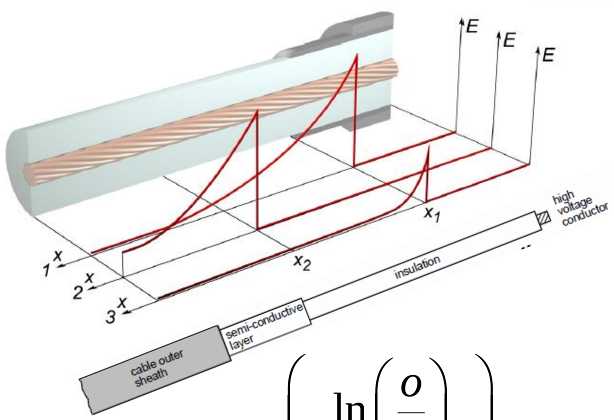
Electric Potential for an applied voltage of 500 kV

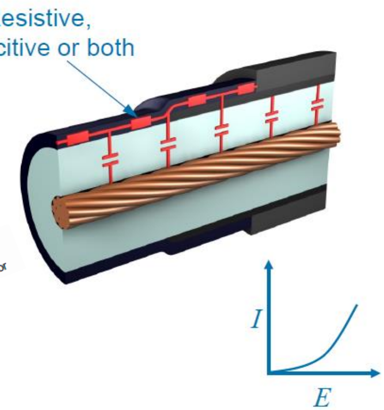


DC

AC

TEMPERATURE





$$R_{th} = \left(\frac{\ln\left(\frac{o}{i}\right)}{2\pi k L_{cable}} \right) \Leftrightarrow \frac{dQ}{dt} = I^2 R$$

Analytically derived thermal resistance analogous to electrical resistance.

$\frac{dQ}{dt}$ Rate of Heat Flow through an area A

L_{cable} Length of the cable

k Thermal Conductivity

$o - i$ Thickness travelled by the heat flow

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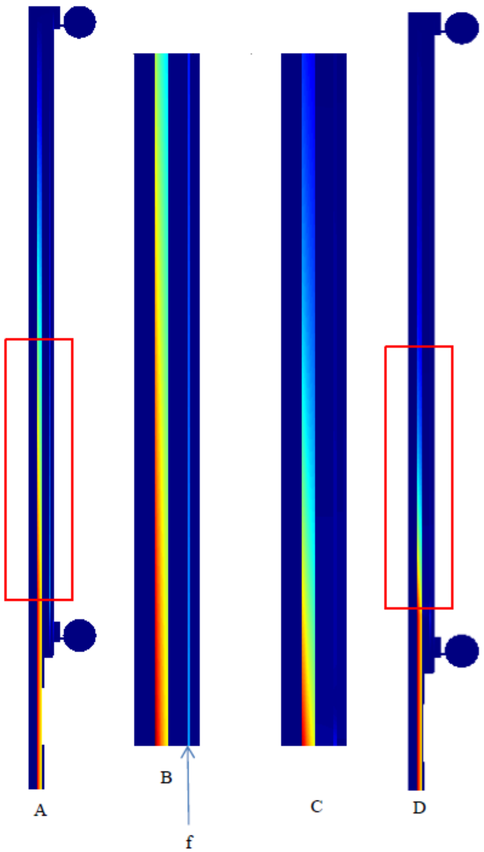
Electric field strength



$$\nabla . E = \frac{\rho}{\epsilon_0} \Leftarrow Gauss's\ Law$$

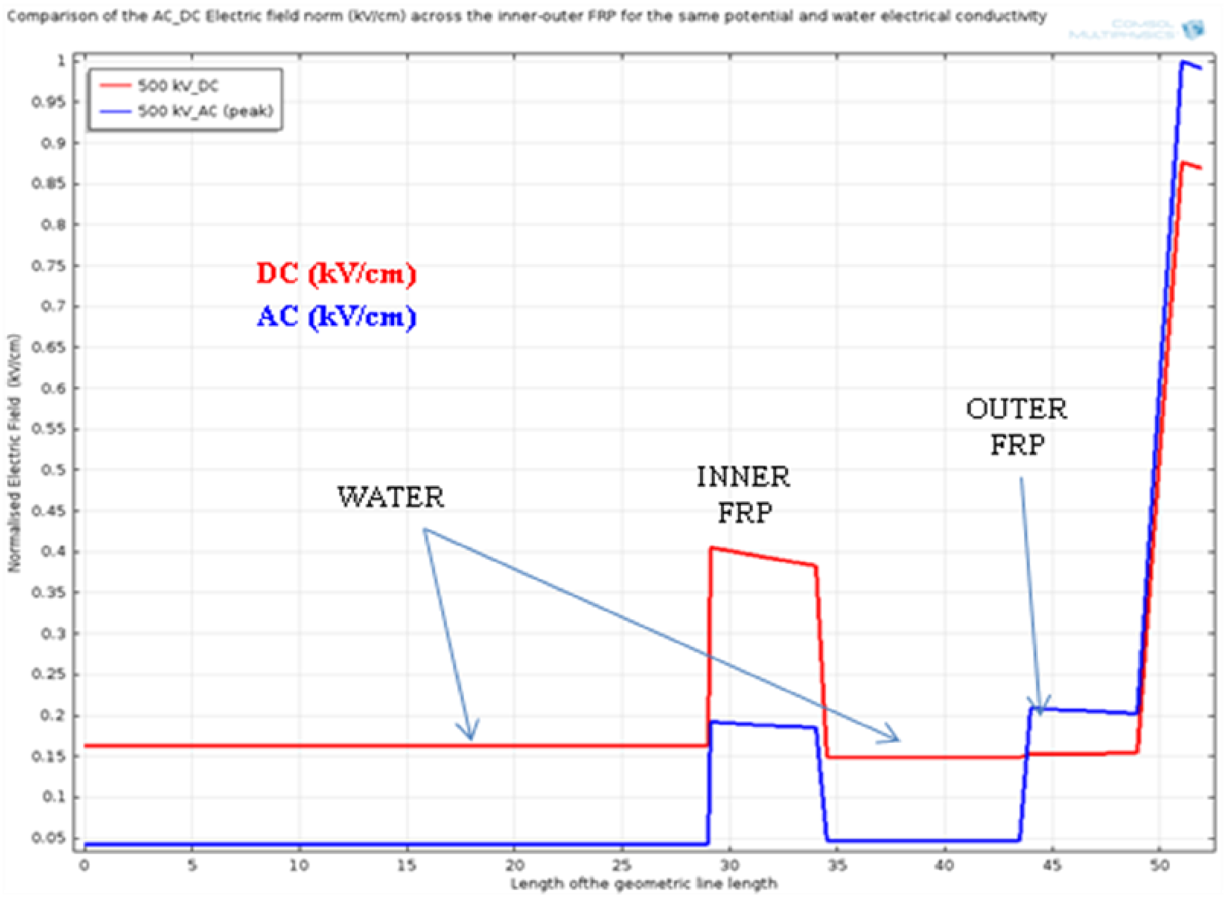
$$D = \epsilon_0\ \epsilon_r \qquad J = \sigma E$$

Relation between the density of charge carriers ρ, the electrical conductivity σ and the electric field strength *E*

- influence of material properties
- variation of permittivity values cause significant influence on electric field strengths
- For DC, electric field influenced by the electrical conductivity

A – for DC Electric Field
D – for AC Electric Field
f – effect on inner FRP tube
B & C – zoomed-in plots for DC & AC respectively

Normalized Electric Field strength – inner water loop to outer FRP



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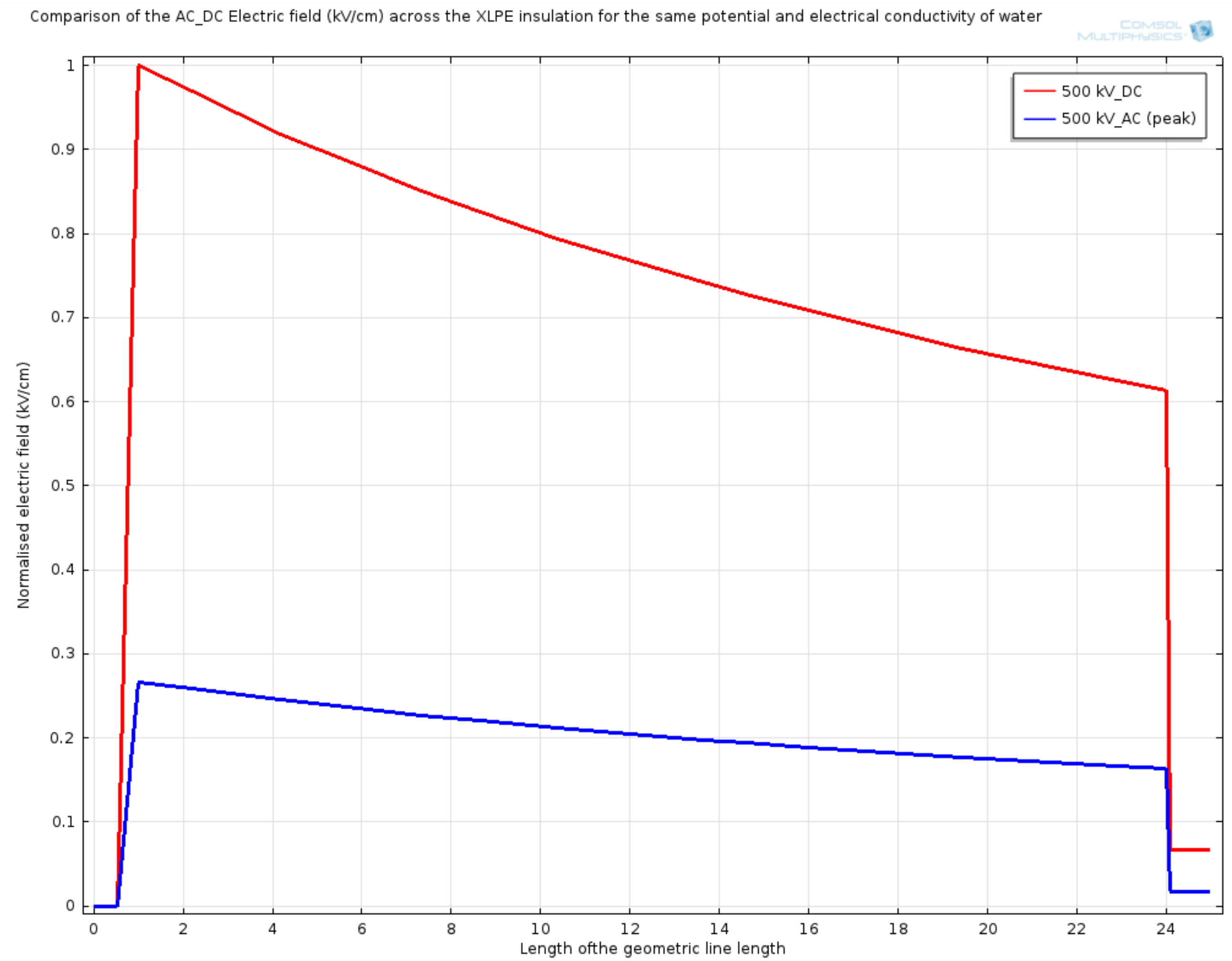
Normalized Electric Field strength – across the XLPE Cable insulation



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CONCLUSION

Modelling flexibility – key to basic R&D and design, optimization process.

FEM Modelling – an important analysis tool in the area of high-voltage technology.

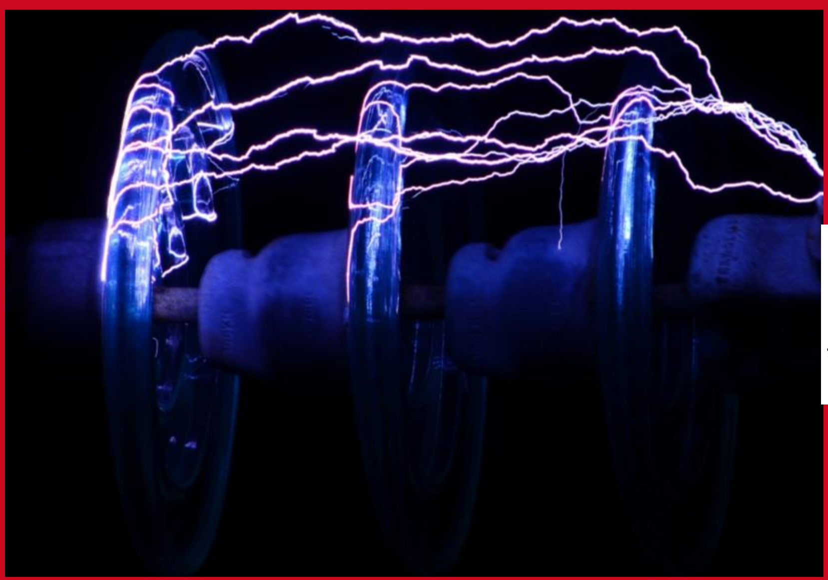
COMSOL Multiphysics® – a supportive methodology in updating and meeting the state-of-the-art requirements of power industry.

Equally important

Simultaneous analytical calculations to help verify simulation results eventhough the modelling work may or may not intend to compare the outcome with experimental results

Thank You for your kind attention!

Your Comments and Questions Please!



AC test system based on transformer DC test system Impulse voltage test system

AC test system; 2400 kVA/1200 kV
Courtesy of HSP, Germany

DC test system;
20mA/1500 kV

Impulse voltage test system;
320 kJ/3200 kV