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Loss-of-life Fraction Estimation for HVDC Extruded Cables in the Presence of Long Temporary Overvoltages Recorded in the Field

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Objective

This study aims at loss of life estimation of XLPE-insulated cables subject to long temporary overvoltage (TOV) measured in the field on the healthy pole of an HVDC cable transmission link during a fault on the other pole.

Cable Characteristics

Parameter	VALUE
Nominal voltage	320 kV
Conductor Material / cross-section	Cu /1600 mm^2
Design temperature of conductor	70 °C
Insulation / Relative permittivity / thickness	DC-XLPE / 2.3 / 17.9 mm
Temp. coefficient of electr. conductivity	0.084 1/°C
Field coefficient of electr. conductivity	0.0645 mm/kV
Soil temperature (° C)	20
Design life (y)	40

TOV Characteristics

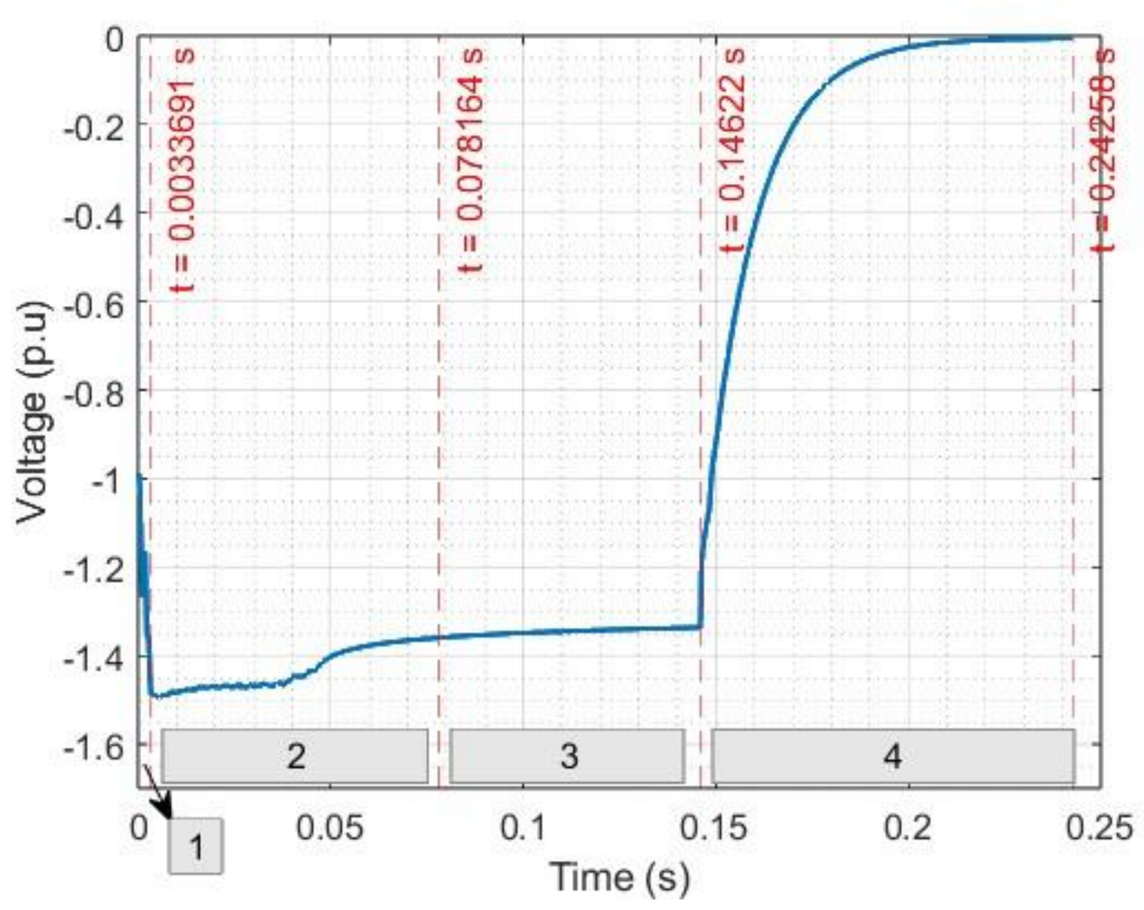

Fig. 1 TOV voltage in p.u. The dashed red lines divide the transient duration into 4 intervals numbered as in the gray boxes.

Transient intervals

Interval number	Description	Time (ms)
1	voltage increase towards the peak ≈ 1.5 p.u.	≈ 3.5
2	voltage decay towards the plateau ≈ 1.35 p.u.	≈ 75
3	the plateau ≈ 1.35 p.u.	≈ 70
4	voltage decay towards zero	≈ 96

Theoretical Background

Electric Field calculation:

- $\nabla \cdot (\varepsilon_0 \varepsilon_r \boldsymbol{E}) = \rho$ (1)
- $\nabla \cdot \boldsymbol{J} = -\frac{\partial \rho}{\partial t}$ (2)
- $\boldsymbol{J} = \sigma \boldsymbol{E}$ (3)
- $\sigma = \sigma_0 \, exp(aT + bE)$ (4)

Life Estimation:

- $L(E,T) = L_D . [E/E_D]^{-(n_D - b_{ET}T")} [E_D/E_0]^{b_{ET}T"} \; e^{-BT"}$ (5)
- $LF_{inter_i}(r) = \int_0^{t_{d,i}} \frac{dt}{L[E(r,t),]}$ (6)

where E = electric field vector (kV/mm), J = direct conduction current density vector (A/m^2), ρ = free charge density (C/m^3), σ = electrical conductivity of the dielectric (S/m), σ_0 = σ(T=0 °C; E=0 kV/mm), a= temperature coefficient of σ (1/°C), b = stress coefficient of σ (mm/kV), ε_0 =vacuum permittivity, ε_r = relative permittivity of the insulation. L = life at DC electric field E and temperature T, T″=1/T_D–1/T (E_D, T_D and L_D being design electric field, temperature and life respectively), n_D = voltage endurance coefficient (VEC) at T_D, b_{ET} = synergism factor between the electrical and thermal stress, $B = \Delta W/K_B$, ΔW = activation energy of the main thermal degradation reaction, K_B= $1.38 \times 10^{-23}\, J/K$ = Boltzmann constant.

Results

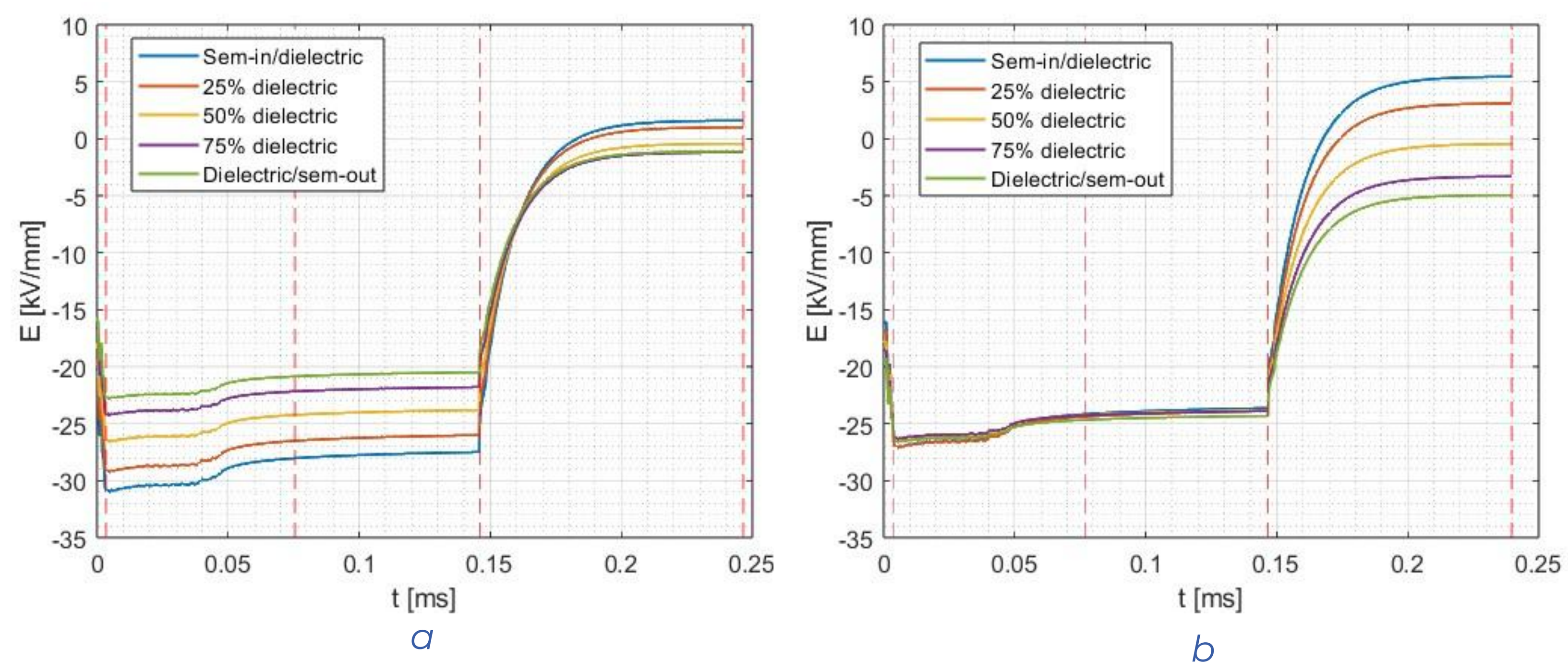

Fig. 2 Electric field distribution at 5 equally-spaced points within the insulation thickness of the cable subjected to TOV divided into 4 intervals in the case of (a) cold cable, (b) hot cable.

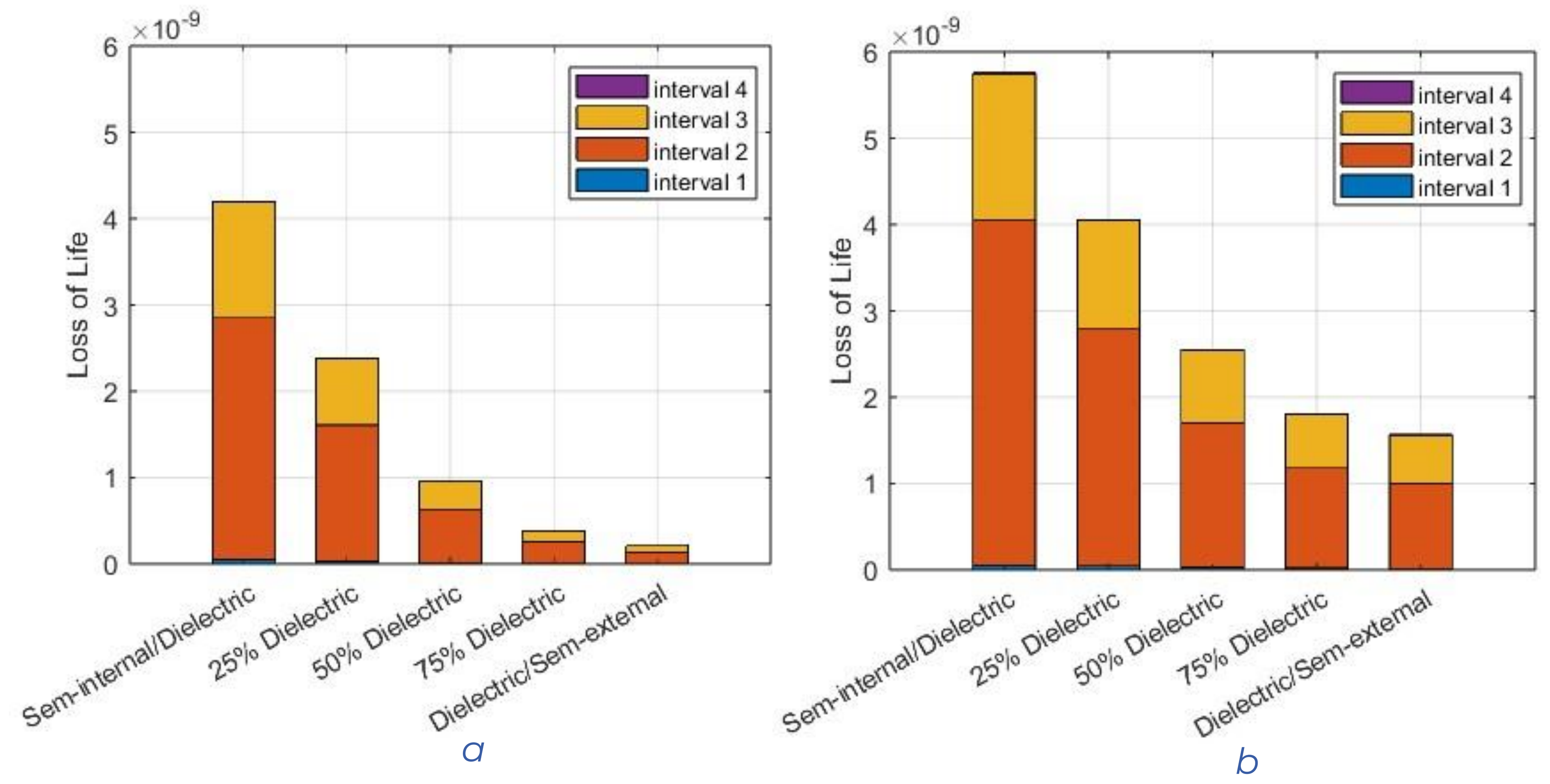

Fig. 3 loss of life at 5 equally-spaced points within the insulation thickness of the cable subjected to TOV divided into 4 intervals in the case of (a) cold cable, (b) hot cable.

Conclusion:

- Overall, results show that the loss of life is **negligible** during the transient compared to cable design life.
- The greatest percentage of the loss of life is noticed during the **peak** and during the **plateau** of the TOV.
- The **inner insulation** is the most stressed point inside the insulation in both hot and cold cable conditions.
- This emphasizes the AC-like contribution of the electric field superimposed onto the DC field.

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