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Preliminary Evaluation of the Challenge Set to HVDC Extruded Cables by Switching Overvoltages due to the Operation of Direct Current Circuit Breakers

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Objective

This study aims at loss of life estimation of HVDC cables subject to zero crossing damped temporary overvoltages (DTOV) with multiple zero-crossings due to the operation of DC Circuit Breakers (DCCBs). DTOVs are investigated for a DC link consisting of a hybrid overhead-cable line connection. The transient behavior of the link for a switching operation of a DCCB is simulated, then loss of life is estimated at 5 points in the insulation

Cable Characteristics

Parameter	VALUE
Rated power (bipolar scheme) (MW)	1,187
Rated voltage (kV)	525
Conductor Material	AL
Conductor cross-section (mm^2)	2,000
Insulation Material	MIND
Relative permittivity	3.2
Rated conductor temperature T_D (° C)	55
Ambient temperature T_a (° C)	20
Insulation thickness (mm)	21.5
Temperature coefficient of electrical conductivity a (1/°C)	0.074
Electric field coefficient of electrical conductivity b (mm/kV)	0.029

TOV Characteristics

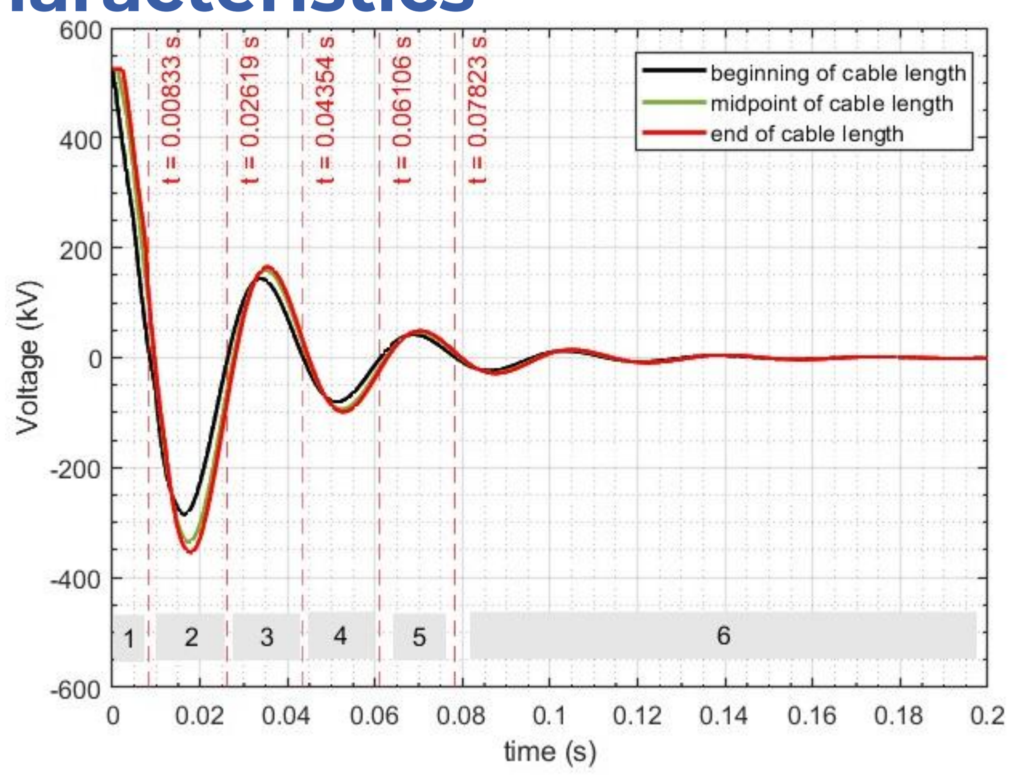

Fig. 1 DTOV at the beginning of the cable length (black curve), at the midpoint of the cable length (green curve), and the end of the cable length (red curve). The dashed red lines divide the transient duration into 6 intervals

TABLE II
Transient intervals

Interval number	Description
1	first voltage decay to zero
2	first opposite polarity half-period
3	first same polarity half-period
4	second opposite polarity half-period
5	second same polarity half-period
6	Rest of the transient period

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:

- $L(E,T) = L_D \cdot [E/E_D]^{-(n_D - b_{ET}T'')} [E_D/E_0]^{b_{ET}T''} e^{-BT''}$ (5)
- $LF_{inter_i}(r) = \int_0^{t_{d,i}} \frac{dt}{L[E(r,t),]}$ (6)

Simulated HVDC system

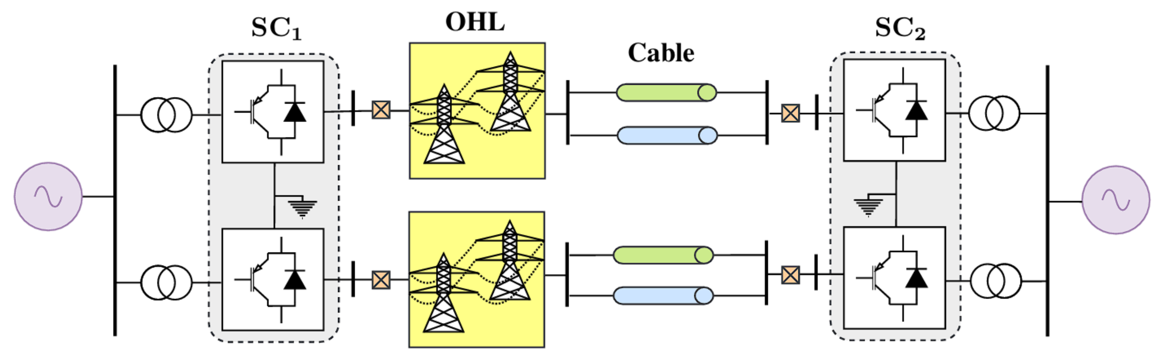

Fig. 1. Scheme of the simulated ±525 kV, 2000 MW, HVDC-MMC cable-OHL line

SC1 and SC2 equipped with half-bridge VSC MMC. OHLs length=170 km, subsea cable length=310 km, total=480 km

Results

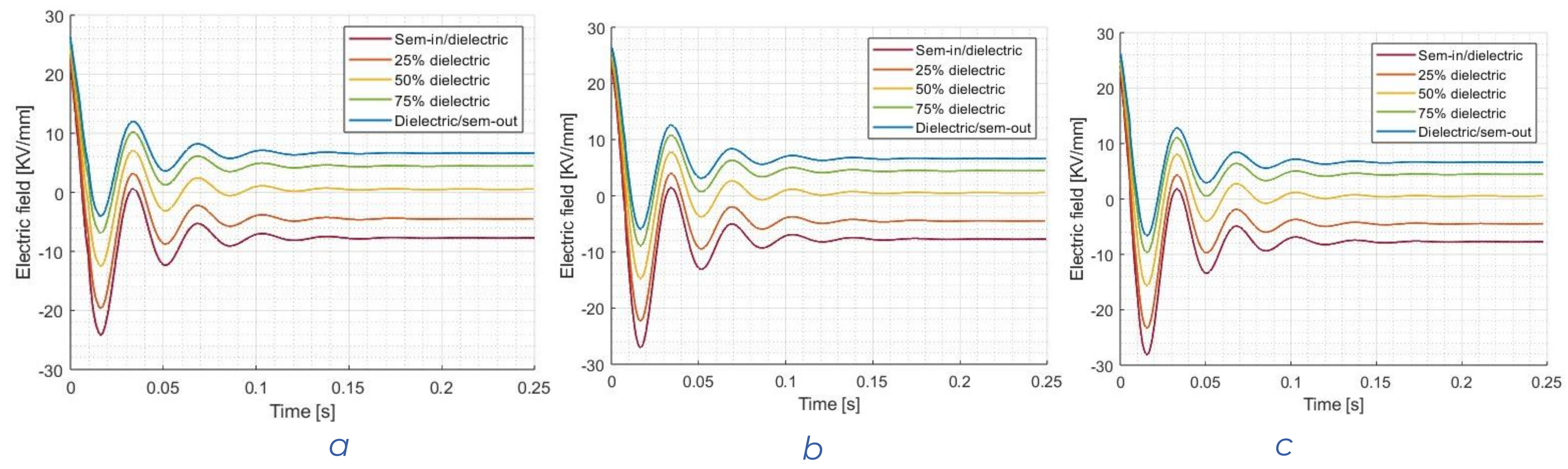

Fig. 2 Electric field distribution at 5 points within the insulation thickness of the HVDC MIND cable subjected to the DTOV divided into 6 intervals as defined in Fig. 1 and Table II, at (a) the beginning of the cable length, (b) the midpoint of the cable length, and (c) the end of the cable length.

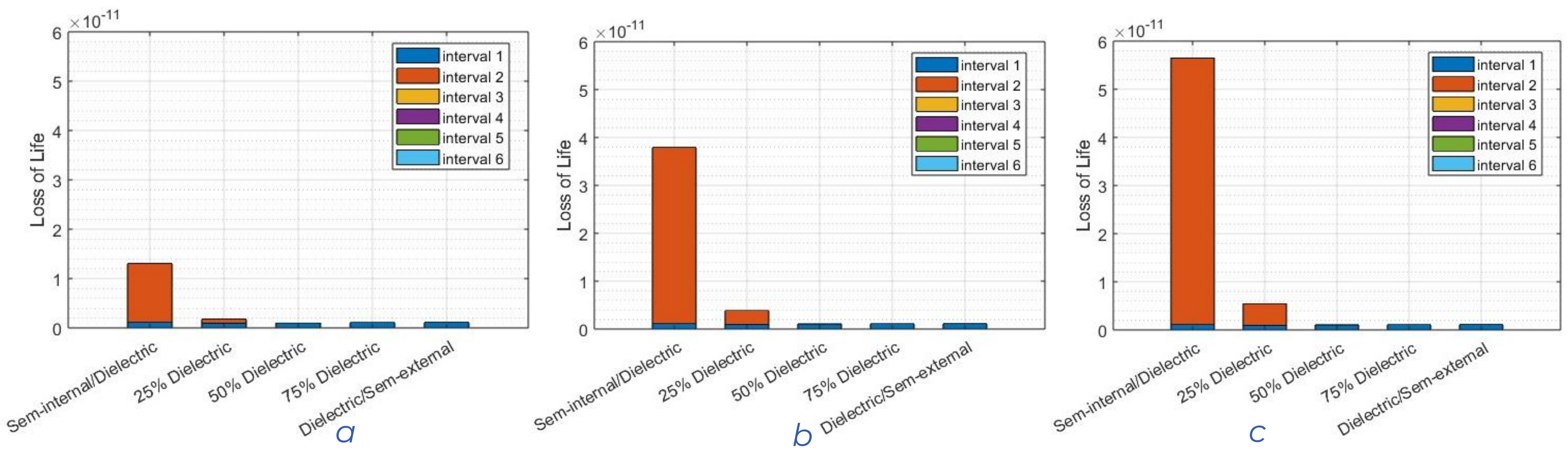

Fig. 3 Loss of life at 5 points within the insulation thickness of the MIND cable subjected to damped oscillating transient voltage divided into 6 intervals as defined in Fig. 1 and Table II, at (a) the beginning of the cable length, (b) the midpoint of the cable length, and (c) the end of the cable length..

Conclusion:

- The maximum voltage peak during the transient ranges from 0.55 p.u. to 0.67 p.u. along the cable length.
- The results show significant negative electric field peaks within the insulation during the first negative oscillation after the beginning of the transient.
- The greatest peak is found at the inner insulation, due to the permittivity-dependent component of the field associated with the transient voltage.
- The overall estimated loss of life is deemed **negligible** under such transients, although greater opposite polarity peaks – which could arise in other transients - might give more severe effects on the cable insulation.

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