EPRG-PRCI-APGA
23rd Joint Technical Meeting
Edinburgh, Scotland • 6–10 June 2022

JTM-23-p08 Assessing High Voltage DC Interference Risks on Buried Pipelines

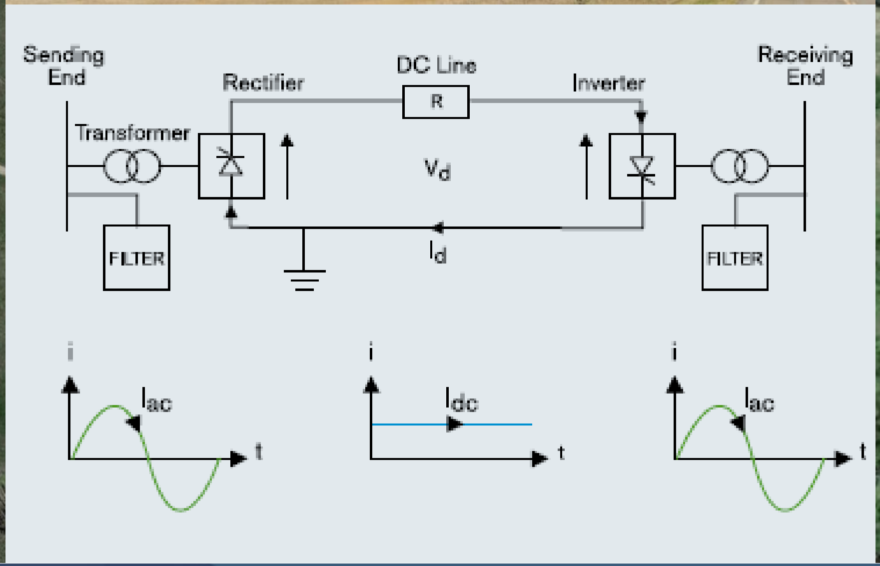
07 June 2022

HVDC systems

Rectifier

Transmission line

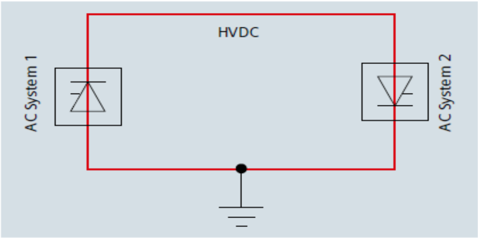
Inverter

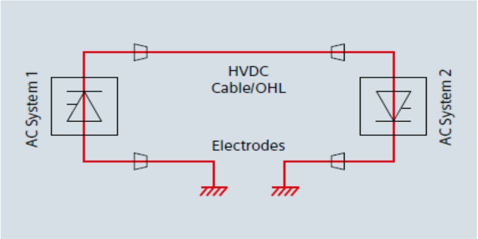


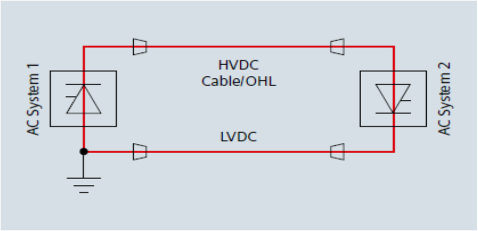
Types of HVDC

Monopolar

- Older/smaller systems
- Subsea cable
- Ground electrode







Types of HVDC

Monopolar

- Older/smaller systems
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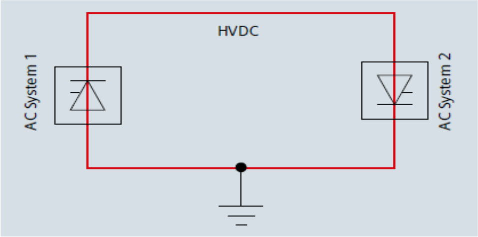
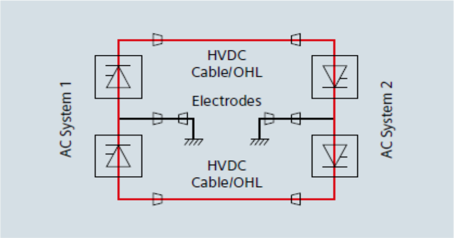
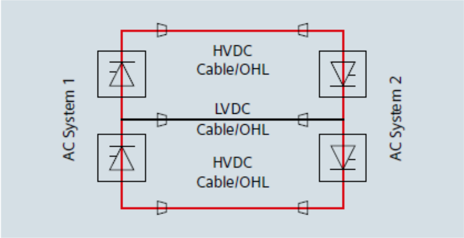
Bipolar/UHVDC

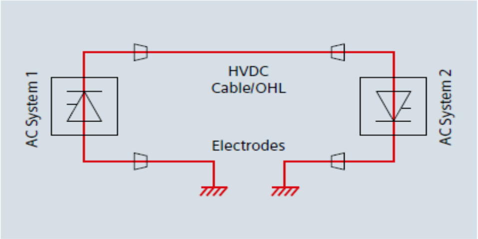
- Newer/higher power
- Overhead lines
- Ground electrode or dedicated metallic return (DMR)

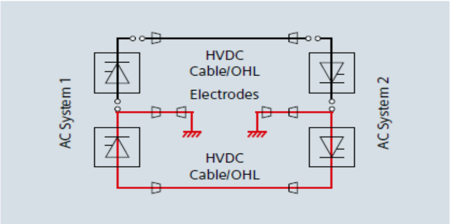
(Solar farms)

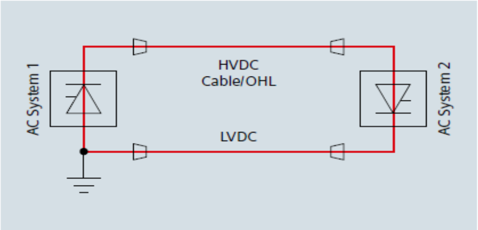


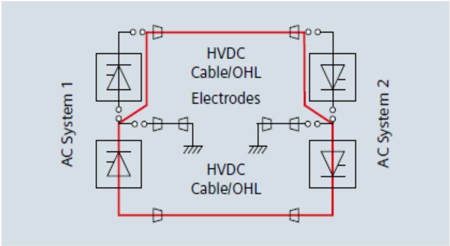












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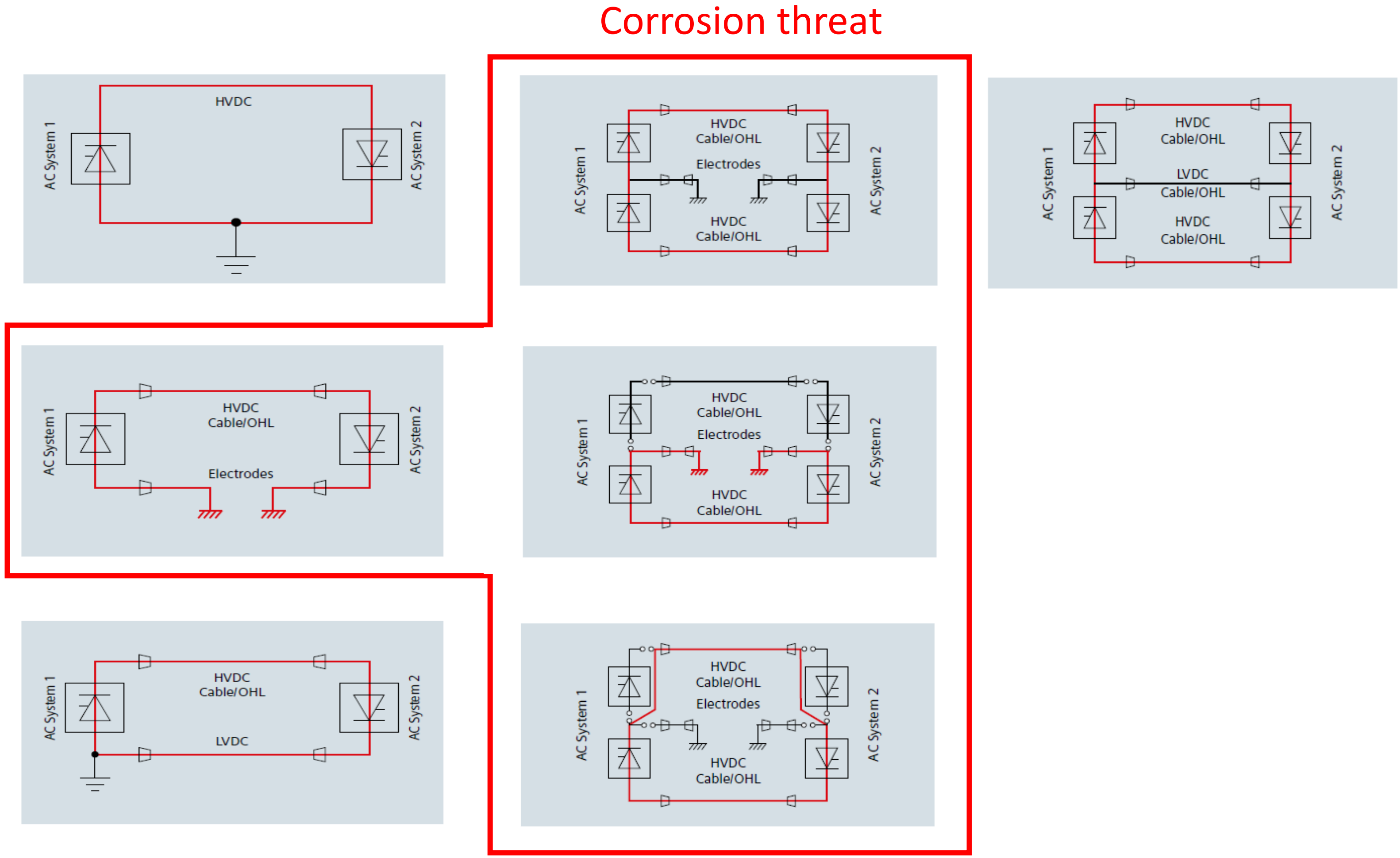

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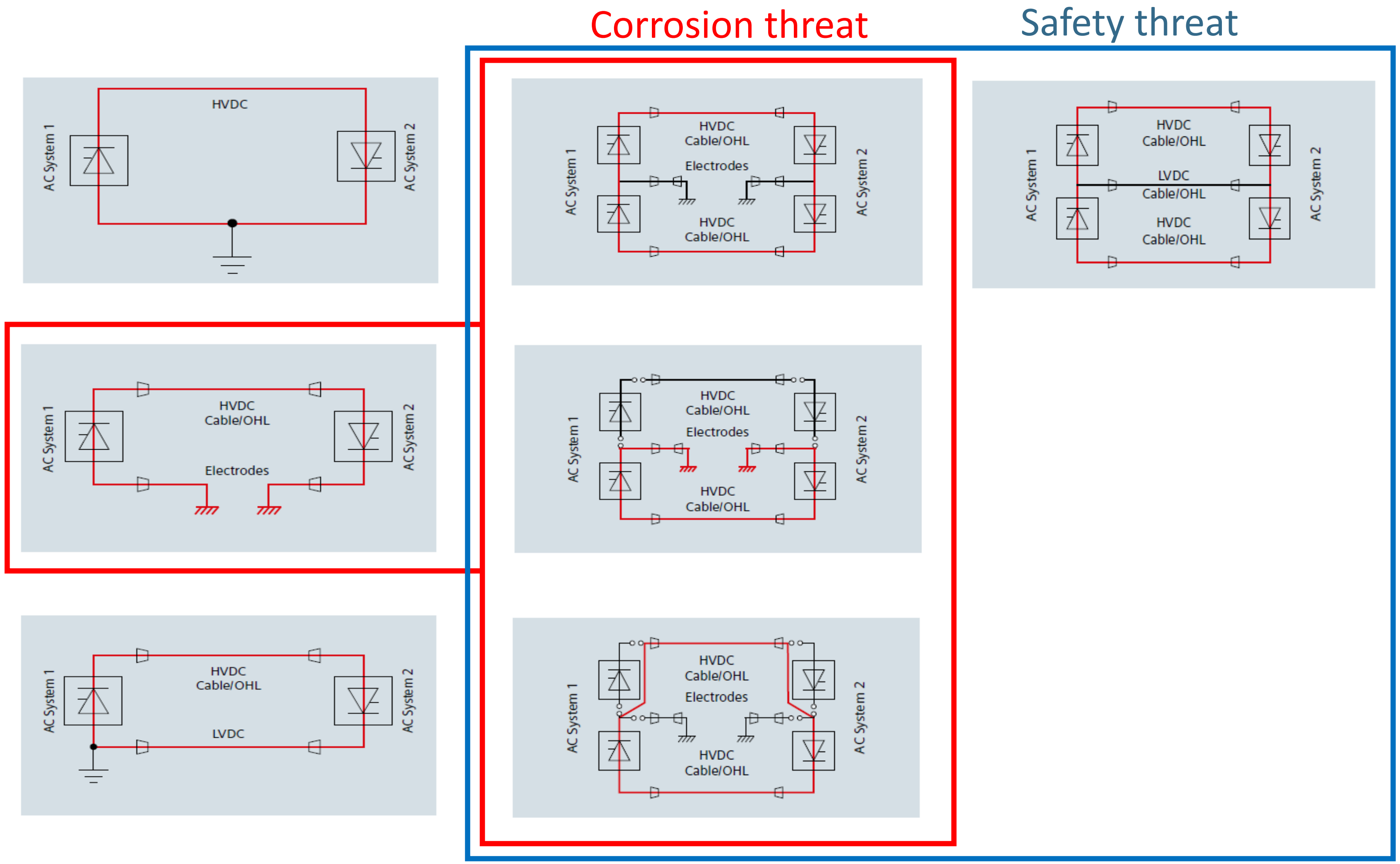
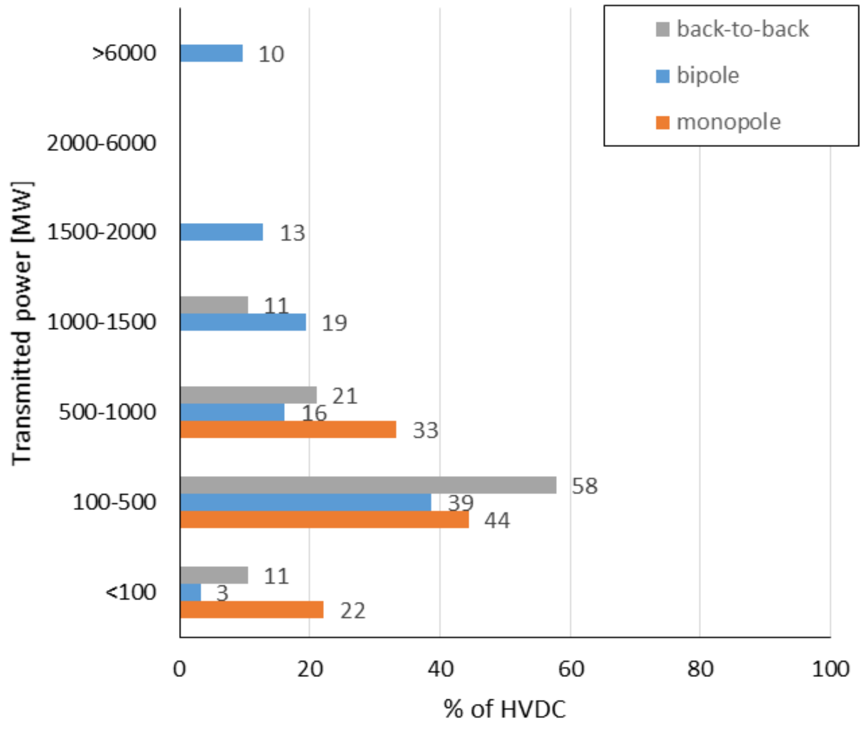
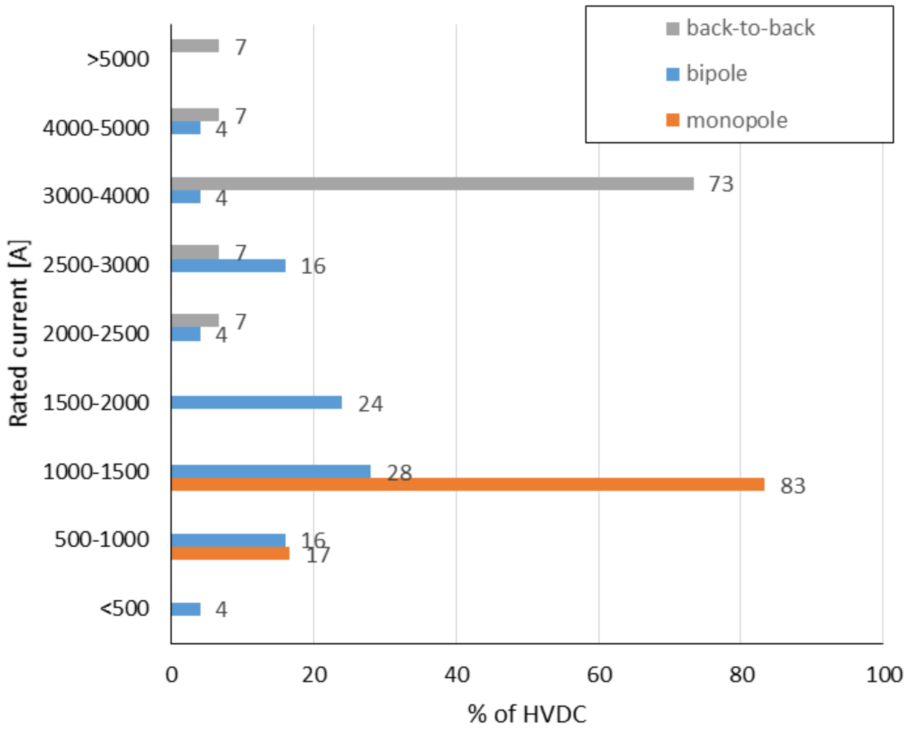


Most common systems

	Africa	Australia & Oceania	Asia	Europe	North America	South America
Operational	3	5	54	53	17	3
Planned (<2020)	0	0	1	9	4	0
Total in 2020	3	5	55	62	21	3





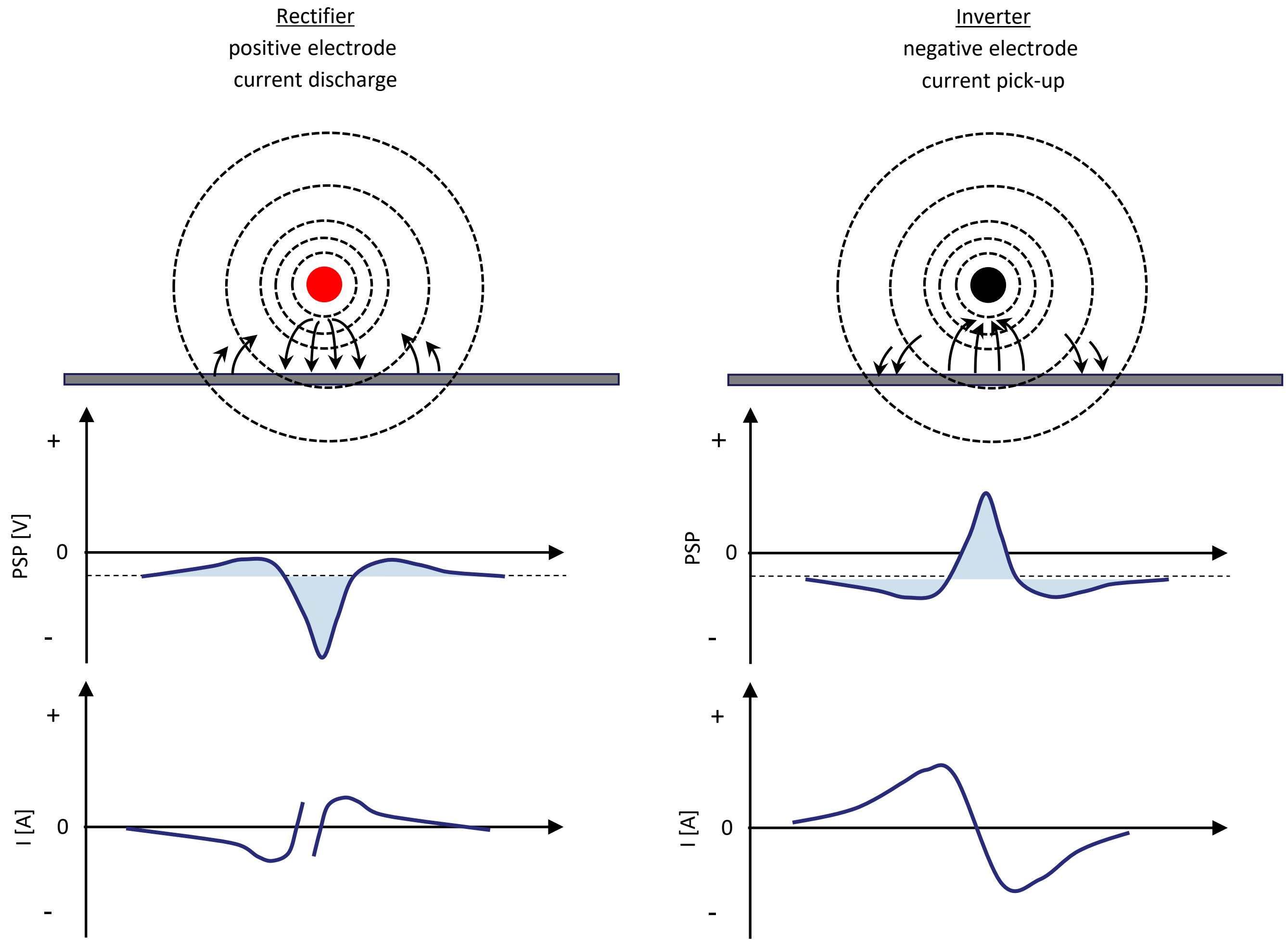
Corrosion threats

Rectifier

- Current discharge by HVDC
- Current pick-up by pipe
- Mainly risks of overprotection (coating disbondment, H_2-cracking)

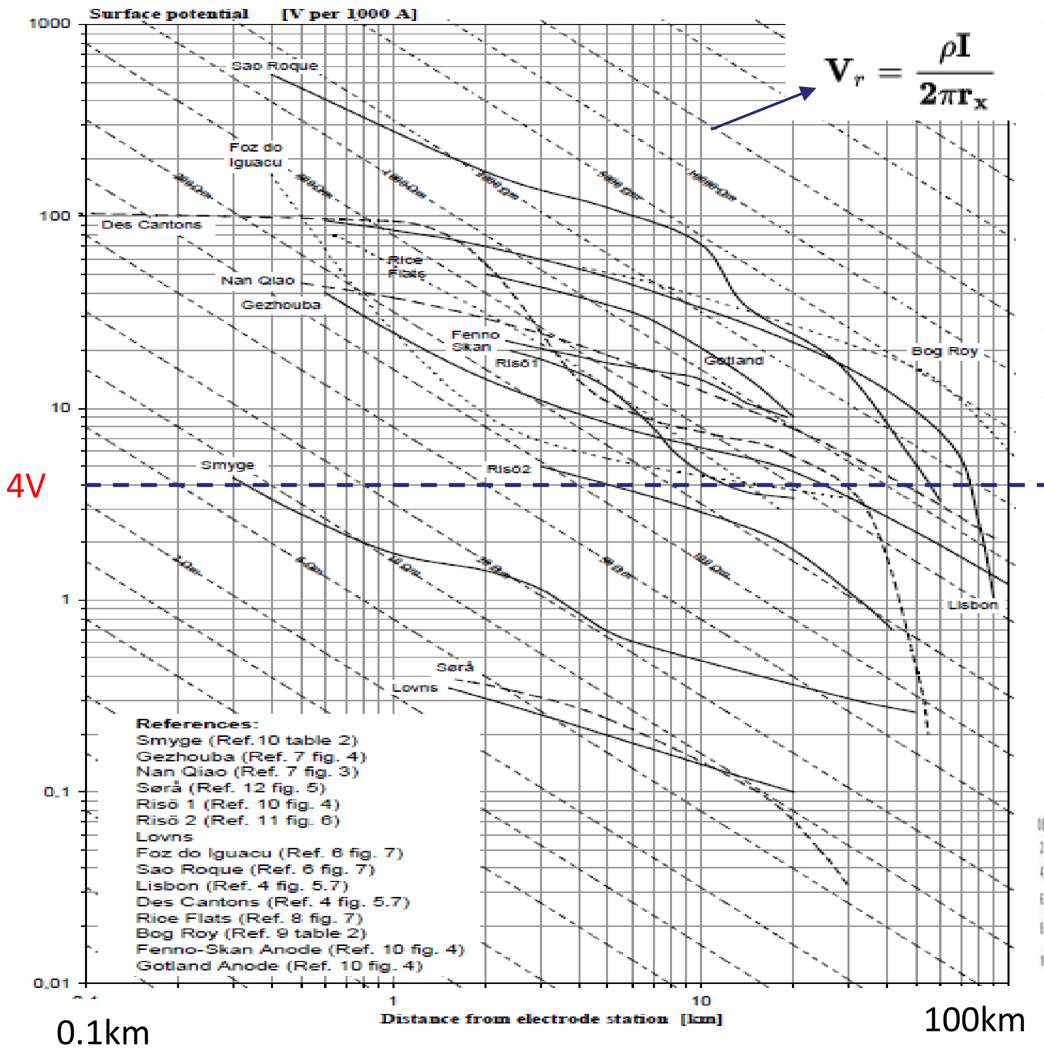
Inverter

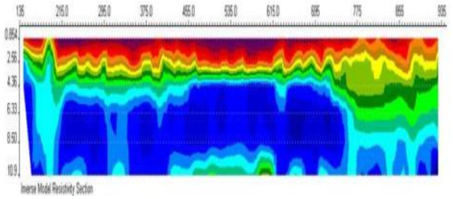
- Current pick-up by HVDC
- Current discharge by pipe
- Mainly risks of corrosion

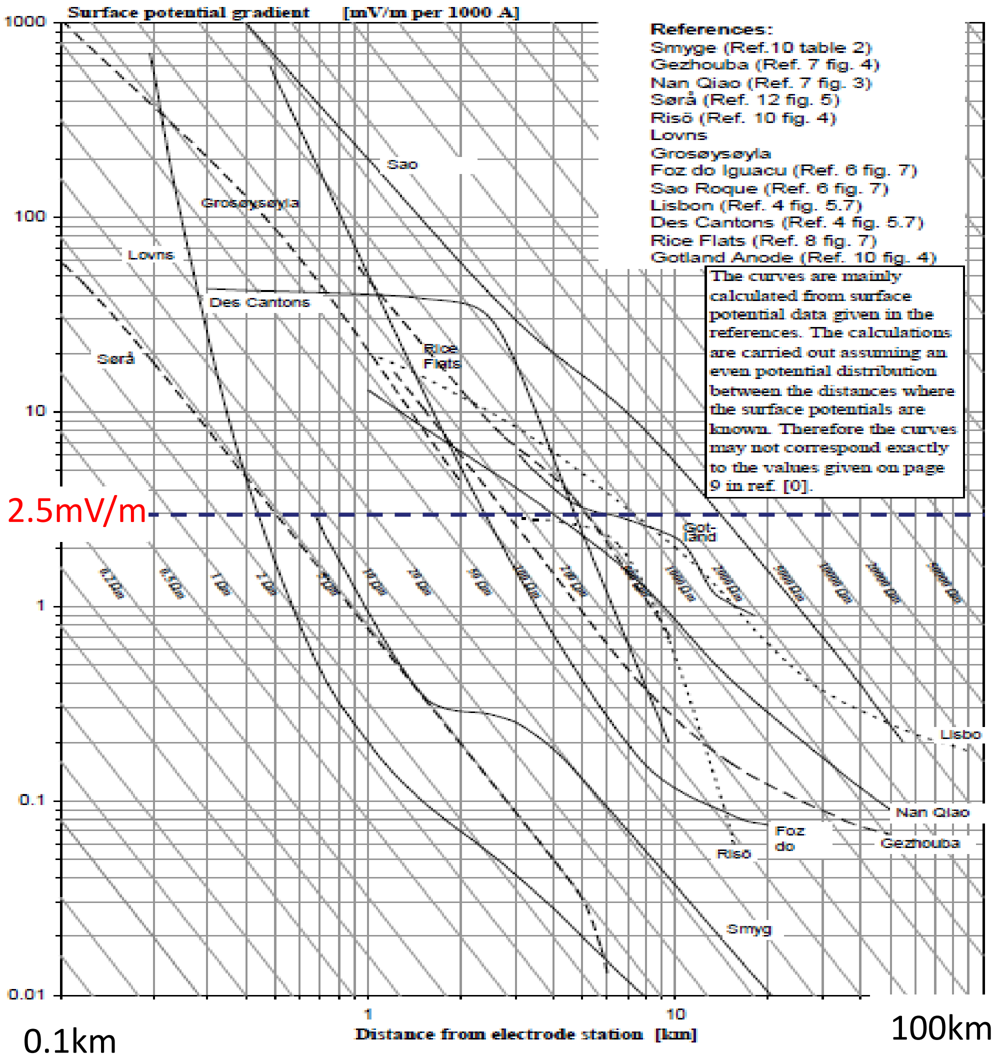


Impact of HVDC electrode

$$V_r = \frac{\rho I}{2\pi r_x}$$







Pipe protection criteria

- Protective measures must be applied if the pipe leakage current density is more than 1 μA/cm^2 (10mA/m^2) or the cumulative corrosion amount (thickness) affects the safe operation.
- DC interference exists if the pipe-to-soil potential is higher than 20 mV positive shift to the pipe natural potential or the DC soil potential gradient near the pipe is greater than 0.5 mV/m.
- For a new pipeline, if a pipeline route is in the zones where the DC soil potential gradient is greater than 2.5 mV/m, the pipeline may be subject to DC interference and therefore must be evaluated.
- For CP protected pipeline the CP criteria shall be met.

Mitigation strategies

Insulation joints

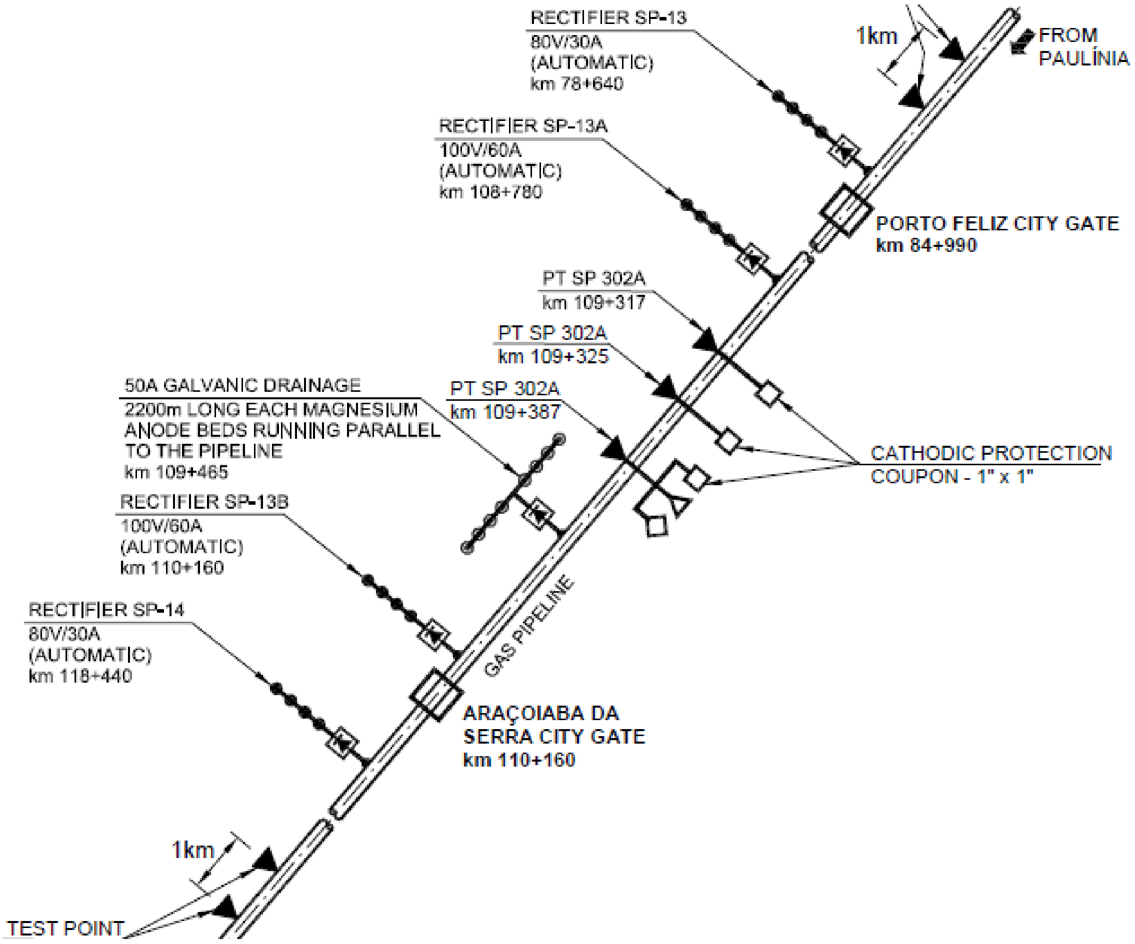
Sacrificial anodes

- Resistance-to-earth < internal pipe R
- Anodic side: J < 1 A/m^2
- Cathodic side: J< 0.3 A/m^2
- Not so effective -> only small stray current

Automated CP system (w/ drainage)

Line current compensation:

- Current control based on voltage gradient
- Difficult (long cables)



Case study

Bipolar HVDC

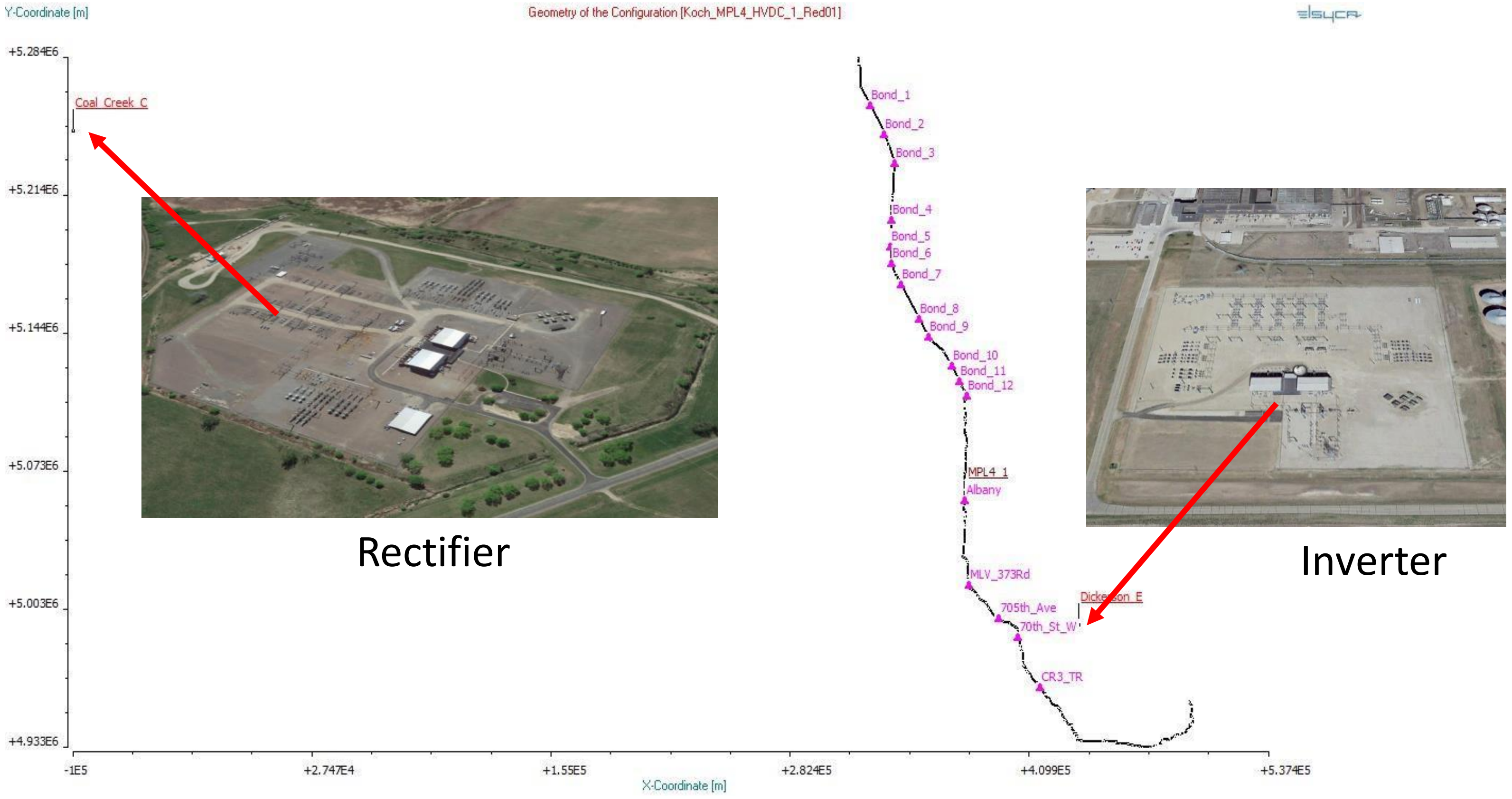
- 500MV nom. power
- 400KV nom. Voltage
- electrode resistance of 0.11 Ω
- 710 km long

Pipeline

- 24” FBE coated
- 20 – 50 Ωm
- 487 km long

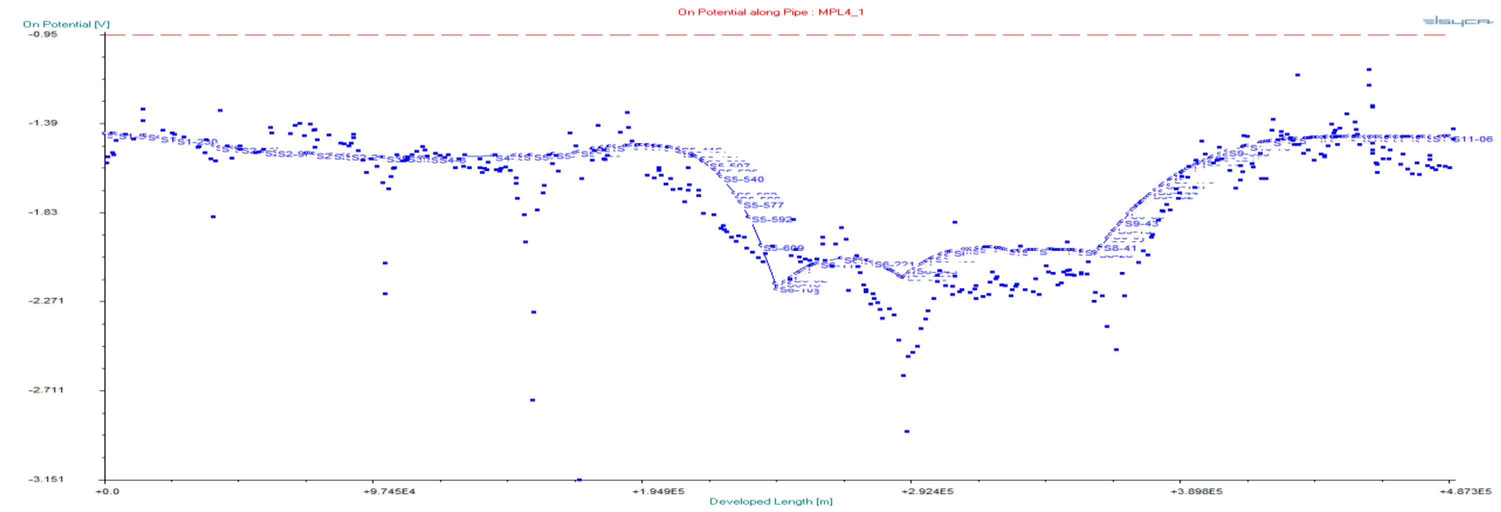
Clearance

- rectifier – 431 km
- inverter – 32 km

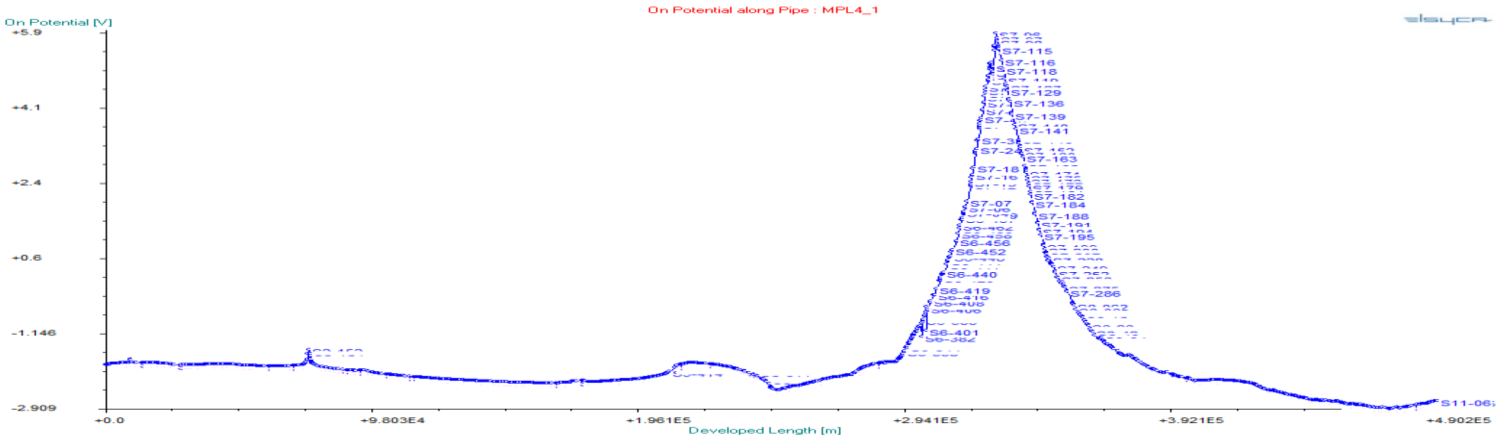


Corrosion threat at inverter

PSP ON – as-found with no interference



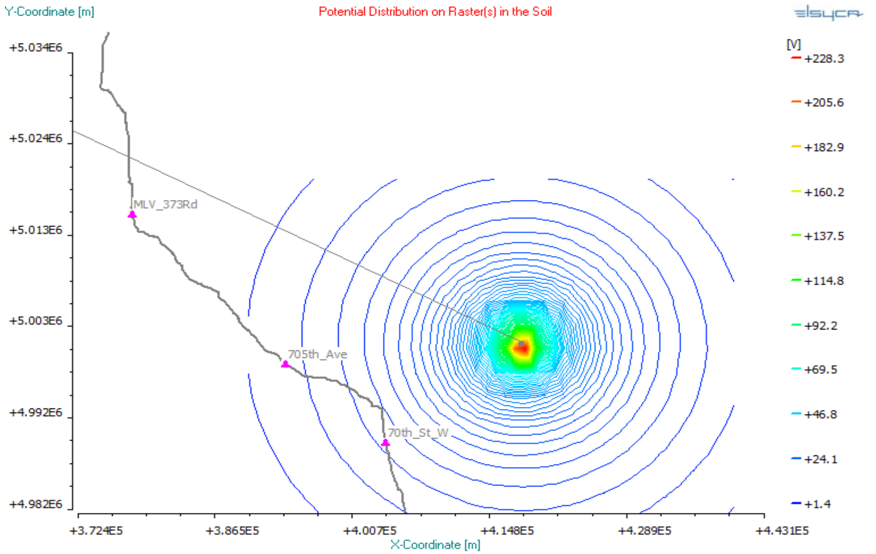
PSP ON – 1375 Amps monopolar operation mode



Corrosion threats at inverter

Computed ground potential rise around HVDC electrode

- -228V@electrode
- -12@pipeline



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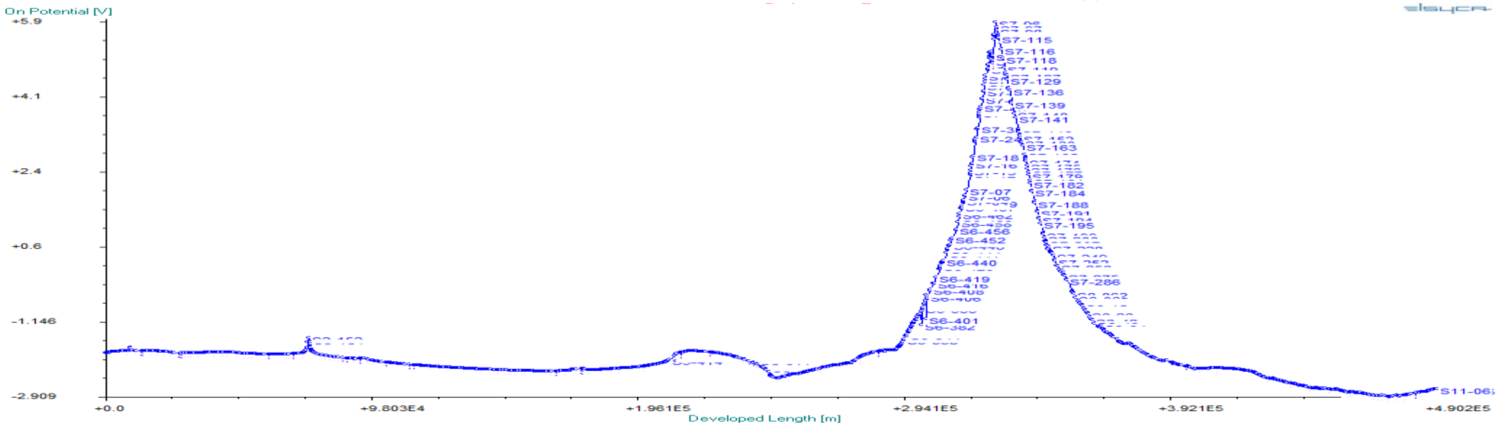
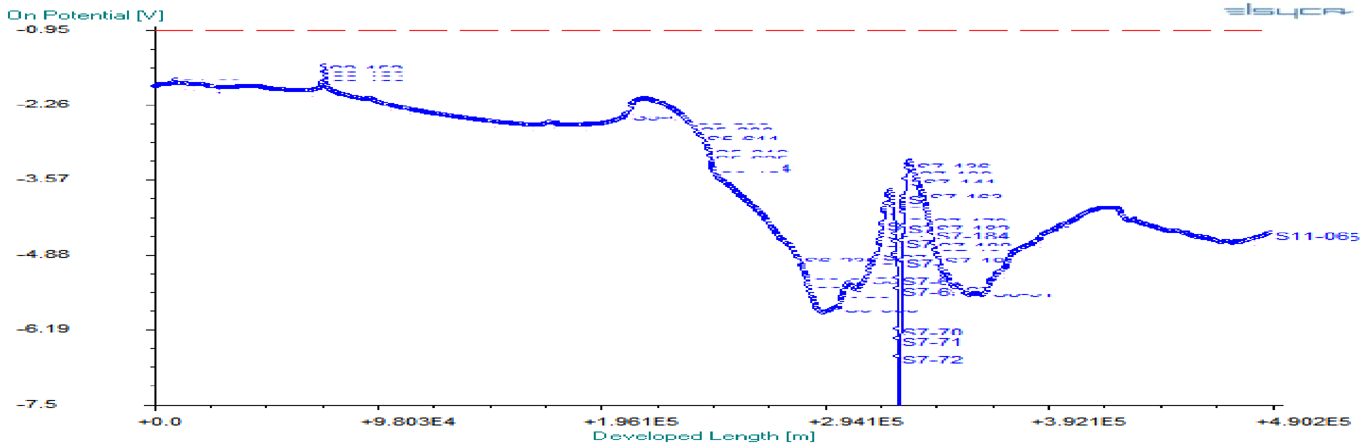
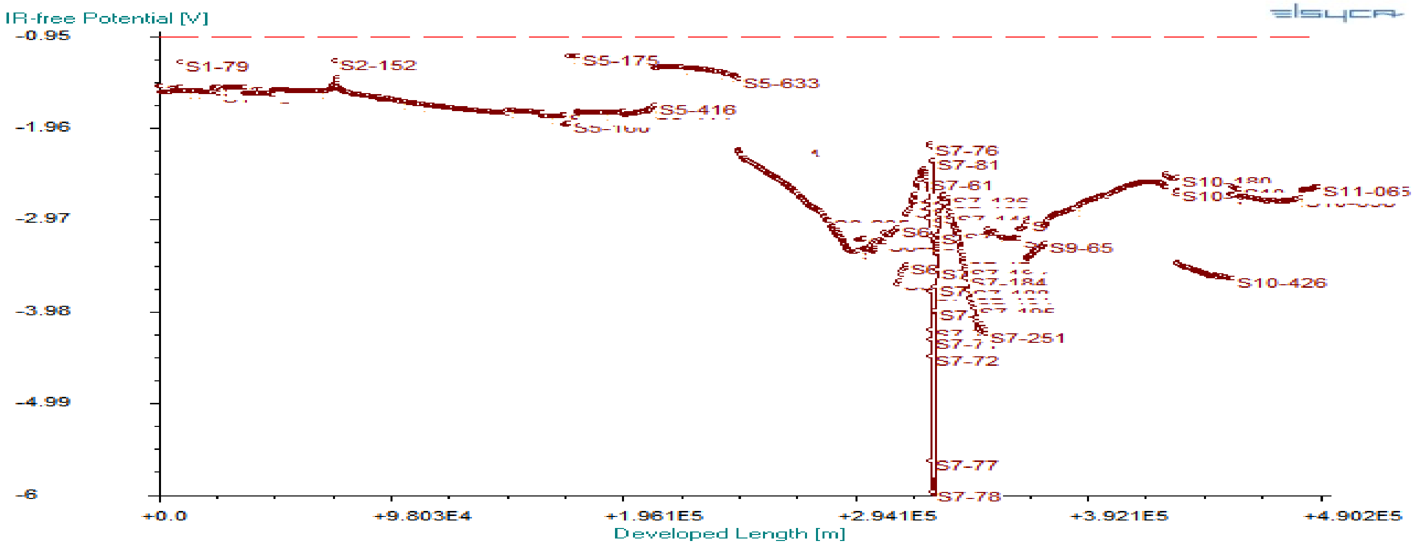


Corrosion prevention

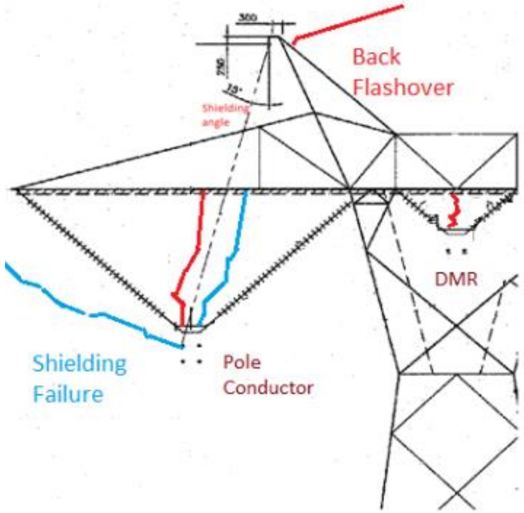
Mitigation system

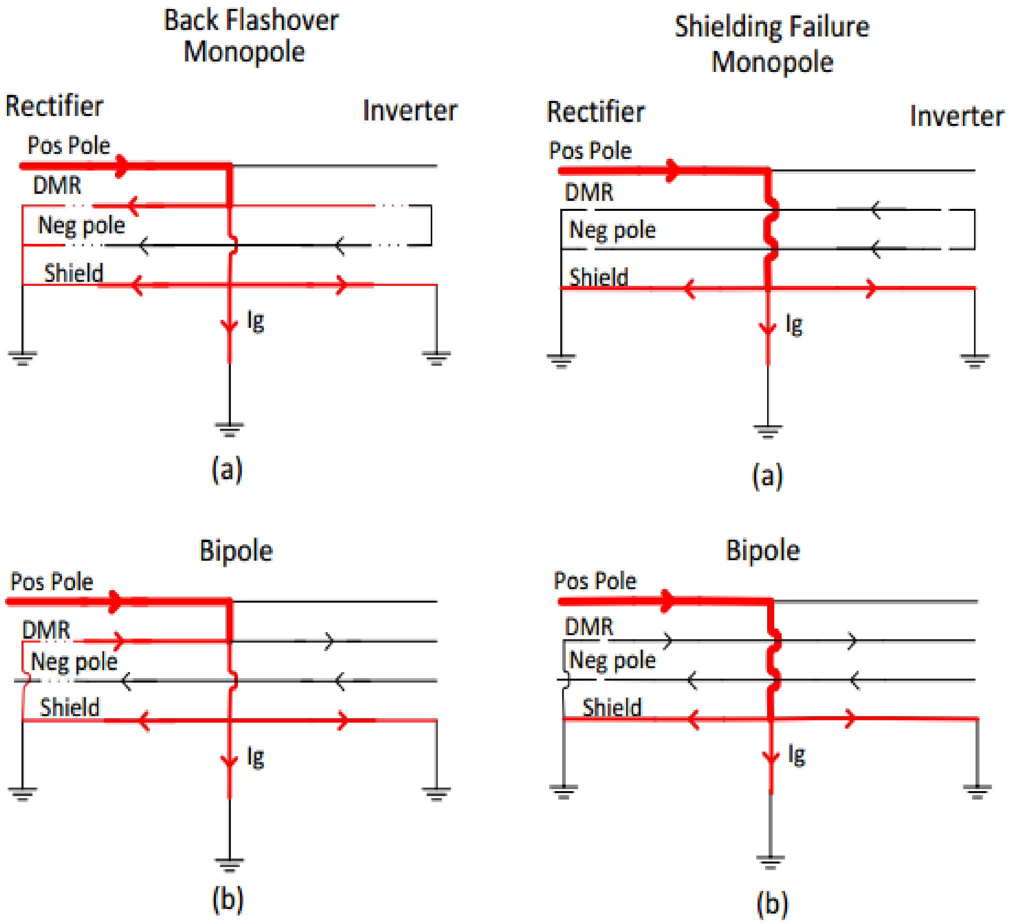
- Voltage controlled rectifier (50V/40A) with deep ground anode bed of 2.74 Ω
- Grounding system of 920 m length in 22 cm backfill having a resistance-to-earth of 0.42 Ω
- Anode potential must compensate the GPR of -12 V





Safety threats

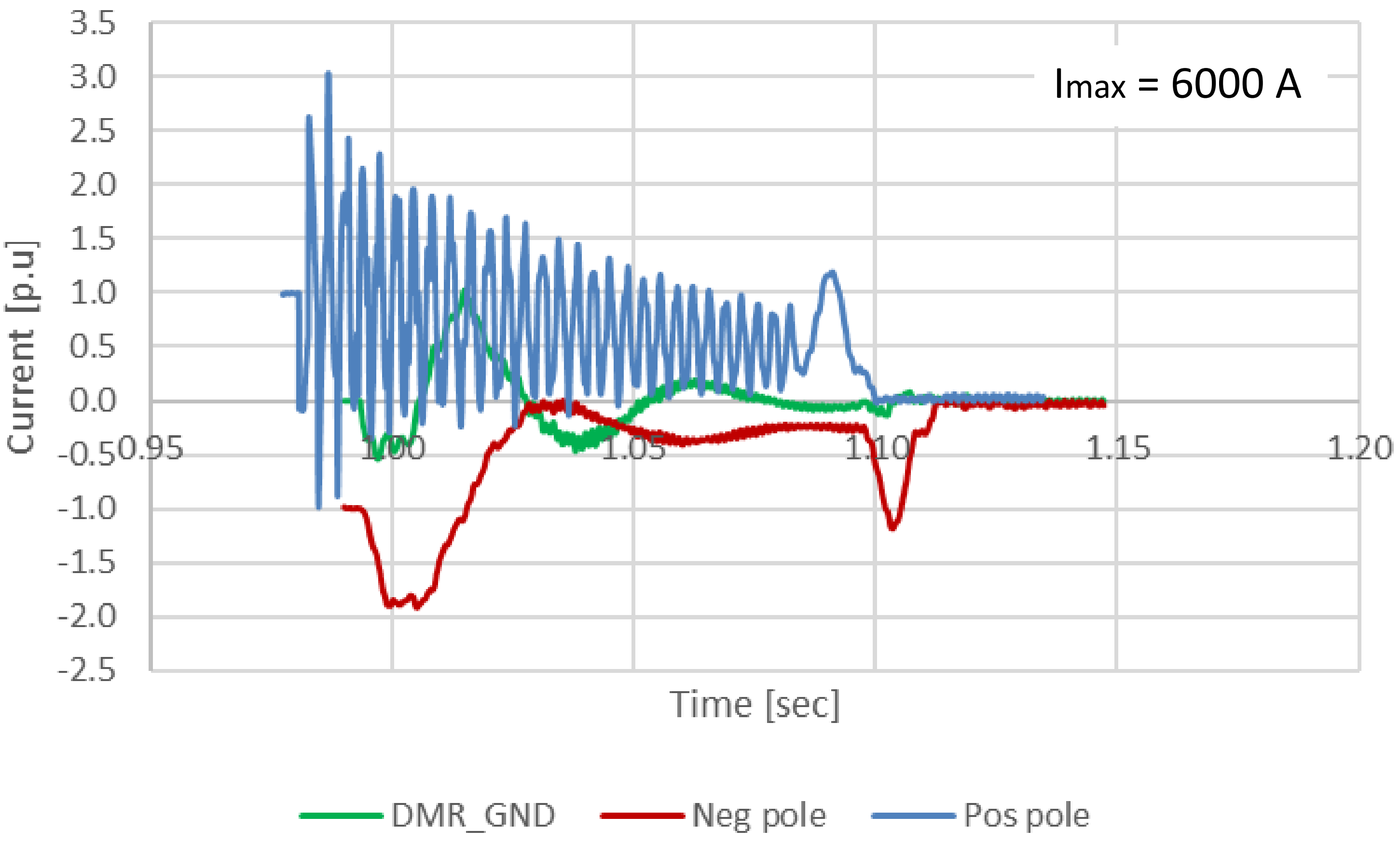




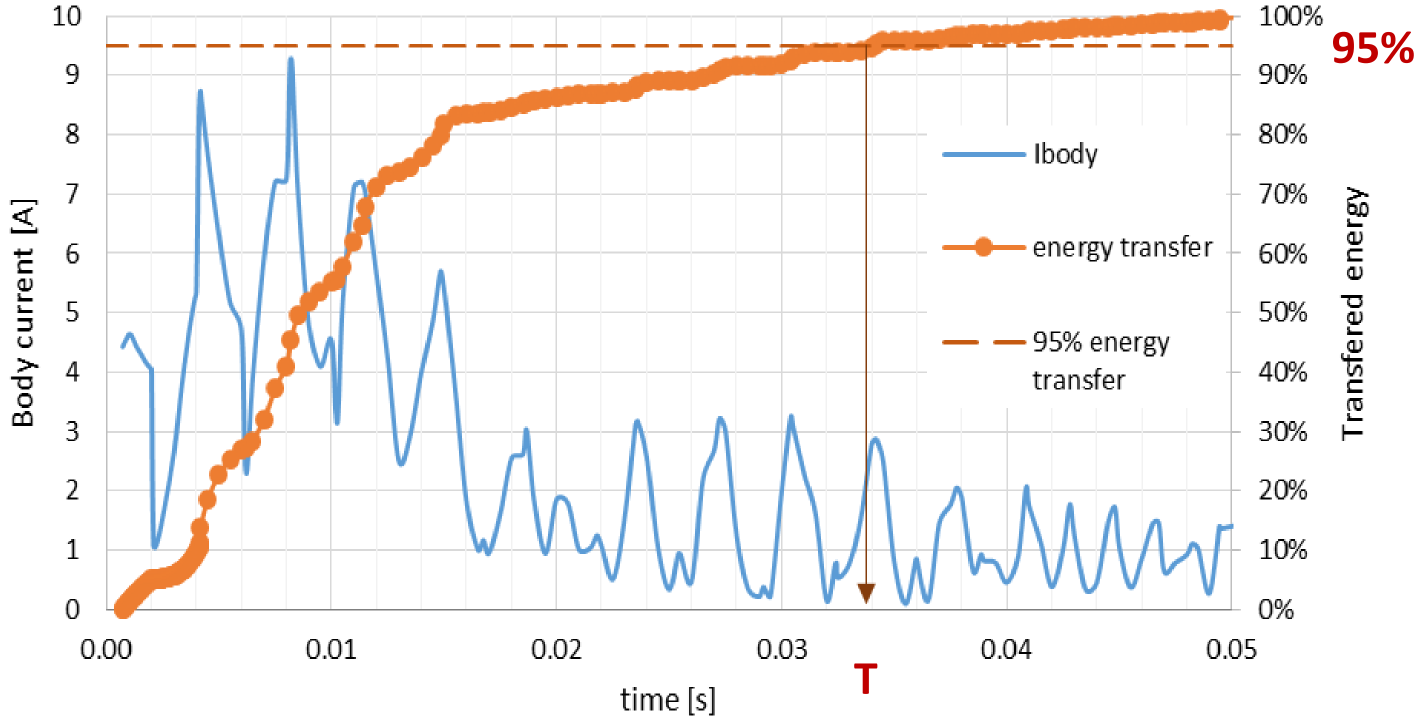
HVDC fault currents

UHVDC with DMR

- 800kVA/6000A nominal
- Rectifier feeds the fault current
- Transient signal
- Higher amplitude than DC (1 p.u.)
- Different phase and frequency in conductors/DMR
- Longer clearing time than AC systems
- Total charge accumulated in body during fault event



Fibrillation risks



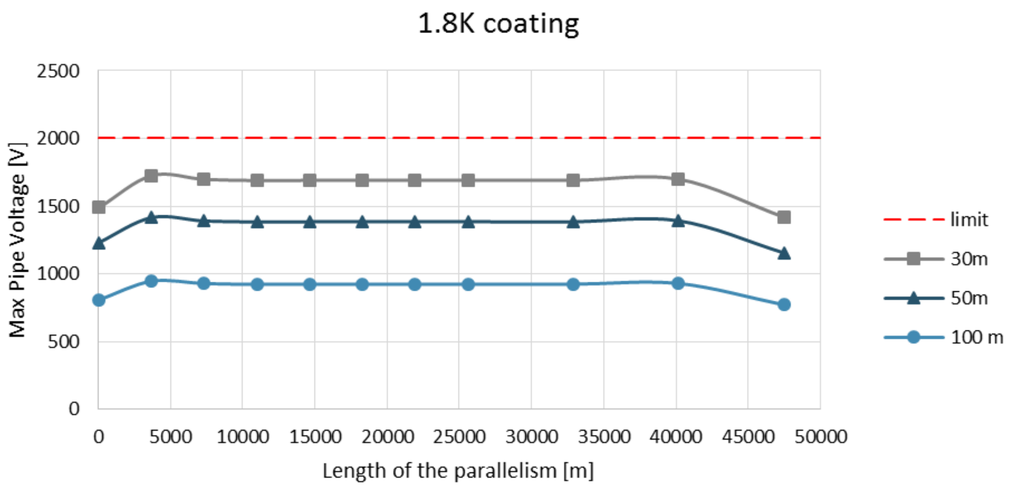
$$I_{crms} = \sqrt{\int_0^T \frac{1}{T} i_b^2(t)dt}$$

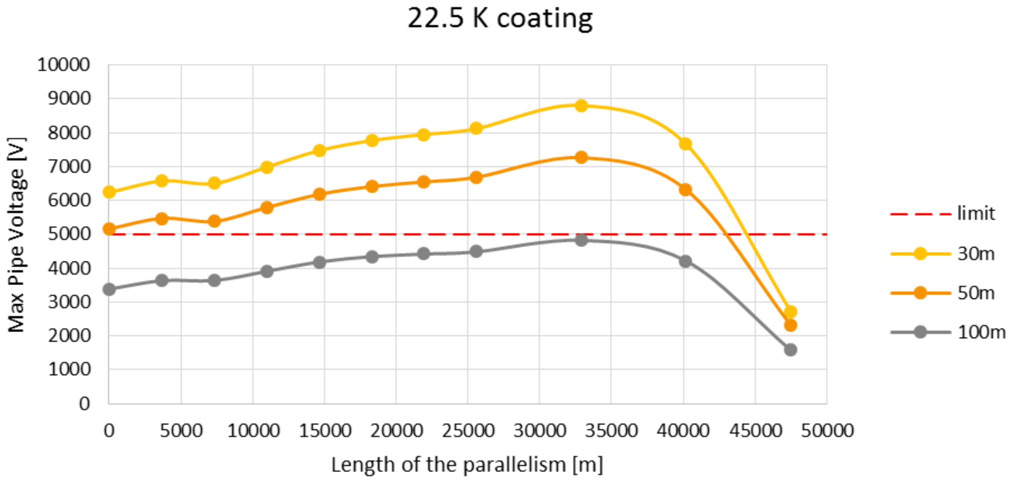
$$I_{B,50} = \frac{0.116}{\sqrt{t_s}} \qquad I_{B,70} = \frac{0.157}{\sqrt{t_s}}$$

$$F_q = I_{crms,T} \times \Delta T \quad with\ \Delta T = 4ms$$

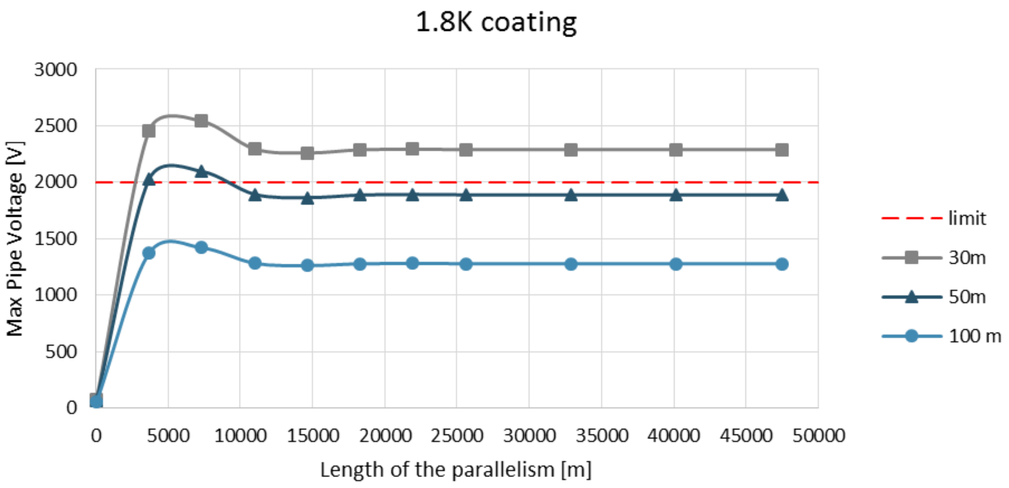
Induced pipeline voltage

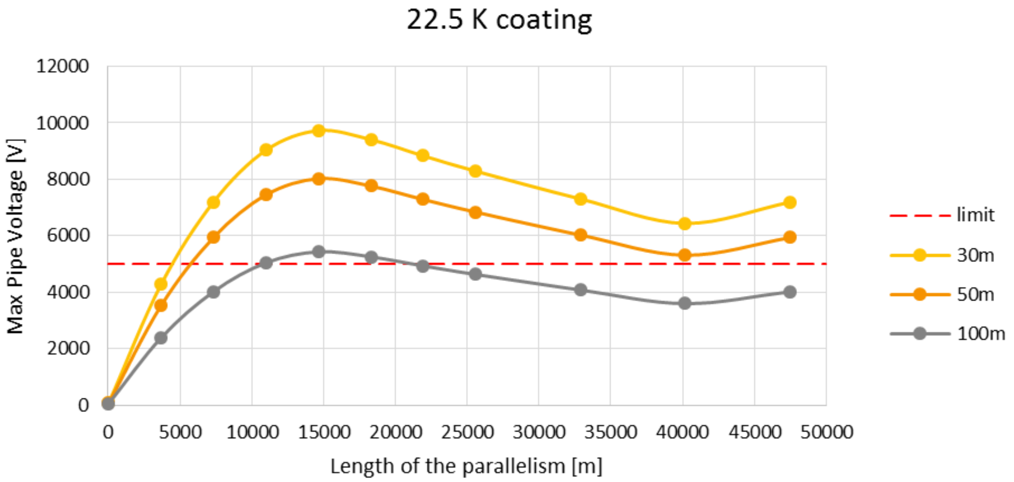
Back flashover





Shielding failure





Case study

HVDC bipolar system

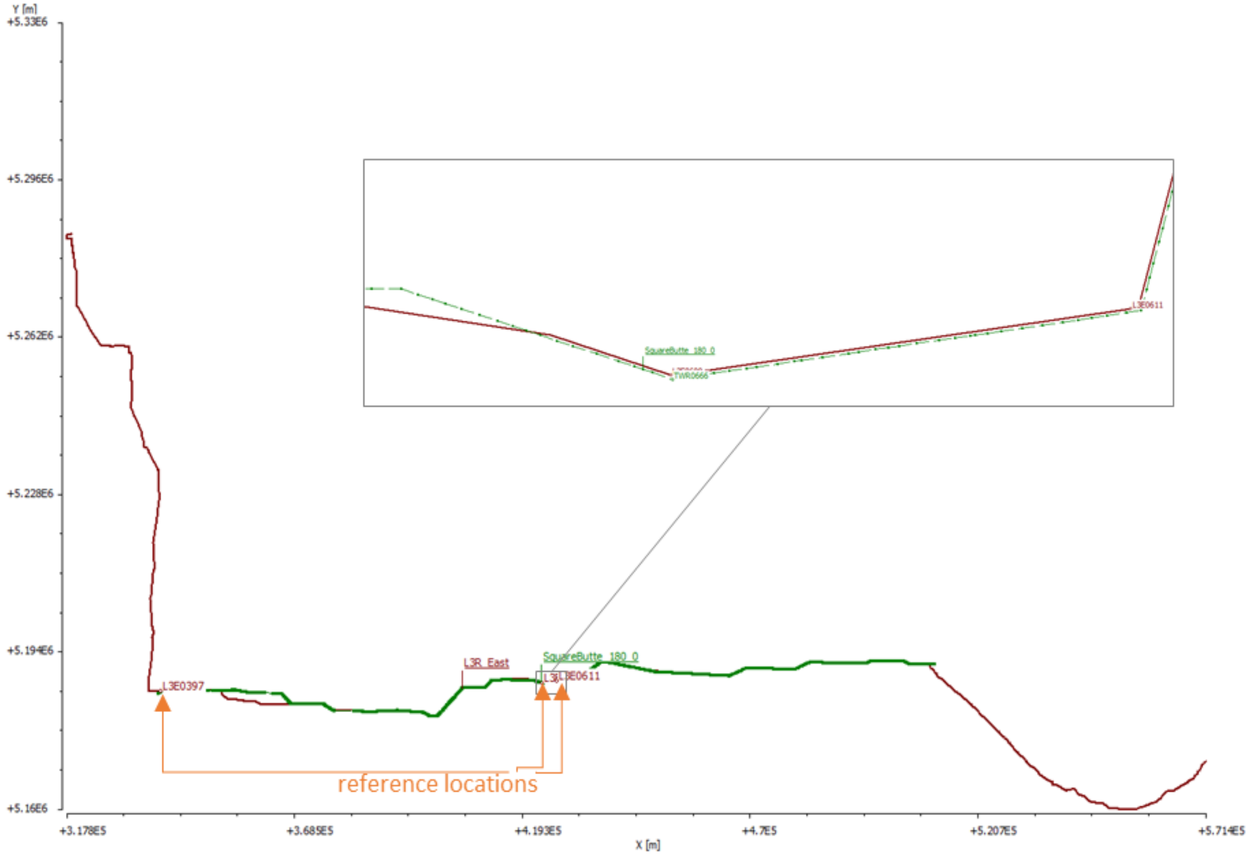
- 250kV, 500MW (2000A)

Pipeline

- 36” FBE coated
- Coating resistance of 78 kΩm2
- 100 mi parallelism

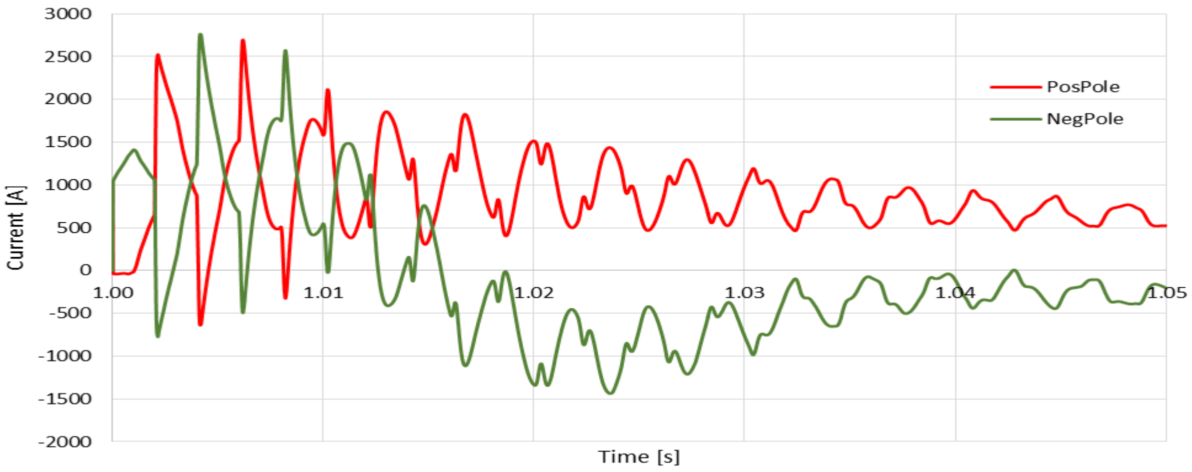
Clearance

- Tower – pipe of 25m

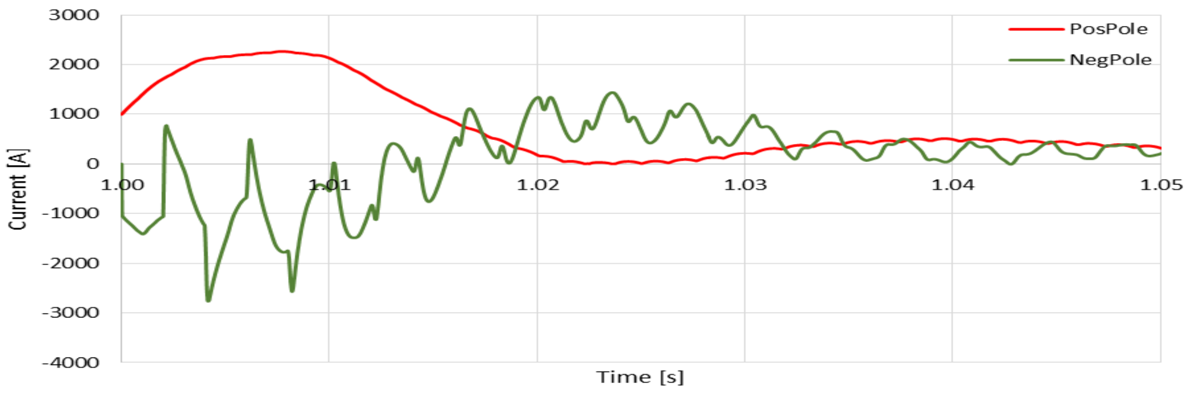


Fault currents

Fault during bipolar mode

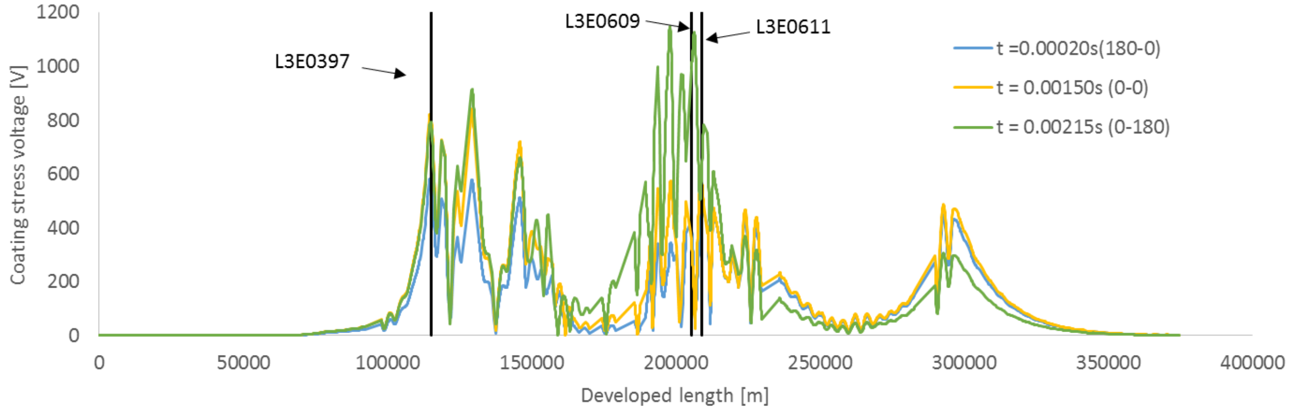


Fault during monopolar mode

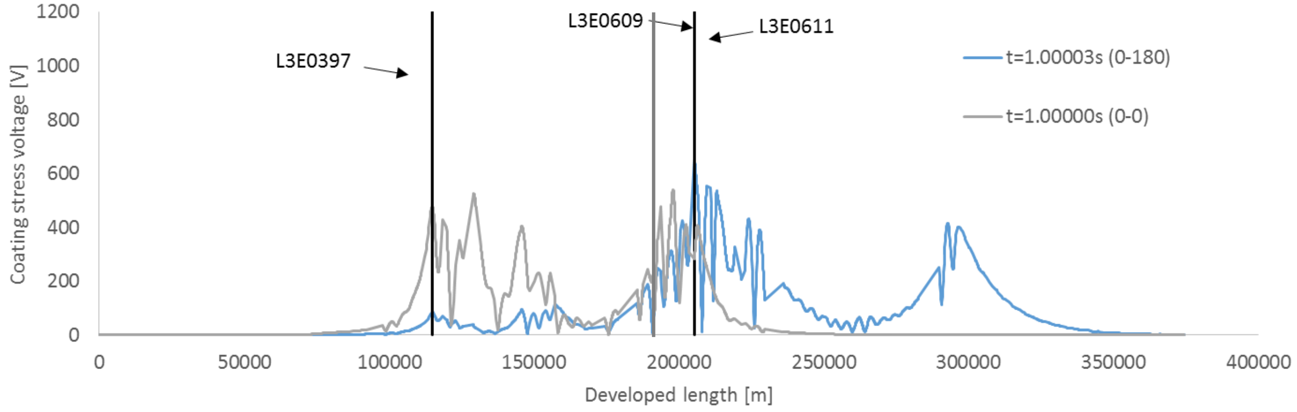


Induced pipeline voltage

Fault during bipolar mode



Fault during monopolar mode



Fibrillation risks

Fault during bipolar mode

Reference location	Event waveform duration [ms]	Total event current [A_{rms}]		Path/Heart current factor	Specific fibrillation charge (4 ms) [mC]	
		Calculated	Safe limit		Calculated	Safe limit
L3E0397	23.9	1.695	0.750	Hand-to-feet, F = 1.0	2.32	2.00
L3E0609	45.3	1.089	0.545	Hand-to-feet, F = 1.0	1.53	
L3E0611	39.6	1.037	0.583	Hand-to-feet, F = 1.0	1.59	

Fault during monopolar mode

Reference location	Event waveform duration [ms]	Total event current [A_{rms}]		Path/Heart current factor	Specific fibrillation charge (4 ms) [mC]	
		Calculated	Safe limit		Calculated	Safe limit
L3E0397	49.5	1.621	0.521	Hand-to-feet, F = 1.0	1.38	2.00
L3E0609	21.1	1.160	0.800	Hand-to-feet, F = 1.0	2.52	
L3E0611	44.75	1.037	0.548	Hand-to-feet, F = 1.0	1.75	

Conclusions & recommendations

Corrosion risks

- Monopolar, bipolar and solar systems with ground return through HVDC electrode
- Stray currents < 2000 Amps under continuous operation (monopolar & bipolar)
- Clearance between pipeline and HVDC electrode < 100 km
- Location near HVDC inverter is most critical
- Criteria of -4V for GPR and 2.5mV/m for electrical field gradient
- Corrosion prevention with grounding systems and potential-controlled rectifiers
- Risk prediction and mitigation design through computational modeling

Conclusions & recommendations

Safety risks

- Bipolar (U)HVDC with overhead lines
- Monopolar and bipolar operation differs
- Clearance from towers <100m
- Location near HVDC rectifier is most critical
- Criteria of 5kV for coating stress and 2mC (4ms) <0.5A (95%) for heart fibrillation
- Safety prevention with conventional grounding systems for reducing induced voltage
- Risk prediction and mitigation design through computational modeling

Thank you for your attention.