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Study Committee B4

DC SYSTEMS & POWER ELECTRONICS

Paper ID_10516

Harmonic and transient interaction due to electromagnetic interference between parallel HVDC and HVAC underground power cables

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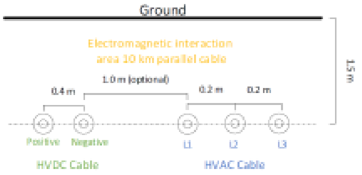
Motivation

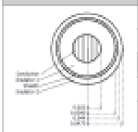
- Increasing risk of EMI in vicinity of underground cables, which received less attention compared to well studied parallel lines
- Investigate impacts of EMI interaction due to parameters such as cable separation, sheath earthing and soil resistivity
- EMI on both steady-state harmonics and transients

Model and study approach

Study model: 10km parallel HVDC and HVAC underground cables, placed 1.5 m underground as in cross-section:



Layout and configuration are chosen uniformly for both DC and AC underground cables in the study as:

Layout	Conductor		Insulator 1	
	DC resistance	0.046 Ω/km	Capacitance	0.3 μF/km
	Resistivity	1.68e-8 Ω·m	Relative permittivity	2.3
	Sheath		**Insulator 2**	
	DC resistance	0.046 Ω/km	Capacitance	1.0 μF/km
	Resistivity	1.68e-8 Ω·m	Relative permittivity	2.3

Study approach

- Modeled based on PSCAD, mutual impedance calculated for the cable coupling
- DC cable operated in pole mode (PM, where current flows in one cable and return in another cable) and ground mode (GM, where current flows in same direction in both cables)
- Voltage and current in AC cable extracted in positive-phase sequence (PPS), negative-phase sequence (NPS) and zero-phase sequence (ZPS)
- Steady-state harmonic induction, calculated by mutual impedance for H1 to H100, where H1 (fundamental) is specified independently for AC => DC
- Transient induction, by worst case cable fault at parallel cables

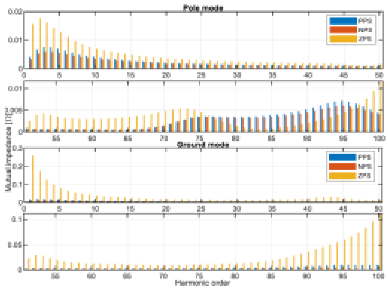
Steady-state induction

DC => AC steady-state

- Generate mutual impedance by injecting 1A current in DC cables in PM and GM
- Measure induced voltage harmonics in AC cables, in positive-phase sequence (PPS), negative-phase sequence (NPS) and zero-phase sequence (ZPS), and linearly summarize mutual impedance

Observations:

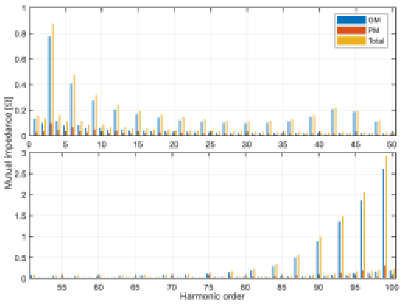
- Low mutual impedance in general
- Resonance noted due to the studied cable length
- Induced ZPS is dominating



AC => DC steady-state

- A source current in PPS, NPS and ZPS is injected into AC cable, note that H1 current is over 1A in total
- Measure induced voltage in PM and GM in DC cable, and linearly summarize mutual impedance

h	Current source [A]			h	Current source [A]		
	PPS	NPS	ZPS		PPS	NPS	ZPS
1	1	0.02	0.01	6	0	0	1
2	0	1	0	7	1	0	0
3	0	0	1	8	0	1	0
4	1	0	0	9	0	0	1
5	0	1	0	[illegible]	1	1	1



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Observation

- Low mutual impedance in general
- Grounding mode is dominating

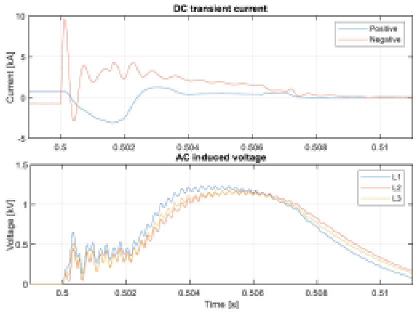
Transient Induction

DC => AC transient

- An example 500MW HVDC system, single pole-to-ground fault applies at negative pole of the end of 10km parallel DC cable for 0.1 second
- DC transient currents and AC induced voltage measured

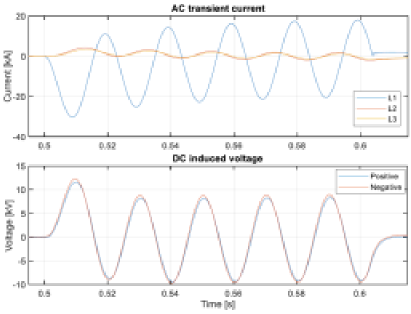
Observation:

- Relatively high voltage induced
- Electrostatic coupling found



AC => DC transient

- A simple AC network by 155 kV voltage source is terminated at both ends of AC cable. A single phase-to-ground fault at L1 is simulated with 0.1 s duration
- Transient current in AC cable and induced longitudinal voltage in DC cable are measured

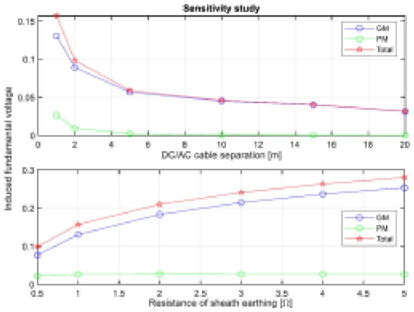


Sensitivity study

Sensitivity has been tested to the two parameters

- Cable separation, between the closest AC/DC cable center
- Resistance of cable sheath earthing

Parameter	Value					
Cable separation [m]	1	2	5	10	15	20
Resistance of cable sheath earthing [Ω]	0.5	1	2	3	4	5



Conclusion

- Harmonic induction in steady-state EMI is observed to be quite low as in general less induction
- The induced fundamental component (50 Hz) in the AC=>DC steady-state model is a potential issue. A high fundamental current flowing in AC cables may induce a relatively high voltage and further current onto DC cables. This fundamental component on the DC transmission would be cross modulated to the AC side of the converter as a direct current, which could potentially cause an asymmetrical saturation of the converter transformer.
- The induced voltage in a transient EMI, for both directions DC=>AC and AC=>DC, is relatively high due to the high fault current in the neighboring cables.
- Sensitivity to DC/AC cable separation and the resistance of cable sheath earthing, shows that:
  - Induction decreases non-linearly with cable separation; this decrease is faster at a closer separation
  - Induction increases non-linearly with resistance of cable sheath earthing; the change is larger at a lower resistance