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ASPECTS OF INSULATION COORDINATION FOR DC LINKS USING HYBRID LINES

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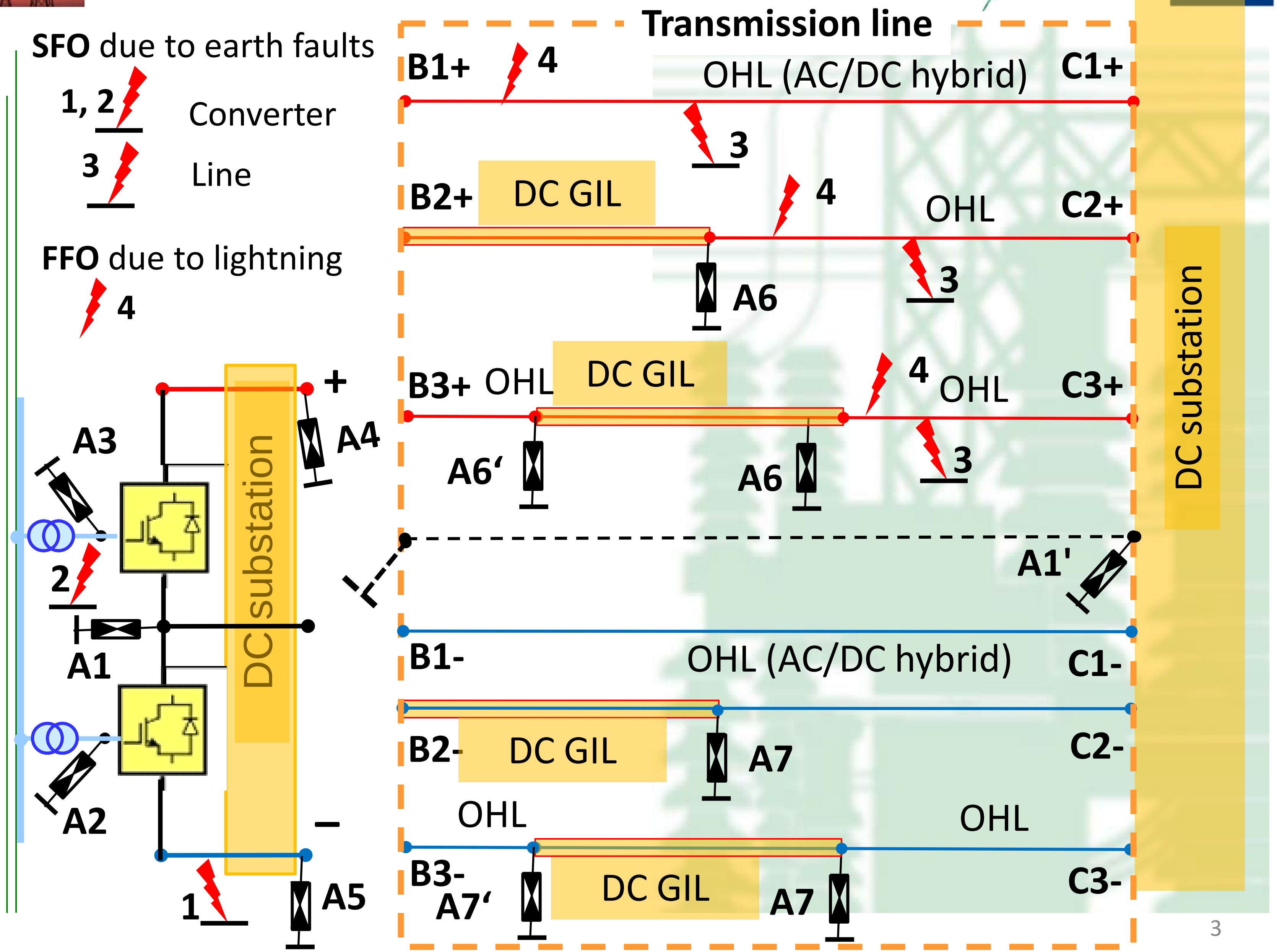
Introduction

- Due to the enormous hype of generation from renewables far away from the load centers long distance transmission based on DC is needed
- Because of the lack of corridors and due to environmental constraints, hybrid systems consisting either of
  - AC/DC overhead lines (OHL) or of
  - DC OHL and underground sections, e. g. DC GIL,

  are of special interest
- Since no standards covering the insulation coordination (IC) of those systems are in place, detailed studies were carried out
- Corresponding with the basic insulation coordination procedure following items are considered:
  - First step: Voltage and overvoltage stresses of both options
  - Second step: Requested voltage strength under consideration of voltages and overvoltages and application of arresters

Configurations under consideration , faults generating SFO & FFO



Slow front overvoltages depending on converter technology under consideration

Simulation results using PSCAD®

SFO in pu at fault location, converter terminal and GIL-OHL interface caused by earth faults at different fault locations, line length 400 km,

SFO at line to earth faults		Bipol								symmetrical monopol, C_{DC} = 100 µF	
		2-level VSC, C_{DC} = 100 µF			MMC			LCC[1)]			
fault location		fault location	conv. term.	GIL-OHL	fault location	conv. term.	GIL-OHL	fault location	conv. term.	fault location	conv. term.
mid	without arresters	2,2	1,5	1,5	1,8	1,2	1,2	1,5	1,2	2,2	2,5
	limited by arresters										1,7
1/8	without arresters	1,7			1,7			1,1	1,1		2,3
	limited by arresters										1,7

1) 750 km

Slow front overvoltages at converter terminals caused by earth fault at the DC side or AC side

SFO at converter faults		Bipol		symmetrical monopol
Overvoltage at converter terminals		2-level VSC, C_{DC} = 100 µF	MMC	
		Overvoltage at converter terminals [pu]		
DC side	without arresters	1,8	1,2	2,3
	limited by arresters	1,6		1,8…2,0
AC side	without arresters		2,5	2,1
	limited by arresters		1,9	1,6…1,8

SFO ≈ 2 pu to be considered for IC

Fast front overvoltages depending on converter technology under consideration

FFO in pu at fault location, converter terminal and GIL-OHL interface caused by lightning

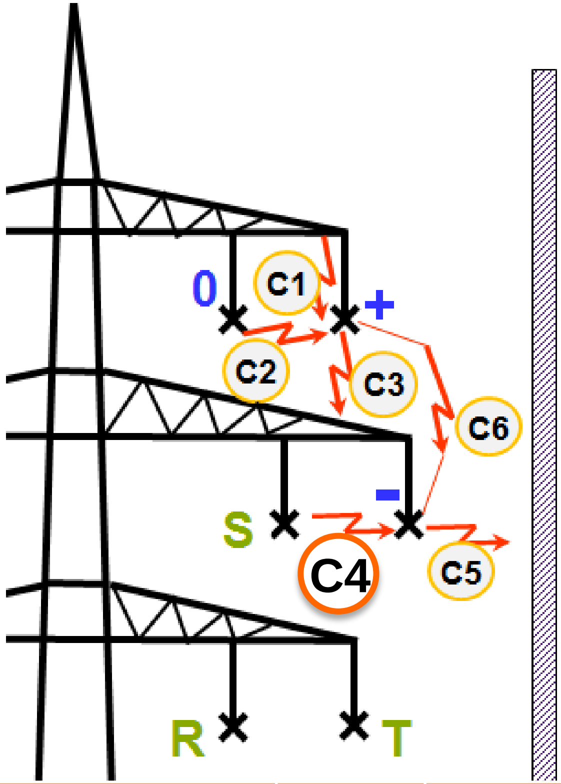
Simulation results using PSCAD®

FFO at llightning strokes to transmission line		Bipol						symmetrical monopol C_{DC} = 1 µF	
		2-level VSC, C_{DC} = 25 µF		2-level VSC, C_{DC} = 1 µF		MMC			
		conv. term.	GIL-OHL	conv. term.	GIL-OHL	conv. term.	GIL-OHL	conv. term.	GIL-OHL
OHL	without arresters	1,15		3,8		16,1		3,8	
	limited by arresters			2,1		2,1		2,1	
OHL/GIL	without arresters	1,15	4,0	3,8	4,0	5,2	5,2	3,8	4,0
	limited by arresters		2,1	2,1	2,1	1,9	2,0	2,1	2,1

FFO ≈ 2.1 pu to be considered for IC assuming adequate arrester ratings

Required voltage strength

Air clearances of AC/DC OHL



SFO: => clearance C4 between AC & DC conductor

$$U_{50\,sf} = K_{g\_sf} * f(d) = K_{g\_sf} * 500 * d^{0,6}$$

$$U_{rw\,sf} = K_{z\_sf} * U_{50\_sf}$$

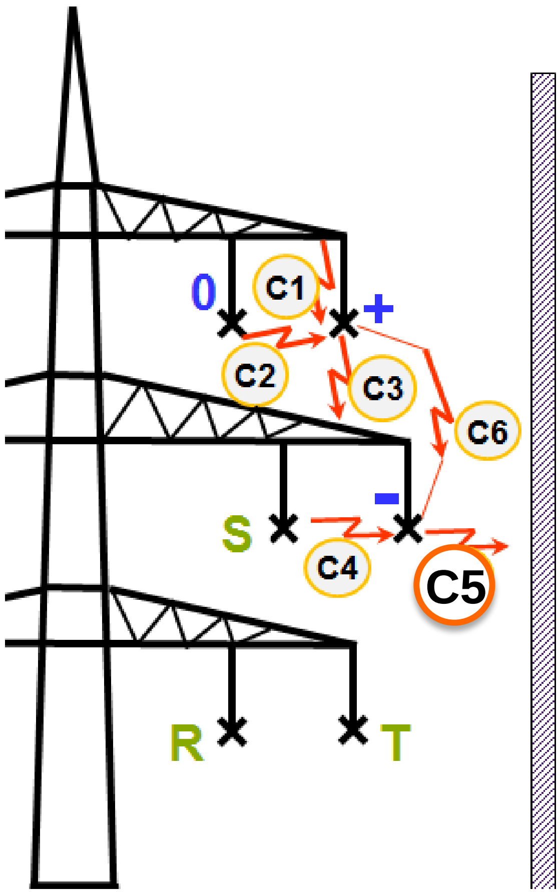
$$K_{z\_sf} = 0.922$$

$$K_{g\_sf4} = 1.48 \ldots 1.56$$

DC service voltage		U_m^+	U_{sf}^+	U_m^-	U_{cw}	α	K_{g_sf}	U_{50}	D_{pp_sf}
kV		kV	kV	kV	kV			kV	m
400	C4a	343	789	400	1189	0.34	1.53	1531	**3.18**
500	C4b	500	1000	343	1343	0.26	1.48	1729	**4.11**

Required voltage strength

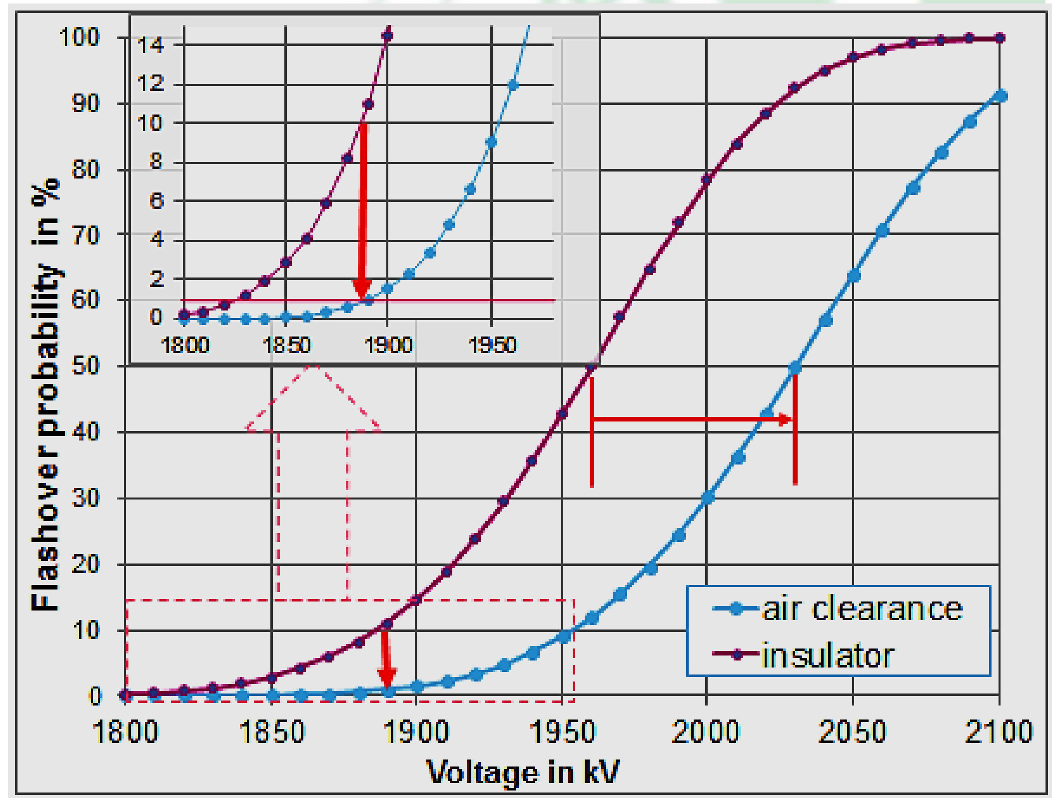
Air clearances of AC/DC OHL



FFO => Safety clearance C5

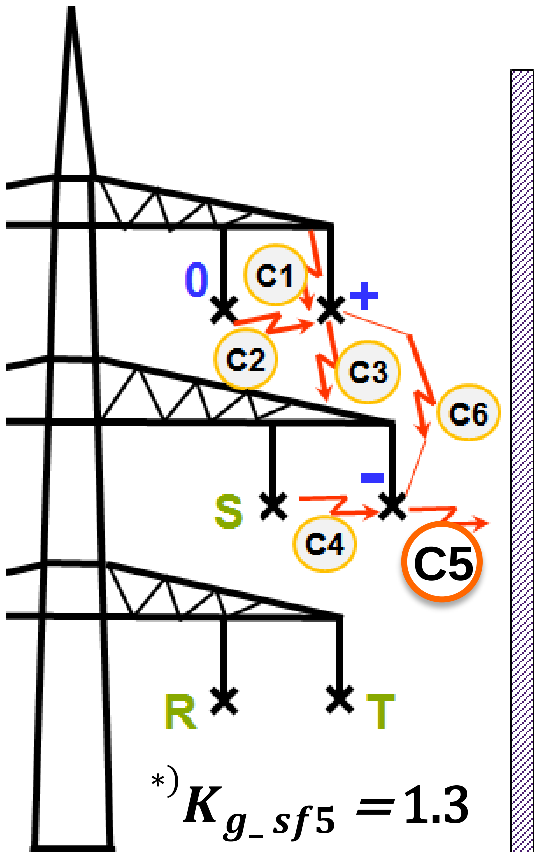
Philosphy:

LIOV => no flashover between conductor & earthed objects, but flashover across adjacent insulator



Required voltage strength

Air clearances of AC/DC OHL



FFO => Safety clearance C5

$$D_{el\_ff\_p} = \frac{U_{50p}}{530 \times K_{g\_ff}}$$

$$D_{el\_ff\_n} = \left(\frac{U_{50n}}{950 \times K_{g\_ff}}\right)^{\frac{1}{0,8}}$$

$$K_{g\_ff\_n} = \left(1,5 - 0,5 \times K_{g_{sf}}{}^{*)}\right)$$

$$K_{z\_ff(10\%)} = 1 - 1,3 * z = 0,961$$

$$K_{z\_ff(1\%)} = 1 - 2.3 * z = 0,931$$

DC service voltage kV		$U_{10\_ff\_is}$	K_z	$U_{50\%}$	K_{g_sf}	D_{el_ff}	D_{el_ff}
		kV		kV		m	m
400	C5 pos	1720	0.931	1847	1.30	3.23	3.25
	C5 neg	1930	0.931	2073	1.30	3.25	

DC OHL with DC GIL sections

Withstand voltage characteristic of typical DC GIL design

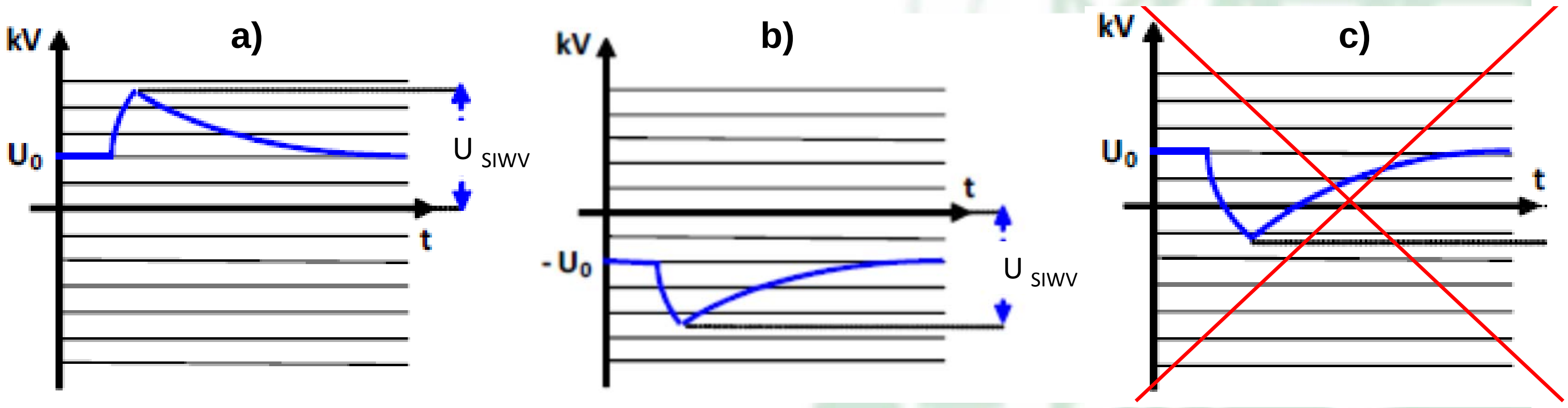
- Energizing the DC GIL => charging process => charge accumulation on the surface and in the bulk material of the insulators
- Transient overvoltages entering the GIL section => stress of pre-charged insulators by a superposition of these overvoltages

➢ Superposition of switching (SIOV) and or lightning overvoltages (LIOV) represents a special stress, the DC GIL has to withstand

- Basically unipolar and bipolar superposition of SIOV & LIOV may be considered

➢ But which superimposed stresses really occur in practice?

Switching impulse voltage superimposed

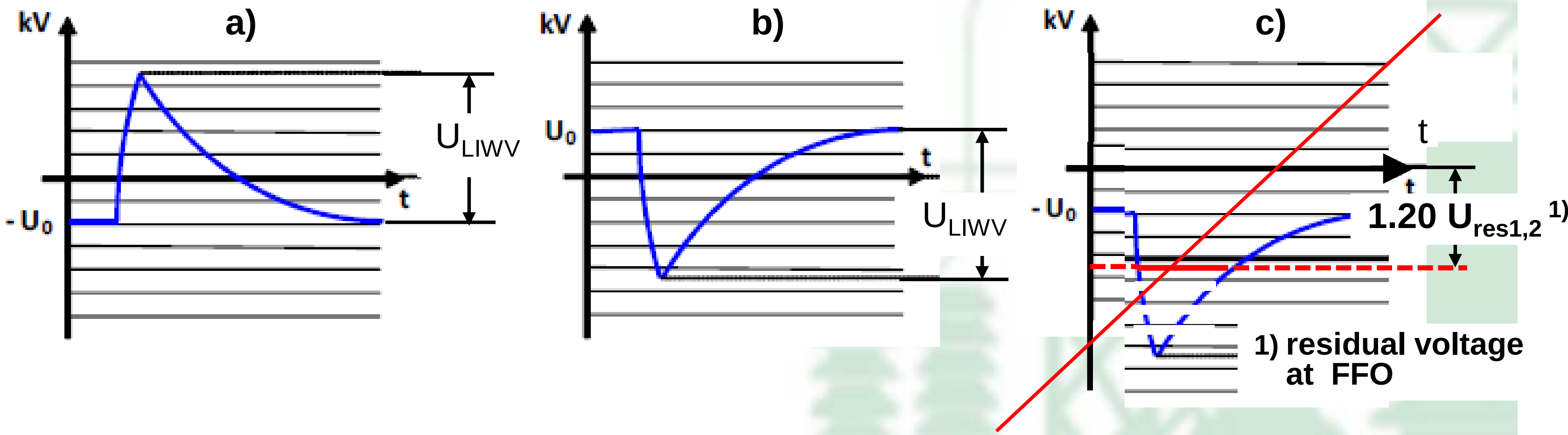


- Earth faults cause slow front overvoltages in the sound pole
- This overvoltage impulse is superimposed on the service voltage of the sound pole

➢ Unipolar wave shapes according to Figure a and b will occur in practice, only

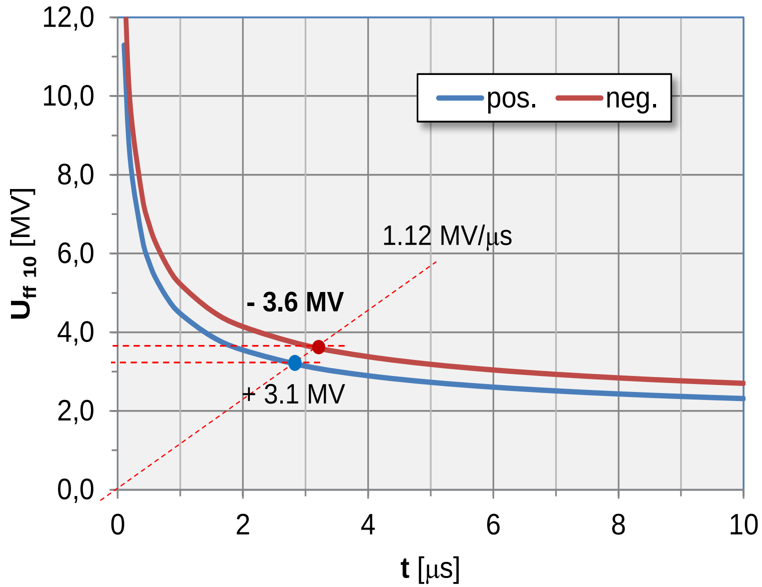
➢ A bipolar wave shape according to Figure c physically not possible

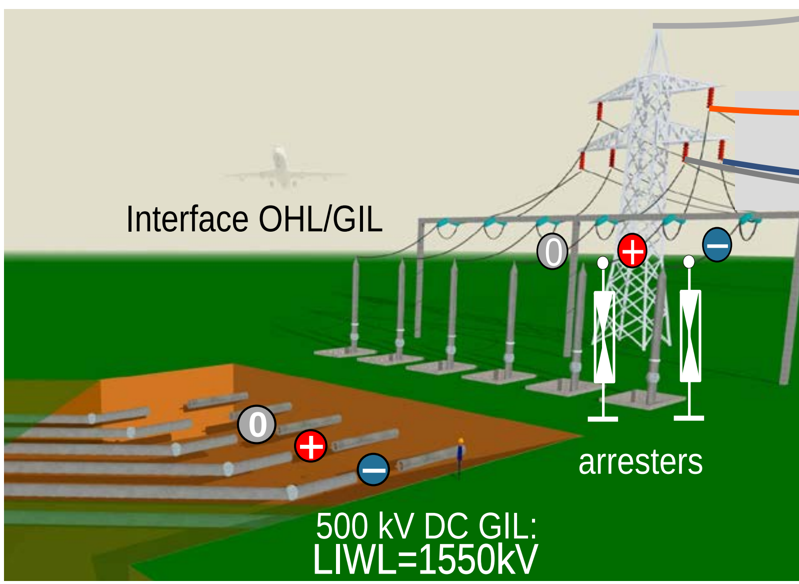
Lightning impulse voltage superimposed

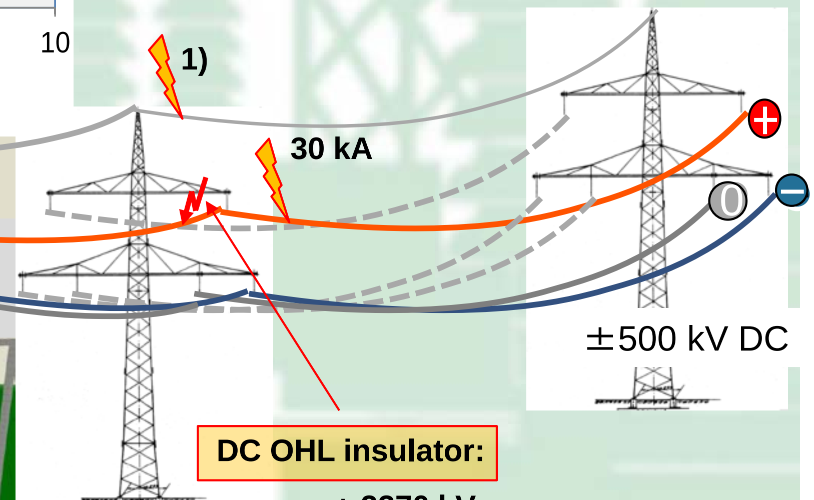


- Bipolar wave shapes according to Figure a & b reasonable in practice, only.
- Unipolar wave shapes (Figure c) are limited by the arrester at interface OHL – GIL.

Lightning overvoltage protection, arrester rating







DC OHL insulator:

LIWV = + 2270 kV / - 2620 kV

1) $U_{ff\ bf}$ at backflashovers < $U_{ff\ sf}$ due to shielding failures as far as earthing impedance <10 Ω

Reduction of residual voltage by switching arresters in parallel => improving U_{cw} / $U_{res\ 1/2}$

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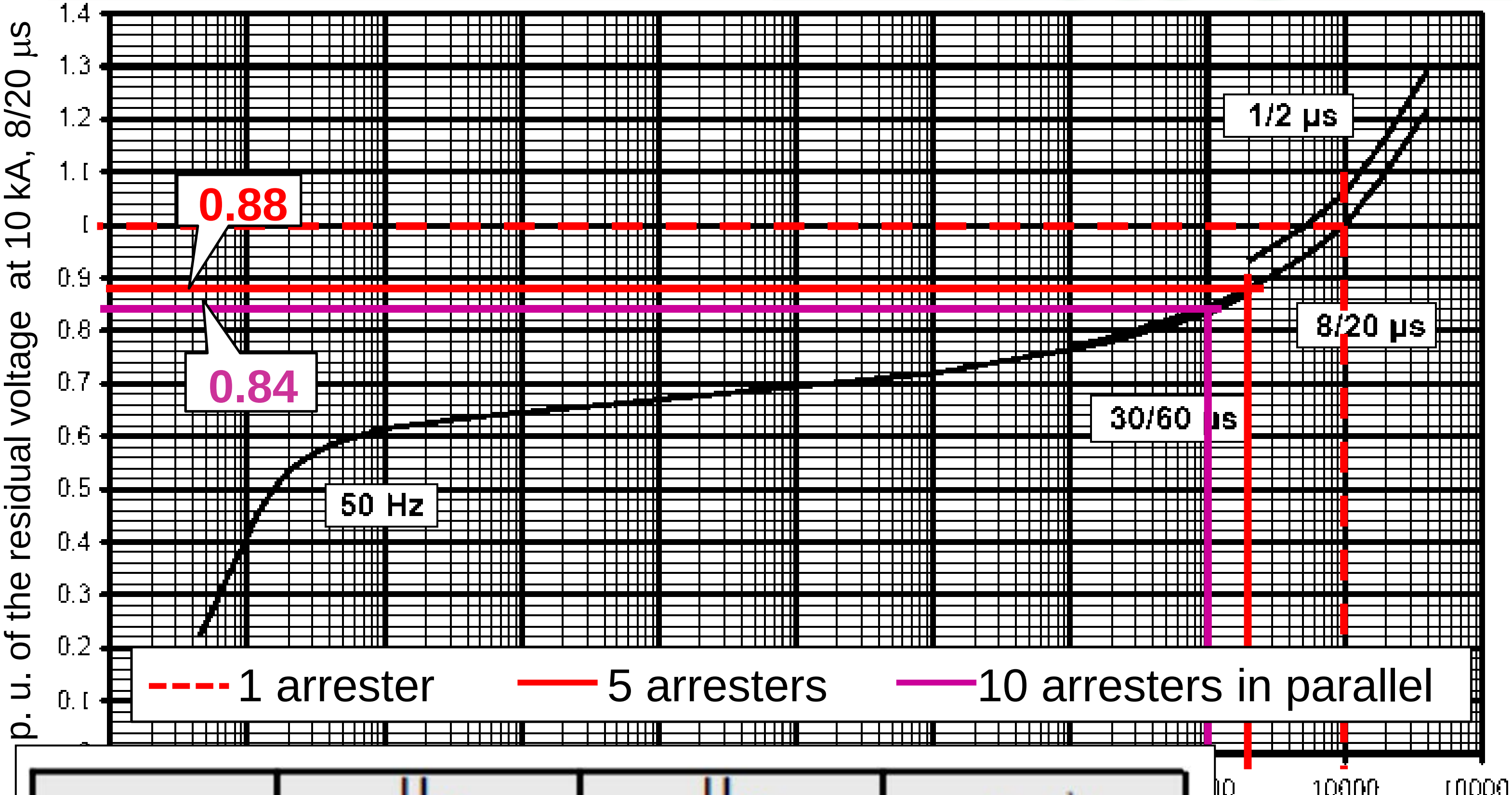

number of arresters	U_{res} (10 kA, 8/20 us) kV	U_{res} (1/2 us) kV	U_{cw} *) / U_{res}(1/2)
1	1220	1281	1,05
5	1074	1127	1,20
10	1025	1076	1,25

*) U_{cw} = 1550 kV/1.15 = 1350 kV

Conclusions

- DC links based on hybrid solutions, i. e.
  - AC/DC overhead lines (OHL)
  - DC OHL with DC GIL sections

are, in general, feasible, but need some special insulation coordination measures to achieve a sufficient level of reliability.

Conclusions

Thank you for your attention!