Sheath over-voltages in cross-bonded underground transmission lines

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Réseau de transport d'électricité

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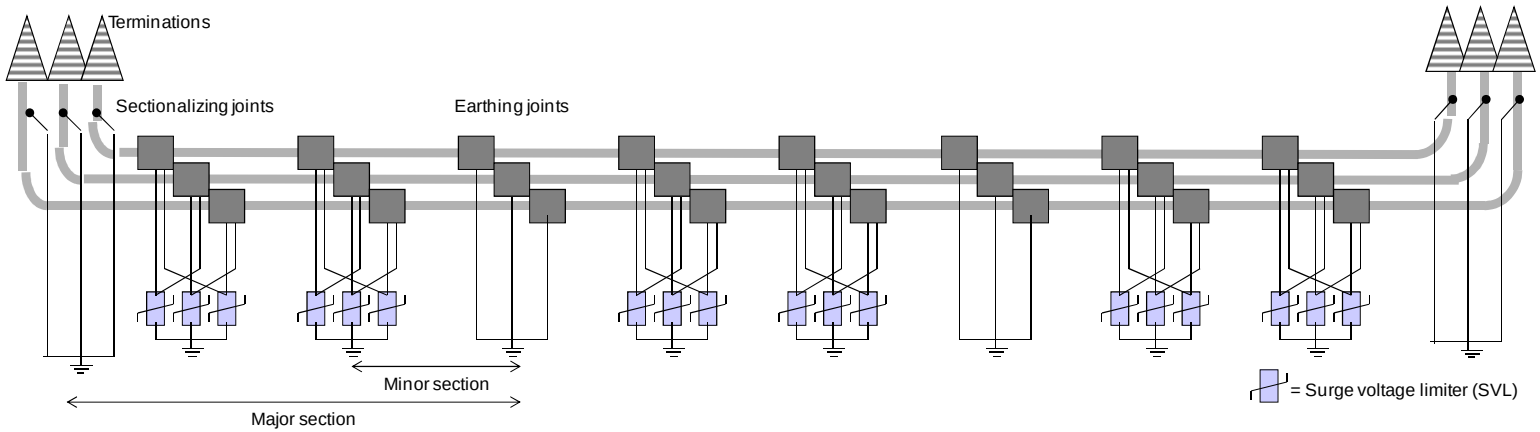
- Case study: modelling of a 90 kV cross-bonded link with EMTP-RV
  - Switching surge
  - Lightning stroke
- Conclusion & perspectives

Introduction

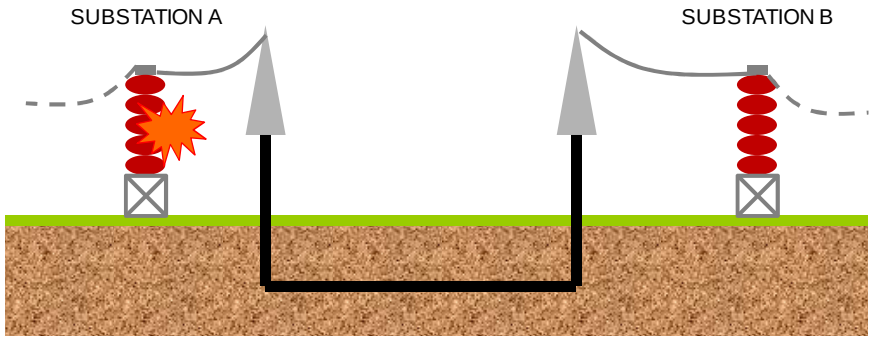
- For long UGL, **sectionalised cross-bonding** is common practice.
- Until recently, SVL were installed at each cross-bonding point.



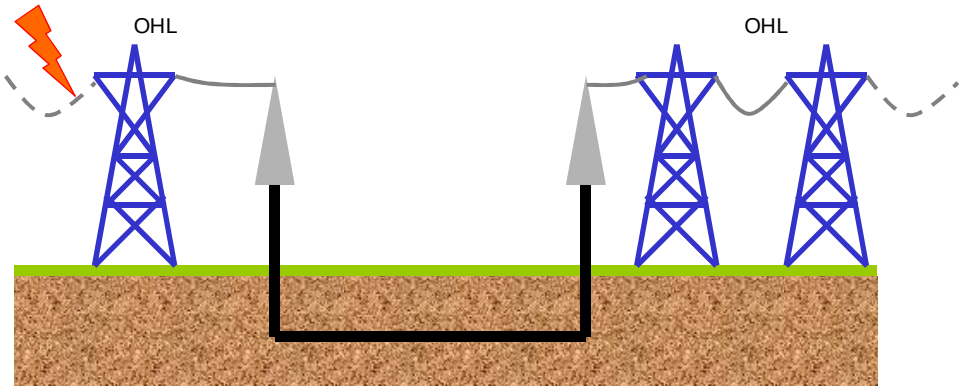
- The availability of reliable tools for transient studies allows the **optimization of the design** of cross-bonded links.

Transients affecting UGL

- UGL between substations: **switching surges**

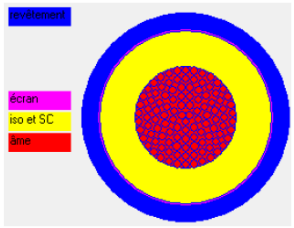


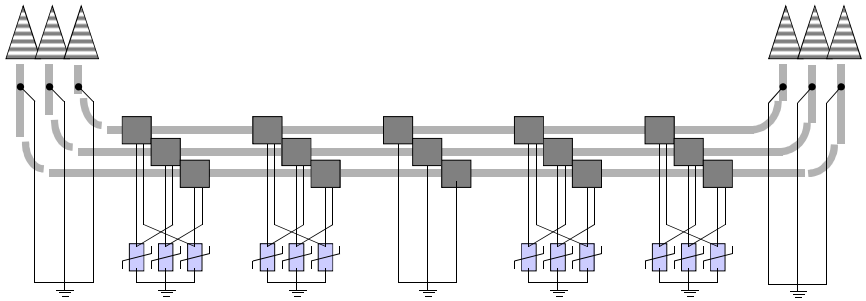
- Siphon: **lightning strokes**



Case study

- Cables: 3 x single-core 1200 mm² Al 90 kV
- Cross-bonded, 2 major sections
- SVL: 12 kV, star connection with grounded neutral



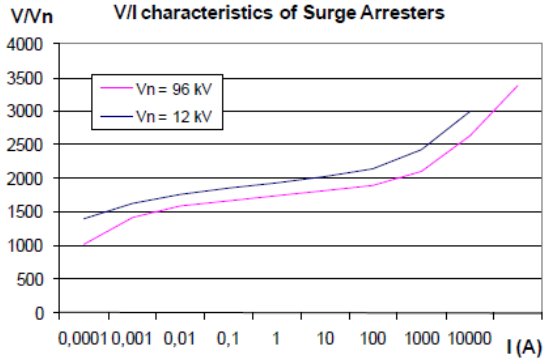


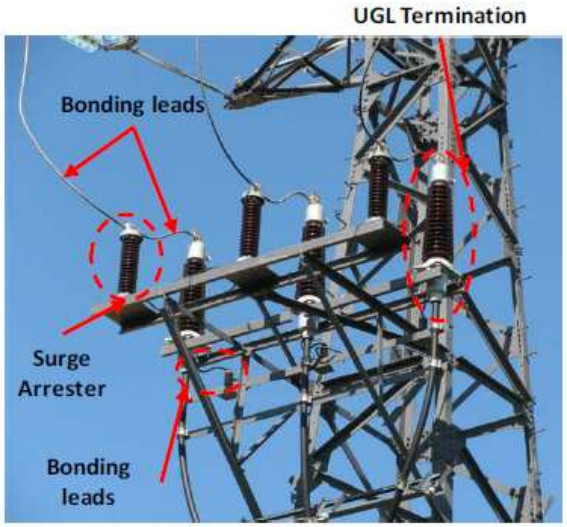
Withstand levels

Main insulation (kV_c)	450
Cable outersheath and joint box (kV_c)	50
Screen interruption of the joints (kV_c)	80

Modelling with EMTP-RV

- **Underground cables**: FDQ model
- **Overhead lines**: FD model
- **Towers**: CP model, with 10 Ω grounding
- **Surge arresters**: non-linear elements
- **Bonding leads**: lumped inductances

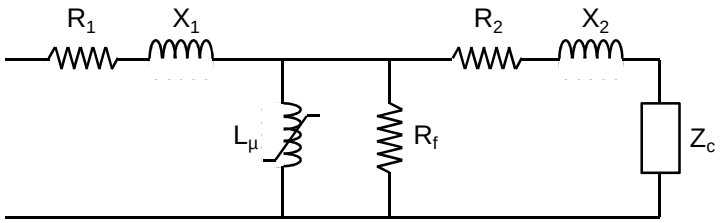




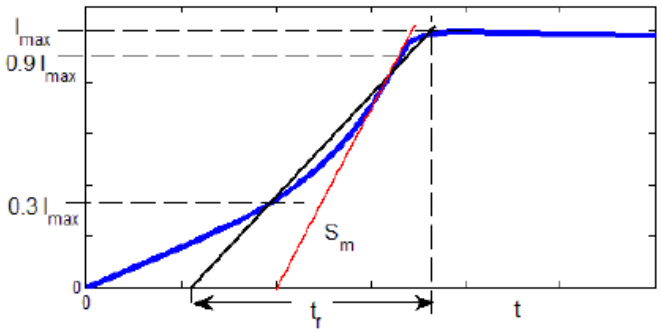
$$L' = \frac{\mu_0}{2\pi} \ln\left(\frac{l}{r} + \sqrt{1 + \left(\frac{l}{r}\right)^2} + \frac{r}{l} - \sqrt{1 + \left(\frac{r}{l}\right)^2}\right)$$

Modelling with EMTP-RV

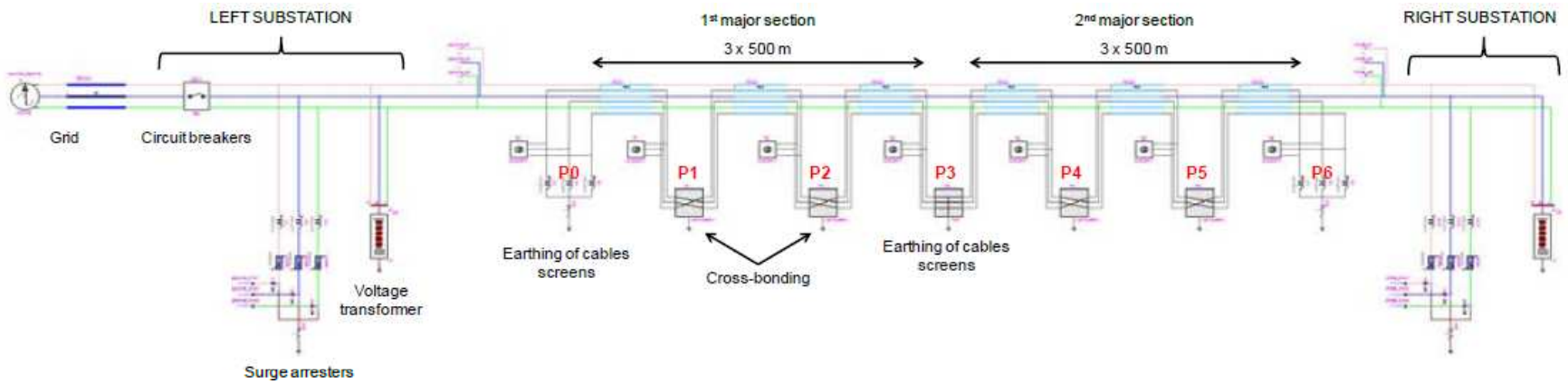
- **Circuit-breakers**: ideal switches
- **Voltage transformers**: RL circuit model

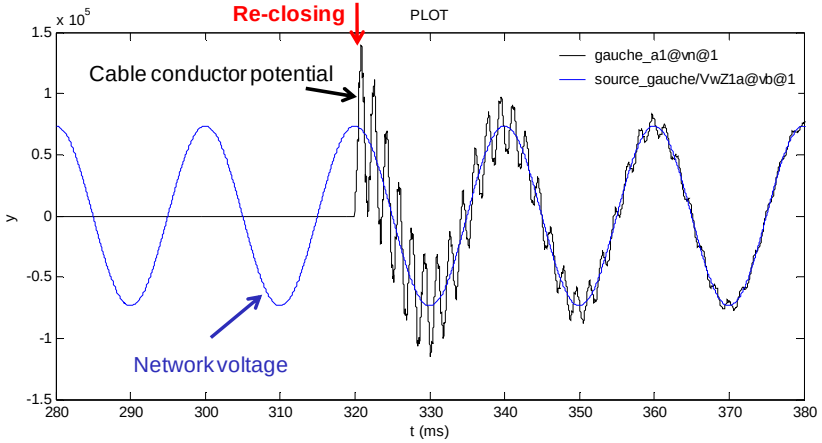


- **Lightning**: current source, Cigré wave shape



Switching surges





- Over-voltages reache 1.7 p.u. at the entrance of the UGL.
- Re-closing occurs on discharged cables, thanks to voltages transformers.
- **Neither phase SA nor SVL become conductive.**

Switching surges - Results

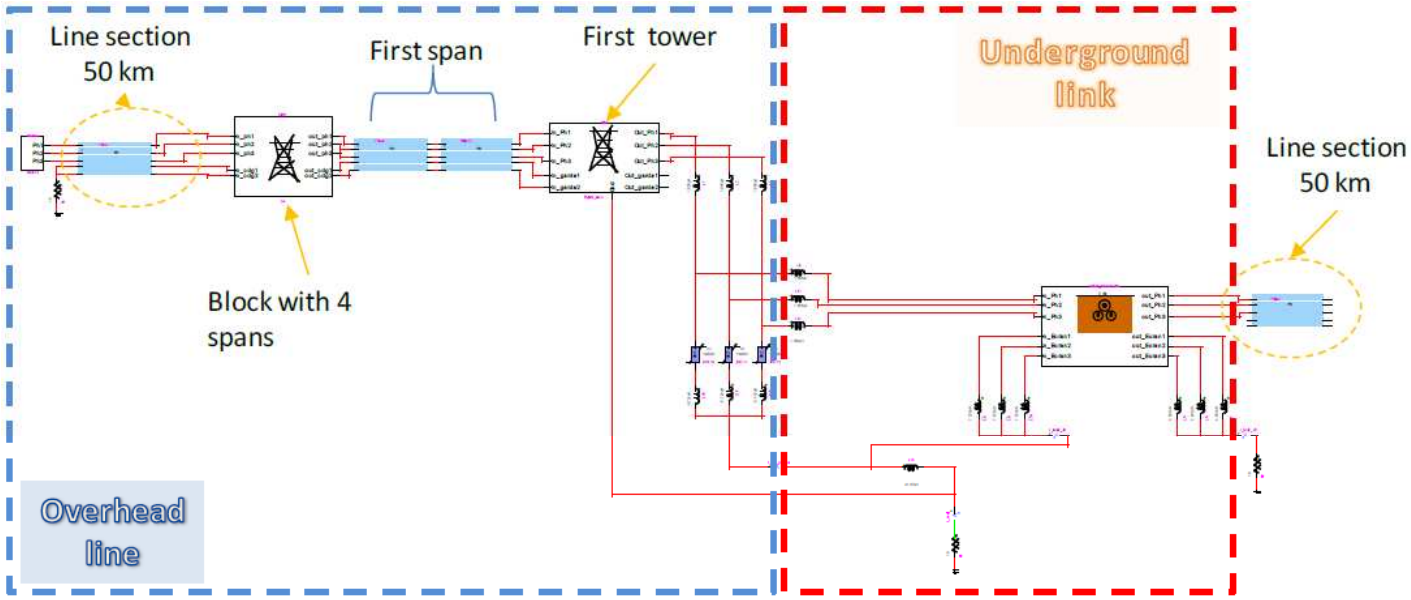
Max. over-voltage (kV_c)		
Localisation	Screen to earth	Screen interruption
P0	1.12	
P1	4.88	9.04
P2	4.85	9.26
P3	0.68	
P4	4.33	7.91
P5	4.18	6.42
P6	0.17	

- Over-voltages applied to cable sheaths and screen interruptions are **far below their withstand levels**.

- This is also true in the worst case of re-closing of a charged cable on voltage of opposite polarity.

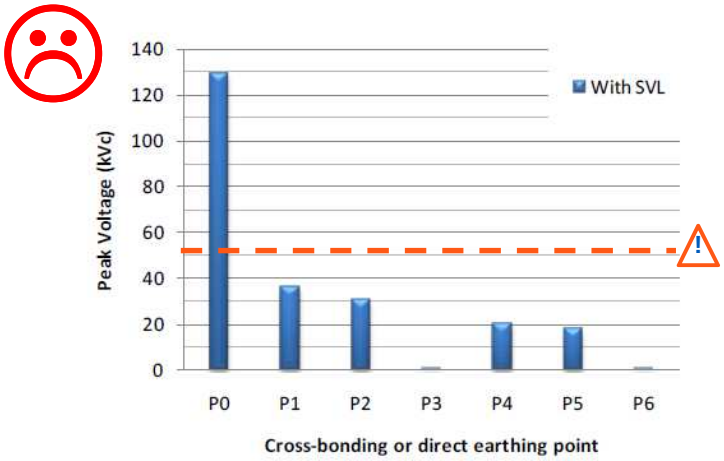
- This is also true when performing a **sensitivity analysis** on re-closing time, length of minor sections, length of bonding leads, earthing resistances, cable cross-section, number of major sections.

Lightning stroke

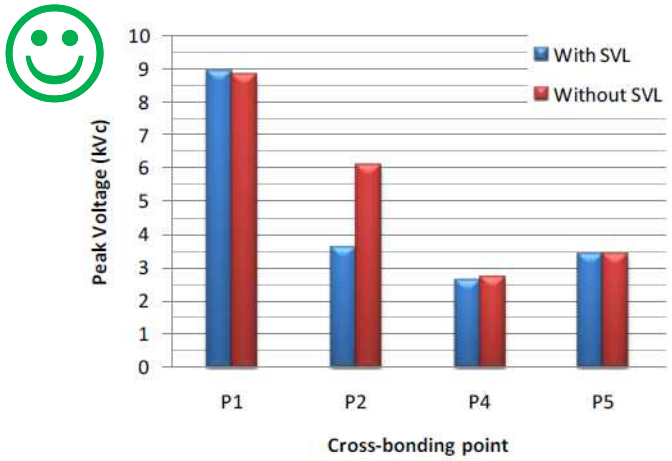


- **Median** lightning stroke: 31 kA, probability 50 %
- **Severe** lightning stroke: 150 kA, probability 0.05 %
- Stroke on the UGL/OHL tower, which is the most severe configuration.

Median lightning stroke



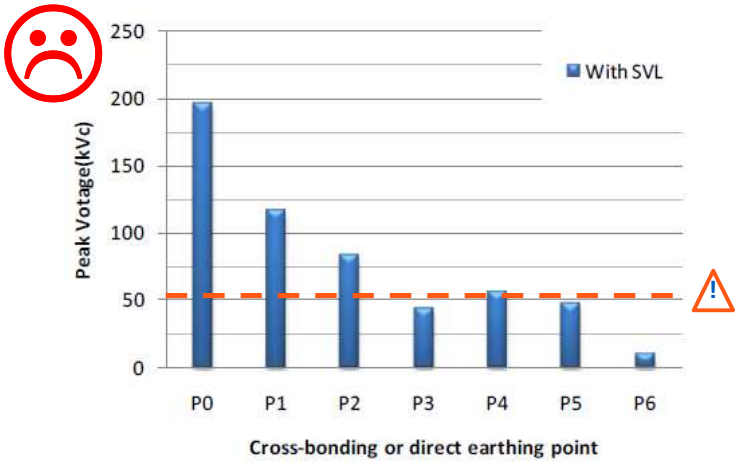
Max screen to local earth over-voltages



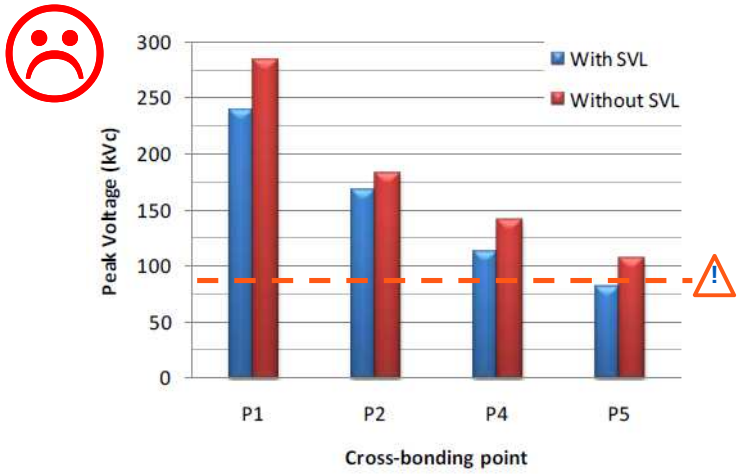
Max screen interruption over-voltages

- Phase SA do not conduct.
- SVL of 1st major section conduct.
- With SVL, **sheath over-voltages are excessive** close to the UGL/OHL transition.
- Without SVL, sheath over-voltages at cross-bonding points are impossible to assess.
- With/wihout SVL, **screen interruption over-voltages are acceptable**.

Severe lightning stroke



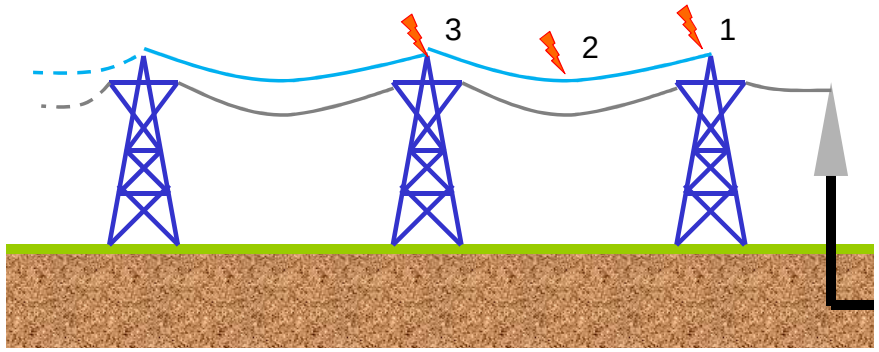
Max screen to local earth over-voltages

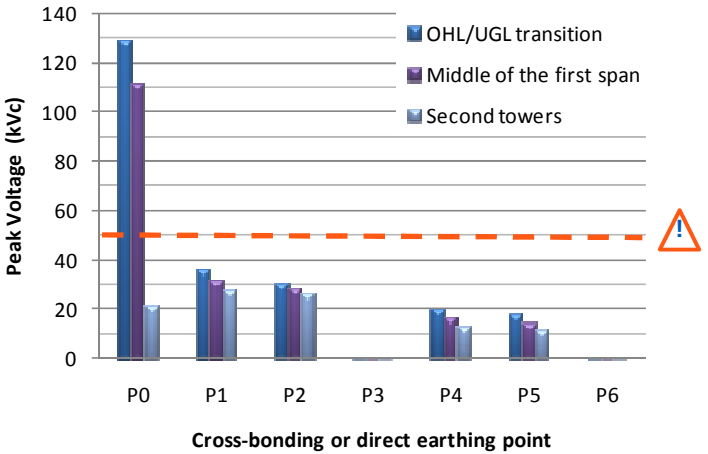


Max screen interruption over-voltages

- Some phase SA conduct.
- SVL of both major sections conduct.
- **Sheath over-voltages are excessive**.
- **Screen interruption over-voltages are excessive**.

Influence of striking location

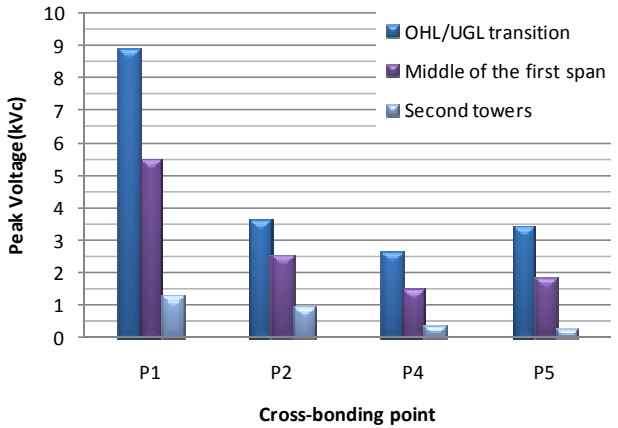




Max screen to local earth over-voltages (median lightning strokes)

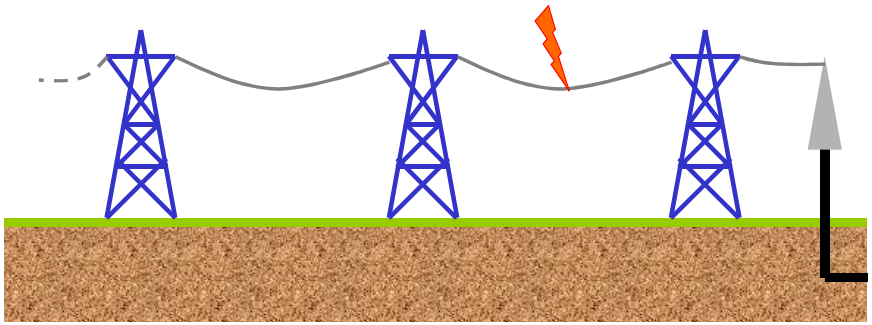
- **Screen interruption over-voltages are acceptable**, even for a severe stroke, if the striking location is the 2nd tower or beyond.

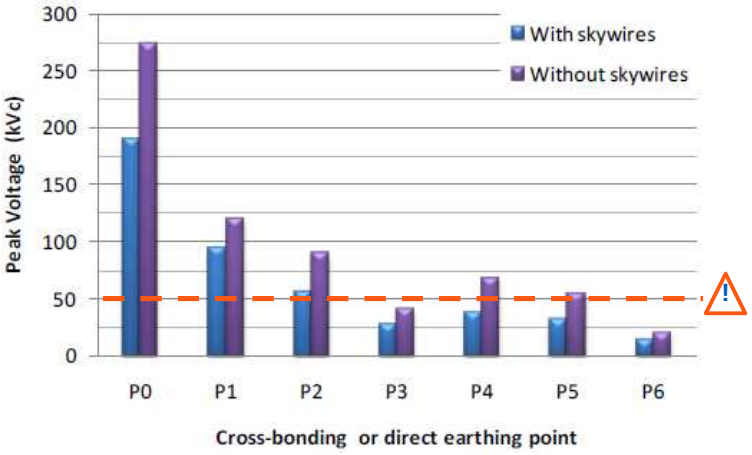
- **Sheath over-voltages** are acceptable if the striking location is the 2nd tower or beyond. This is not true for a severe stroke.



Max screen interruption over-voltages (median lightning strokes)

Influence of skywires

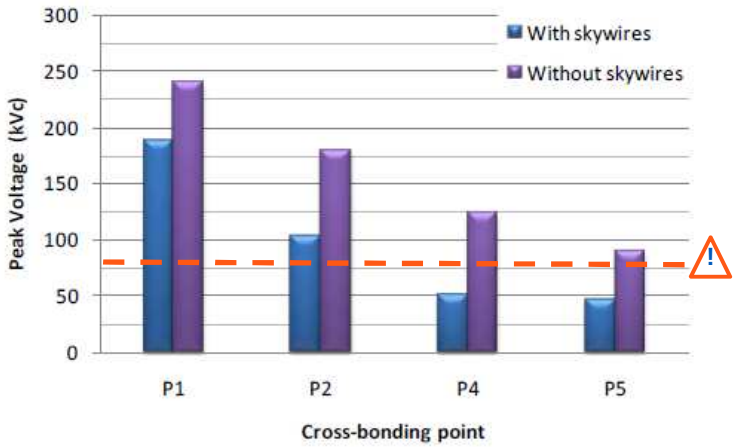




Max screen to local earth over-voltages (severe lightning strokes)

- For a **median stroke**, sheath over-voltages are excessive, whereas screen interruption over-voltages remain acceptable.

- For a **severe stroke**, both sheath and screen interruption over-voltages are excessive.



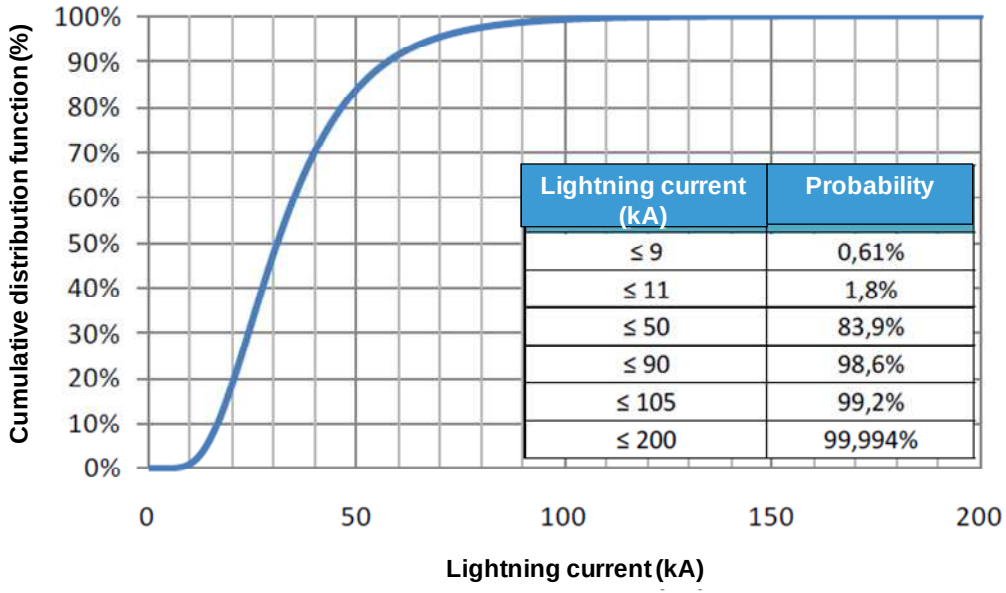
Max screen interruption over-voltages (severe lightning strokes)

Probability of lightning strokes

Max lightning current for material

	1st tower	Mid-span	2nd tower
Oversheath	9 kA	11 kA	105 kA
Screen interruption	50 kA	90 kA	200 kA

according to Cigré TB 63



Lightning current (kA)	Probability
≤ 9	0,61%
≤ 11	1,8%
≤ 50	83,9%
≤ 90	98,6%
≤ 105	99,2%
≤ 200	99,994%

- For **screen interruptions**: the probability of destructive strokes is low.
- For **oversheaths**: the probability of destructive strokes on the 2nd tower is low.

Conclusion & perspectives

- **Switching surges are not likely to cause excessive over-voltages**, even without SVL.
- M**edian lightning strokes (50 % probability) are not harmful if beyond the 2nd tower.**
- In case of strokes of very large magnitudes (0.05 % probability), excessive over-voltages occur.

- Moreover, in case of a lightning stroke:
  - SVL do not significantly reduce screen interruption over-voltages.
  - Sheath over-voltages are excessive close to the UGL/OHL transition.

- Further studies should be carried out to decide whether higher withstand levels of screen interruptions should be asked for, while suppressing the SVL.
- **Tests on the field will be performed** in order to validate the computations.
- These issues should be considered for other voltage levels, such as 225 kV.

Thank you
for your attention.

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