Secondary arc extinction in AC/DC overhead lines

Background of the paper published in CSE journal

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SuperGrid Institute
Shaping power transmission

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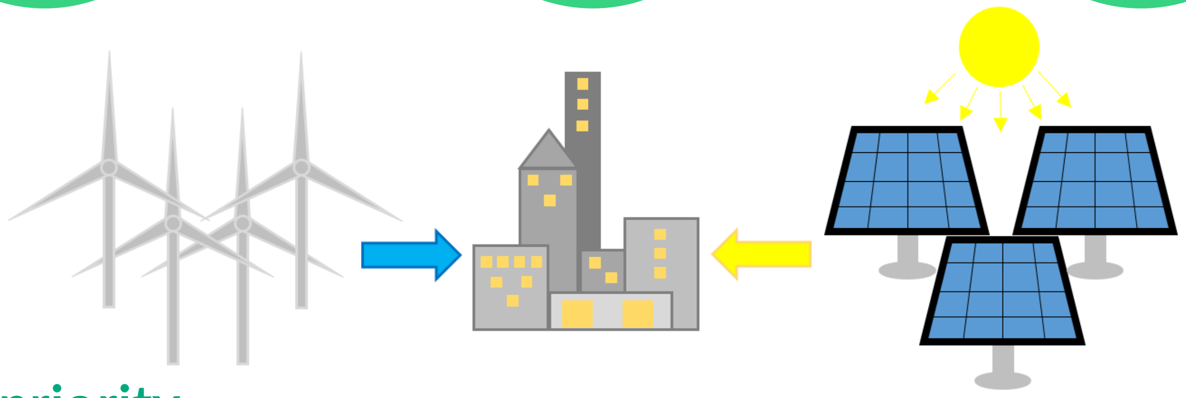
1. Introduction

A Possible solution – Upgrading OHL from AC to DC (1)

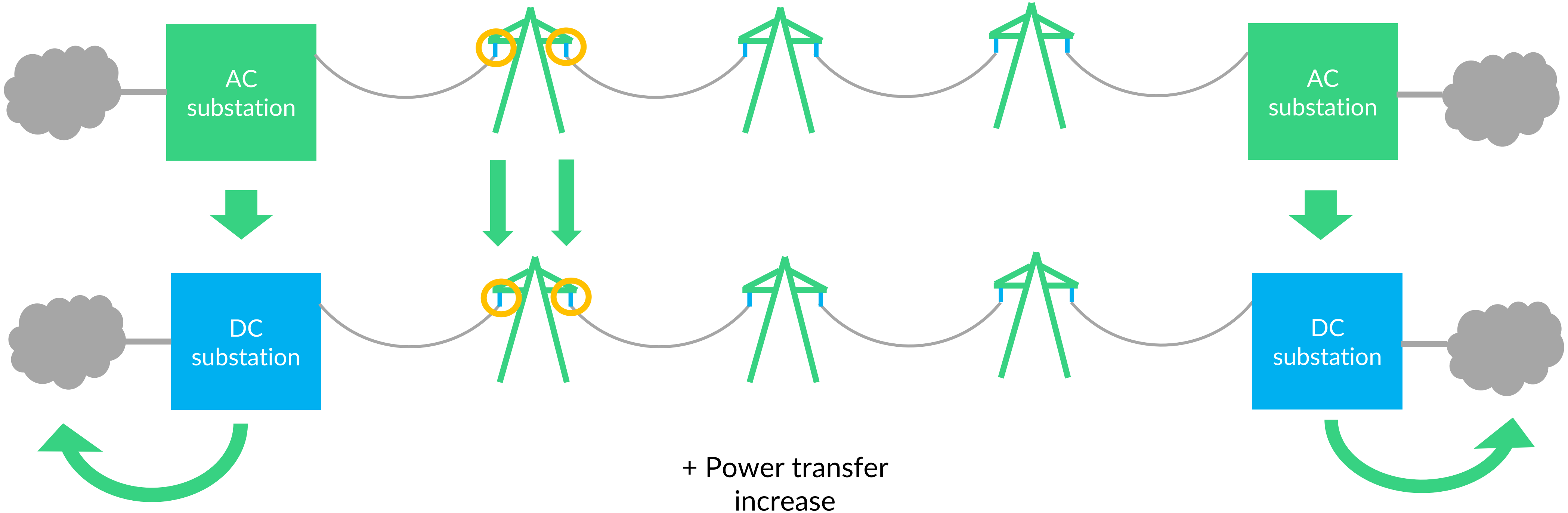
Massive introduction of RES in EU + Free electricity market = Need for increased transmission capacity



- **Flexibility → priority**
- **Existing AC lines capacity cannot be fully utilized due to different transmission stability concerns**
- **AC lines are usually enhanced by:**
  - FACTS devices
  - Uprating existing corridors
  - Creating new corridors

Not enough to keep up with the grid development

A Possible solution – Upgrading OHL from AC to DC (1)

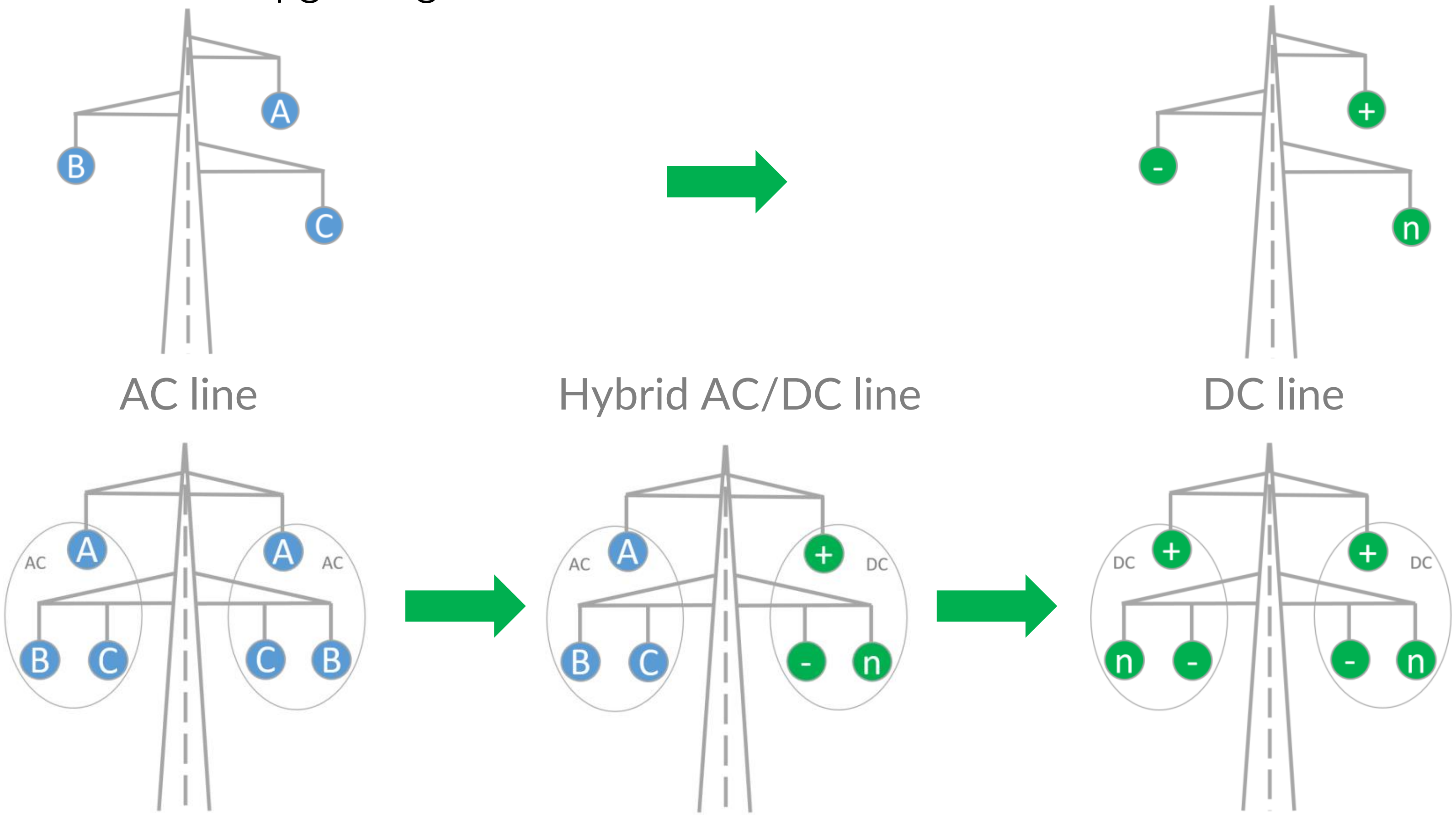


Additional services to the grid

+ Power transfer increase
+ Lower transmission losses

Additional services to the grid

A Possible solution – Upgrading OHL from AC to DC (2)



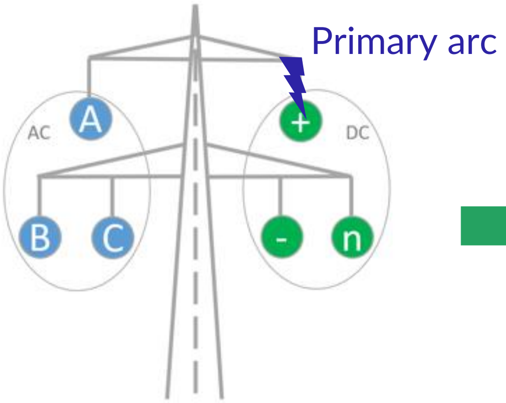
- Advanced power flow, protection and stability control features
- Faster timeframe for projects, compared to building a new line
- An increase in power transfer, utilizing the same ROW

2. Secondary arc phenomenon

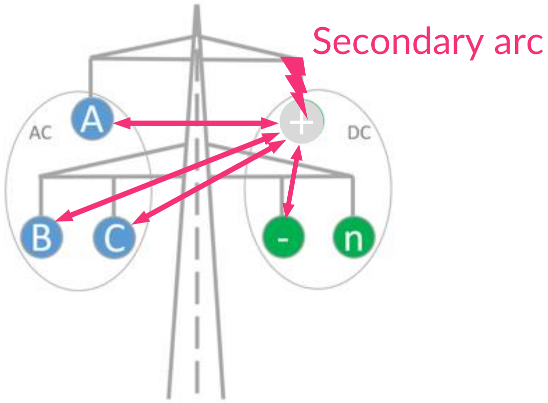
Hybrid lines

Pole to ground temporary fault

Electrostatic and electromagnetic coupling



Circuit Breakers open the faulty pole
DC SPAR
(Single Pole Auto Reclosure)



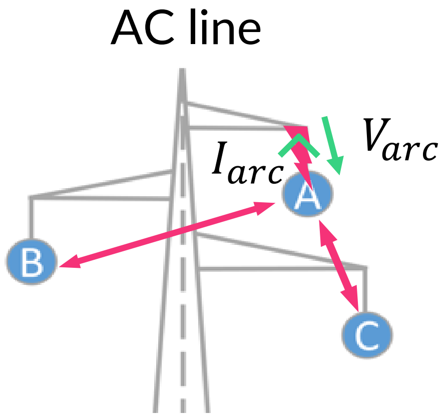
The secondary arc must be extinguished before the line is closed.

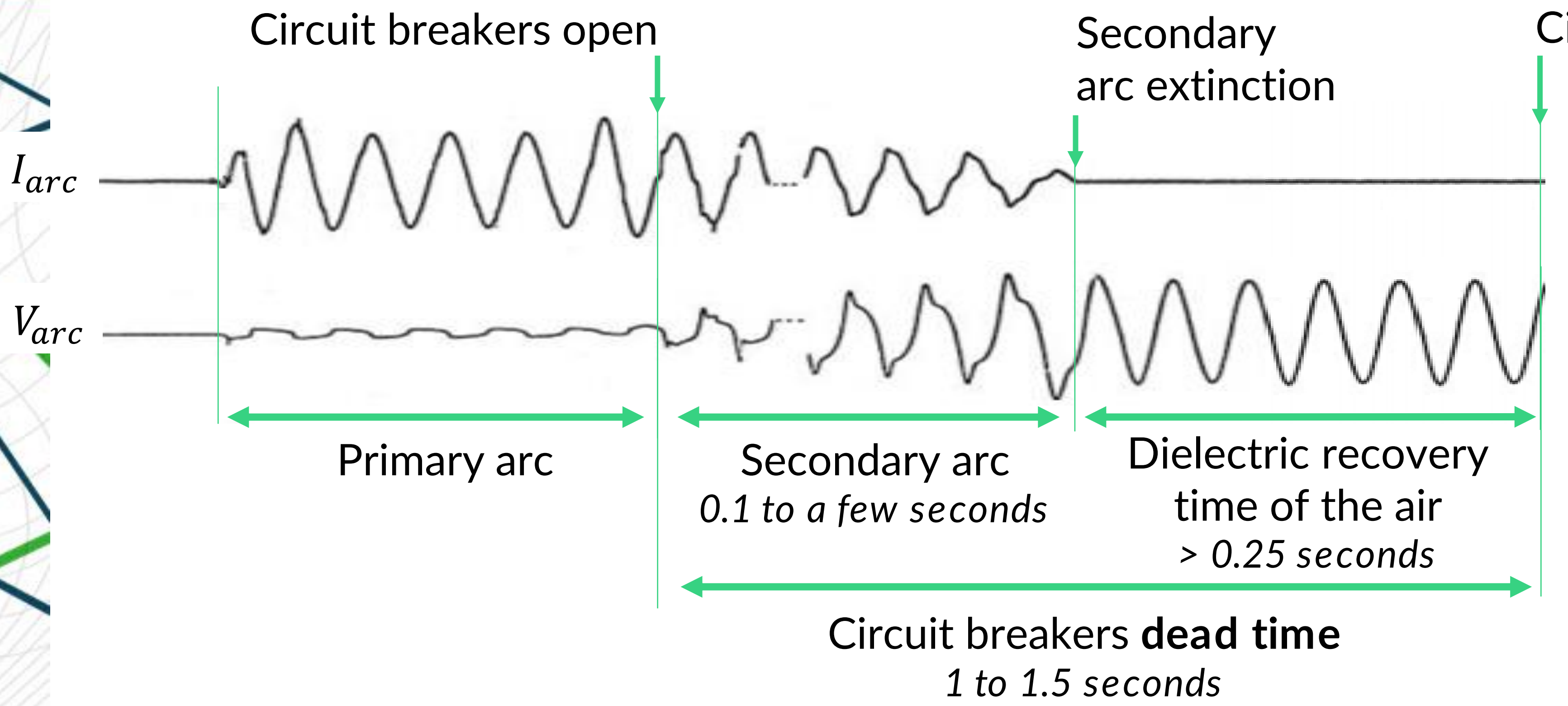
2. Secondary arc phenomenon

Behavior on AC lines

Secondary arc in Extra High Voltage AC lines

- A 300 km, 700 kV AC line :
  - I_s : ~ 80 A
  - V_s : ~ 80 kV



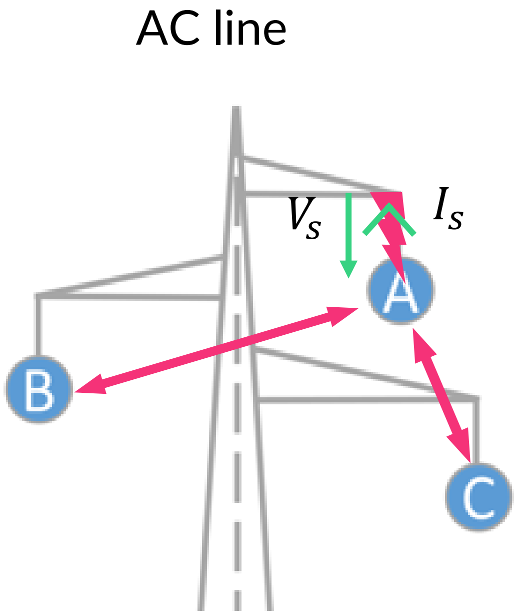


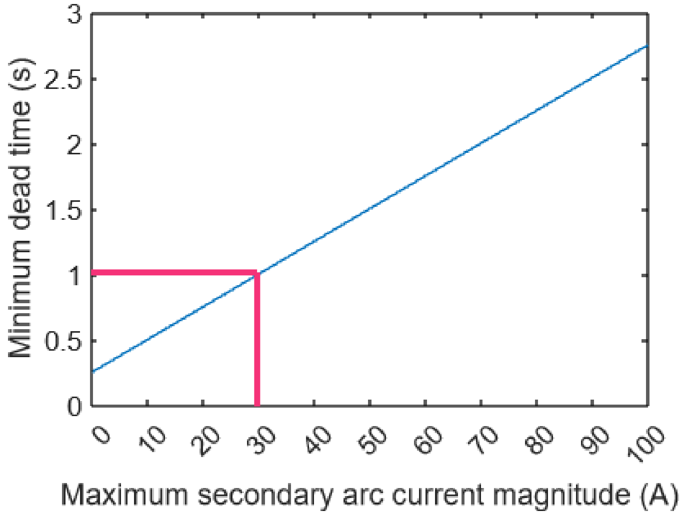
Design criteria:

The secondary arc must be extinguished in less than 0.75s.

Extinction time influencing factors

- Line length
- Primary arc current
- Secondary arc length
- Wind speed
- …
- **Secondary arc voltage V_s**
- **Secondary arc current (SAC) I_s**
- $T_{dead} = \frac{I_s}{40} + 0.25 < 1\ s$



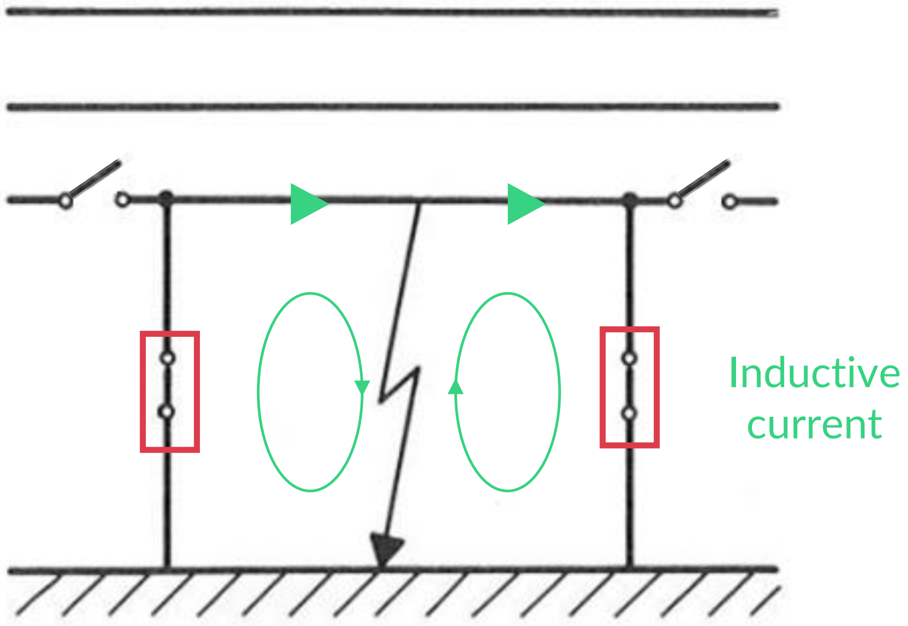


Validation criteria :

$I_s < 30$ A

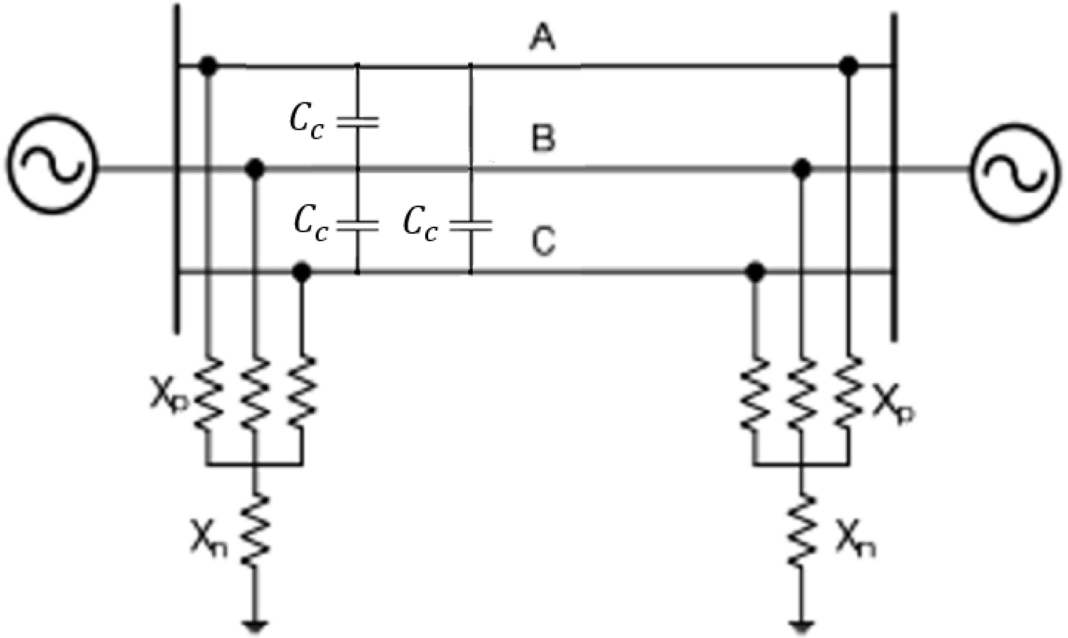
High speed earthing switches (HSES)

- Voltage reduction
- Current reduction



High speed earthing switches (HSES)

- Capacitive secondary arc current



Our approach

Modelling

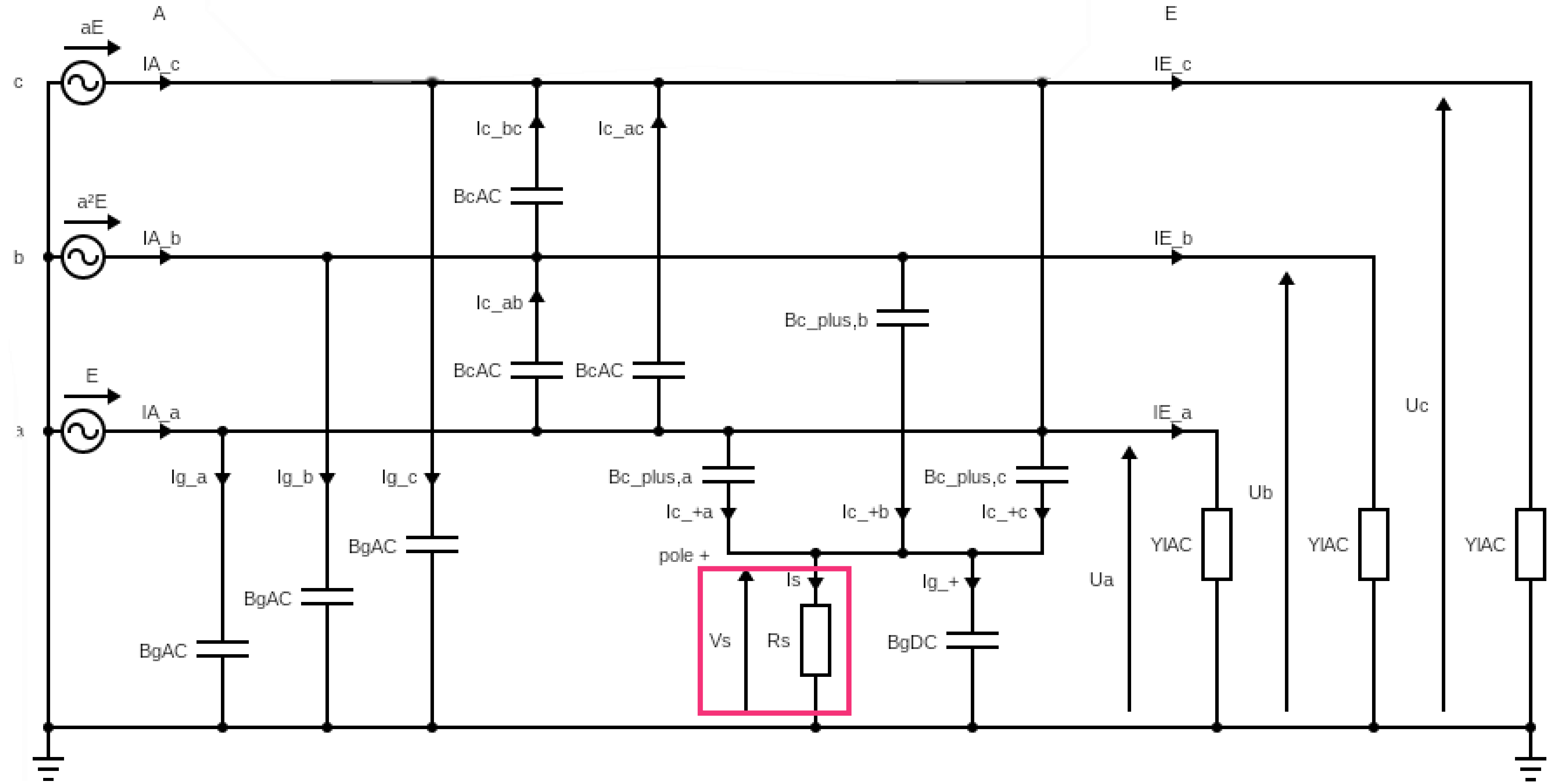
- Understand the physical phenomenon
- Explain the physics of results
- An equivalent solution to the shunt reactors in hybrid lines ?

Sensitivity analysis on EMTP version 4.0.1.

- Understand the arc behavior
- Select best parameters tuning

Building a solution to reduce the secondary arc extinction time

Analytical calculation



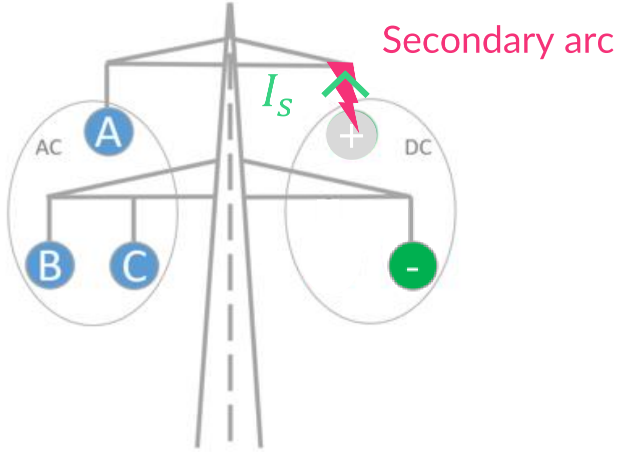
$$I_s = E\frac{B_c^{+a} + a^2 B_c^{+b} + a B_c^{+c}}{1 + R_s(B_c^{+a} + B_c^{+b} + B_c^{+c} + B_g^{DC})} = 24{,}04\ A\ (peak)$$

$a = e^{\frac{i\pi}{3}}$: cubic root of unity

Simulation : $I_s = 24.5\ A\ (peak)$

Objectives

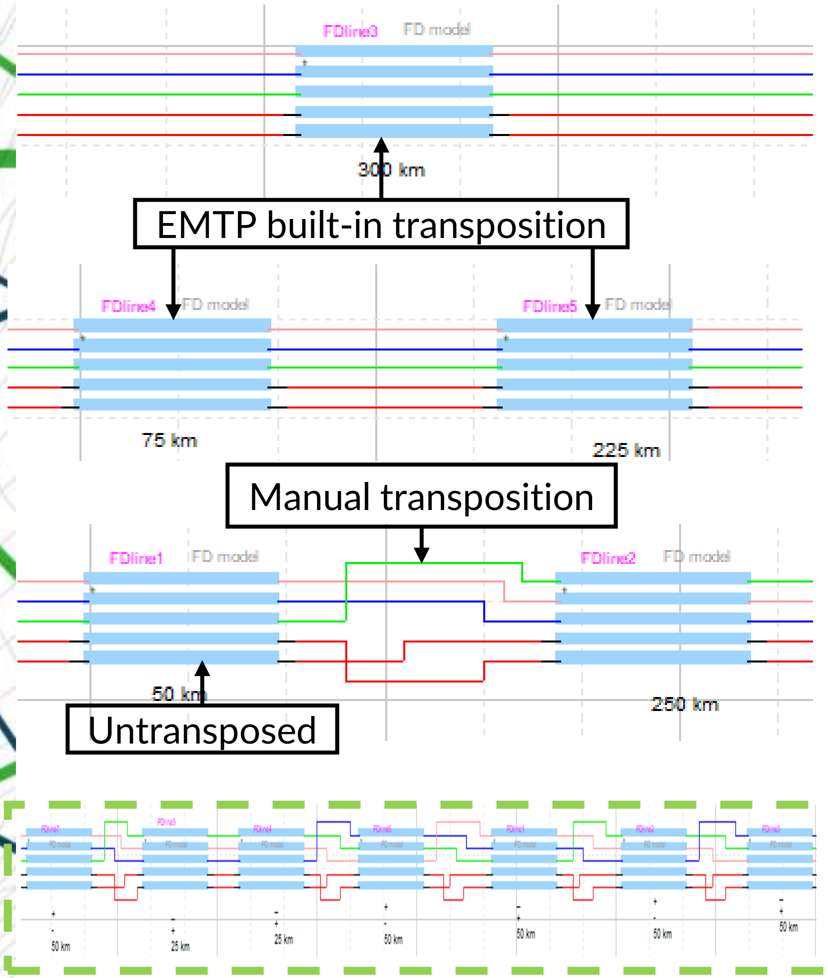
- **Measurement in faulty steady state**
  - I_s magnitude
- **Factors studied**
  - Earth resistivity
  - Inclusion of sub-conductor steel core
  - Metallic return
  - Fault resistance
  - Line length
  - Number of conductors per bundle
  - Fault location and AC current
  - Sky wire
  - DC pole positions
  - Line transposition



- **Case study parameters**
  - 300 km
  - AC : 400kV, 1kA RMS
  - DC : ±400kV, 1kA
  - Fault on positive pole
  - DC SPAR

Minimum significant dead time variation : 50 ms => I_s variation of 2A

Line transposition comparison



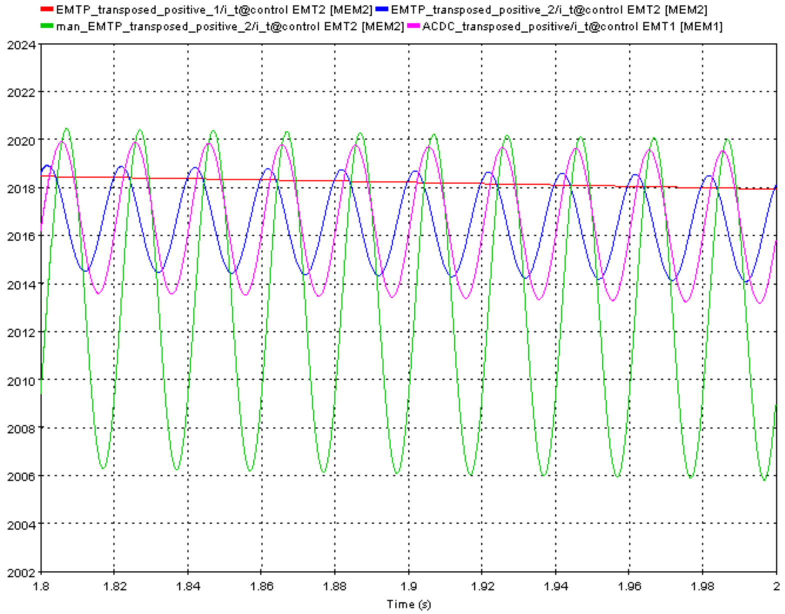
1 block

2 blocks

2 blocks, 1st transposition manually

Manually transposed

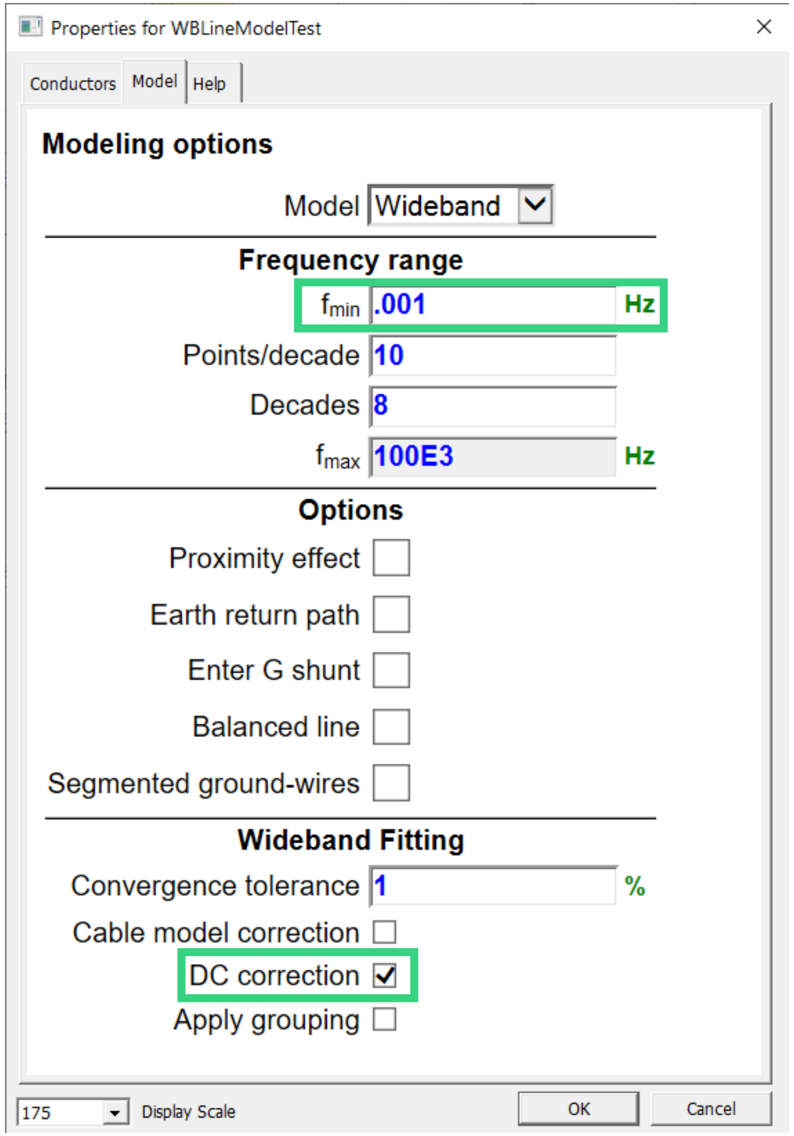
Time domain simulations are not suited for line transposition with several line blocs.



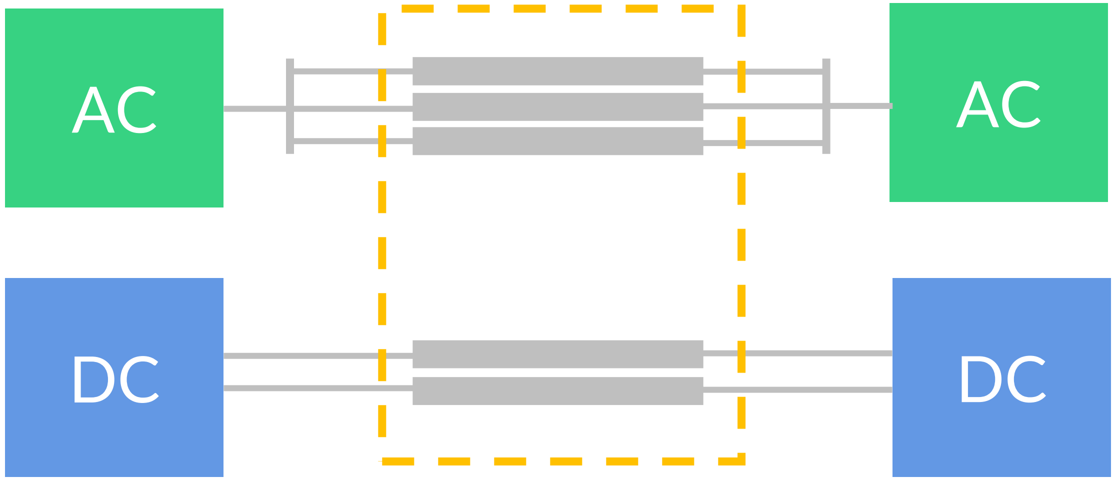
Positive pole current

4. Sensitivity analysis with EMTP

Time domain precision issues – possible solution



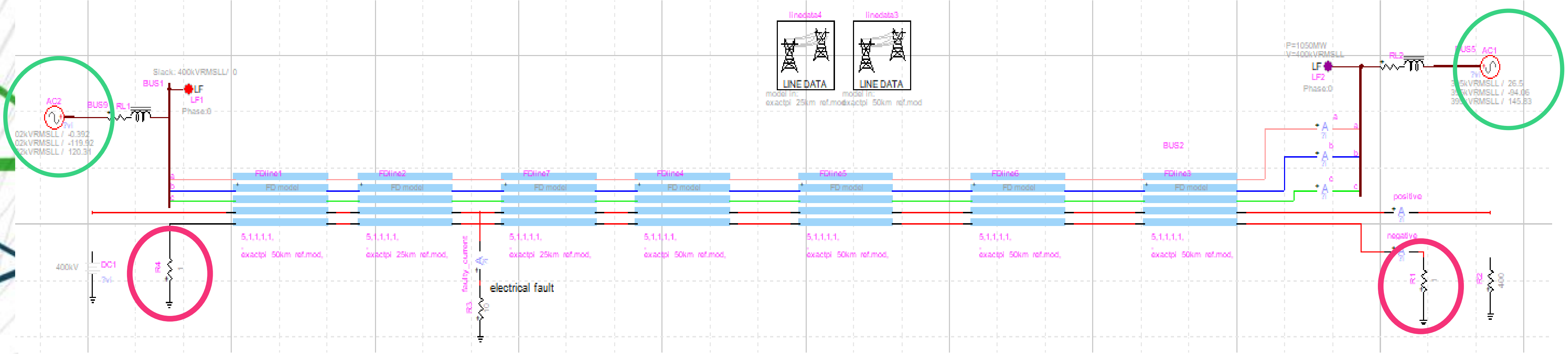
- **Good results are achieved with WB model and the 4.2.1 EMTP-RV version**
  - No built-in transposition



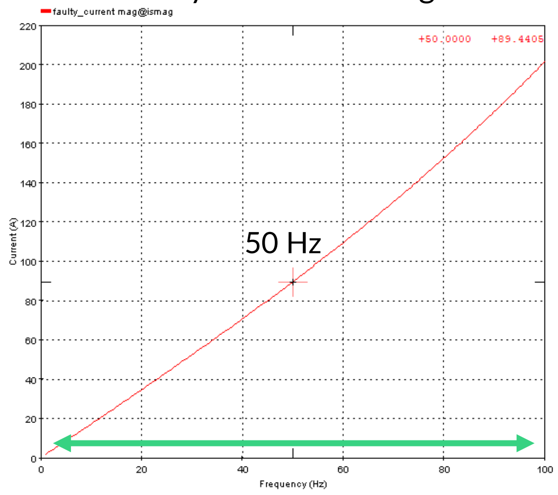
On the same tower

Reference scheme

Frequency scan



Secondary arc current magnitude

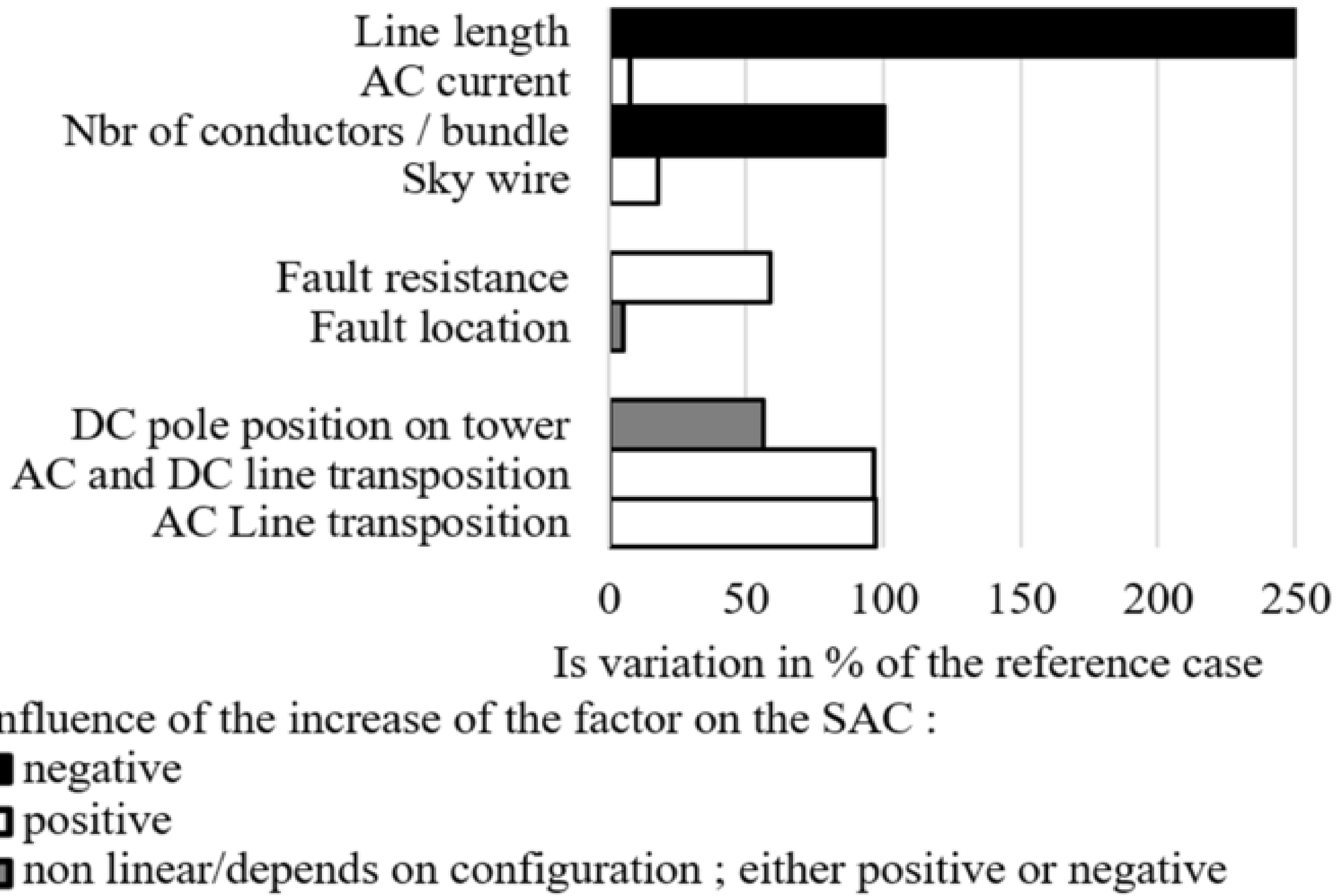


$$I_s = 24.5\ A\ (peak)$$

Validation criteria : $I_s < 30$ A

4. Sensitivity analysis with EMTP

Influence of factors on the secondary arc current magnitude



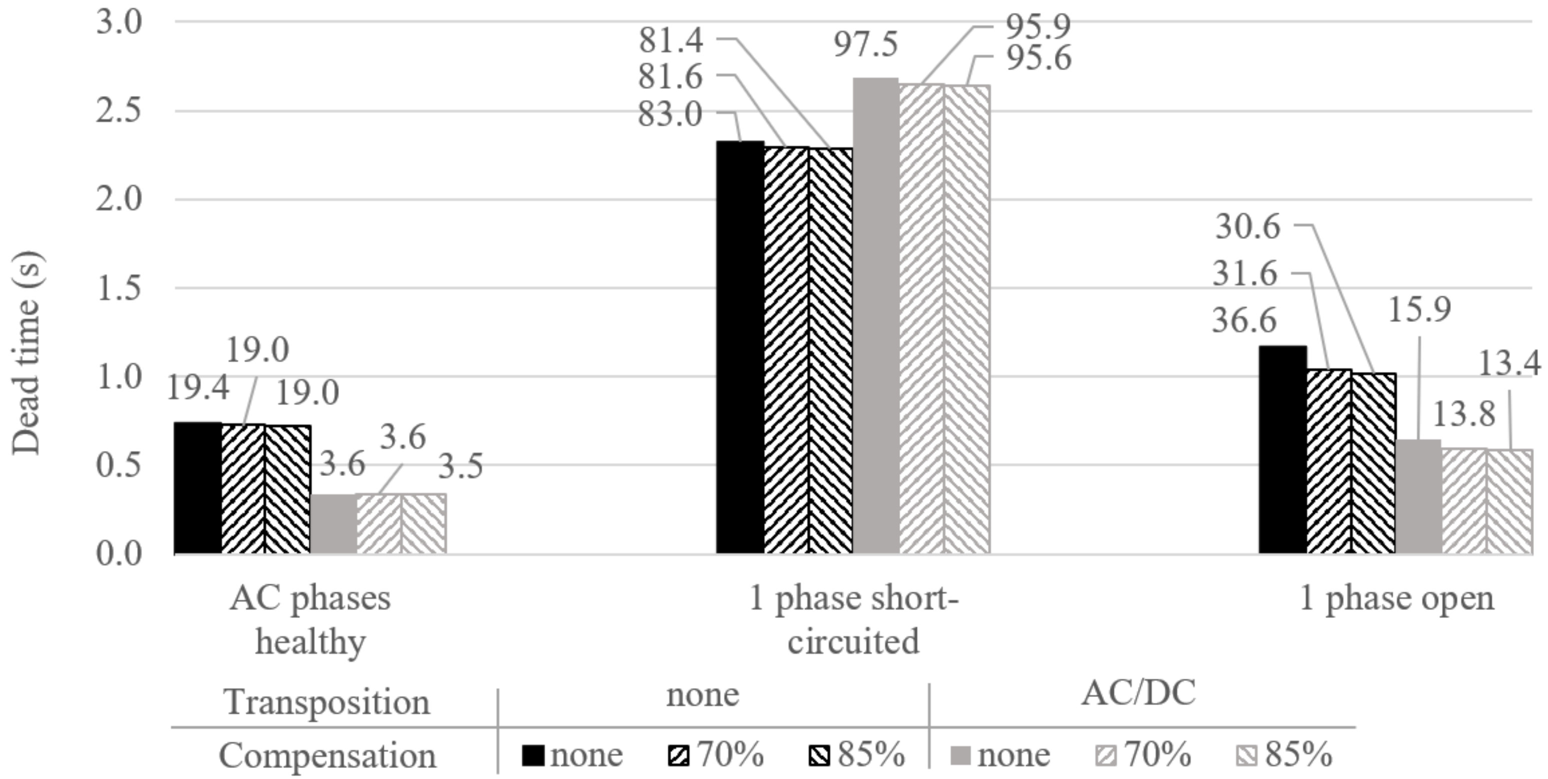
Contextual features
Can not be changed

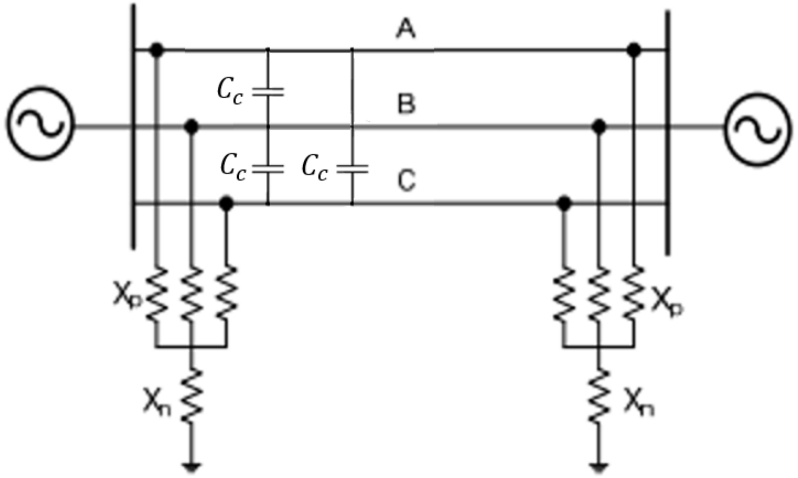
Can not be controlled

Can be changed

5. Investigation of solutions

Four-legged AC shunt reactors





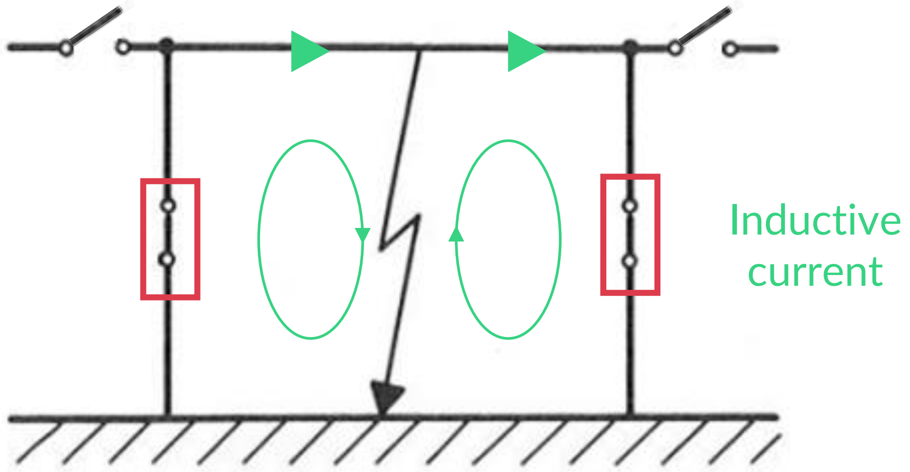
- The presence of the four-legged AC shunt reactors does not worsen the situation regarding the SAC and dead time

5. Investigation of solutions

High speed earthing switches

Transposition case	HSES position	Phase a		
		Healthy	Short-circuited	Open
No transposition (ref)	/	19.2 A 0.730 s	/	/
AC	Beginning	37.8 A 1.195 s	3046 A 76.4 s	120.7 A 3.268 s
	End	3.9 A 0.348 s	979.7 A 24.743 s	191.6 A 5.04 s
	Both ends	35.9 A 1.146 s	3488 A 87.450 s	12.4 A 0.559 s
AC / DC	Beginning	33.5 A 1.088 s	3061.5 A 76.788 s	119.4 A 3.235 s
	Both ends	39.8 A 1.245 s	3498.6 A 87.715 s	12.5 A 0.563 s

The association of line transposition and HSES is to be avoided.



The association of line transposition and HSES is to be avoided because it could even lead to permanent faults

6. Conclusions

- A numerical expression of this current was calculated and validated via EMTP simulations for a line without metallic return
- A sensitivity analysis was conducted to determine the influence of different line and system parameters on the SAC
  - The SAC increases mainly with the line length and the number of conductors per bundle
  - It is lower for some faulted pole location on the tower, with the presence of a sky wire, or with a higher arc resistance
- Transposition was found as the most efficient method to decrease SAC.
  - The best transposition configurations to reduce the SAC of more than 90% (dead time order of value of 285 ms)
- Line transposition with HSES should be avoided because this association of solutions worsen the SAC
- The four-legged shunt reactors have no influence on the DC SAC
- In future work AC and DC protection coordination could be studied to maximize the reduction of the dead time while ensuring continuity of service as much as possible on healthy conductors.

Thank you for your attention!

Q&A