AC PROTECTION NEAR VSC HVDC CONVERTERS

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2023 EUROPEAN RTDS TECHNOLOGIES INC. USER'S GROUP MEETING 2023

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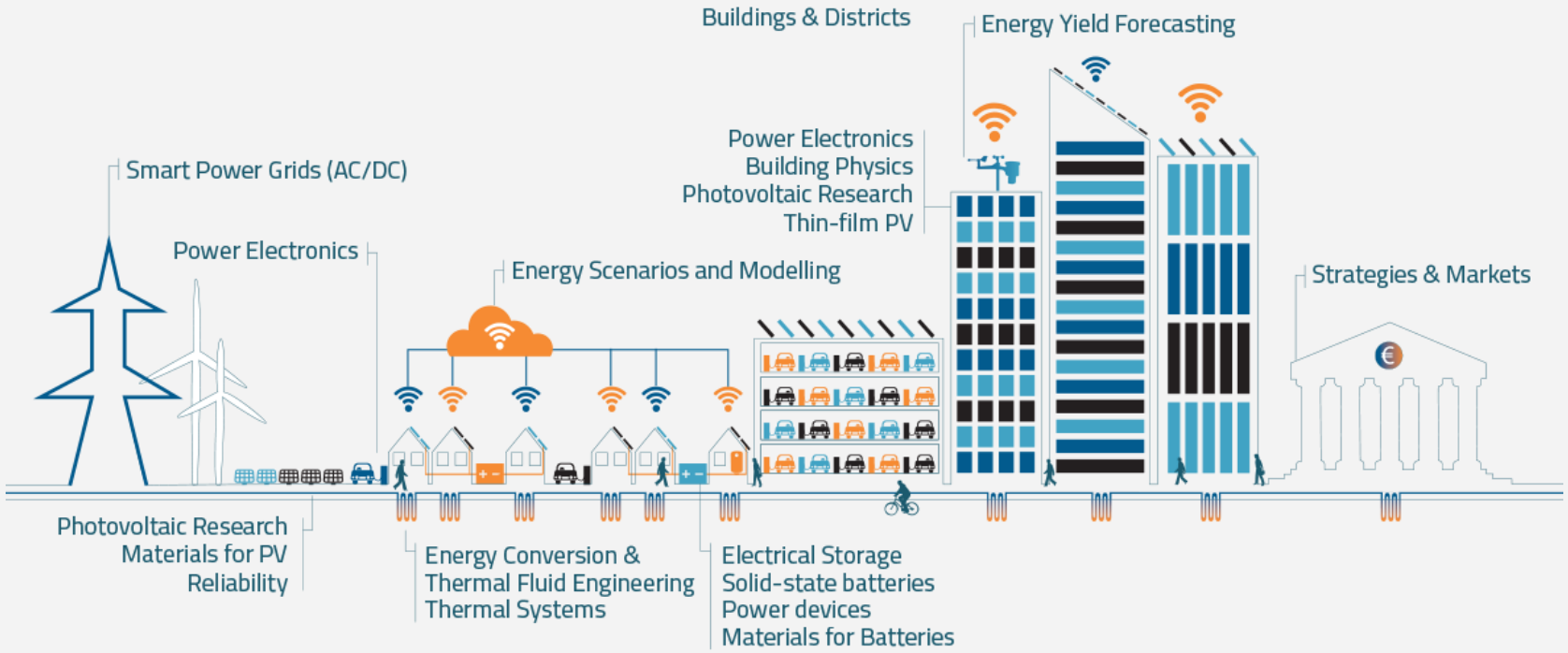
RTDS Technologies AMETEK

ENERGYVILLE

- A collaboration



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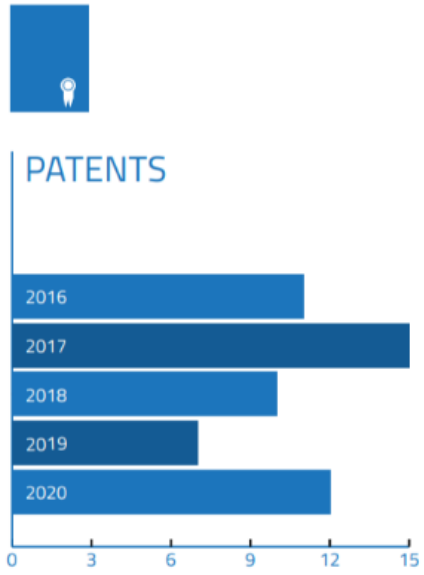
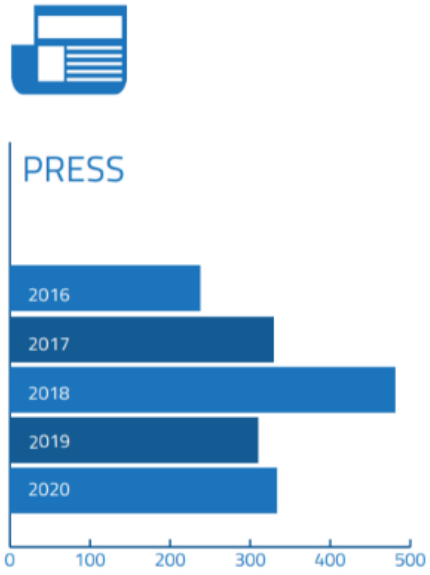
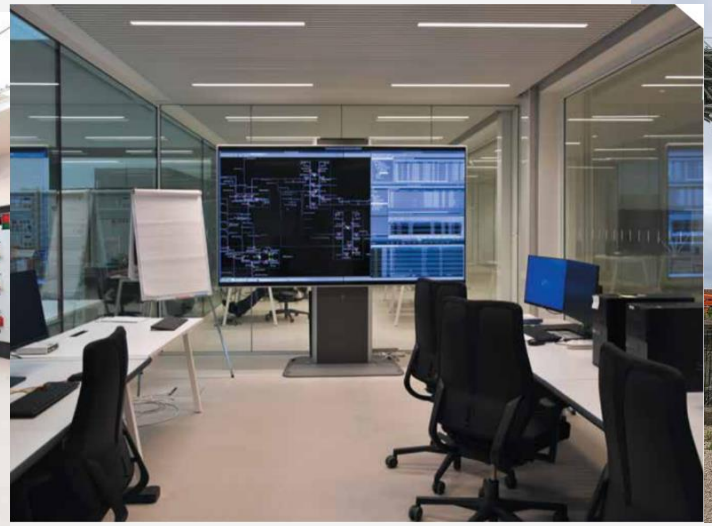
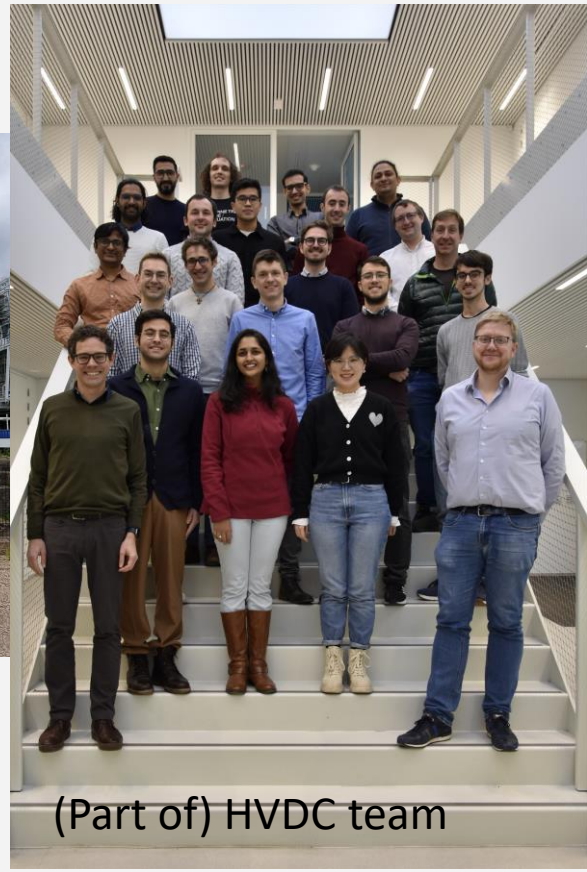




ELECTRICAL NETWORKS

HVDC, control, protection, planning …

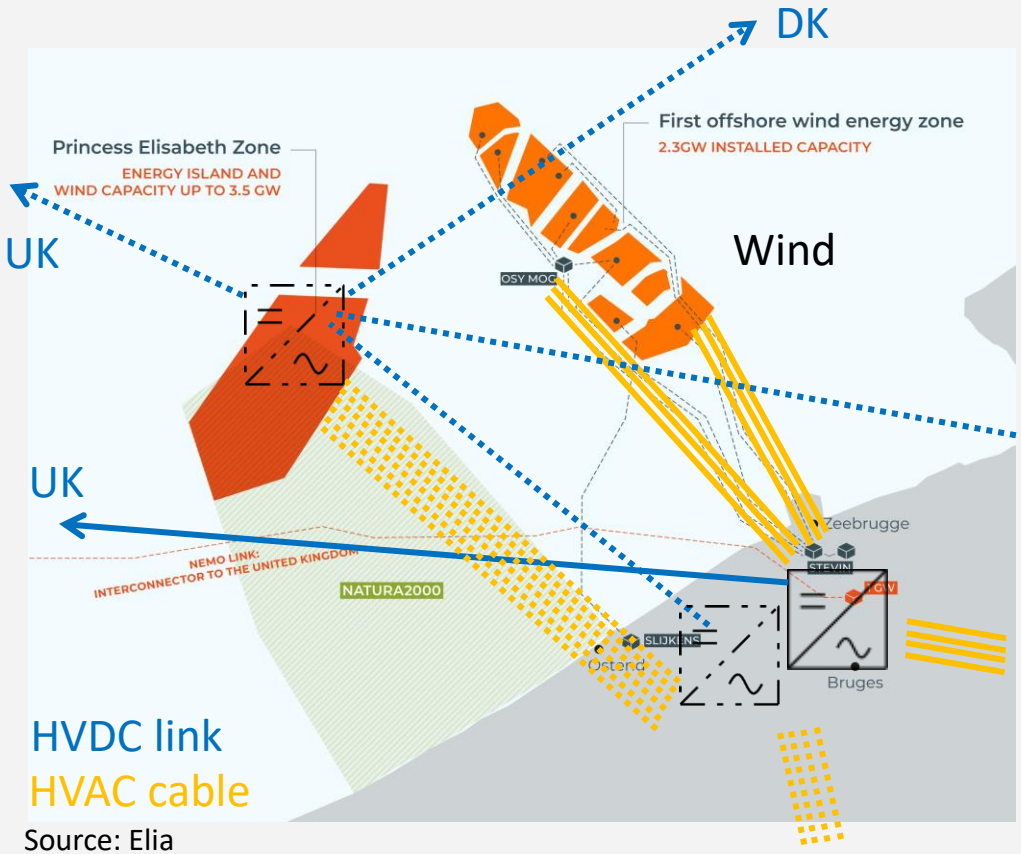




(Part of) HVDC team

CHANGING GRID CHALLENGES CURRENTLY INSTALLED PROTECTION

- Converter interfaced grid elements replace conventional sources
  - E.g. in Belgium: new HVDC links, nuclear phase-out, increasing number of wind farms
- Change in the system's response to faults
  - Limited fault current, controlled current injection
  - Decreasing resonance frequencies
- Challenging for protection
  - Distance protection malfunctions



Source: Elia

HOW TO PROTECT THE FUTURE POWER SYSTEM?

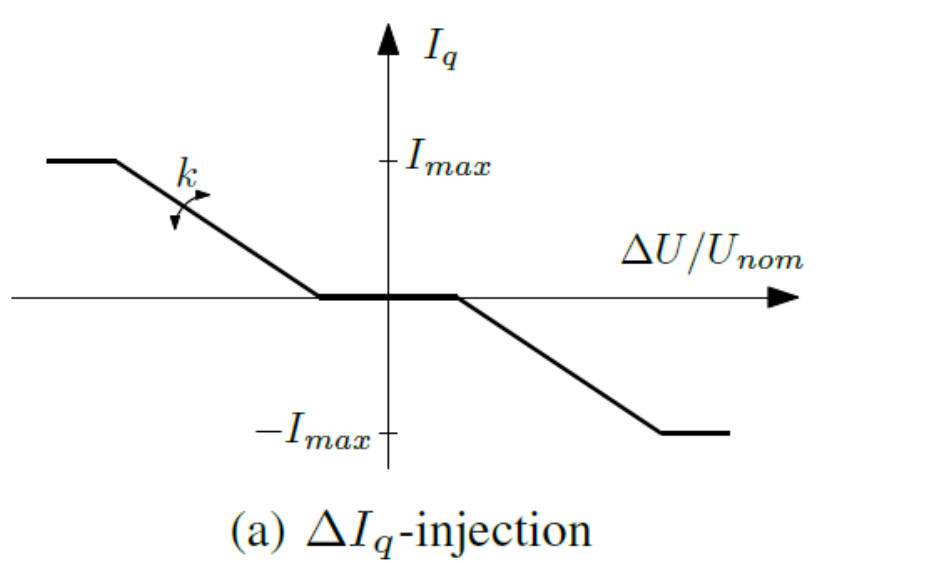
- Power-electronic interfaced grid elements replace conventional sources
  - Increased use of HVDC, larger number of wind farms
- Not only overhead lines, but more and more underground cables
- Also developments in protections: faster communication, new algorithms, faster hardware, better sensors

CONTROLLED FAULT CURRENT INJECTION

Fault ride through strategy:

voltage support

- Actively controlled fault response
- Reactive current injection
- Different implementations in EU

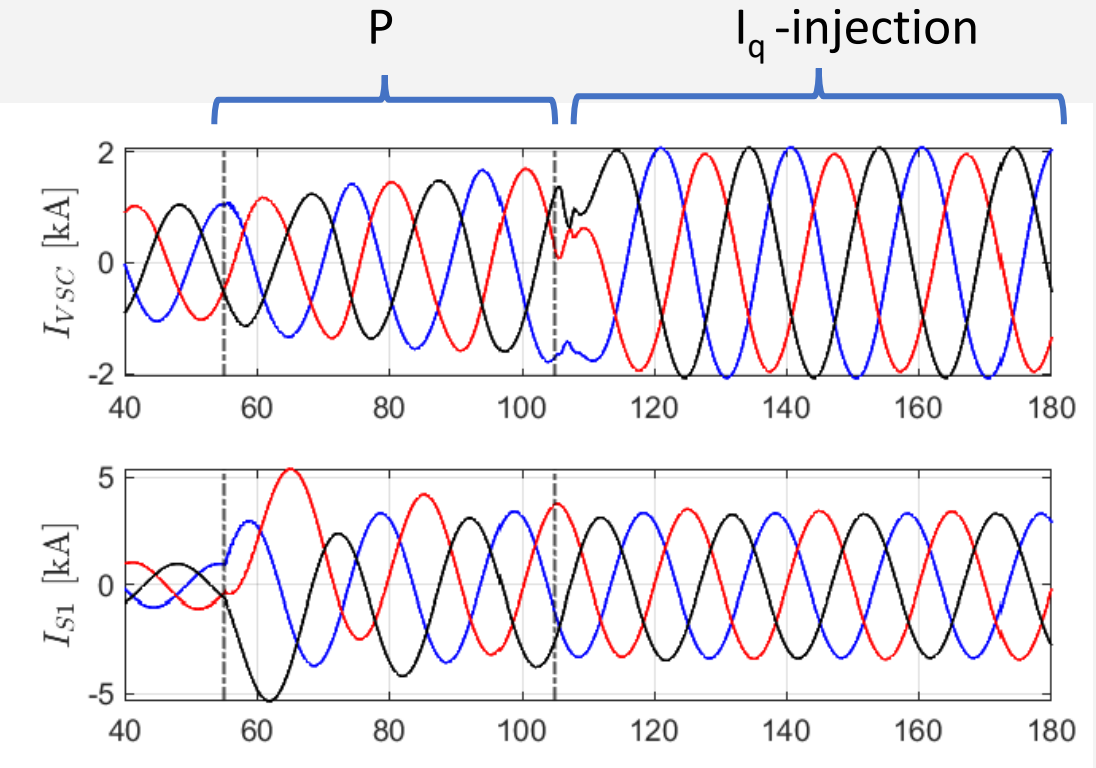


(a) ΔI_q-injection

FROM “PASSIVE” RESPONSE TO ACTIVELY CONTROLLED RESPONSE

Converter

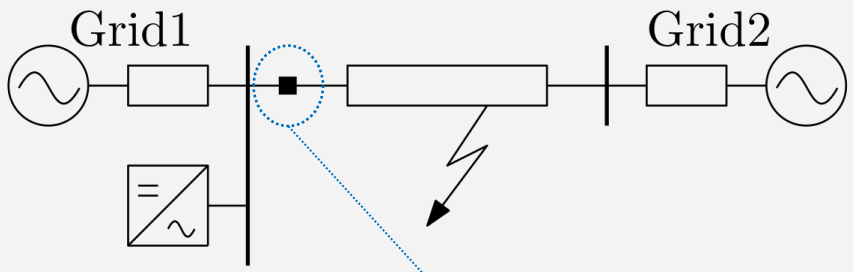
Conventional generator



* Exaggerated delay of fault current injection for purpose visualisation

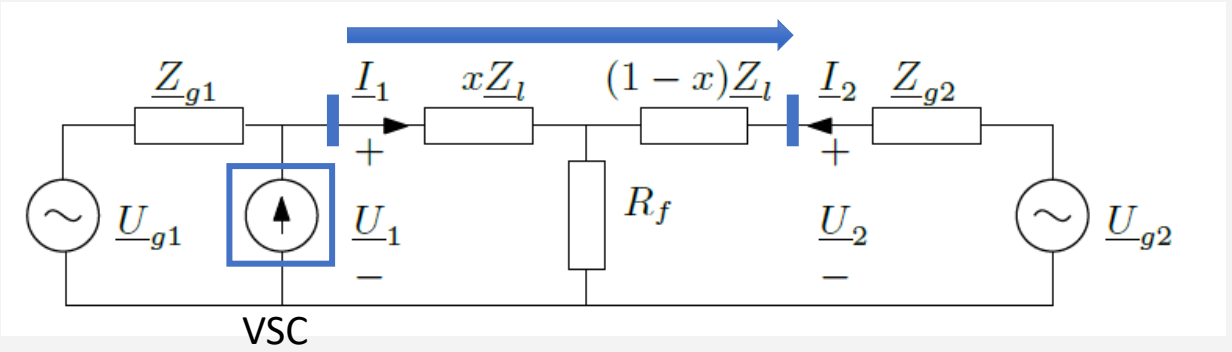
DISTANCE PROTECTION IN THE VICINITY OF VSC

Steady-state assessment of impedance locus



$$\underline{Z} = x\underline{Z}_l + R_f + \frac{\underline{I}_2}{\underline{I}_1} R_f,$$

$$\frac{\underline{I}_2}{\underline{I}_1} R_f = \frac{|I_2|}{|I_1|} e^{j(\phi_2 - \phi_1)} R_f,$$

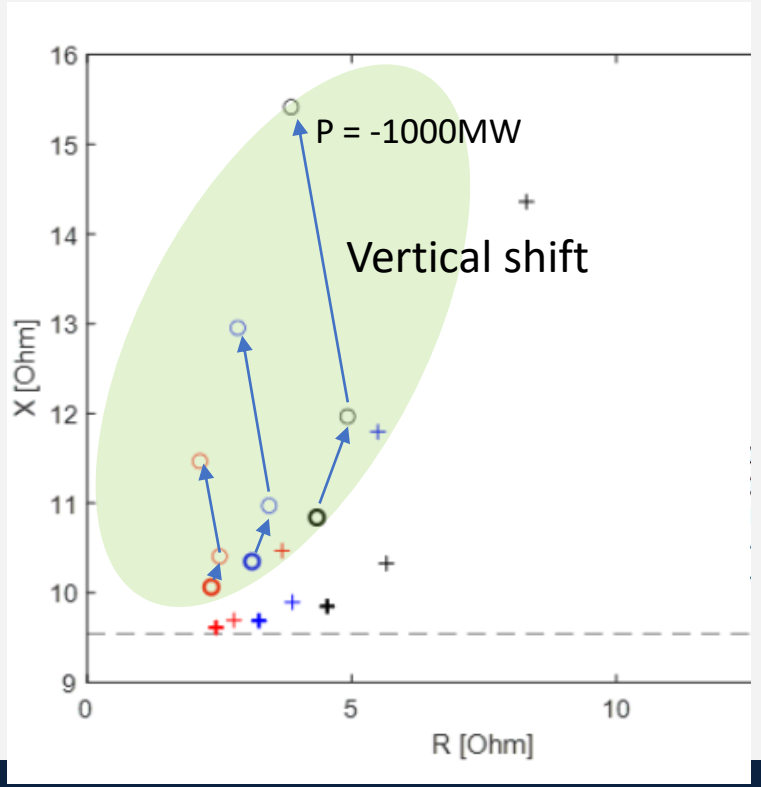


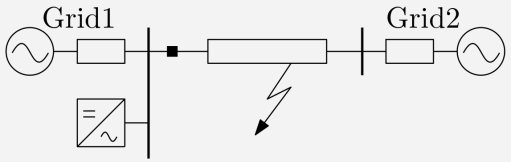
DISTANCE PROTECTION IN THE VICINITY OF VSC

Steady-state assessment of apparent impedance

Effect of VSC on apparent impedance by variation of relative grid strength ($SCP_{grid\ 1}$ ↘).

- Small effect on magnitude
- Significant change in angle





DISTANCE PROTECTION IN THE VICINITY OF VSC

Steady-state assessment of apparent impedance

Dependencies on local and remote grid: largest impact when

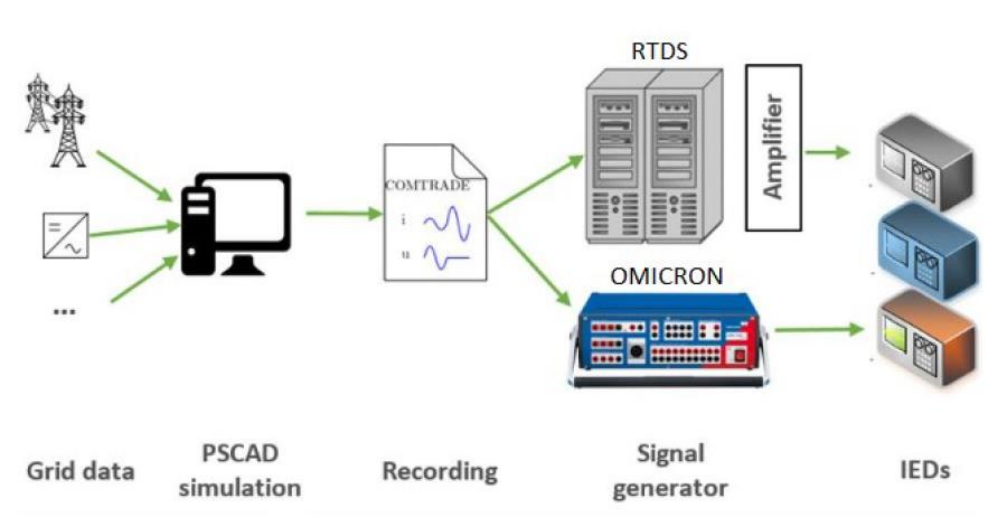
- a converter is dominating the local short-circuit current,
- and there is a large remote short-circuit current.

Influence of pre-fault power flow

DISTANCE PROTECTION IN THE VICINITY OF VSC

Validation with EMT models & real relay response

- Replay recordings on relays in the lab
- Validation of impedance locus with steady-state simulations



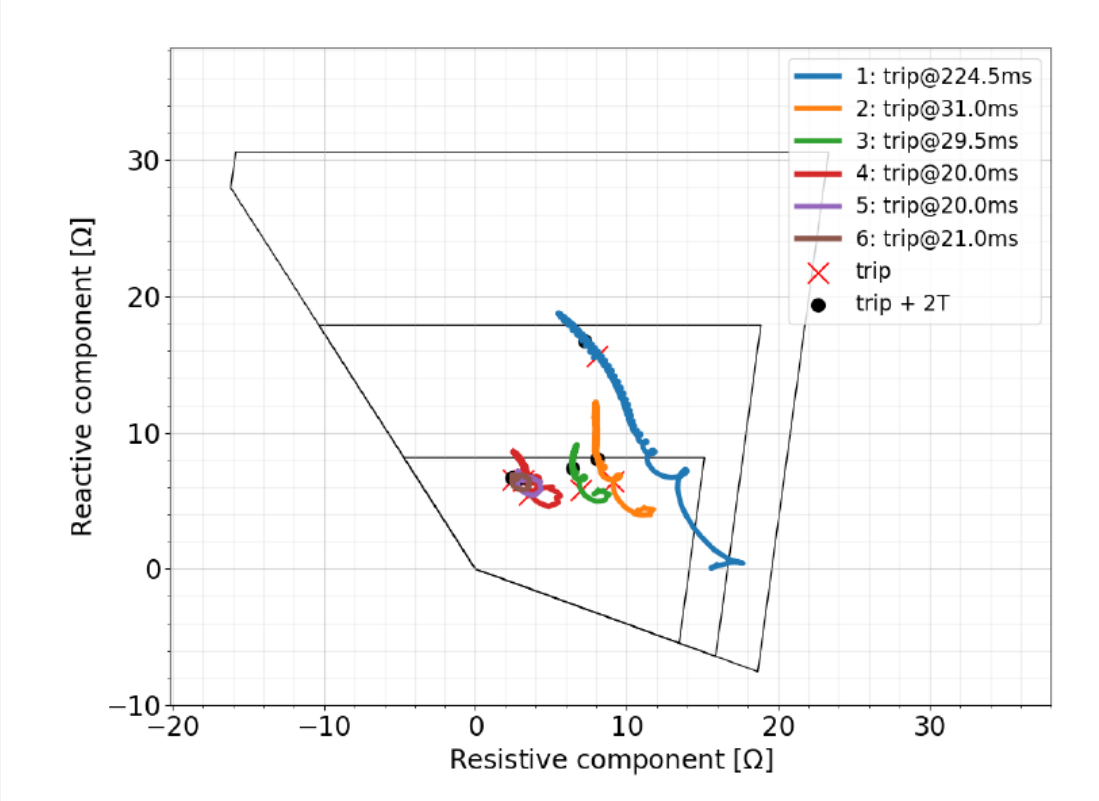
DISTANCE PROTECTION IN THE VICINITY OF VSC

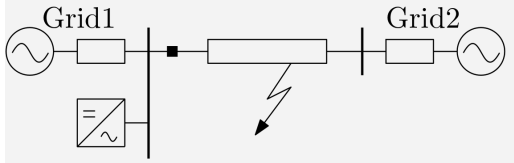
Project with TSO

black box manufacturer model

Similar observations

- Incorrect zone decision
- Extended settling times





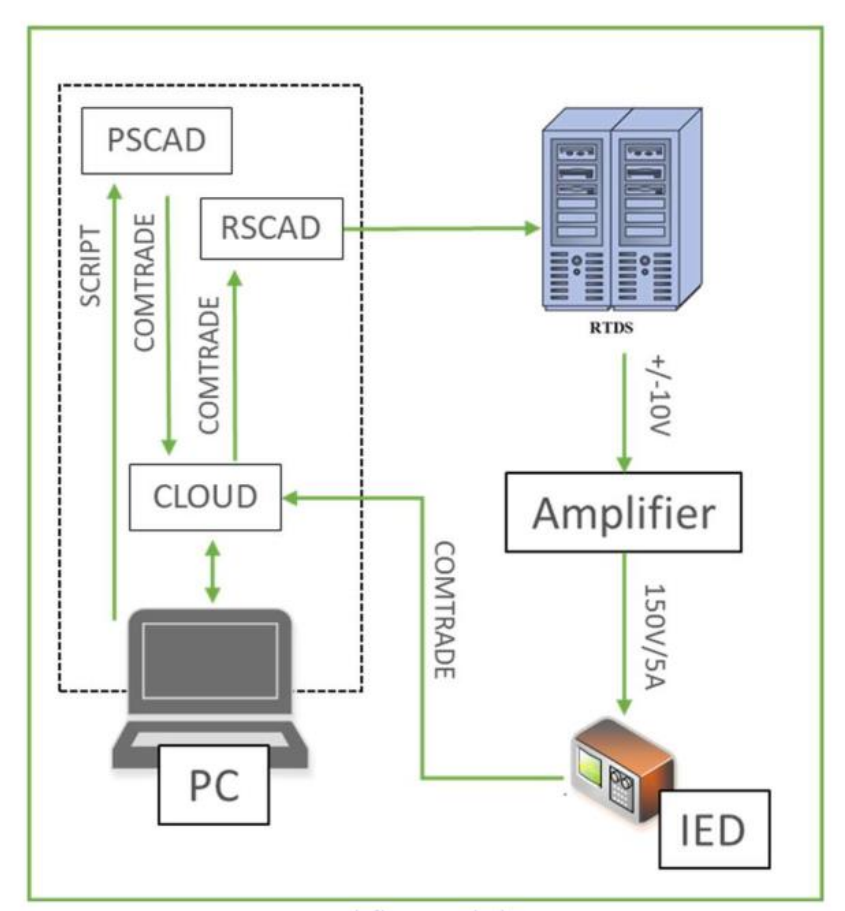
DISTANCE PROTECTION IN THE VICINITY OF VSC

Practical limitations

Project with TSO → manufacturer black box model

- Non-real time simulations
- Waveforms stored in COMTRADE files
- RTDS used as 'waveform generator'

- No direct feedback on simulated system
- But iterations possible



DISTANCE PROTECTION IN THE VICINITY OF VSC

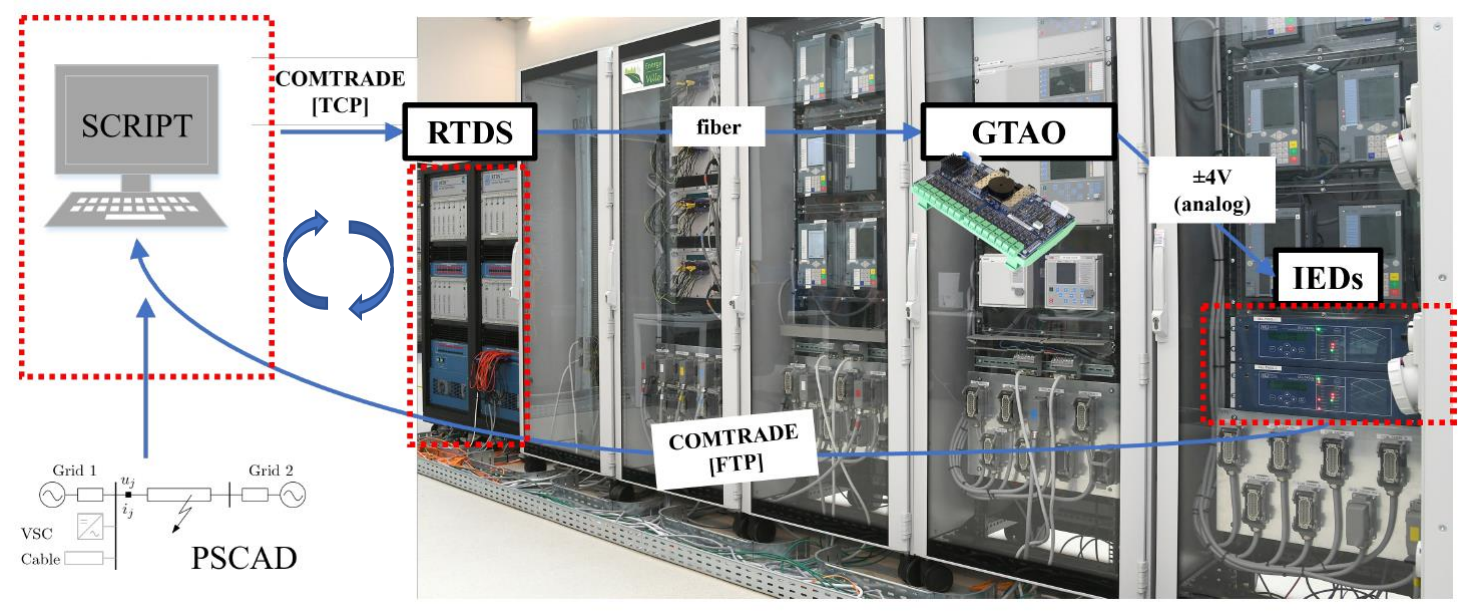
- Distance protection is vulnerable
- Should we go for other algorithms (IQ/TW) or improve distance protection functioning?

TIME DOMAIN PROTECTION NEAR VSC

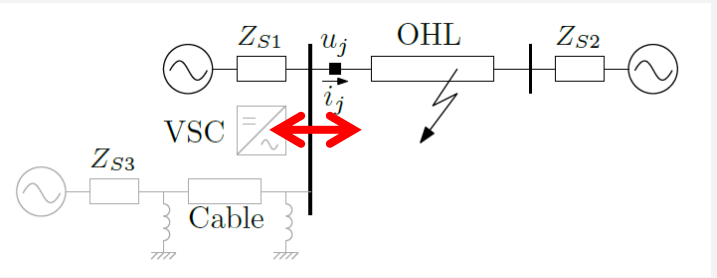
Lab setup

Relay:

- LV interface
- 1MHz sampling
- Traveling wave

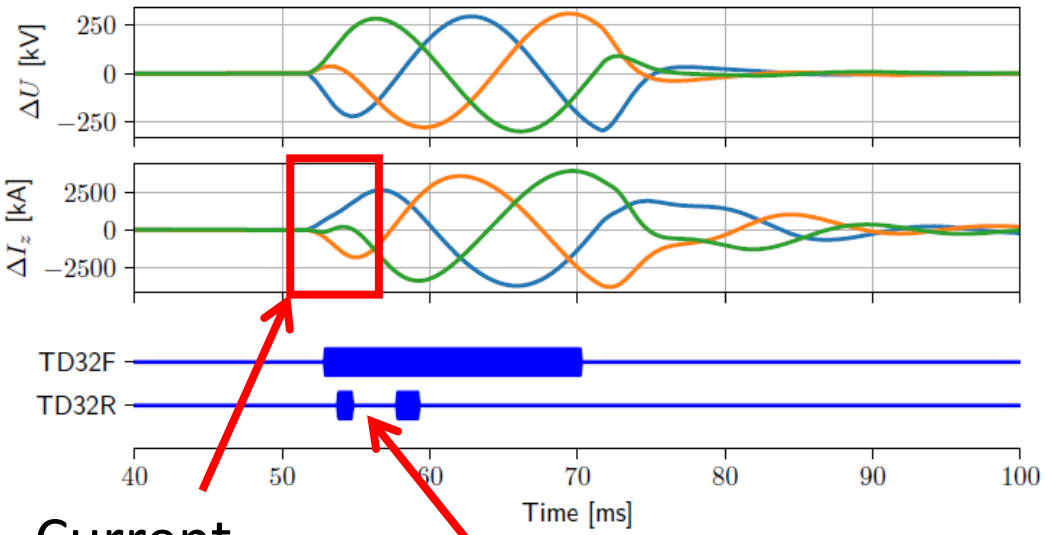


TIME DOMAIN PROTECTION

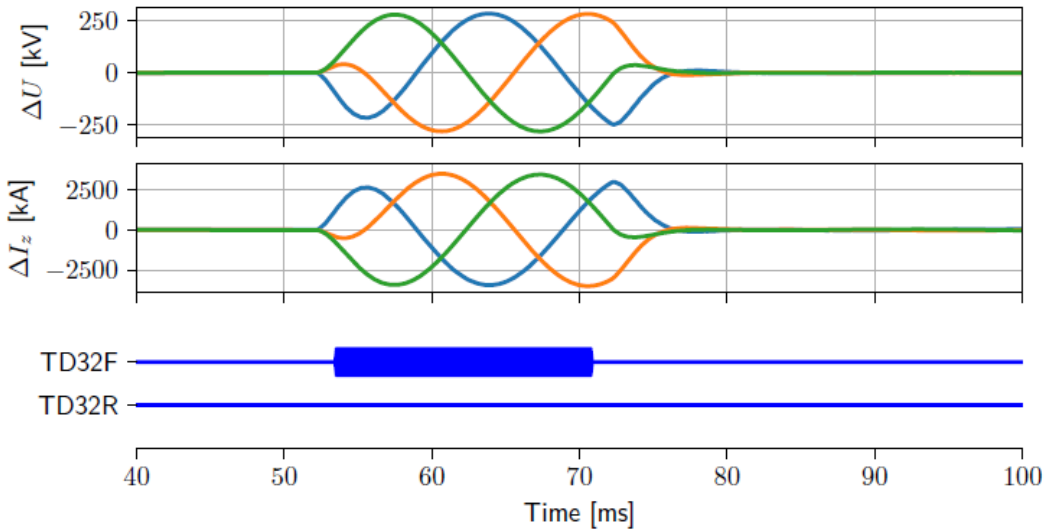


Phase shift in incremental current by VSC controls

VSC



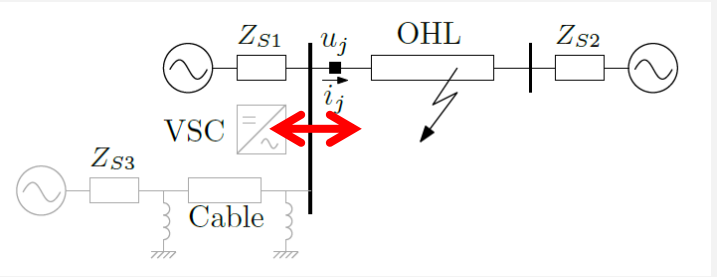
Benchmark



Current phase shift

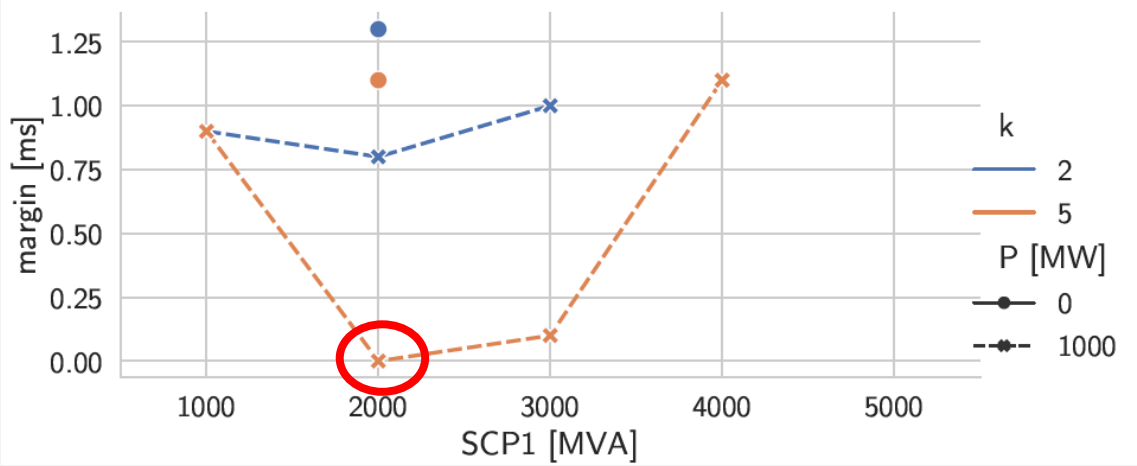
Forward & Reverse assertion

TIME DOMAIN PROTECTION



VSC impact on incremental quantity protection

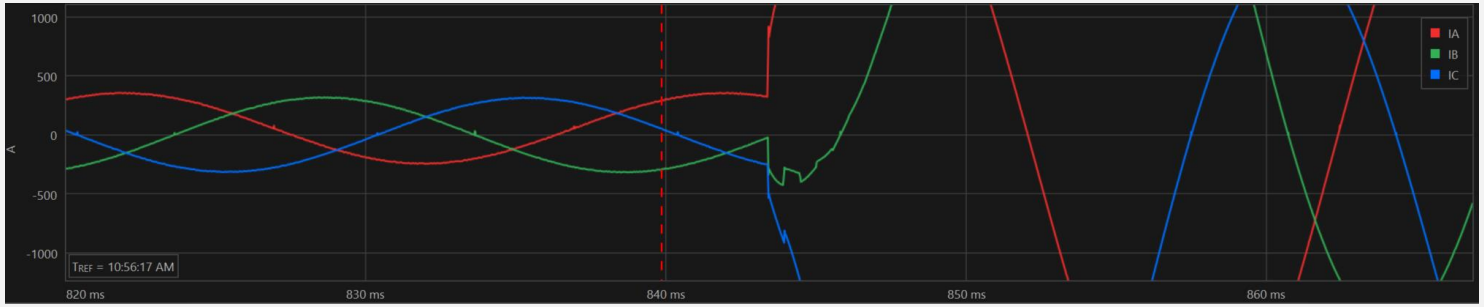
- Fast reactive current injection by a VSC causes a phase shift of the incremental current quantity which can cause malfunction of incremental quantity protection.



TIME DOMAIN PROTECTION NEAR VSC

Lessons learned

- Detailed converter models: offline simulations instead of real-time
  - Black box manufacturer models
  - Conversion of large (detailed) models would require extensive validation
- GTAO: V1 cards introduce spikes on zero-crossings that can be picked-up by traveling wave protection (which is sensitive to such spikes).



CONCLUSIONS

- Most problems arise in a situation where a converter is dominating the local short-circuit current and there is a large remote short-circuit current
- Models are not always available in / transferrable to RSCAD
- EMT-type simulations computationally heavy; difficult to use in a screening exercise
  - Are generic models good enough or should we use manufacturer (black-box) models?

W. Leterme, G. Chaffey, R. Loenders, J. Vermunicht, S. M. Shoushtari and D. V. Hertem, "Systematic study of impedance locus of distance protection in the vicinity of VSC HVDC converters," *16th International Conference on Developments in Power System Protection (DPSP 2022)*, Hybrid Conference, Newcastle, UK, 2022, pp. 19-24, doi: 10.1049/icp.2022.0905.

Vermunicht, Joachim, Willem Leterme, and Dirk Van Hertem. "Analysing the performance of incremental quantity based directional time-domain protection near HVAC cables and VSC HVDC converters." *Electric Power Systems Research* 223 (2023): 109599.

THANK YOU