

DC protection specifications, standardisation, and real time testing

Geraint Chaffey (KU Leuven / EnergyVille)

with contributions from PROMOTiON WP4, PROMOTiON WP9, PROMOTiON WP11

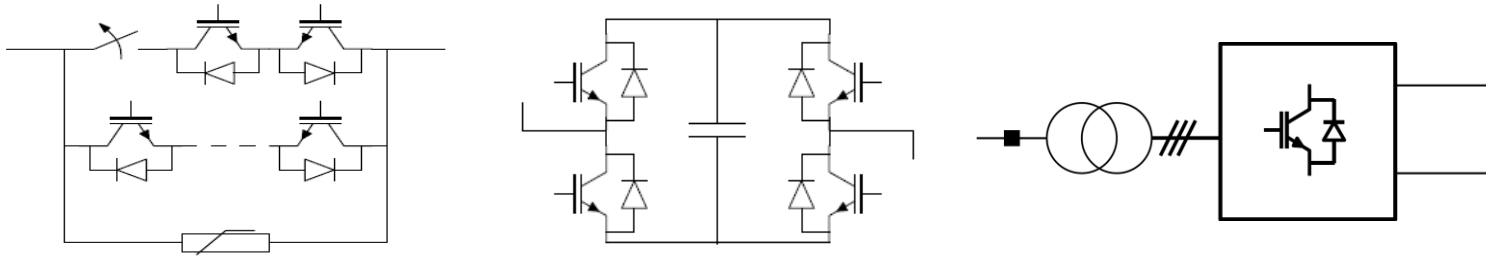
Summary

- Real time testing of HVDC protection
 - Protection IED unit testing
 - Protection IED system testing
 - Overall protection system testing
- Working towards demonstration of realistic (protection) systems
- Towards harmonisation in HVDC systems

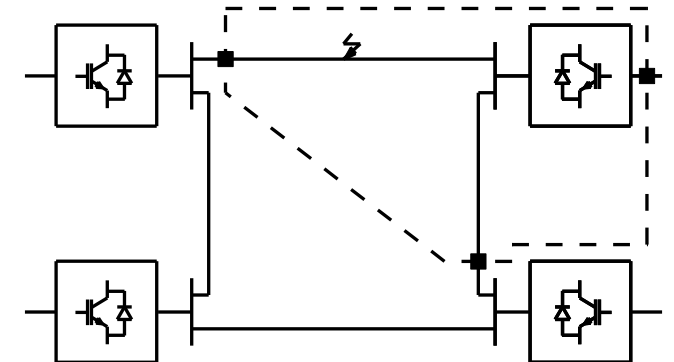
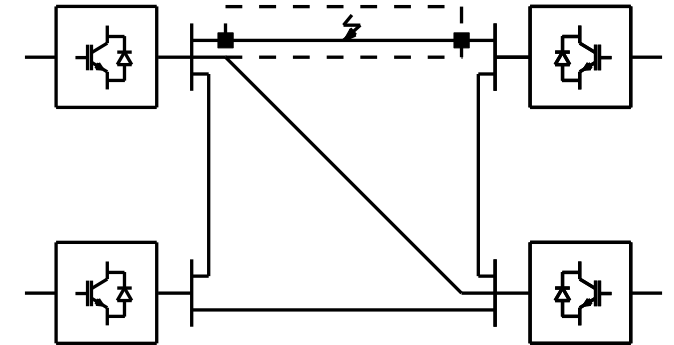


Introduction

- Wide range of work developing knowledge in HVDC protection systems
 - **Protection systems/strategies from WP4**
 - Protection IEDs from WP4
 - Circuit breaker models from WP6



Protection zone		C1	C2	C3	C4	Protection equipment in operation
1	$F_{L1.ptq}$	CO	CO	PS	CO	Br_1, Br_2
2	$F_{L2.ptq}$	CO	CO	CO	CO	Br_3, Br_4
3	$F_{L3.ptq}$	CO	CO	CO	CO	Br_5, Br_6
4	$F_{L4.ptq}$	CO	CO	CO	CO	Br_7, Br_8



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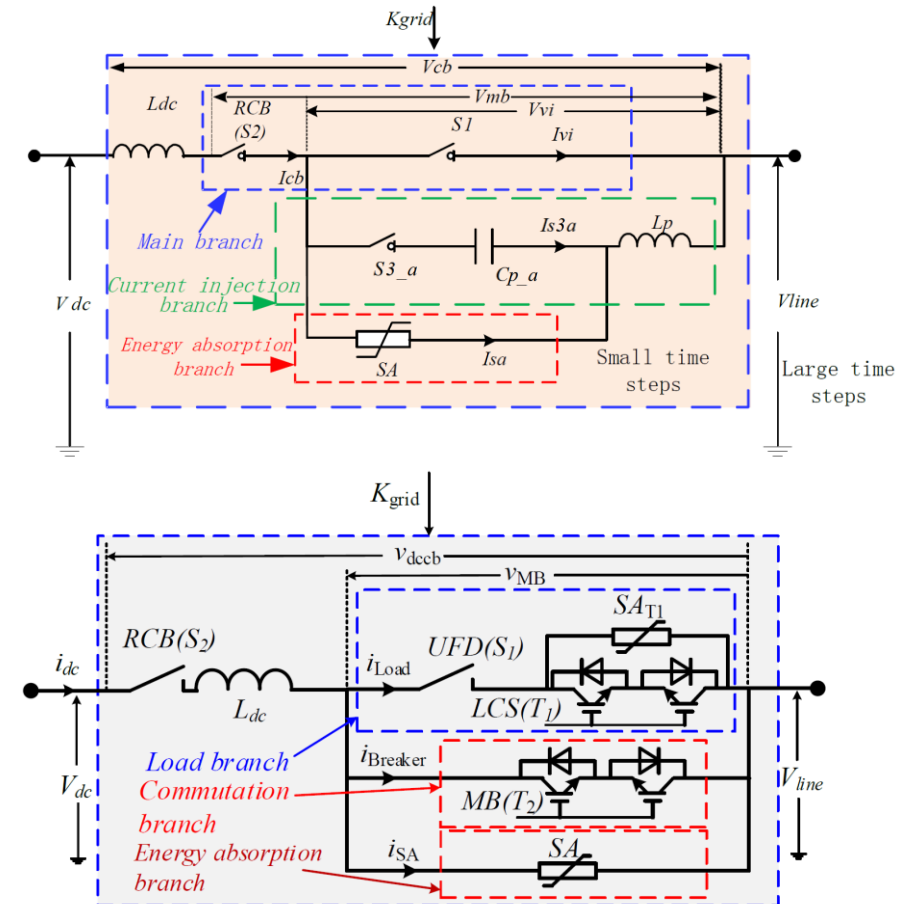
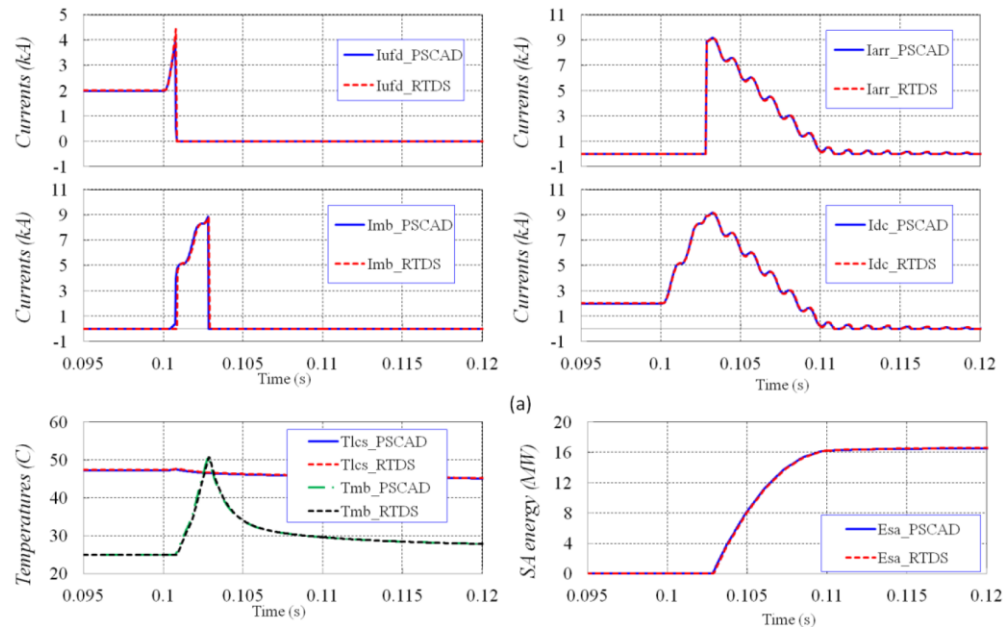


- PROMOTioN HVDC Protection IED prototype
 - Developed at KTH
- Mitsubishi Electric HVDC Protection IED Prototype
 - Developed in Japan and programmed as part of the PROMOTioN project



Introduction

- Wide range of work developing knowledge in HVDC protection systems
 - Protection systems/strategies from WP4
 - Protection IEDs from WP4
 - **Circuit breaker models from WP6**



Introduction

- Wide range of work developing knowledge in HVDC protection systems
 - Protection systems/strategies from WP4
 - Protection IEDs from WP4
 - Circuit breaker models from WP6
- **Towards real time testing and protection system demonstration**
 - Above elements brought together in real time environment
 - Realistic network parameters for realistic protection system demonstration
 - Aim to demonstrate successful operation of a protection system



Requirements for HVDC protection IED testing

Novel unproven technology:

- HVDC protection IEDs for MTDC
- HVDC protection strategies (partially selective, fully selective, ...)
- Novel hardware?

To increase confidence:

- Realistic real time testing (dynamic validation testing...)

Towards future large scale (= multi vendor) systems:

- Requirements for common expectations of
 - Device ratings
 - Expected performance
 - Performance compliance

... all towards harmonised specification and test



Requirements for HVDC protection IED testing

Taking inspiration from AC IED standardisation, many tests are likely required.

PROMOTiON WP4 and WP9 focus on protection system and device functionality

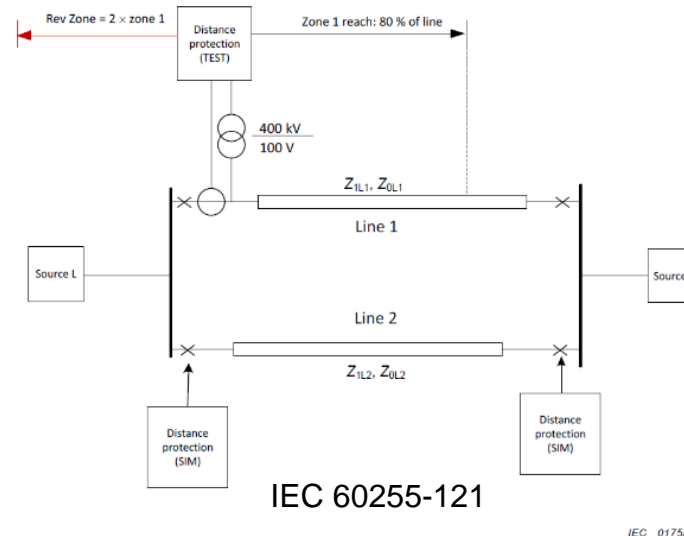
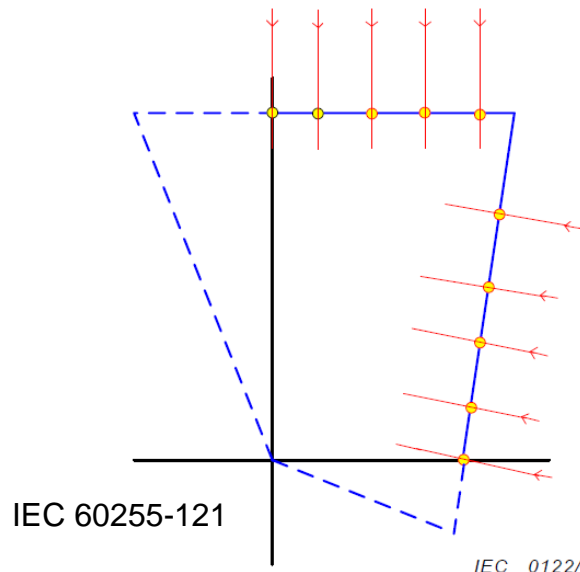
Relevant tests to examine functionality of HVDC protection algorithms/IEDs/strategies

NETWORK PROTECTION & AUTOMATION GUIDE

Protective Relays, Measurement & Control

Relay Testing and Commissioning

- 21.1 Introduction
- 21.2 Electrical Type Tests
- 21.3 Electromagnetic Compatibility Tests
- 21.4 Product Safety Type Tests
- 21.5 Environmental Type Tests
- 21.6 Software Type Tests
- 21.7 Dynamic Validation Type Testing
- 21.8 Production Testing
- 21.9 Commissioning Tests
- 21.10 Secondary Injection Test Equipment
- 21.11 Secondary Injection Testing
- 21.12 Primary Injection Tests
- 21.13 Testing of Protection Scheme Logic
- 21.14 Tripping and Alarm Annunciation Tests
- 21.15 Periodic Maintenance Tests
- 21.16 Protection Scheme Design for Maintenance



Network Protection and Automation Guide,
Alstom Grid, 2011



Requirements for HVDC protection IED testing

Several tests are underway:

- **Functional type testing (unit testing)**
- **Dynamic validation type testing (unit testing)**
- **Dynamic validation type testing (system testing)**

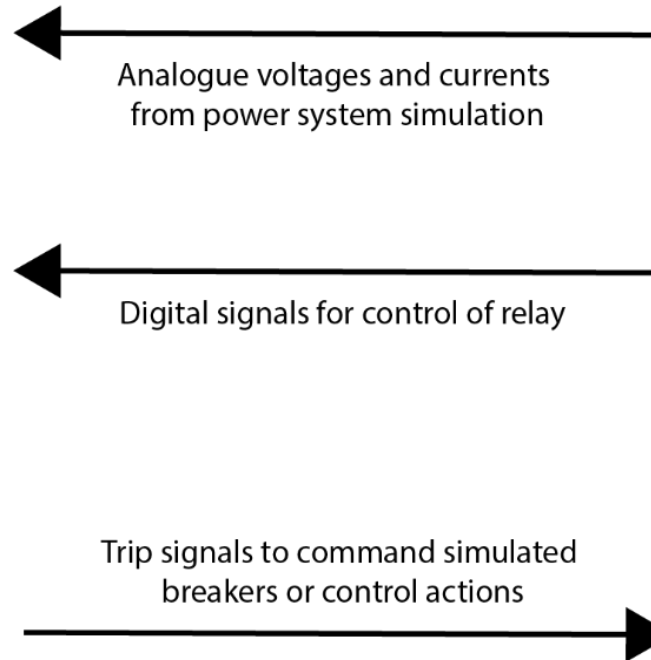


Protection IED Testing and Test Procedures for HVDC IEDs - Unit testing

'Control hardware in the loop' configuration for testing of relay operation and performance



Industrial protection relay for multiterminal HVDC networks



Power system simulation on real time simulator



Requirements for HVDC protection IED testing

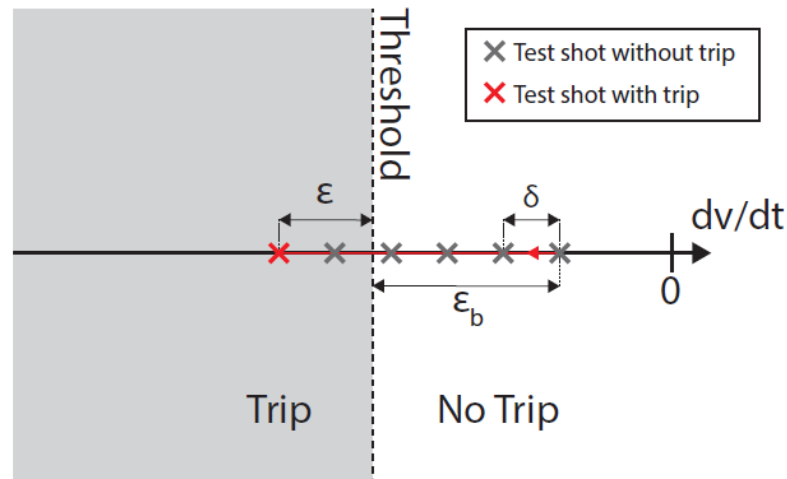
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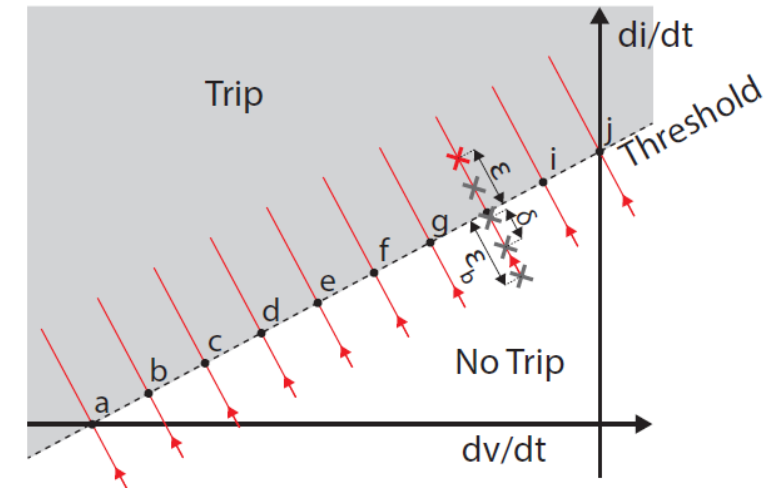
- Synthetic waveforms
- Evaluation of algorithm

- E.g. examining basic characteristic accuracy
- Single IED (typically)

dv/dt algorithm



TW based algorithm



Basic characteristic accuracy:

IED setting (kV/ μ s)	0.3	1.0
ϵ (%)	4.65	1.35

IED setting (kV/ μ s)	0.3	1.0
ϵ (%)	4.2	4.0

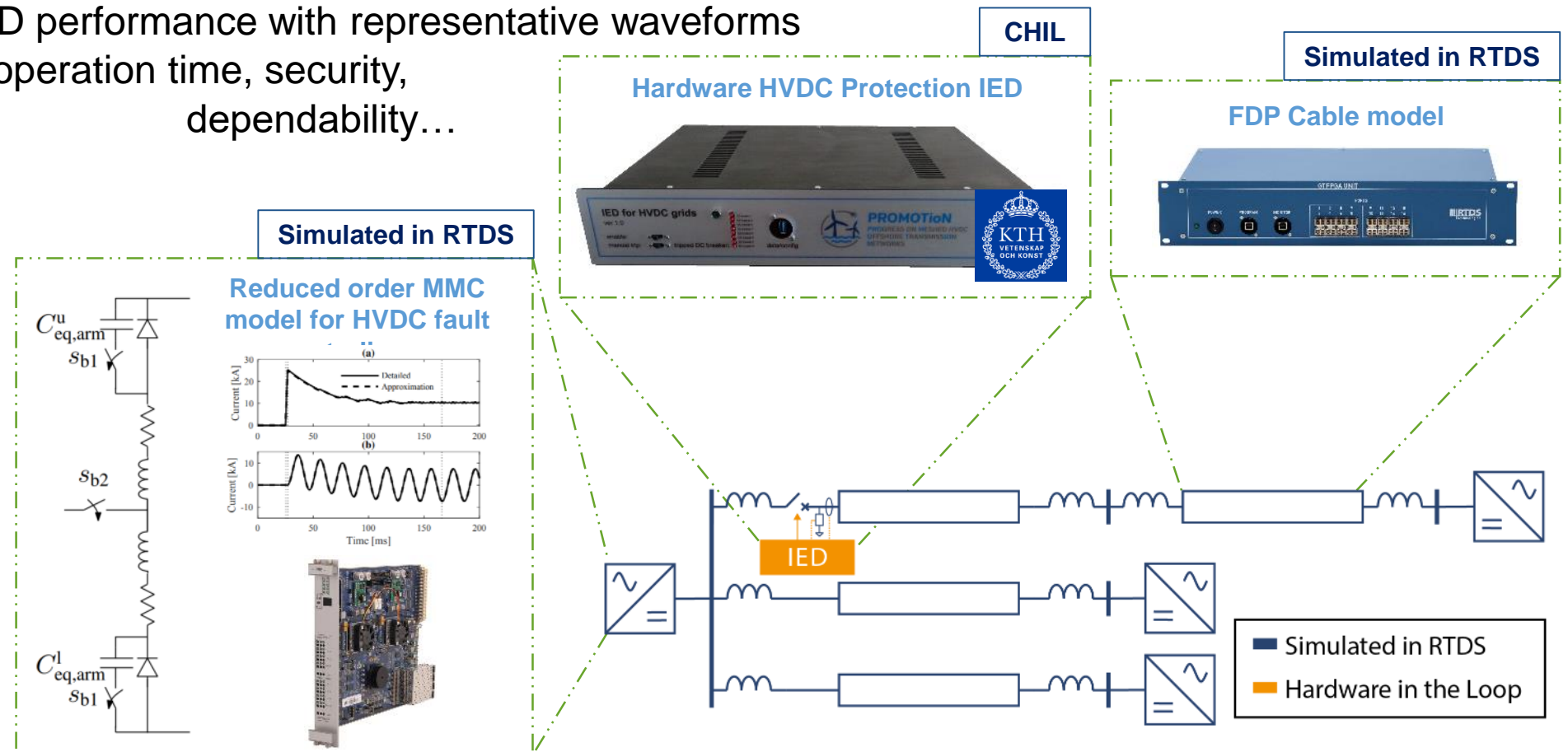


Requirements for HVDC protection IED testing

Several tests are underway:

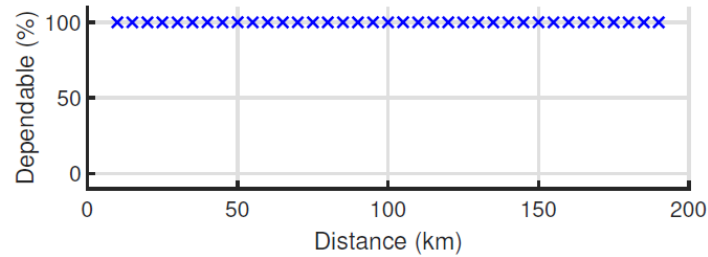
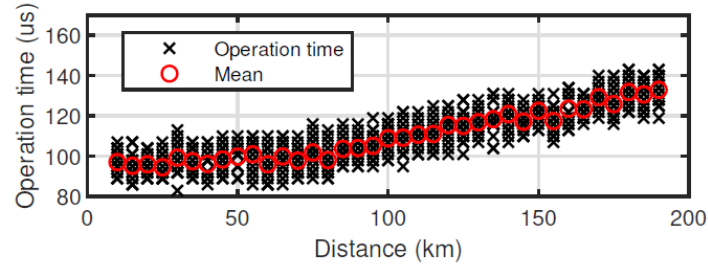
- **Dynamic validation type testing (unit testing)**

- Evaluation of IED performance with representative waveforms
- E.g. examining operation time, security, dependability...
- Single IED

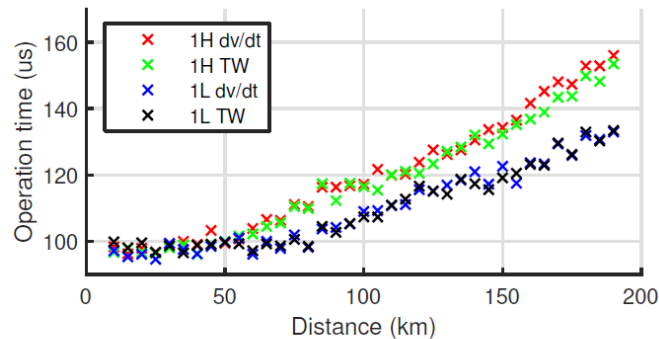




Dynamic validation type testing – example: dv/dt algorithm



Repetitive dependability / security testing

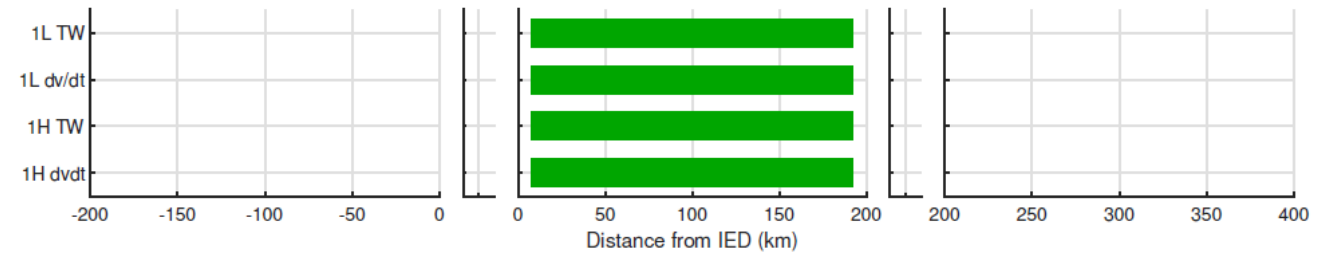


(b) Mean IED operation time

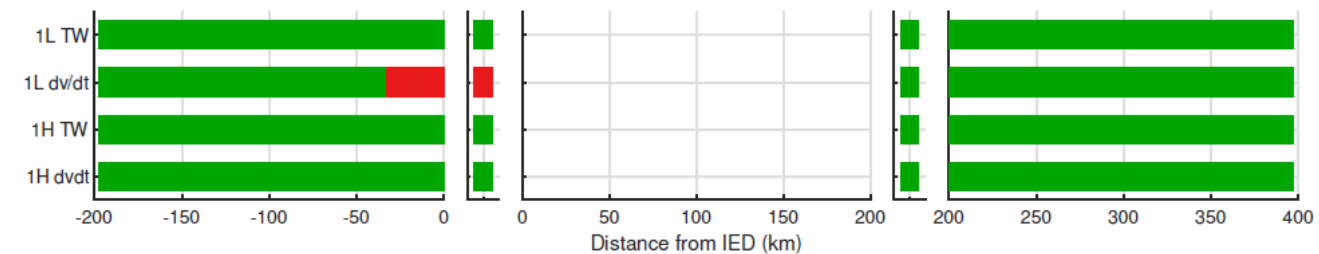
Comparison of performance



(a) Network where dot indicates IED measurement location



(b) Dependability. Green = 100% dependable.



(c) Security. Green = secure. Red = not secure.

Evaluating dependability and security for network

Requirements for HVDC protection IED testing

Several tests are underway:

- **Dynamic validation type testing (system testing)**
 - Examination of performance of IED(s) in system
 - Examination of performance of overall protection system
 - Typically multiple IEDs.



Work Package 9



HIL demonstration of
fault clearing strategies (real system)

AC breaker non-selective
Sym monopole configuration

Partially selective
Sym monopole configuration

Full-selective
Sym monopole configuration



HIL demonstration of **Non-selective**
fault clearing strategies

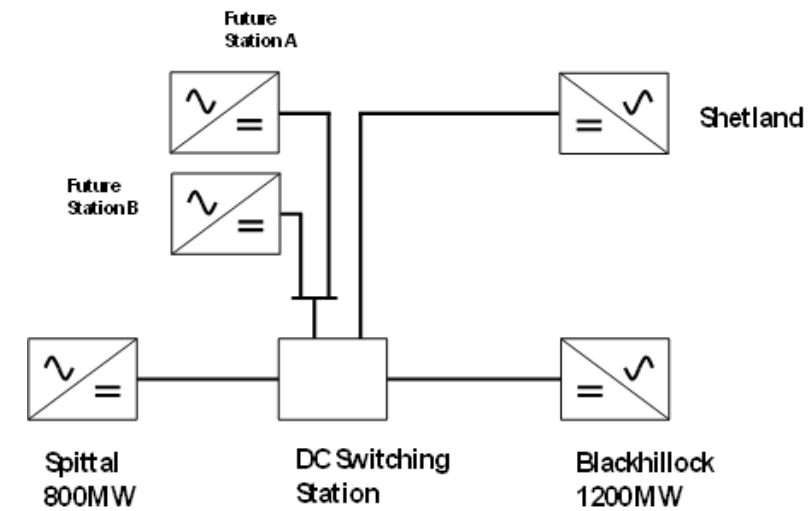
Converter-breaker strategy
Bipole configuration

Converter-breaker strategy
Sym monopole configuration

FB converter strategy
Bipole configuration

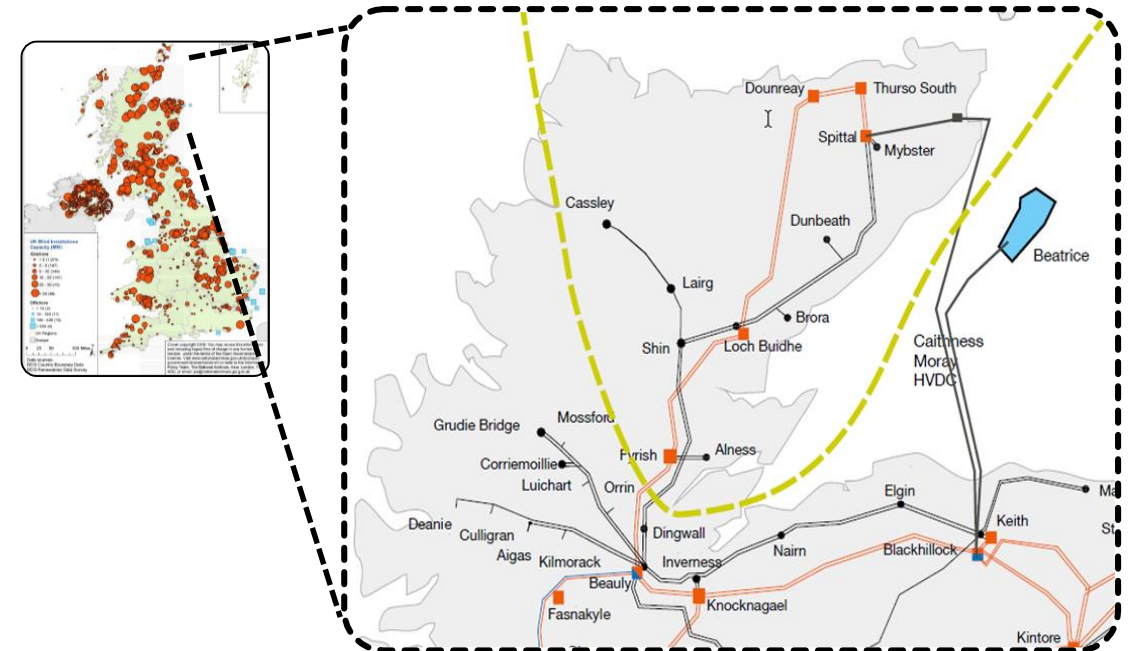
Base Real Network

- Caithness-Moray (CM) HVDC Link
 - Phase 1 is a point-to-point HVDC link between Spittal (in Caithness) and Blackhillock (in Moray)
 - Designed as a 5 terminal system



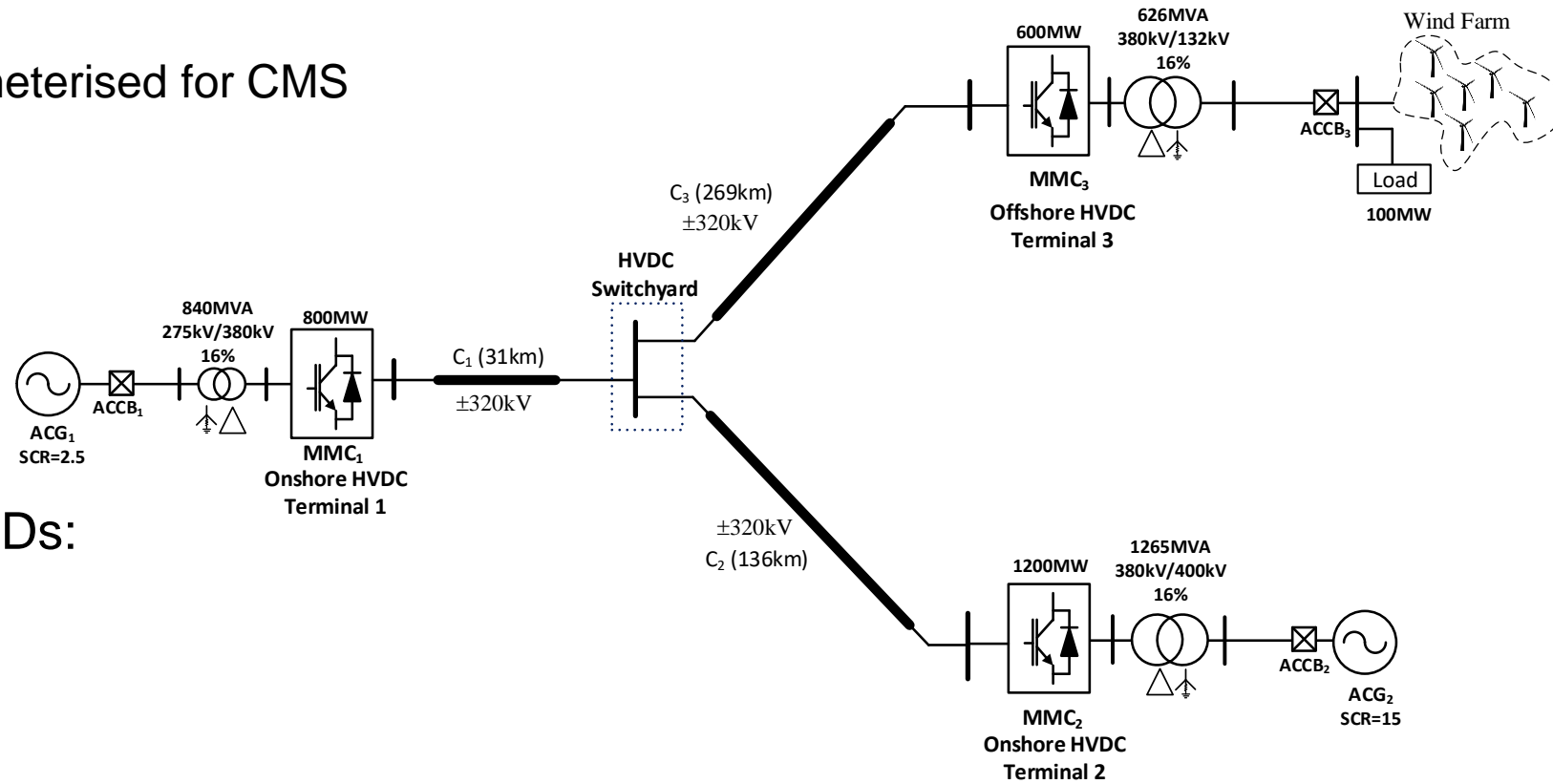
Protection strategies tested on **study network**:

- Study case with parameters based on the Caithness Moray Shetland (CMS) HVDC network
- Partially selective and fully selective protection



Protection system demonstration – components

- Converter stations
 - Open source converters parameterised for CMS
- DC switching station
- HVDC cables
- HVDC circuit breakers
 - Hybrid circuit breaker
 - Mechanical circuit breaker
- Hardware HVDC protection IEDs:

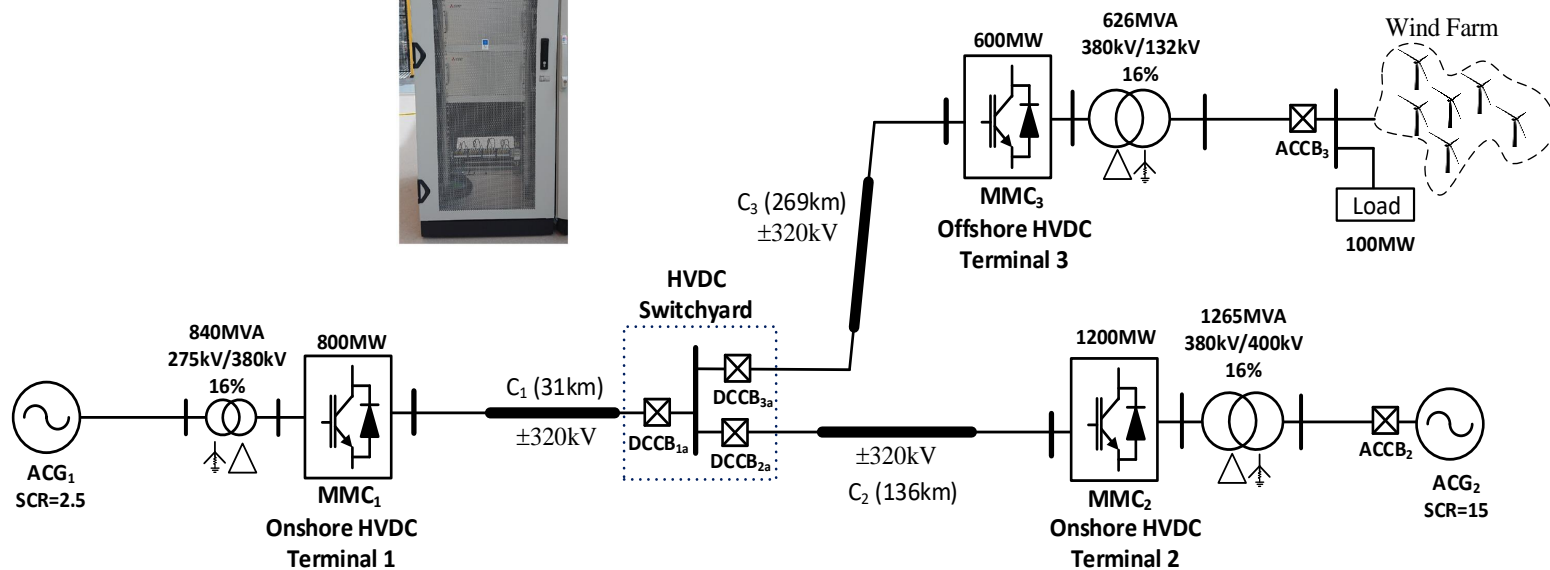


Protection System Demonstration - overall

Study case with parameters based on
Caithness Moray HVDC system



Industrial validation of protection system



Protection system demonstration: System test aims

- Verify performance of HVDC protection IEDs in realistic system
 - Primary protection
 - Backup protection
 - IED performance in a realistic system
- Verify successful operation of overall protection system
 - Assessment of system KPIs
 - Security/selectivity
- Examine multivendor interoperability
 - DCCBs
 - Protection IEDs
 - DCCBs / protection IEDs
- **Demonstrate successful operation of overall multivendor protection system**



Present state of demonstration / results

- Both PROMOTioN protection IED and Mitsubishi Electric IED have been unit tested (at KU Leuven / EnergyVille)
 - Standalone performance verified
- HVDC IEDs have been installed at The National HVDC Centre and ‘unit testing’ has been performed to verify successful installation and performance.
- Initial system tests are in progress. Model validation, protection system design,... ongoing.
- Successful integration between PROMOTioN IED, Mitsubishi Electric IED, converter models and network case study already achieved!
- First multivendor tests already performed (DCCB / IED)!



Towards standardisation in HVDC protection, HVDC grids, ...

- Little/no existing standardisation for (e.g.):
 - Multiterminal HVDC protection systems
 - HVDC circuit breakers
 - HVDC GIS
 - ...
- Future multivendor systems demand best practices / harmonisation / standardisation in (e.g.):
 - Device specifications, device ratings
 - Compliance test procedures
 - Terminology
 - ...



Towards standardisation in HVDC protection, HVDC grids, ...

- PROMOTioN contributing to harmonisation/standardisation in:
 - HVDC control and protection
 - HVDC connected wind power plants
 - HVDC circuit breakers
 - HVDC GIS
 - ...
- Wide range of activity 'levels'
 - Direct contribution to active standards
 - Initiation of harmonisation activity
 - Presentation of PROMOTioN work to harmonisation bodies
 - Recommendations to harmonisation bodies for future topics



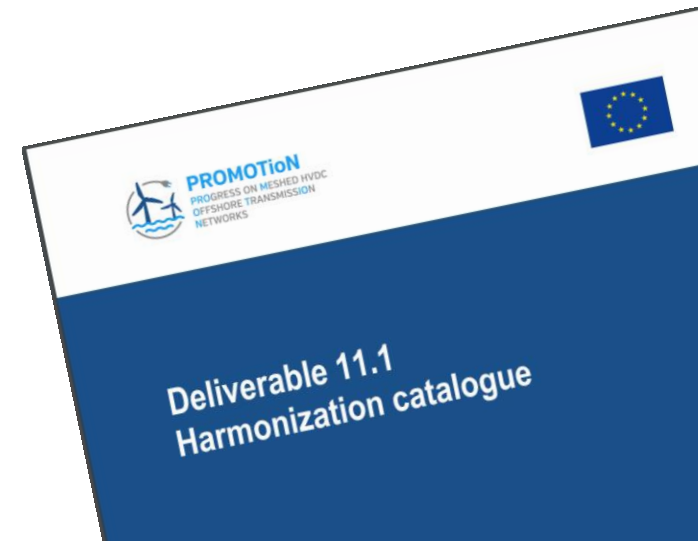
Towards standardisation in HVDC protection, HVDC grids, ...

- PROMOTioN contributing to harmonisation/standardisation in:
 - HVDC control and protection
 - CIGRE
 - IEEE
 - IEC
 - ENTSO-E
 - ...



Towards standardisation in HVDC protection, HVDC grids, ...

- Sample of DC CB and DC protection related topics:
 - Approach to modelling of HVDC circuit breakers
 - Testing of HVDC circuit breakers
 - Classification of protection systems
 - Performance evaluation of protection systems
 - Cable overvoltages
 - Testing of protection devices
- More specific topics, working groups, status of contribution can be found in the [PROMOTioN harmonization catalogue \(D11.1\)](#).



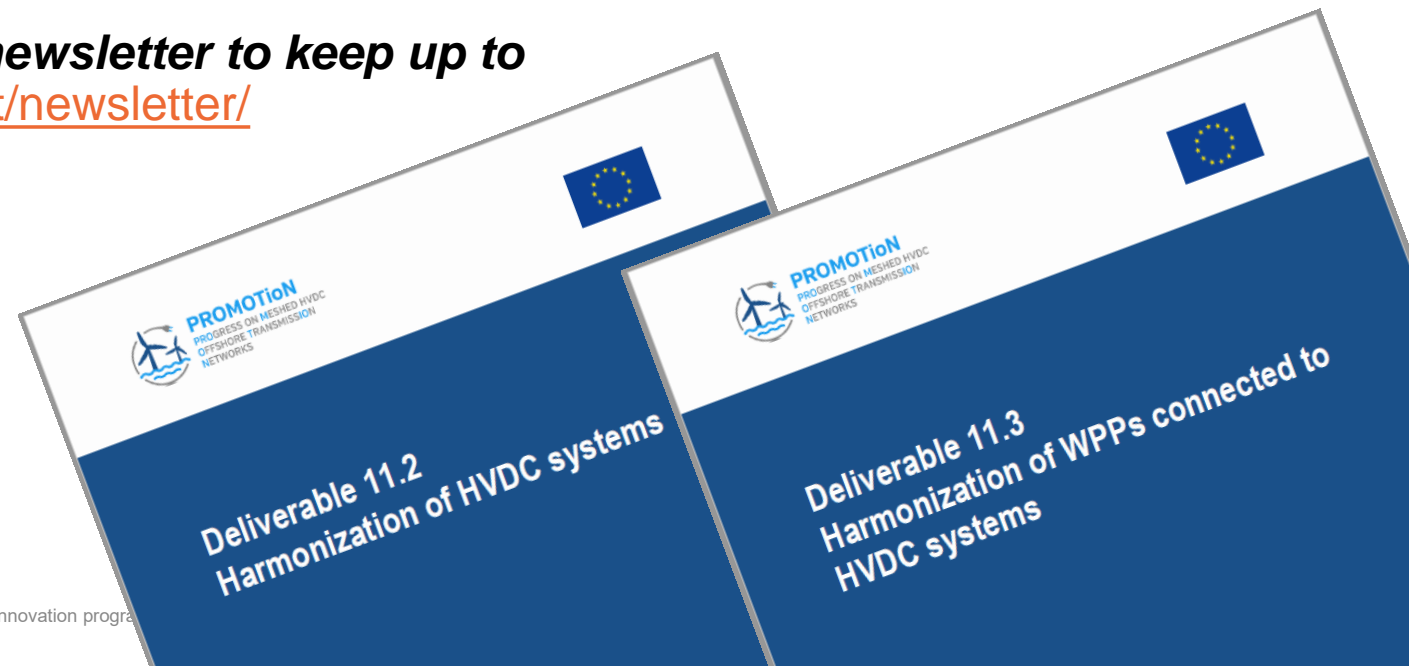
Towards standardisation in HVDC protection, HVDC grids, ...

- Sample of DC CB and DC protection related contributions:
 - CENELEC working group TC 8X WG06 - System aspects of HVDC grids
 - CIGRE WG B4/B1/C4.73 - “Surge and extended overvoltage testing of HVDC Cable Systems”
 - CIGRE JWG A3B4.34 (2014-2017) on HVDC switchgear (incl. HVDC circuit breakers)
 - CIGRE WGA3.39 (2017-2020) on surge arresters (including those used in HVDC circuit breakers)
 - CIGRE WG A3.40 (2018-2021) on MV HVDC systems and switchgear
 - CIGRE JWG B4A3.80 (2019-2022) on HVDC circuit breaker requirements
 - IEC AHG4 (2016-2017), on market relevance of HVDC switchgear
 - IEC AHG60 (2017-2018), on existing standards of HVDC switchgear
 - ...
- More specific topics, working groups, status of contribution can be found in the [PROMOTioN harmonization catalogue \(D11.1\)](#).



Towards standardisation in HVDC protection, HVDC grids, ...

- Recommendations for future harmonisation to be provided by end of project
 - Contributions from all technical WPs!
- Keep an eye out for future public deliverables:
 - D11.2: Report on harmonization of HVDC systems
 - D11.3: Report on harmonization of WPPs connected to HVDC systems
 - ...and more!
 - **Consider subscribing to PROMOTioN newsletter to keep up to date...** <https://www.promotion-offshore.net/newsletter/>



Conclusion

- Protection system testing/demonstration underway:
 - IED unit testing
 - Advanced stage
 - IED system testing
 - Preliminary stage
 - Overall protection system performance and demonstration
 - To be performed
- Harmonisation activity ongoing throughout PROMOTioN project, with various ongoing and planned activities regarding HVDC circuit breakers and HVDC protection



DC protection specifications, standardisation, and real time testing

Contact:

Geraint Chaffey

geraint.chaffey@kuleuven.be

Dirk Van Hertem (WP4)

dirk.vanhertem@esat.kuleuven.be

Ian Cowan (WP9)

ian.L.Cowan2@sse.com

Poul Sørensen (WP11)

posq@dtu.dk