RTDS User Spotlight Series – September 2020

Demonstration of Partially and Fully Selective Protection for Multiterminal HVDC Systems

Geraint Chaffey, KU Leuven and Md. Habib Rahman, The National HVDC Centre

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691714.

KU LEUVEN

Geraint Chaffey
KU Leuven, Belgium

Postdoctoral Research

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- EXPERIENCE
  - Postdoctoral researcher at KU Leuven since 2017.
  - PhD in HVDC protection: 'The impact of fault blocking converters on HVDC protection' (Imperial College London, UK).
  - Research interests in HVDC protection systems, functional testing of protection systems (towards industrialisation of HVDC protection).
  - Active in Cigré, IEEE, IEC.

- PROJECT ROLE
  - Design of protection systems
    - Developing functional tests for HVDC protection IEDs
    - Protection system design, including case studies on South West Link and Hansa Power Bridge DC connection and the Caithness Moray Shetland system
  - **Demonstration of protection systems**
    - Design, specification, modelling and testing for device level and system level testing in partially and fully selective protection strategies
  - Harmonisation towards standardisation
    - Towards harmonisation in HVDC protection topics
    - Reporting of protection system harmonisation activity

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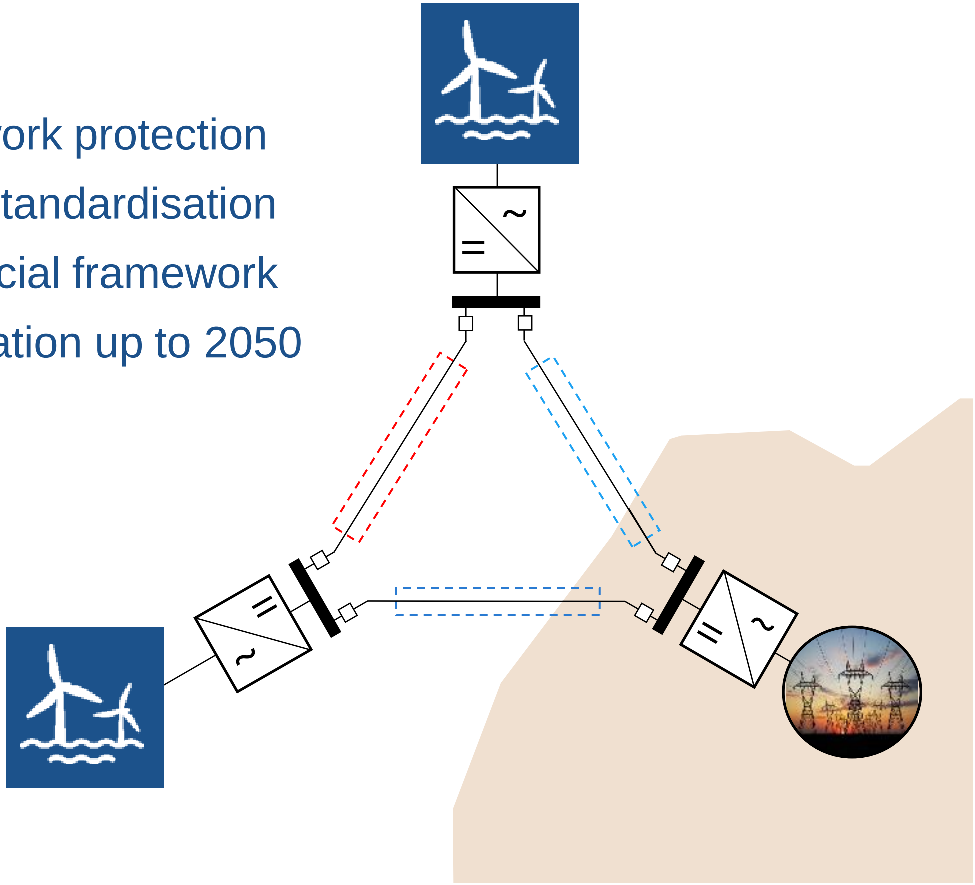
The PROMOTioN Project

Progress on Meshed Offshore HVDC Transmission Networks

Enabling the North Sea power house

- Develop interoperable & reliable HVDC network protection
- Work towards technology interoperability & standardisation
- Recommendations for EU regulatory & financial framework
- Deployment plan & Roadmap for implementation up to 2050
- Full scale technology demonstrations of:
  - HVDC control & protection systems
  - Converter harmonic model validation
  - HVDC gas insulated switchgear
  - HVDC circuit breakers



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The PROMOTioN Project - Consortium

TSO's

- TenneT – Taking power further
- sse
- ENERGINET.DK
- Rte
- SVENSKA KRAFTNÄT
- EIRGRID

Vendors

- ABB
- MITSUBISHI ELECTRIC
- SIEMENS
- GE
- Prysmian Group
- SCiBreak – Enabling the Supergrid
- MHI VESTAS OFFSHORE WIND

Wind Developers & Consultants

- DNV·GL
- TRACTEBEL Engineering – GDF SUEZ
- DEUTSCHE WINDGUARD
- Ørsted
- equinor

Academia

- RWTH AACHEN UNIVERSITY
- UNIVERSITY OF ABERDEEN
- UNIVERSITAT POLITÈCNICA DE VALÈNCIA
- KTH – VETENSKAP OCH KONST
- DTU
- KU LEUVEN
- TU Delft
- rijksuniversiteit groningen
- European University Institute
- University of Strathclyde

Associations, Institutes & Foundations

- STIFTUNG OFFSHORE WINDENERGIE
- CARBON TRUST
- T&D europe
- FGH
- SuperGrid Institute

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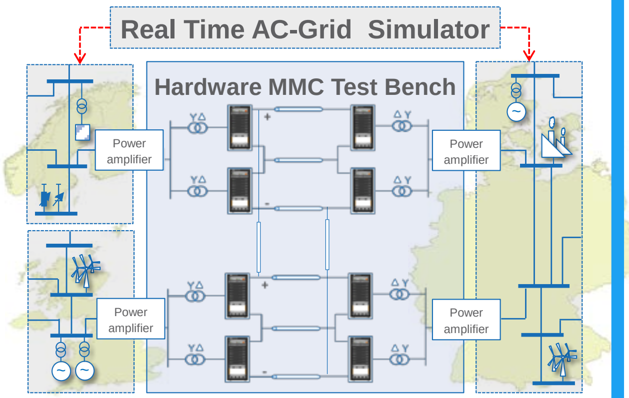
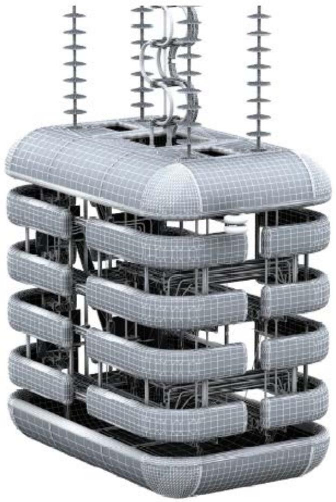
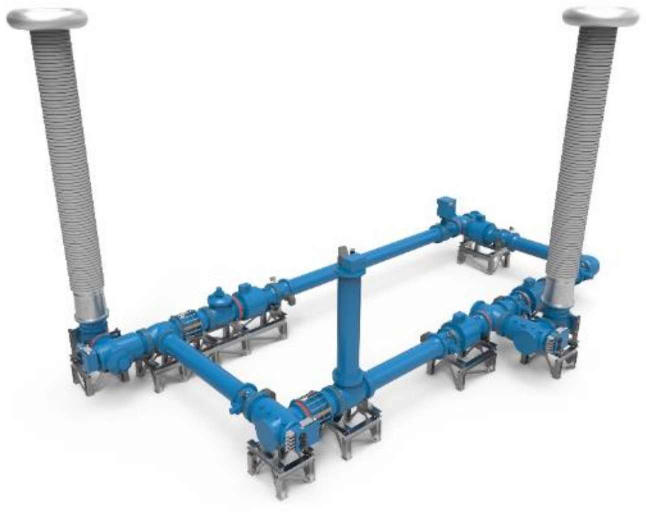
The PROMOTioN Project – Technology Demonstrators







HVDC network control

MMC test bench
RWTH Aachen
Aachen, Germany

HVDC network protection

Multi-terminal test centre
SHE Transmission
Glasgow, UK

HVDC circuit breakers

KEMA High Power Lab
DNV GL
Arnhem, Netherlands

HVDC gas insulated system

KEMA High Voltage Lab
DNV GL
Arnhem, Netherlands

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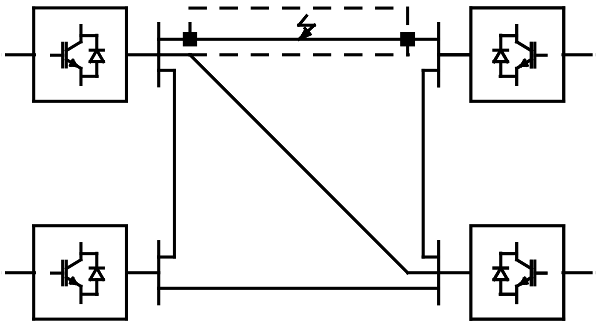
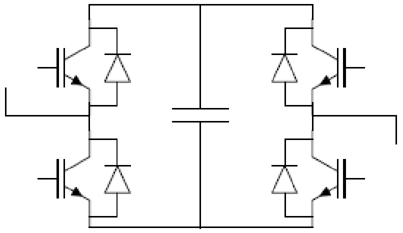
Protection of HVDC networks

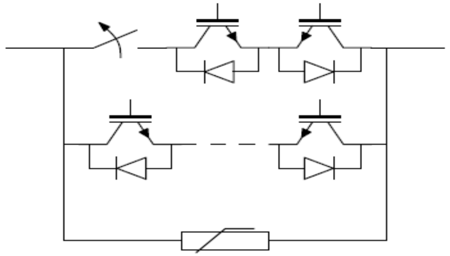
Research and industry moving towards MTDC with DC-side protection

Wide range of recent protection developments:

- Protection system design
  - Protection strategies (and trade-offs)
  - Protection devices
- DC CB development and test
- HVDC protection algorithms and IEDs
- Some industrial systems already near reality (e.g. Zhangbei).







Mitsubishi Electric / DNV-GL / PROMOTioN DCCB testing 2017

GEIRI, SGCC

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HVDC Protection IEDs

Protection IEDs (sometimes known as a protection relay):

- Execute protection algorithms
- Order protection/control action (typical: trip circuit breaker)

Two prototypes:

- PROMOTioN/KTH
  - Open source design for research and education
  - 6 functional units with flexible design (algorithms may be written by user)
- Mitsubishi Electric
  - Industrial prototype on industrial control hardware
  - 6 functional units (2 poles x 3 locations)

Overall aim of work: Demonstrate HVDC protection system in industrial case study network

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The National HVDC Centre

Habib Rahman

Simulation Engineer

The National HVDC Centre (SHE Transmission)

md.rahman@sse.com

- EXPERIENCE
  - Simulation Engineer @ The National HVDC Centre since 2019
  - MSc Sustainable Electrical Power @ The Brunel University

- PROJECT ROLE
  - Contribution to Work package WP9 (Demonstration of DC Grid Protection): Task 9.2, 9.4, 9.5 and 9.6 since 2019

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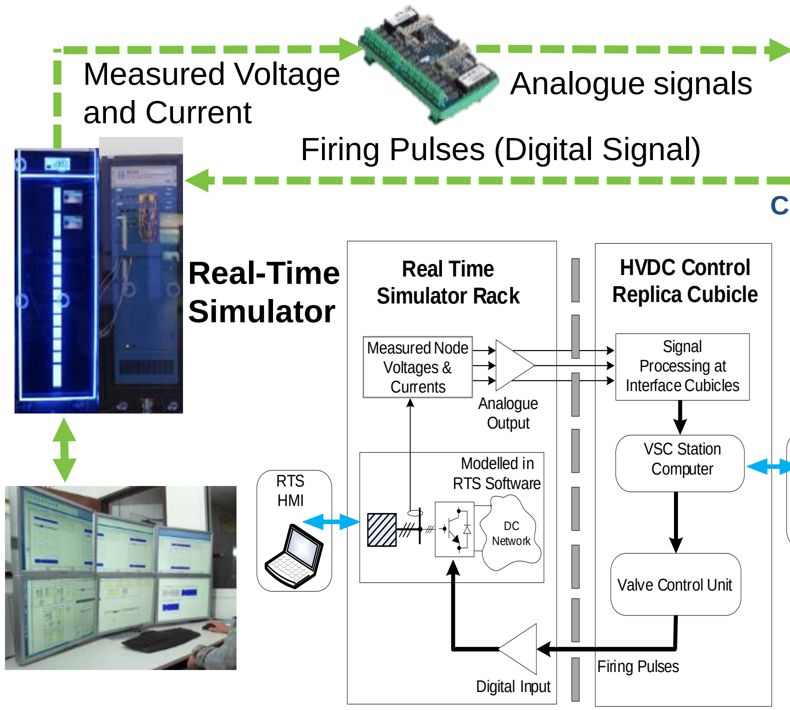
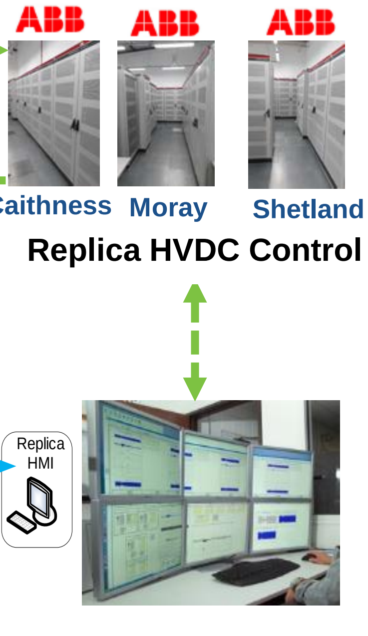
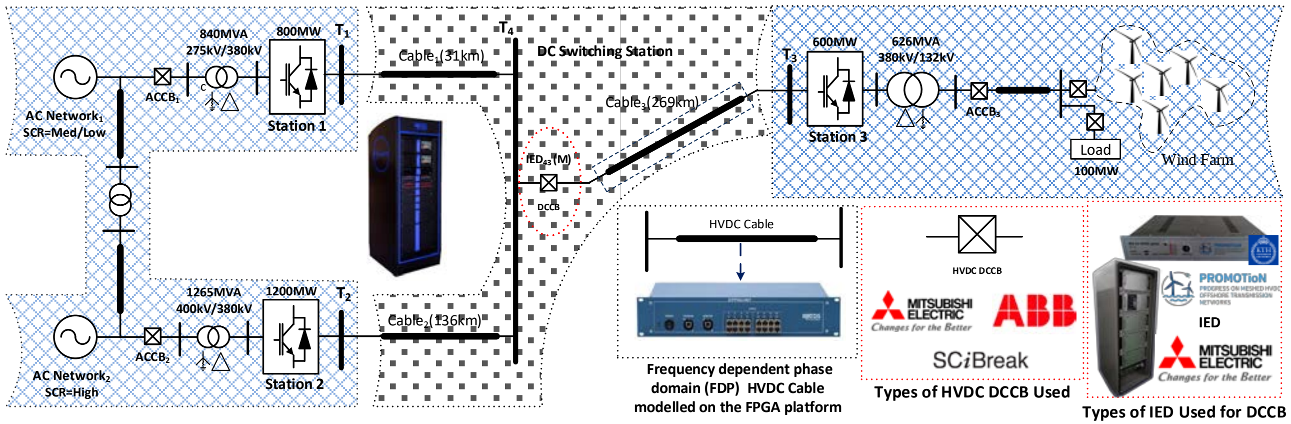
Hardware Setup: Replica(C&P) based CMS Network Model





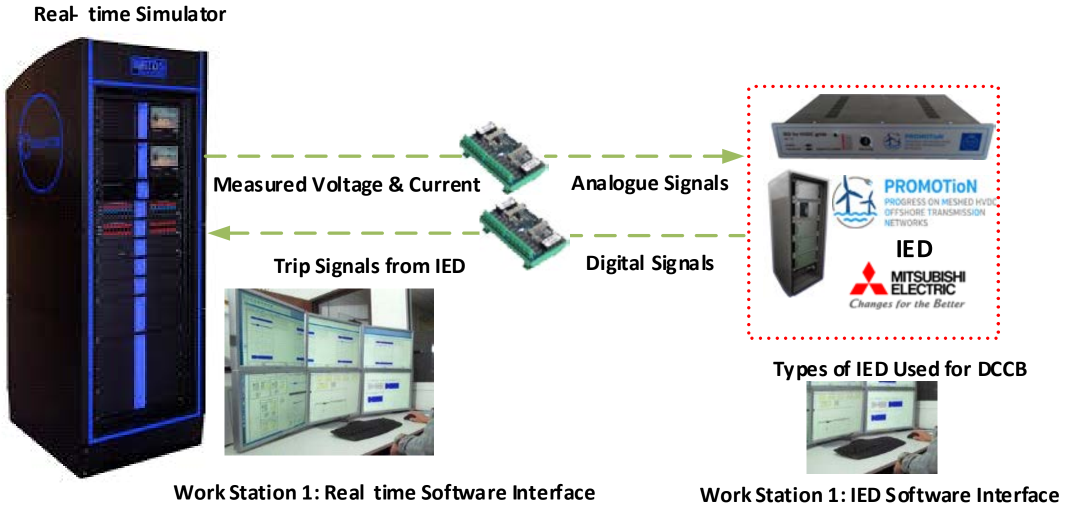


Real-time Simulator Runtime Interface

- Apply network faults
- Change generation dispatch

Operator Work Station

- Start up / shut down
- Change control mode
- Change set points



Changes to existing Model

- HVDC Cable model
- HVDC Circuit Breaker
- IED Hardware Setup

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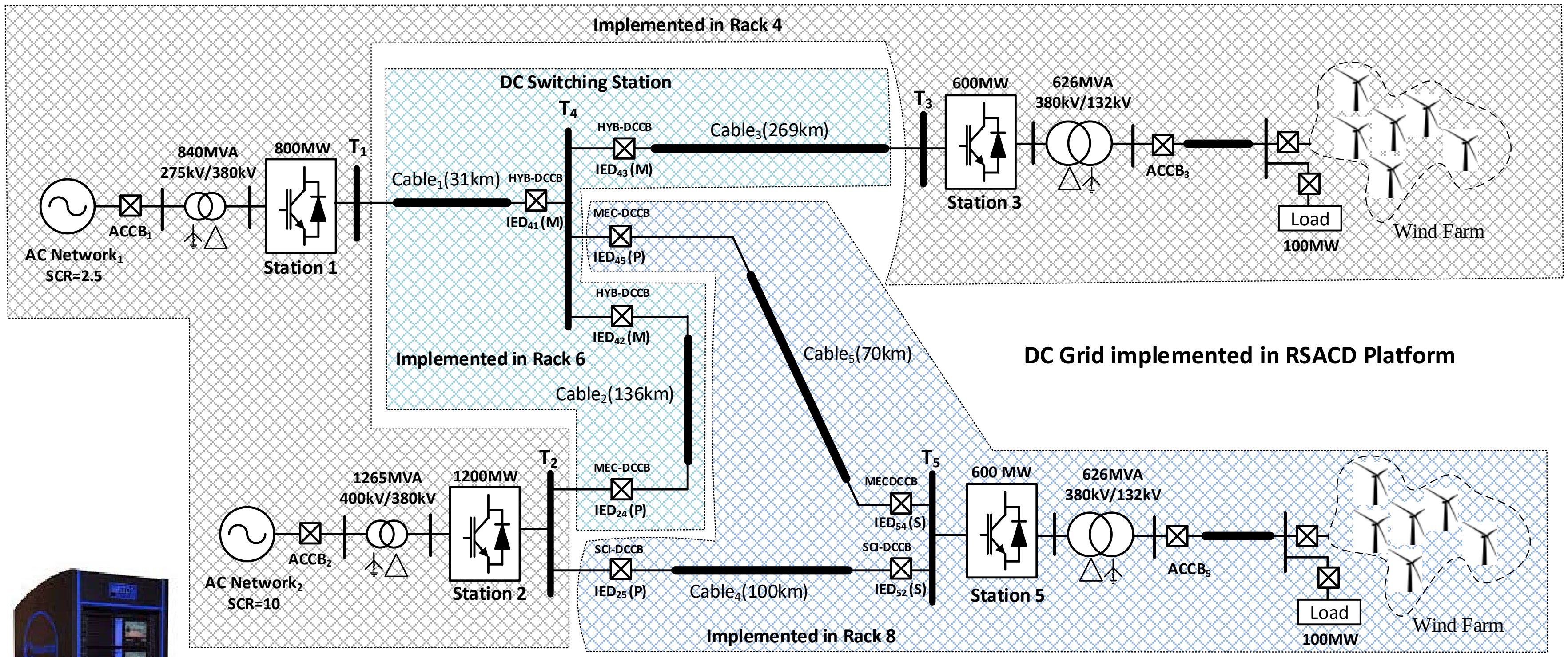
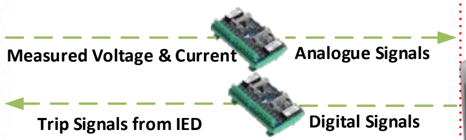
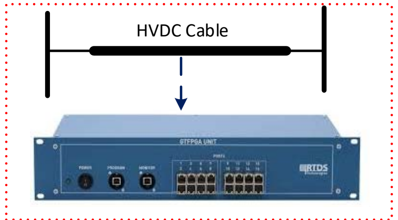
Hardware Setup: PROMOTioN 4T Model Hardware Setup

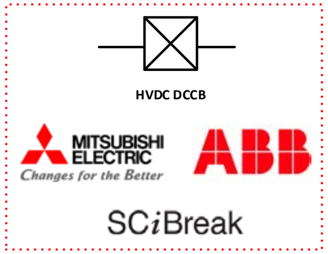




Types of IED Used for DCCB



Frequency dependent phase domain (FDP) HVDC Cable modelled on the FPGA platform



Types of HVDC DCCB Used

Work Station 1: Real-time Software Interface

Work Station 1: IED Software Interface

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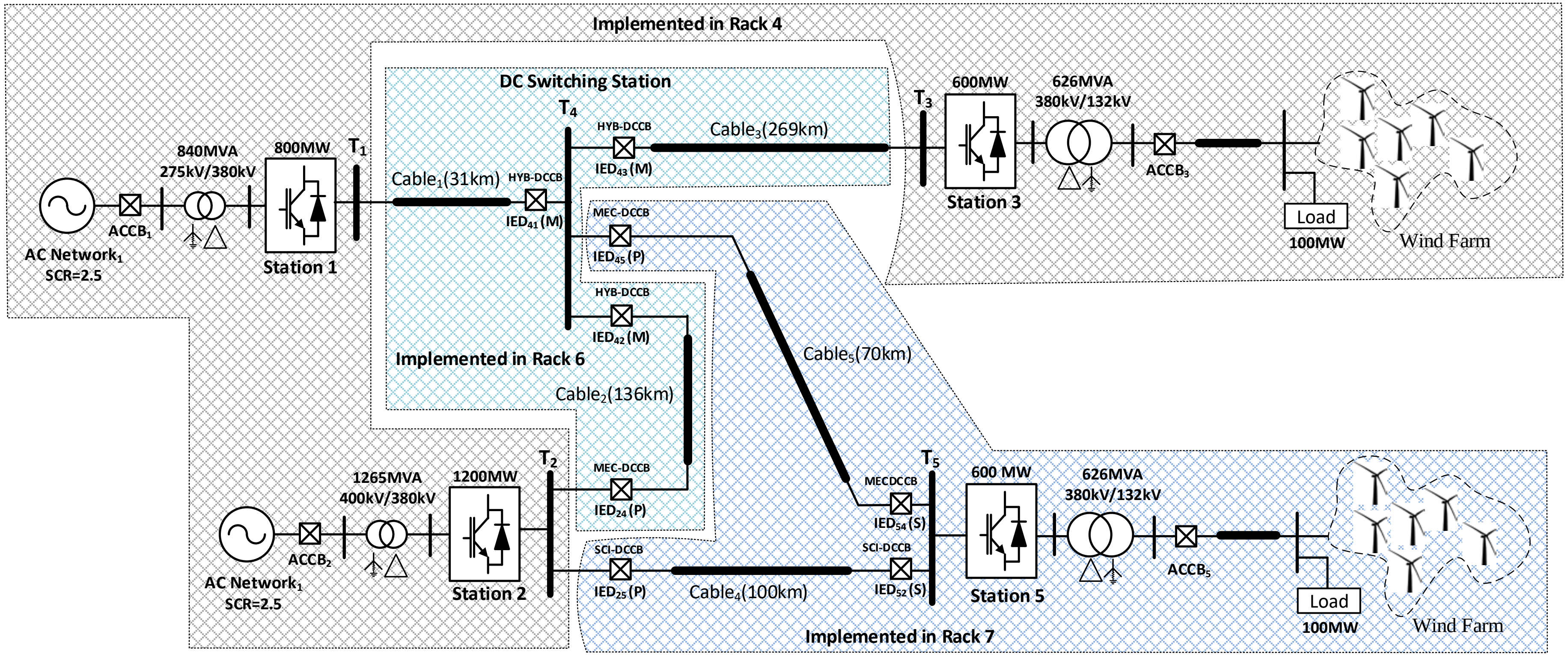
Implementation of Model: PROMOTioN 4T Model

- System Modelling
  - Converter Modelling
  - Converter Control
  - DC Circuit Breaker (DCCB)
  - Others
- DC Grid Configuration
  - AC and DC Network Model
  - HVDC Cable Model
  - IED Configuration
- DC Grid: Overview in run-time window
- Key Challenges



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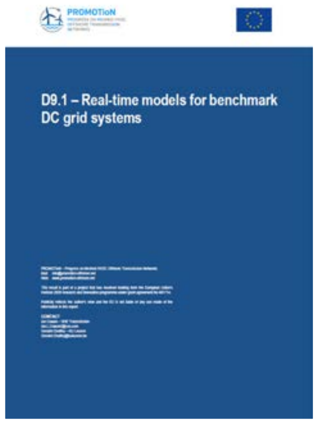
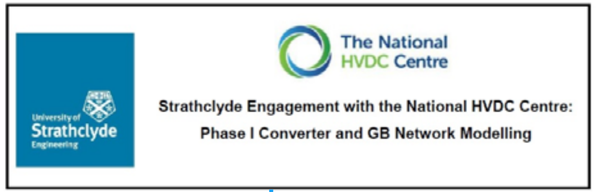
Implementation of Model: Converter Modelling

Open-source converter model: developed through a research project in collaboration with the University of Strathclyde, UK.

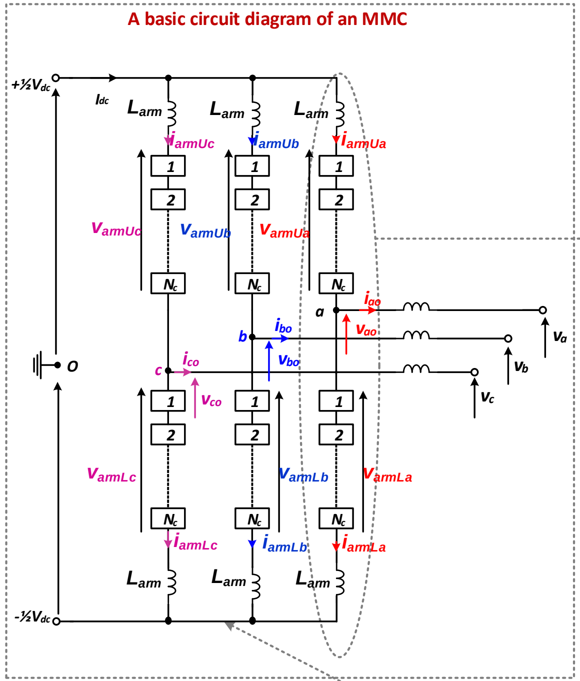
- Converter Modelling
  - ✓Open source Converter Model
  - ✓Converter topology-HB MMC
  - ✓Average HB-MMC
- Converter Control Design
  - ✓High level Control
  - ✓Low level control
- Real-time Implementation
  - ✓Small-time step
  - ✓Large-time step
  - ✓Interface

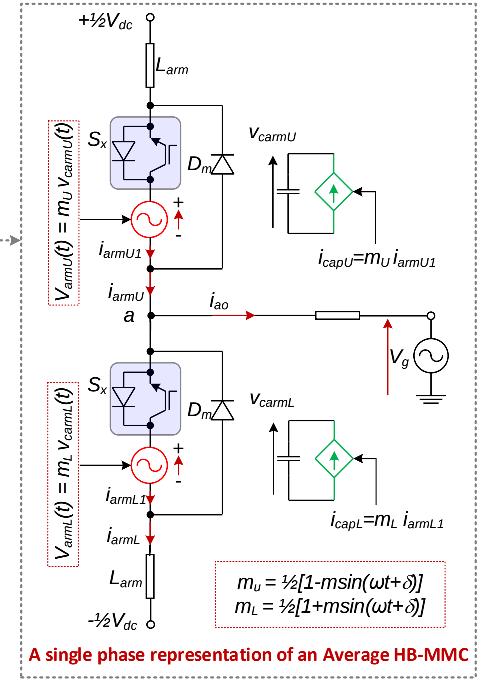


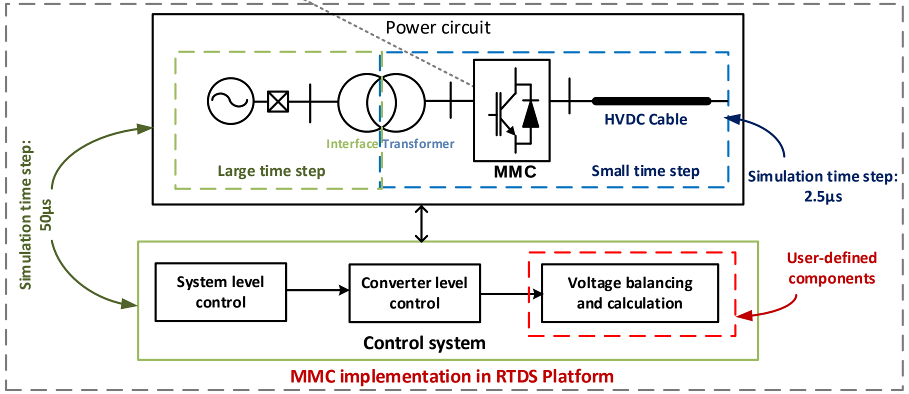
Model details available in D9.1



https://www.hvdccentre.com/open-source-converters/







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Implementation of Model: HVDC Circuit Breaker

Developed by PROMOTioN WP6 in collaboration with industrial partners. To be used for WP9 demonstration:

✓Partially-selective DC protections strategies

✓Fully-selective DC protections strategies

- ABB Hybrid DCCB
  - ✓A rated current of 16 kA
  - ✓2ms operation time
- Mitsubishi Electric Mechanical DCCB
  - ✓A rated current of 16 kA
  - ✓8ms operation time
- VSC Assisted Resonant Current (VARC) DCCB
  - ✓A rated current of 16 kA
  - ✓~3ms operation time

All developed DCCB models are validated against PSCAD model

HVDC DCCB

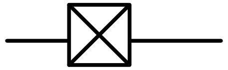
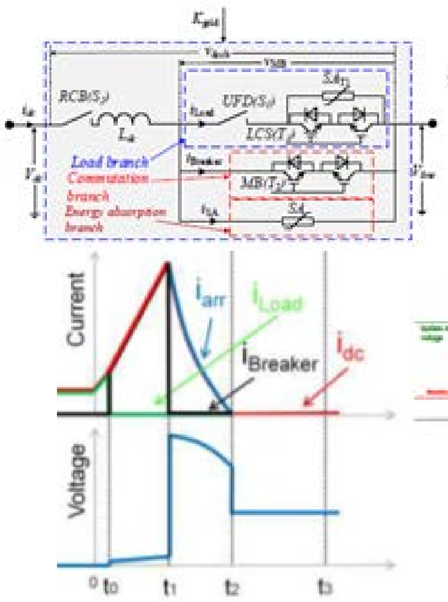
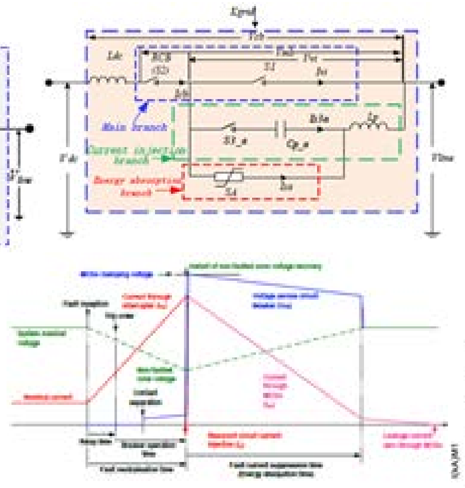


ABB | MITSUBISHI ELECTRIC Changes for the Better | SCiBreak



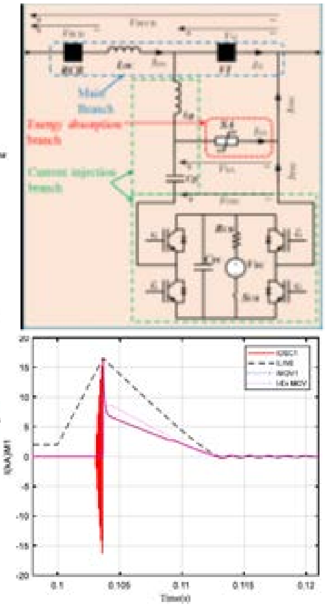
Hybrid DCCB

Source: PROMOTioN WP6: D6.9



Mechanical DCCB

Source: PROMOTioN WP6: D6.9 & D6.2



VARC DCCB

Source: PROMOTioN WP6: D6.8

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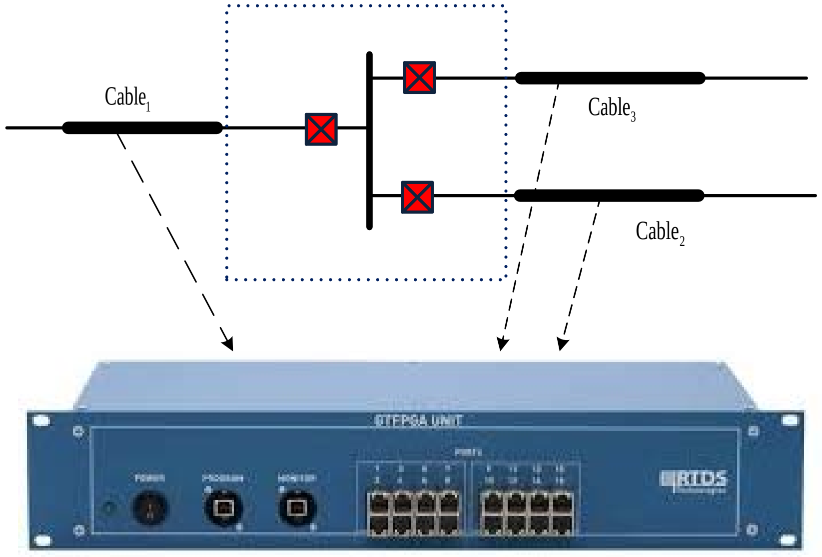
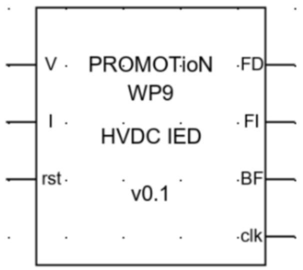
Implementation of Model: Cable Modelling and Others

- HVDC Cable
  - ✓Cable parameters are representative of the CMS HVDC project
  - ✓Travelling wave frequency-dependent phase cable model is used
  - ✓Avoid the use of long interface Bergeron lines
  - ✓Modelled in small-time step
  - ✓More accurate representation of electrical network resulting in more representative results from IED tests
- Simulated IED
  - ✓Avoid complexity when testing a large network
  - ✓Used when physical IED number is limited
- Other Components
  - ✓Converter Transformer
  - ✓AC breaker
  - ✓High Speed DC Switch(HSS)
  - ✓Surge Arrestor (Type 3 Arrestor-similar arrestor model in PSCAD)





Simulated IED

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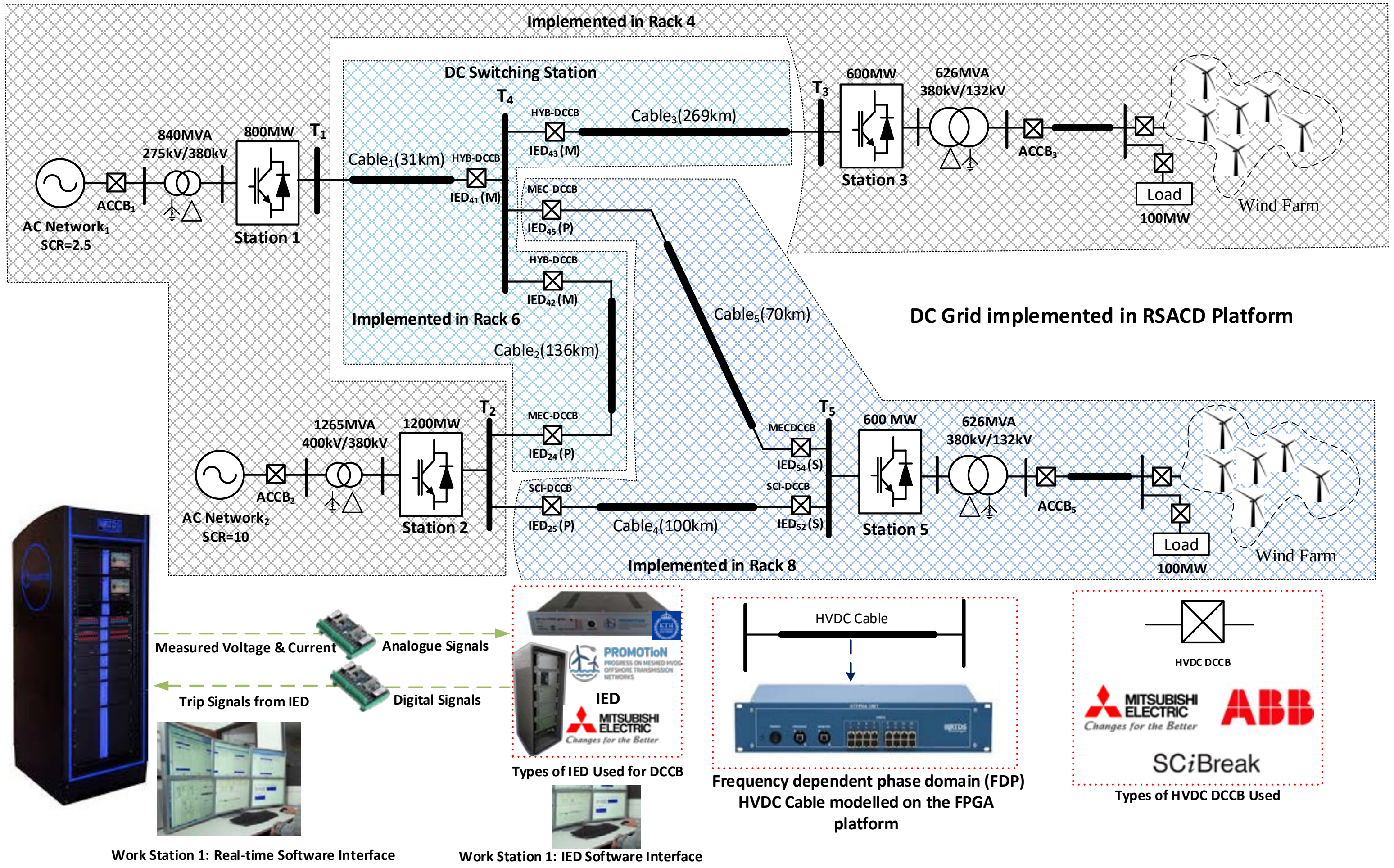
Implementation of Model: DC Grid Configuration

- Converters and DC-side electrical elements are modelled in the small-time step (~4μs)
- Small-time Step: 9 VSC Bridge Boxes are used
- AC-side circuits and converter control are modelled in the main time step (50μs)
- AC networks are modelled as a source and equivalent impedance
- Cables are modelled in the small-time step on GTFPGA units
- Hardware requirement for four-terminal network implementation:
  - ✓3x NovaCor chassis
  - ✓5x GTFPGA Units
  - ✓1x Global Bus Hub
  - ✓1x Global Bus Hub
  - ✓1x IRC Switch
  - ✓6x GTAO card
  - ✓2x GTDI card
  - ✓1x GTDO card



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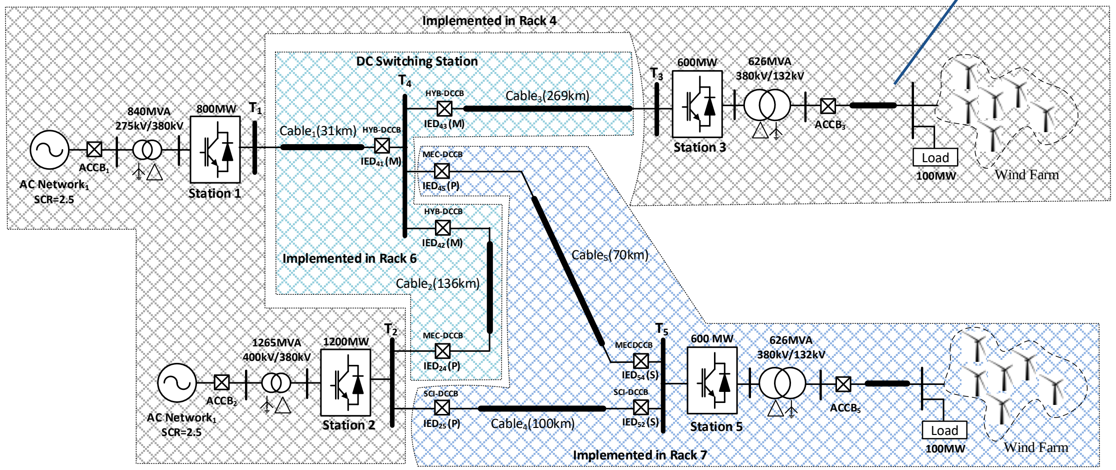
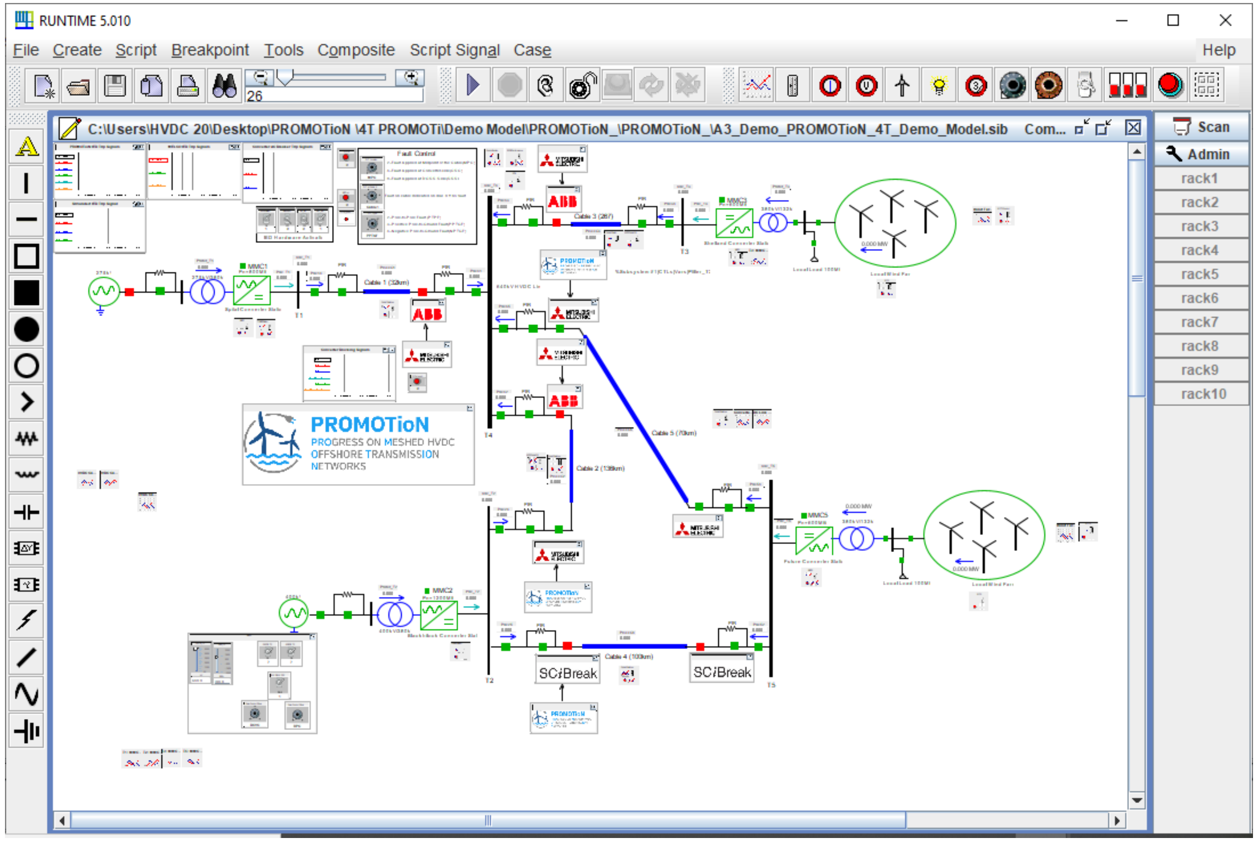
Real-time Simulation Test Setup: RSCAD Simulation run-time window

- Converter BLK-DBLK
- Automated repetitive scripts
- Fault Control
  - ✓ Cable selection
  - ✓ Fault location selection
  - ✓ Fault type selection
- Transition between SW and HW IED





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Implementation of Model: key Challenges

- Cable modelling-additional hardware requirement
- Avoiding interfaces between large time-step and small time-step
- Small time-step interface between different:
  - ✓ bridge boxes
  - ✓ GTFPGA Unit
  - ✓ MOV model
- Impedance of the interface t−line ($Z_o = \sqrt{L/C}$) has to be compensate with other network elements:
  - ✓ DCCB
  - ✓ HVDC Cable
- Developed model structure varies depending on particular test cases:
  - ✓ Multi-vendor
  - ✓ different DCCB topologies
  - ✓ different IED configurations

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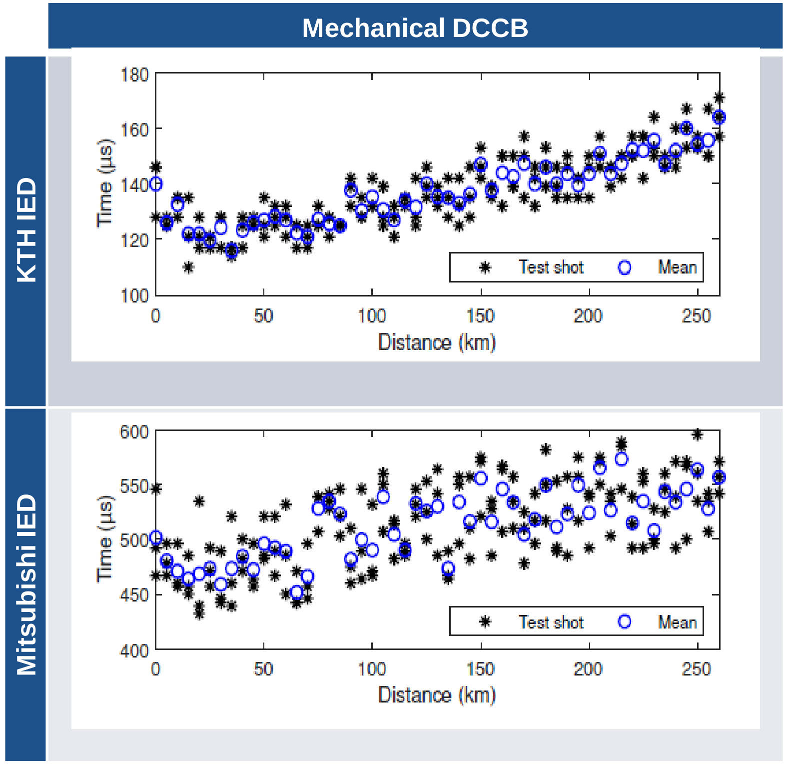
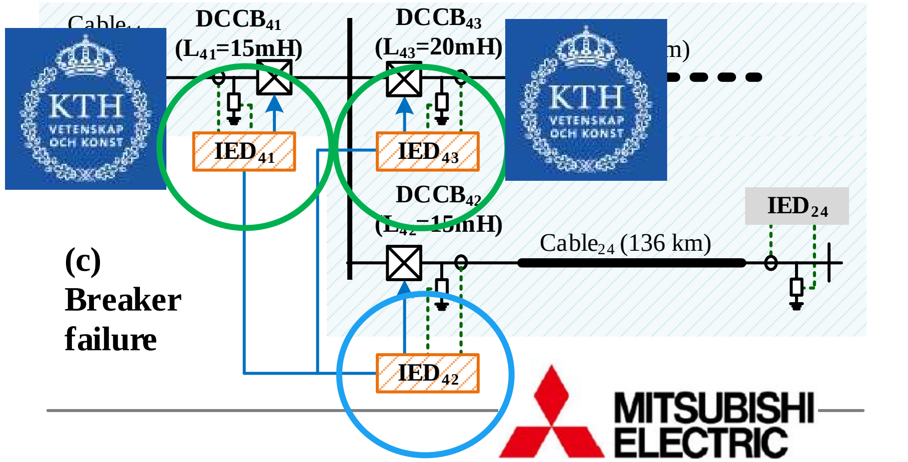
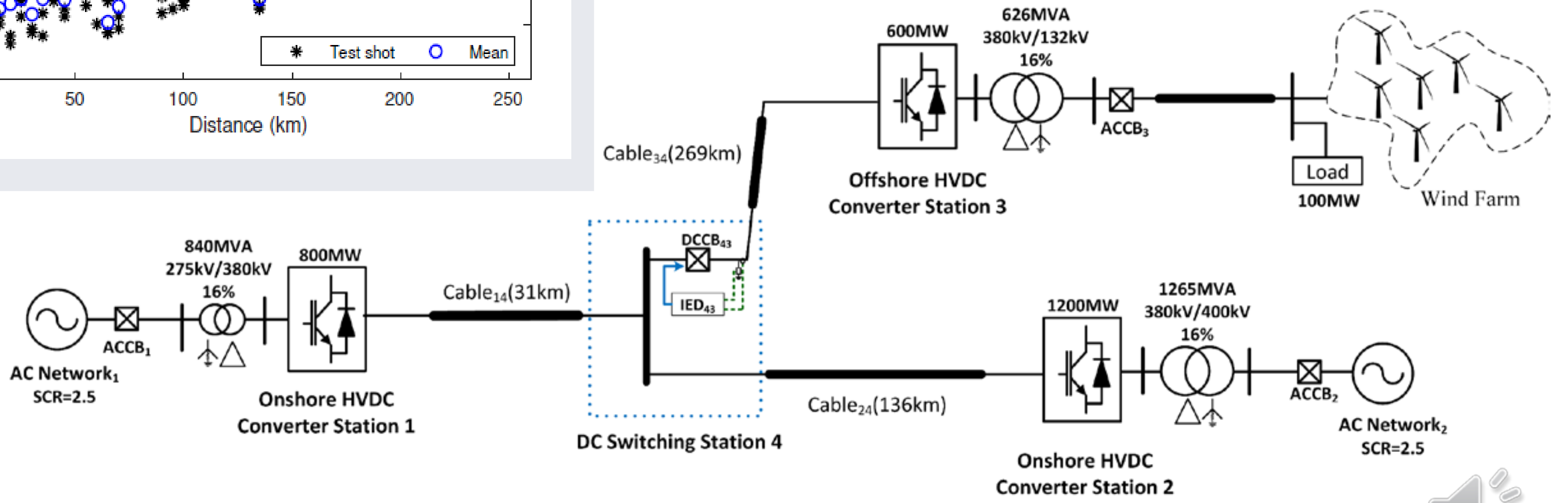
Single and Multivendor Testing of HVDC Protection IEDs

- Aim: **testing to demonstrate performance of IEDs**
- Several cases already studied on 3T CMS system
- Single vendor cases:
  - Partially selective
  - Fully selective
- Multivendor cases:
  - Fully selective
- IEDs perform in 100us to 600us depending on case study and IED







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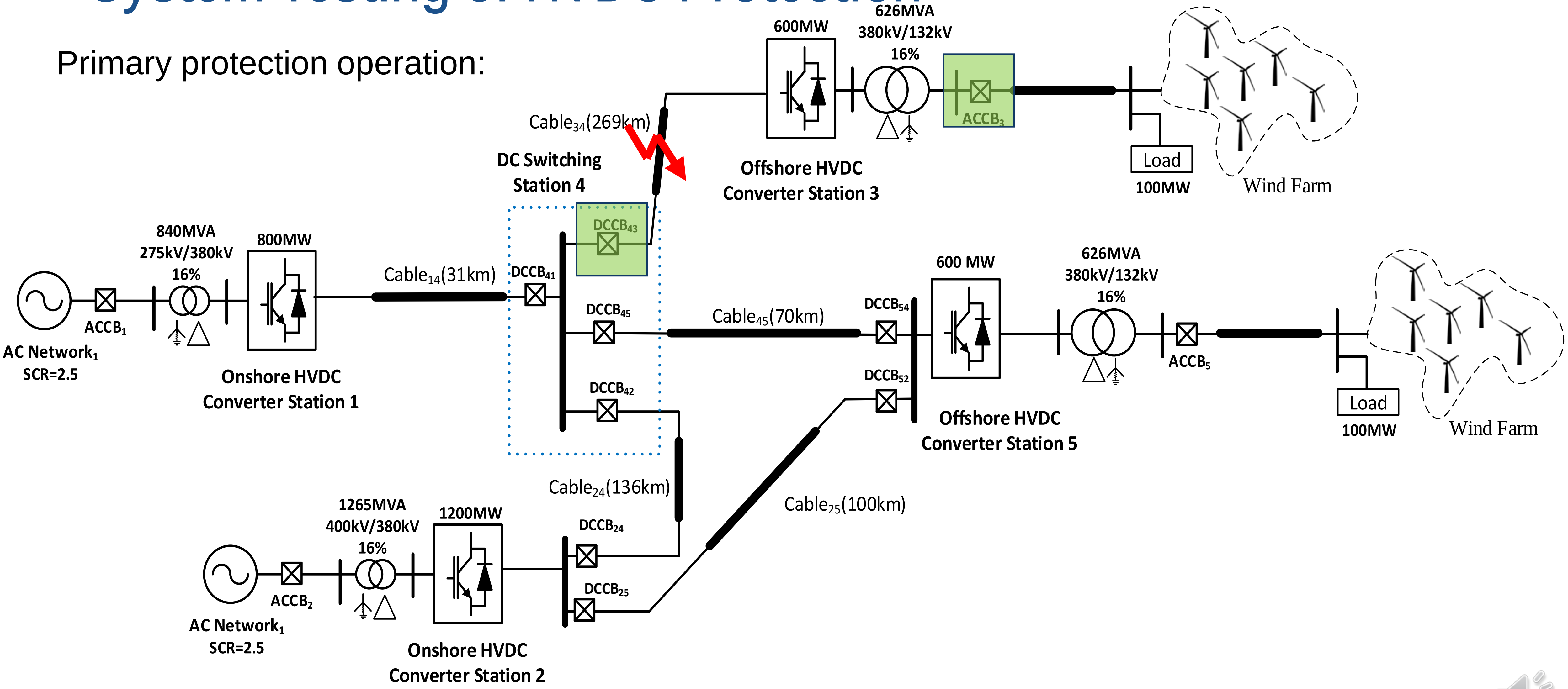
System Testing of HVDC Protection

Primary protection operation:



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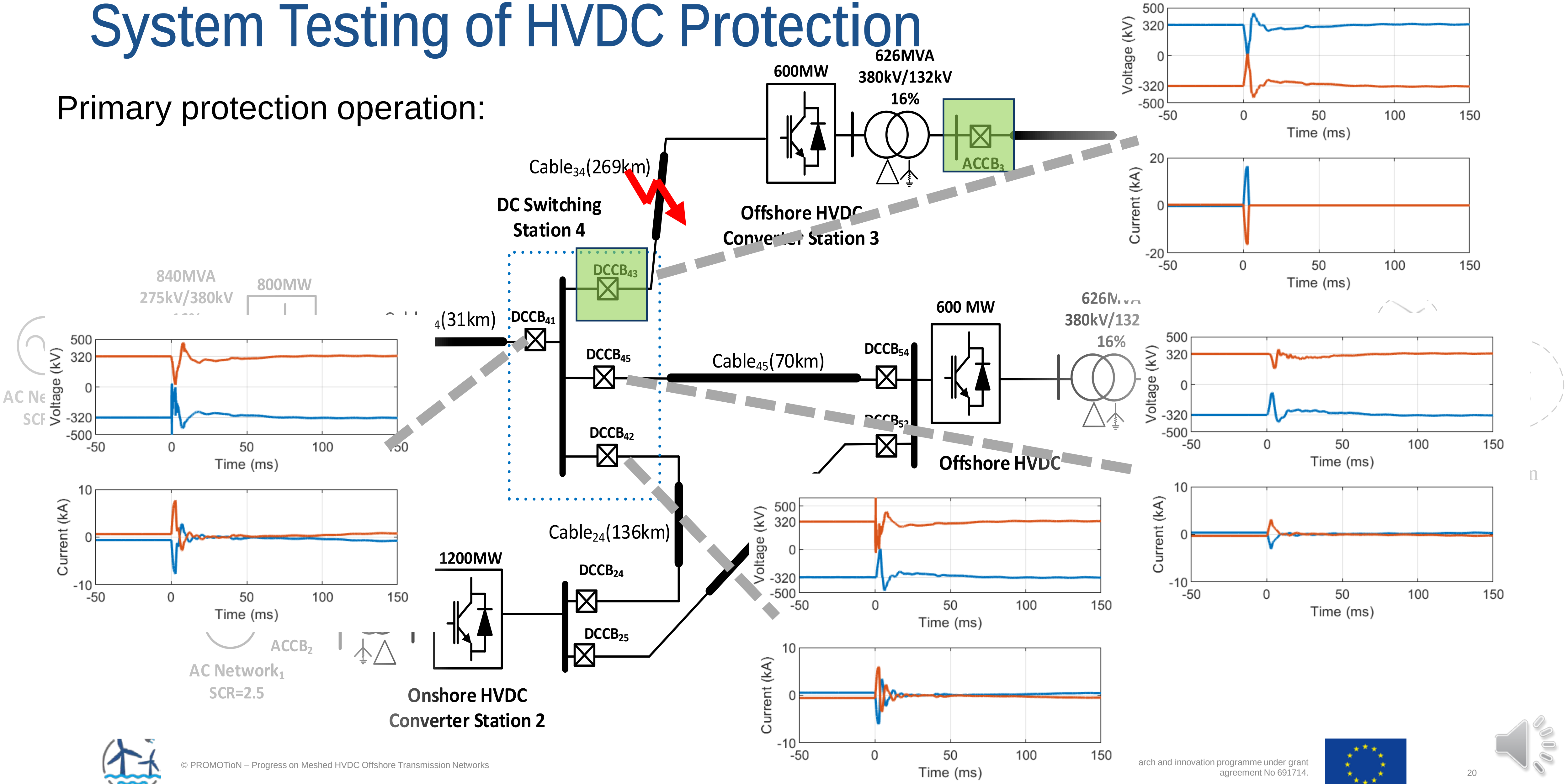
System Testing of HVDC Protection

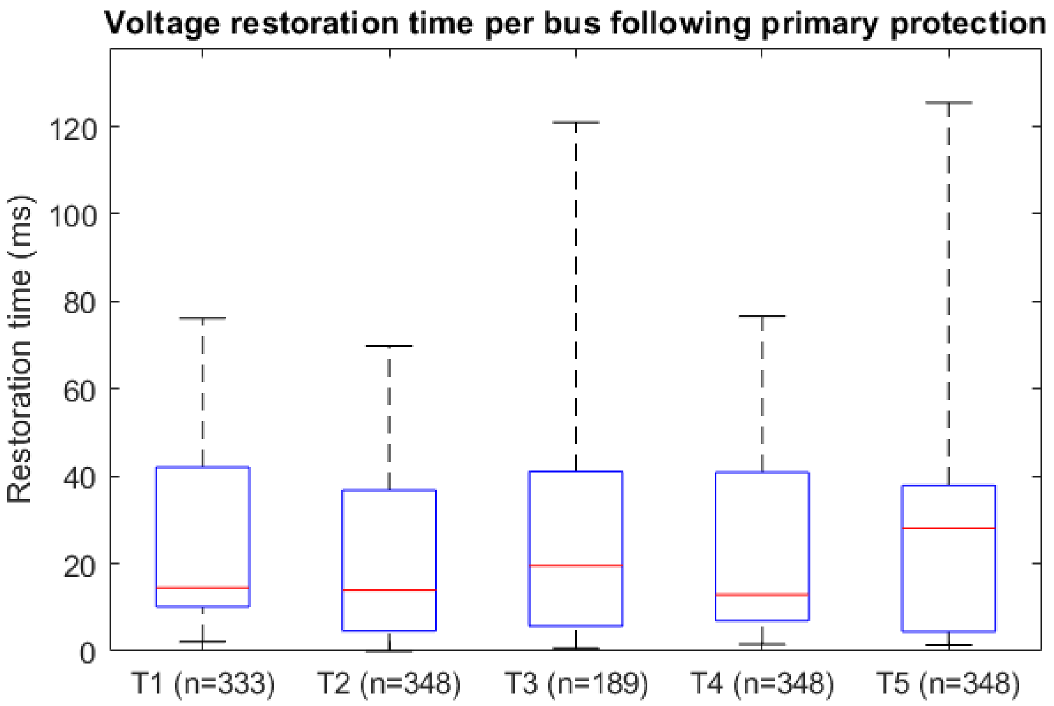
Primary protection operation:

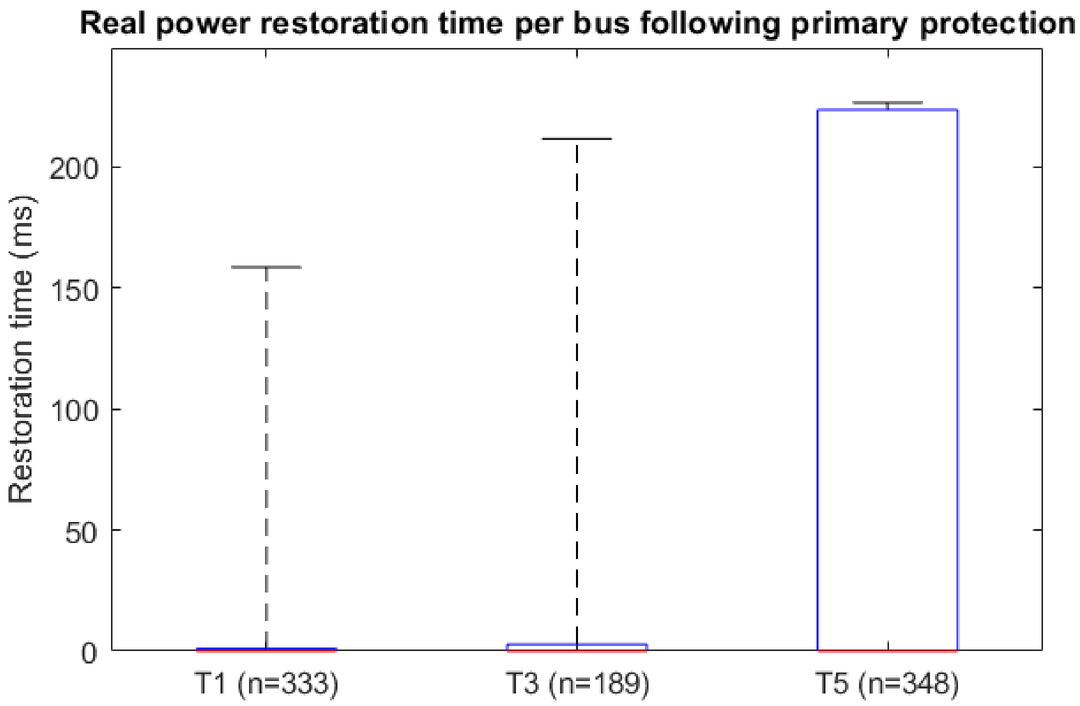


arch and innovation programme under grant agreement No 691714.

System Testing of HVDC Protection

Repetitive testing evaluated with generic Key Performance Indicators (KPIs):





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Testing with Converter Control Replicas

Control Replica	Protection IED	DC CB	Successful operation
ABB	MITSUBISHI ELECTRIC	SCiBreak	✓
ABB	MITSUBISHI ELECTRIC	ABB	✓
ABB	MITSUBISHI ELECTRIC	MITSUBISHI ELECTRIC	✓
ABB	PROMOTioN PROGRESS ON MESHED HVDC OFFSHORE TRANSMISSION NETWORKS	SCiBreak	✓
ABB	PROMOTioN PROGRESS ON MESHED HVDC OFFSHORE TRANSMISSION NETWORKS	ABB	✓
ABB	PROMOTioN PROGRESS ON MESHED HVDC OFFSHORE TRANSMISSION NETWORKS	MITSUBISHI ELECTRIC	✓

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Conclusions

We have demonstrated:

- Successful operation of HVDC protection IED prototypes
- Successful operation of HVDC CB models
- Overall protection system performance:
  - Fully selective protection
  - Primary protection
  - Backup protection (not shown in this presentation)
- Exhaustive testing of overall protection system and resulting system response
- Several example cases of high level multivendor interoperability

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Public Demonstration – Partially and Fully Selective HVDC Protection

- For more information on the topic presented today, please join our (virtual) demonstration:
- Demonstration of HVDC grid protection system - **September 9th, 2020**, 13:00 – 15:30 (BST)
- Registration:

https://speakeasy.eventsair.com/ssen-event/ssenpromotion/Site/Register

13:00	Event begins
	Presentation: Welcome on behalf of PROMOTioN Cornelis Plet, DNV GL, PROMOTioN Project Coordinator
	Presentation: How to protect a DC grid? Dirk van Hertem, KU Leuven, PROMOTioN Work Package 4 Leader
	Presentation: What are DCCBs? Dragan Jovcic, University of Aberdeen, PROMOTioN Work Package 6 Leader
	Presentation: Why is this demonstration important? Ian Cowan, The National HVDC Centre, PROMOTioN Work Package 9 Leader
	Presentation: What is the test setup? Habib Rahman, The National HVDC Centre
	Presentation: What is the PROMOTioN IED? Ilka Jahn, KTH
	Presentation: What is the MELCO IED? Frederick Page, Mitsubishi Electric Corporation

14.15	*Presentation*: What will the results be? Geraint Chaffey, KU Leuven
	Demonstration: Operation primary protection using test IEDs with test system
	Demonstration: Operation of backup protection using test IEDs with test system
	Demonstration: Operation of primary protection using test IEDS with replica HVDC control and protection cubicles from real project
	Presentation: Overview of complete results Geraint Chaffey, KU Leuven
	Summary and Q&A
15.30	End of Event

Final PROMOTioN Conference

- For more details on the outcomes of PROMOTioN, please follow the final conference:

https://www.promotion-offshore.net/news_events/final_conference_2020/

North Sea Grid for the European Green Deal

How to unlock Europe's Offshore Wind potential – a deployment plan for a meshed HVDC grid

Pre-Conference Sessions

08/24/20 – 09/18/20

24 AUG
2:00 – 5:30 PM
PROMOTioN @ CIGRE
Join the PROMOTioN Team on Channel 4 at the CIGRE 2020

Breakout Sessions

Pre-recorded presentations available Mondays each week, live Q&As with our experts every Friday

31 AUG – 04 SEP
Offshore HVDC Grid Technology
Live Q&A: Friday, 09/04/20, 10:00 AM – 12:00 PM

07 SEP – 11 SEP
HVDC Technology qualification
Live Q&A: Friday, 09/11/20, 10:00 AM – 12:00 PM

Legal, Regulatory & Economic Aspects
Live Q&A: Friday, 09/11/20, 1:00 PM – 3:00 PM

14 SEP – 18 SEP
Meshed Offshore Grid Planning
Live Q&A: Friday, 09/18/20, 10:00 AM – 12:00 PM

Virtual Conference Agenda

Live Event, 09/21/20

10:00 - 10:20 AM	Keynotes & Welcome Address
10:20 - 10:45 AM	**Introduction to PROMOTioN:** How to approach the creation of a European offshore grid
10:45 - 11:00 AM	Feedback Round
11:00 AM – 12:00 PM	Reports from the Breakout Sessions
12:00 - 12:30 PM	**Lessons from PROMOTioN:** Key steps towards a meshed HVDC offshore grid
12:30 - 1:00 PM	Lunch Break
1:00 - 2:30 PM	**Live Panel Discussion: Fitting the puzzle pieces**
2:30 – 2:45 PM	Feedback round
2:45 – 3:00 PM	Wrap up & Concluding remarks

PROMOTioN
PROGRESS ON MESHED HVDC OFFSHORE TRANSMISSION NETWORKS

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691714.

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USER SPOTLIGHT SERIES BY RTDS Technologies

Co-funded by the Horizon 2020 programme of the European Union

Demonstration of Partially and Fully Selective Protection for Multiterminal HVDC Systems

RTDS User Spotlight Series – September 2020

Thank you for your attention.

Protection System Demonstration
9th September ->

PROMOTioN Final Conference
21st September ->

Geraint Chaffey, KU Leuven and Md. Habib Rahman, The National HVDC Centre

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