Studies of dynamic interactions in hybrid ac-dc grid under different fault conditions using real time digital simulation

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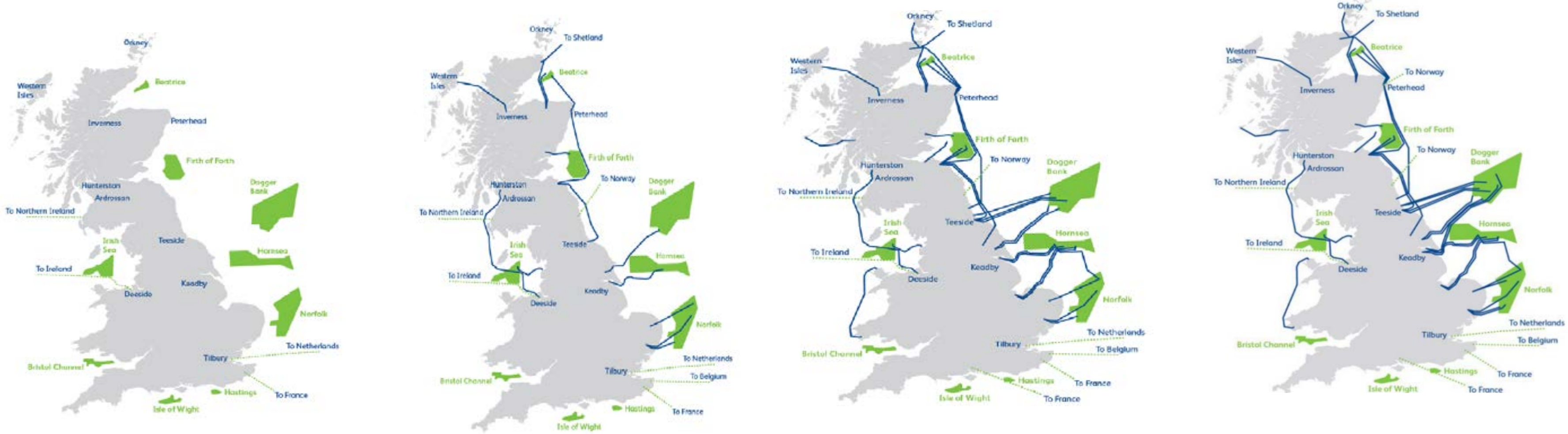
Outline

- Challenges
- Modelling of the DC-AC grid in RTDS and validation tests
- Simulation results of dynamic interaction between the AC and DC grid under different fault conditions
- Proposed protection solution
- Conclusion

Challenges: moving to hybrid AC-DC systems

UK Future Grid 2015-2030



2015 2020 2025 2030

- DC grids can carry large amount of power up to tens of GWs, and are very sensitive to faults on the DC sides, and to other contingencies such as sudden trip of converters in particular the converter controls the grid DC voltage.

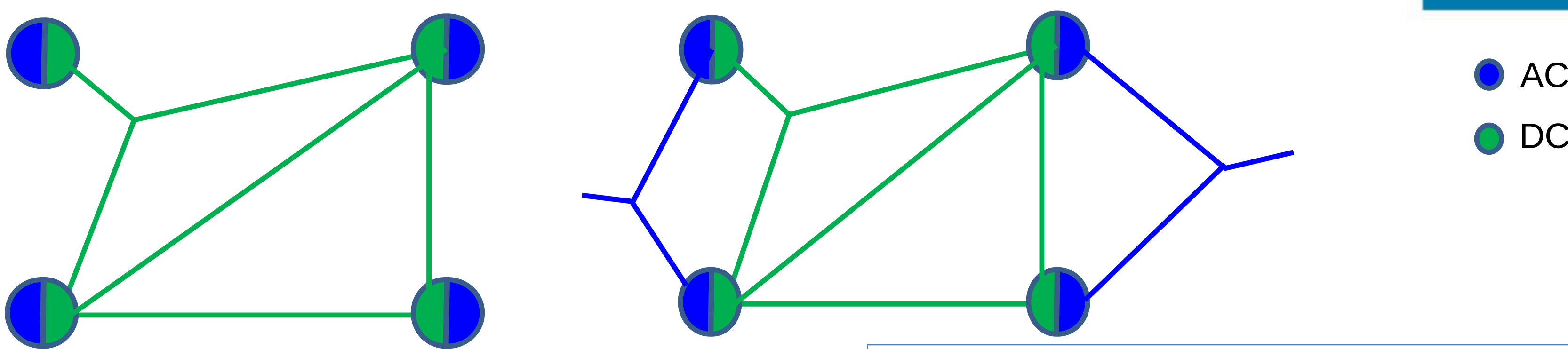
- Unlike AC systems, the propagation of voltage disturbances can be very rapid, leading to the interruption and imbalance of large amount of power between DC grid and surrounded AC systems and important parameters such as **DC voltages** and **AC frequency** to be adversely impacted.

- There is still a need to be fully understand how existing AC grids will interact with the embedded DC grid in order to enable new protection and control strategies to be developed and validated.

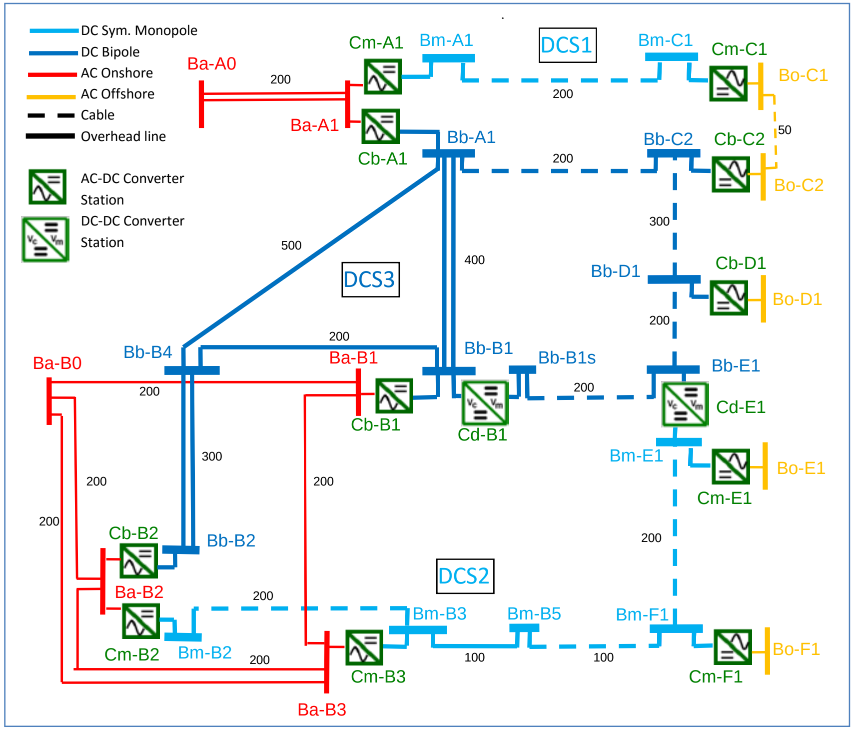
Electricity Network Innovation Competition submission from SHE Transmission Ltd – Multi-Terminal Test Environment (MTTE) for HVDC Systems available at https://www.ofgem.gov.uk

Modelling: DC grid

Meshed DC grid (Cigré workgroup B4-52 considers only this as a real DC grid)



- More nodes to receive/send power (higher power transfer capabilities)
- Redundant lines (better reliability)
- DC flows can not be directly controlled
- Reliable DC protection is required



CIGRE B4 DC Grid Test System

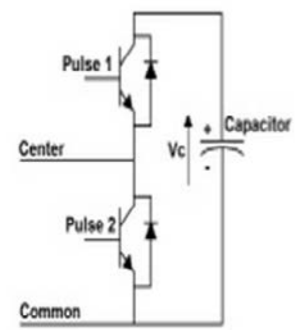
Modelling: DC grid converter technologies

LCC

2level-VSC

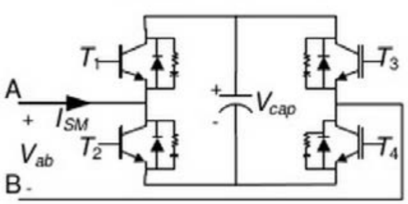
MMC

HB



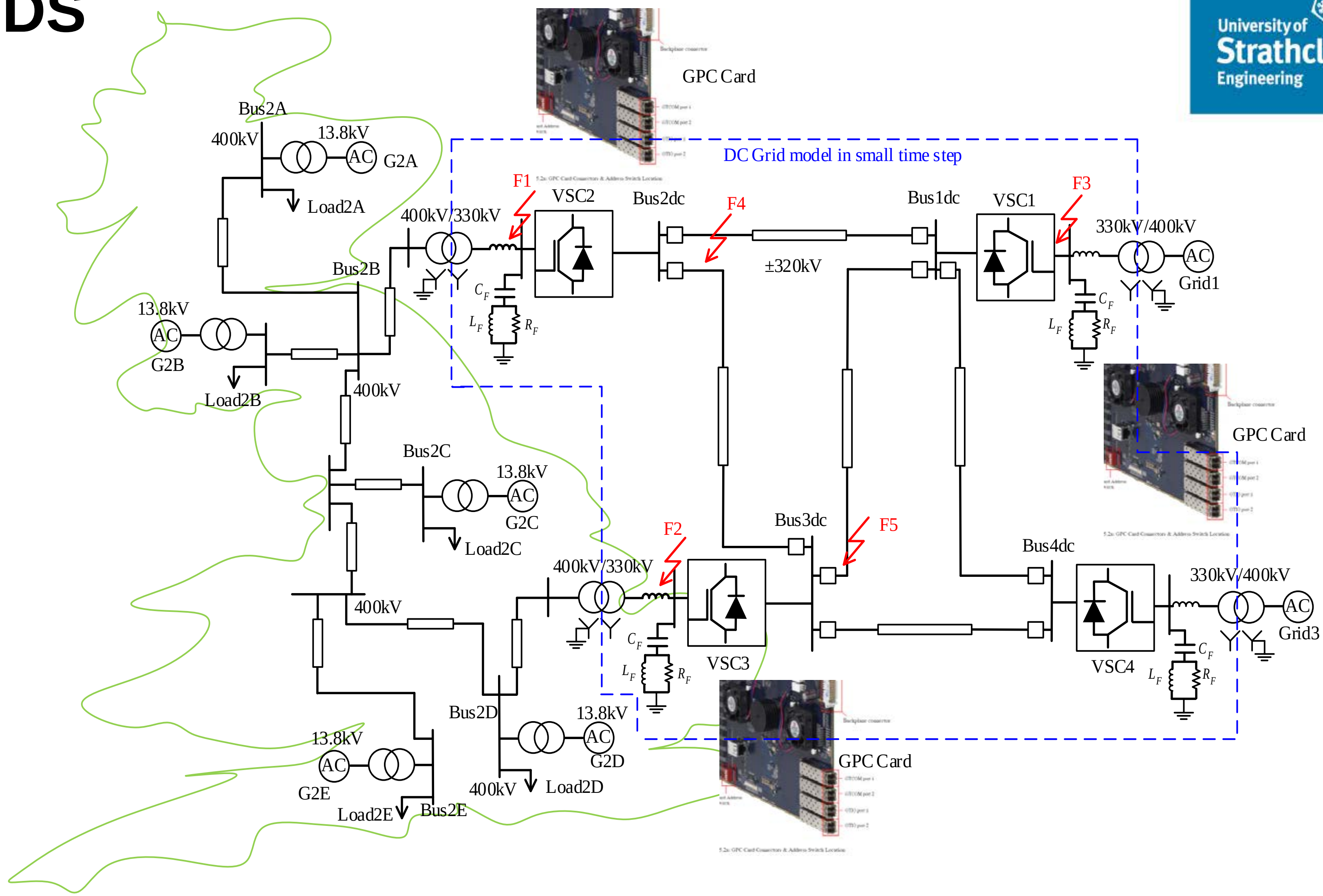
No fault blocking capability

FB



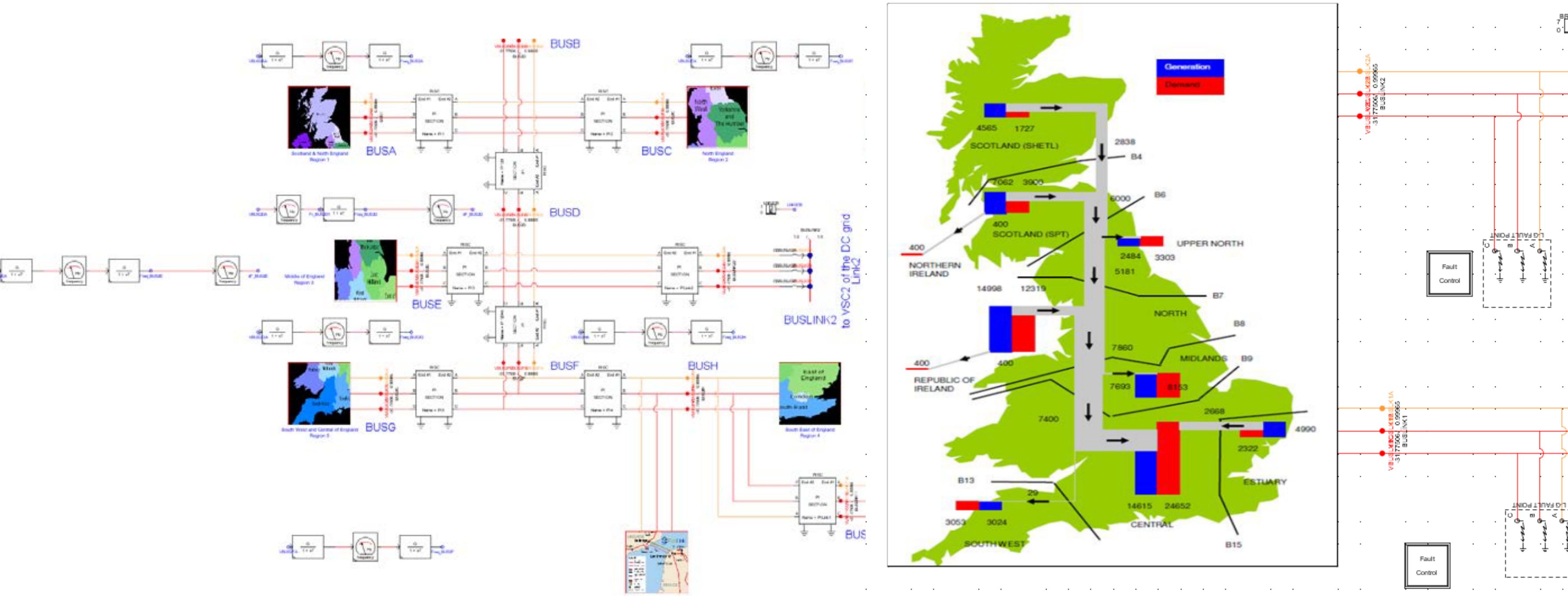
With fault blocking capability

Modelling: Hybrid AC-DC- grid modelled in RTDS



Simulating very stressed events and understanding the resilience (the dynamic interaction) of the hybrid AC-DC grid

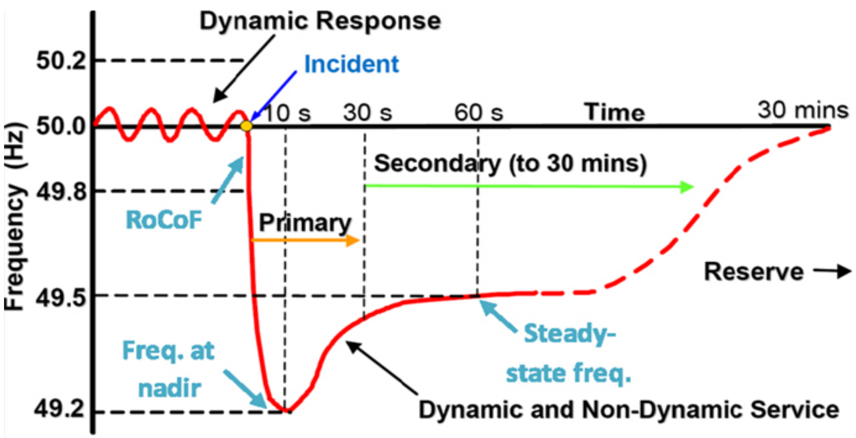
Modelling: AC grid model

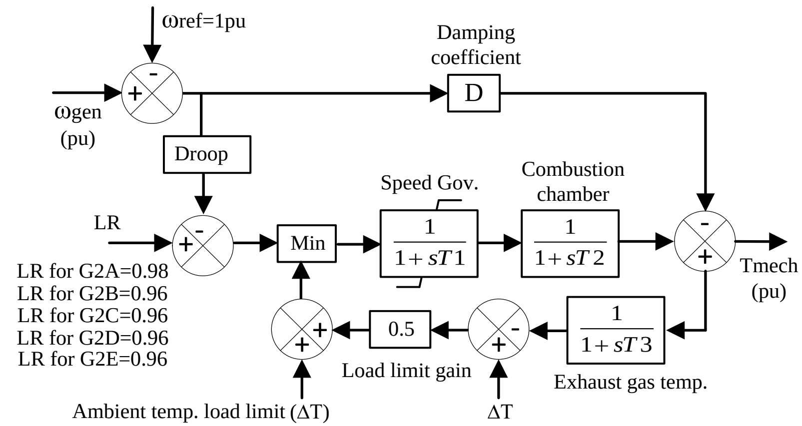


- Representing key generation, load areas, and main transmission routes
- Based on real power flow data of eight areas as presented in the ETYS of the UK NG
- Each AC generator is modelled as an aggregated large machine + the widely used IEEE ST1 static type excitation and GAST gas turbine and speed governor to control the generators
- The demand in each area has been modelled as a fixed average real and reactive power based on UK 2017 winter peak consumption

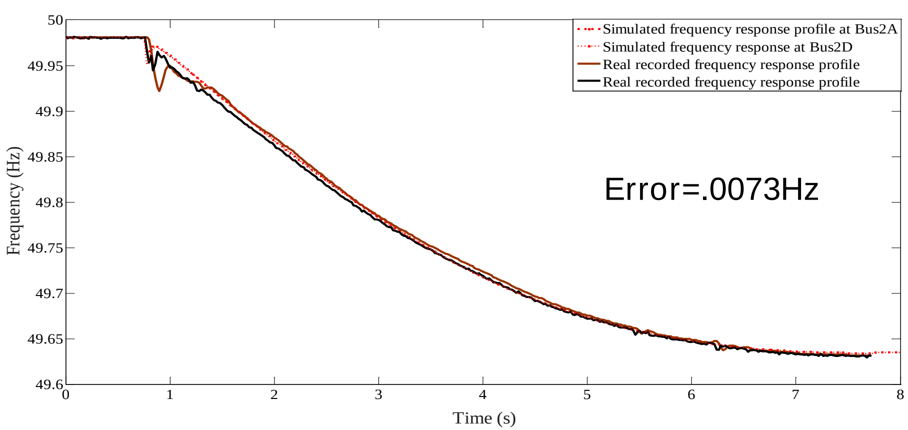
Modelling: Validation tests

- Initial load flow validation (initial conditions) to evaluate the steady state performance of the model
- Frequency (dynamic) response test to compare the model performance against real recorded frequency deviation data obtained from PMUs **(the loss of ~1GW on 11th of Jan 2016 due to the trip of the UK-France HVDC interconnector)**



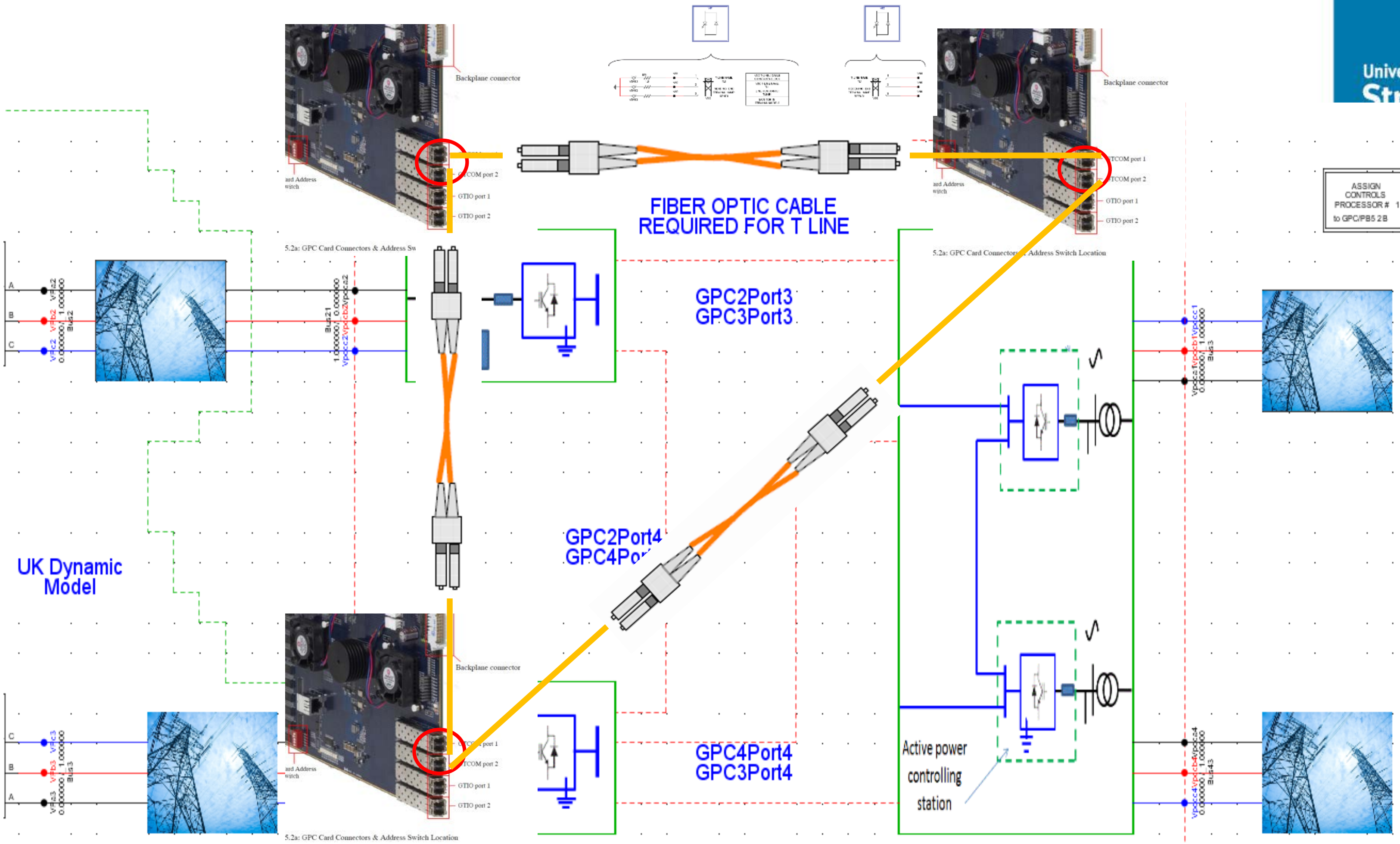


GAST gas turbine and speed governor model

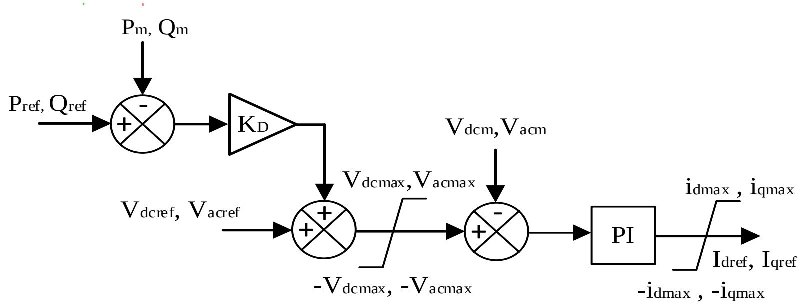


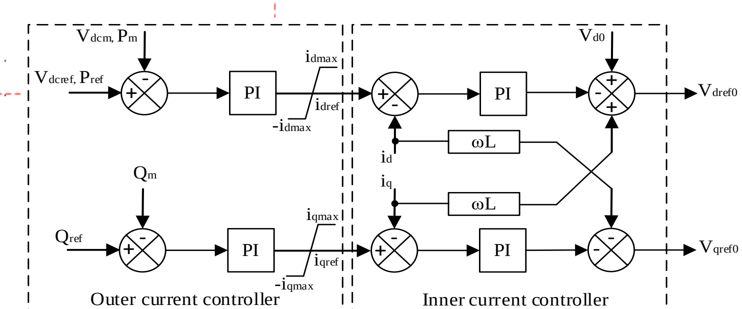
	Gen G2A	Gen G2B	Gen G2C	Gen G2D	Gen G2E
LR					
Inertia					
Droop					
T1					

Modelling: DC Grid model

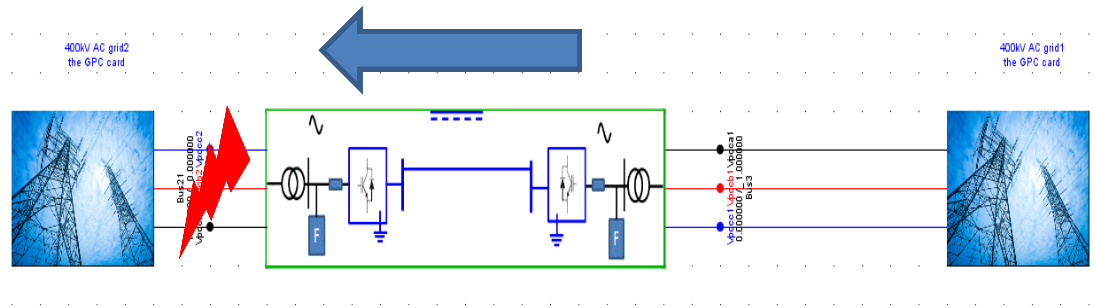


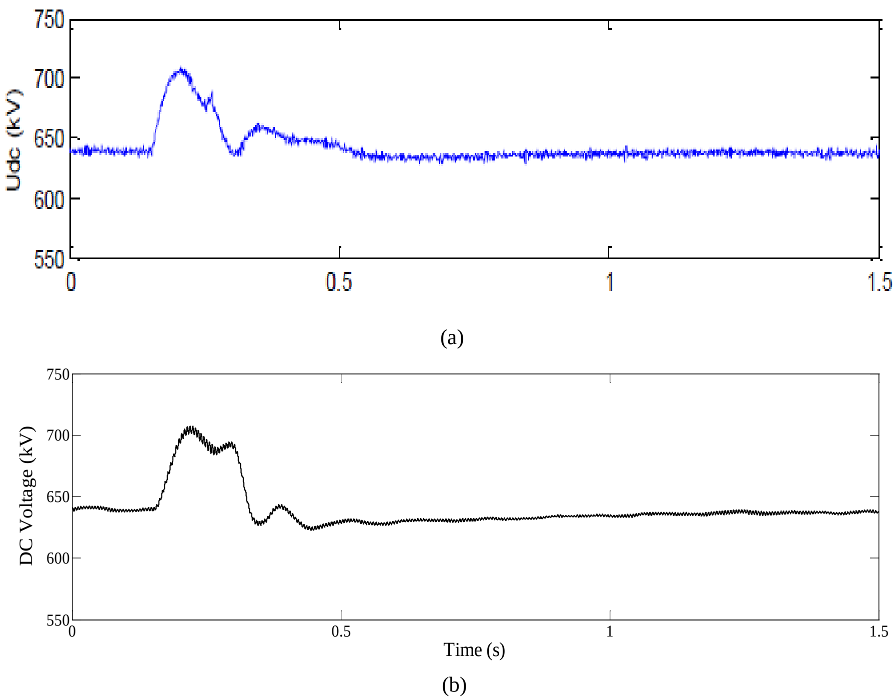
DC Grid control strateg

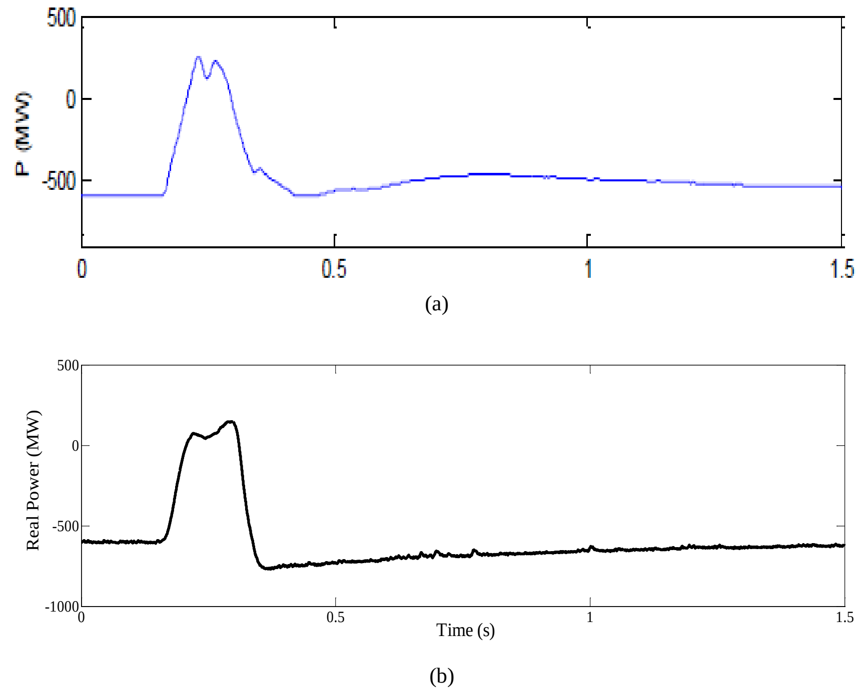




Modelling: Validation tests





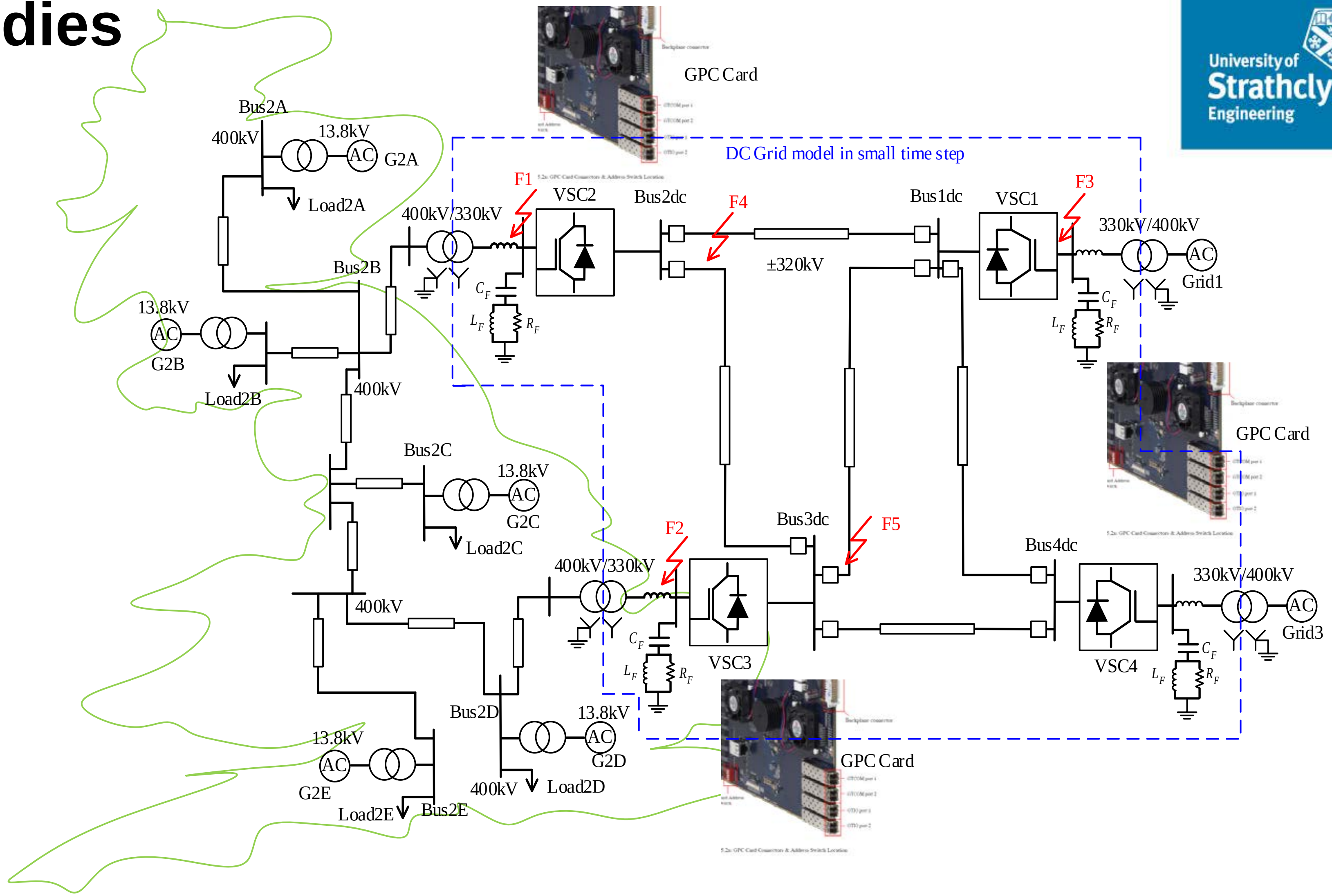


DC voltage response (a) ABB PSCAD/EMTDC detailed model results, (b) RTDS simulated results

Real power response (a) ABB PSCAD/EMTDC detailed model results, (b) RTDS simulated results

[1] Mitra, P.; Vinothkumar, K.; Lidong Zhang, "Dynamic performance study of a HVDC grid using real-time digital simulator", Complexity in Engineering (COMPENG), 2012

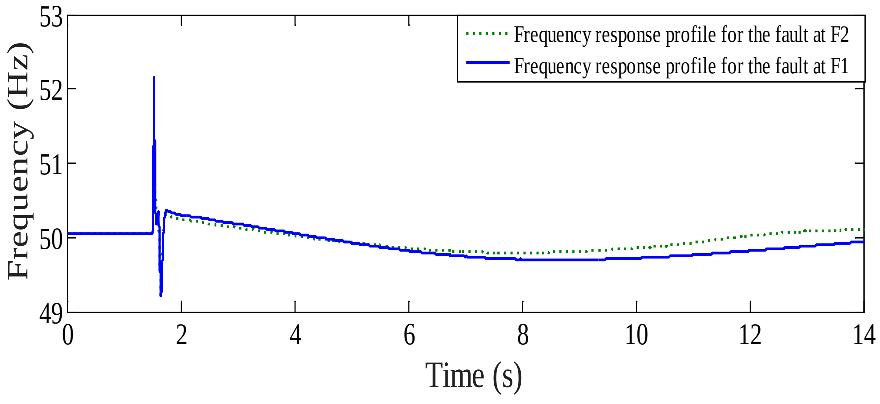
Simulation studies: extreme contingency studies

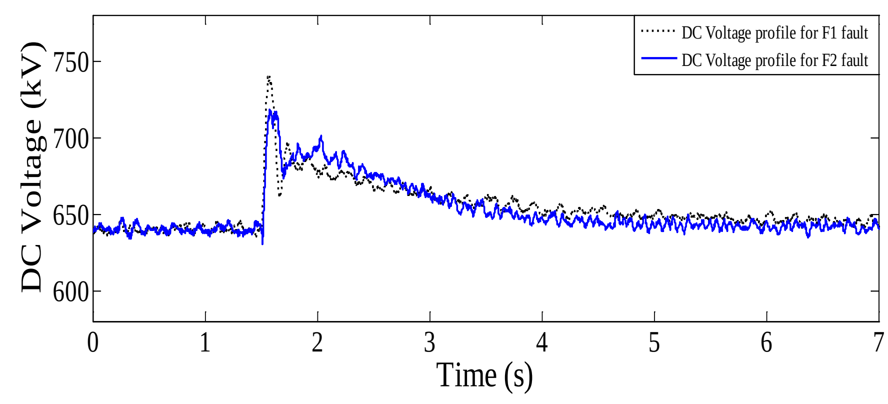


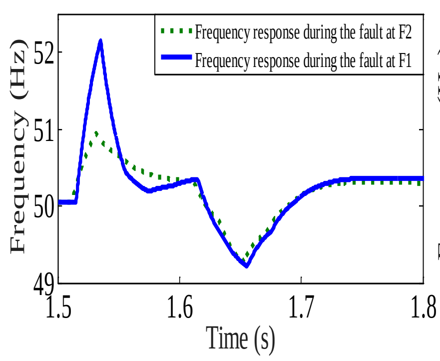
- AC grid-side three-phase symmetrical fault (followed by trip of the associated VSC station)
- Pole-to-pole DC fault and cascading trips of VSCs

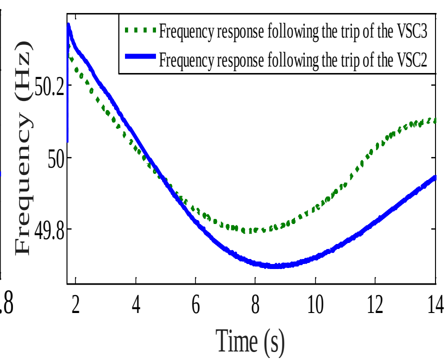
Simulation studies

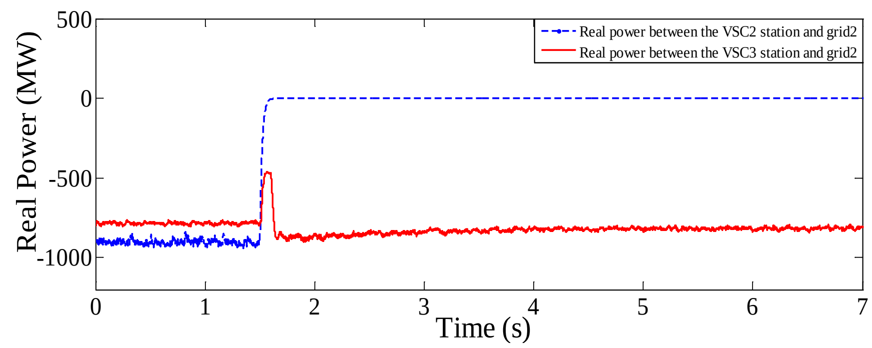
AC grid-side three-phase symmetrical fault







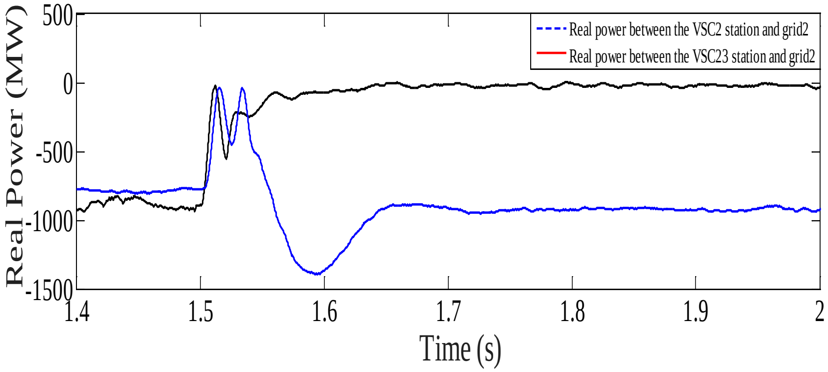


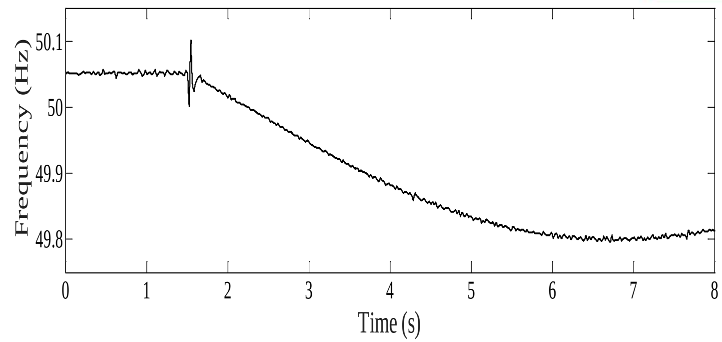


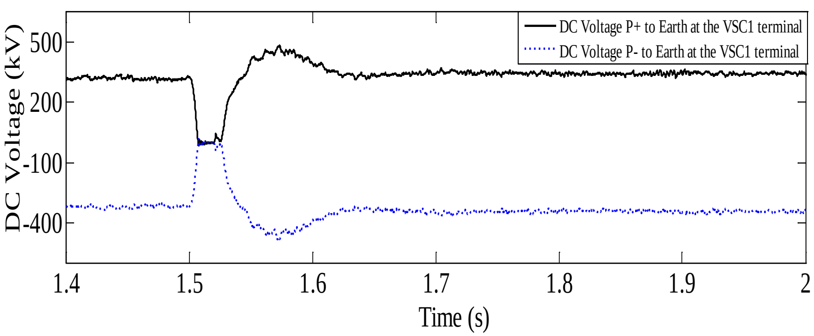
$$\left(V_{dc}(peak)\right)^2 - V_{dc0}^2 = \frac{(P_0 - P).T_{fault}}{2C_{dc}}$$

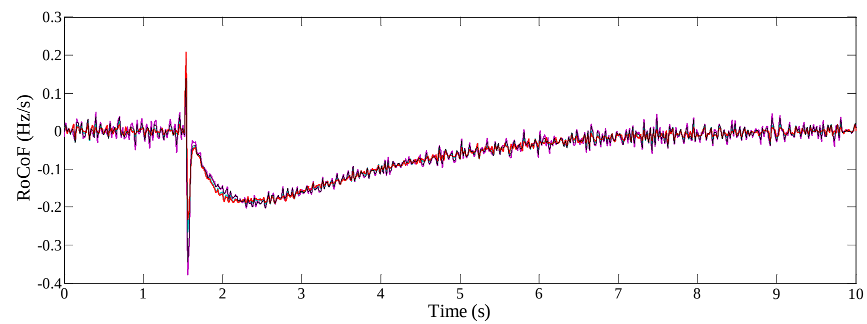
Simulation studies

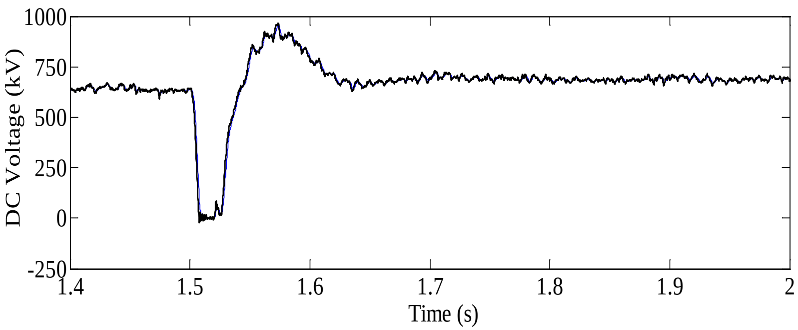
Pole-to-pole DC fault is applied at Bus2dc





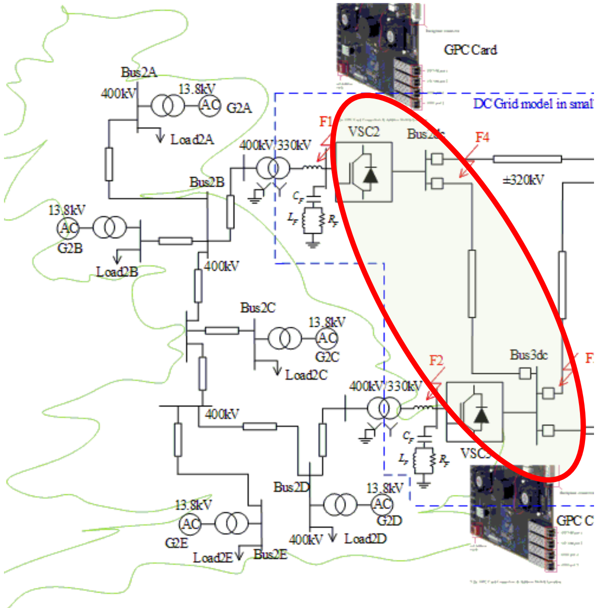


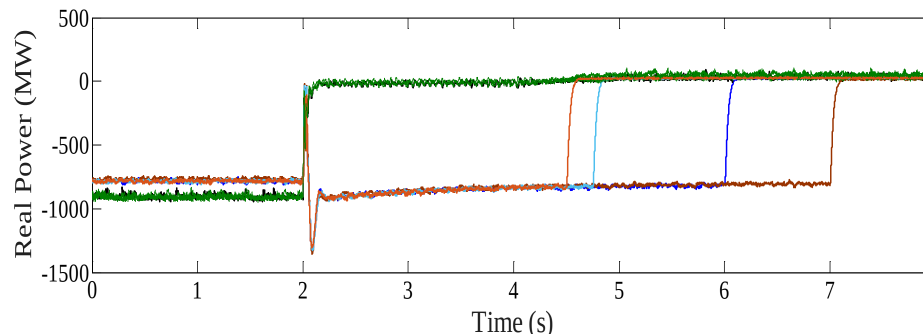


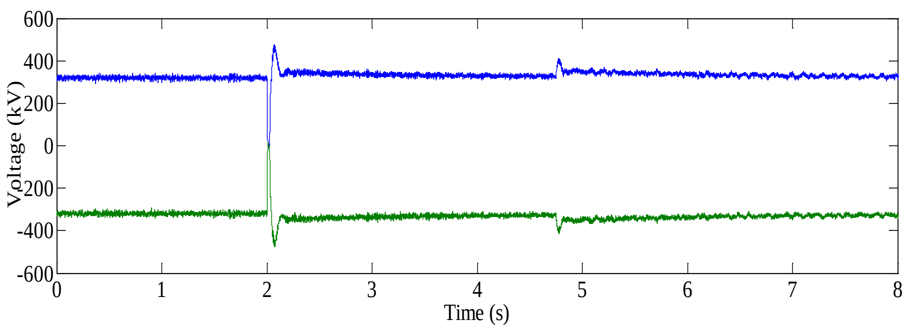


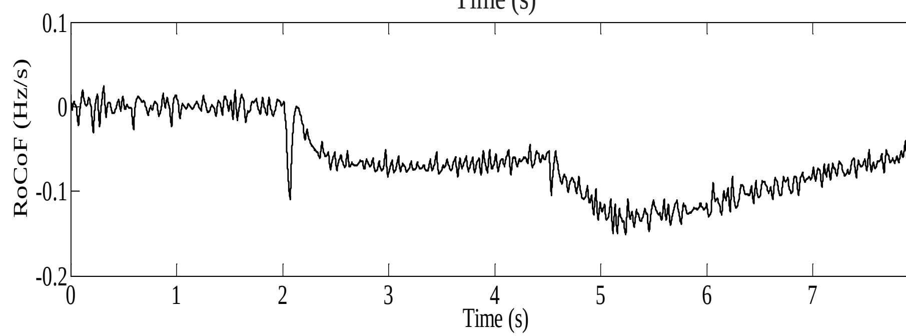
Simulation studies

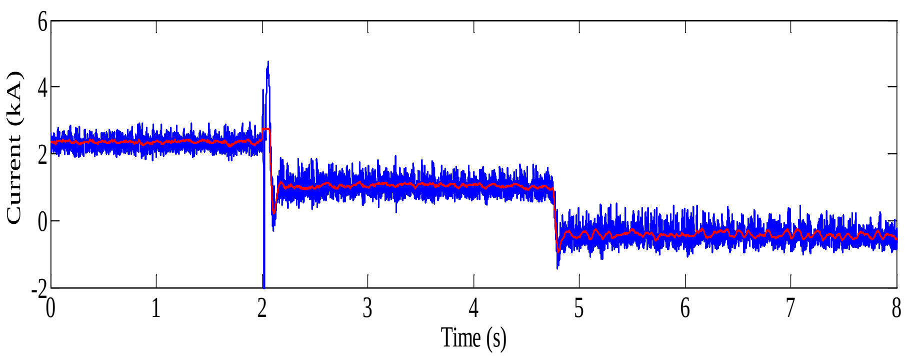
Pole-to-pole DC fault followed by cascading trip of VSCs

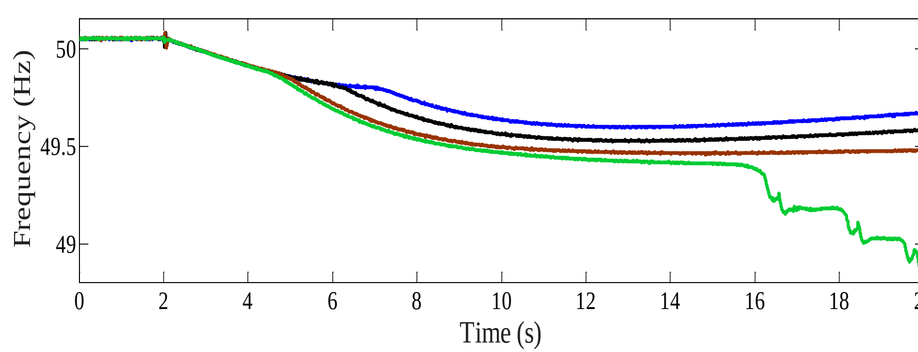






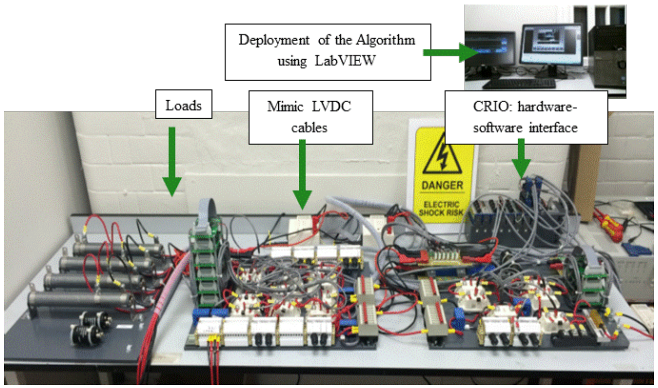


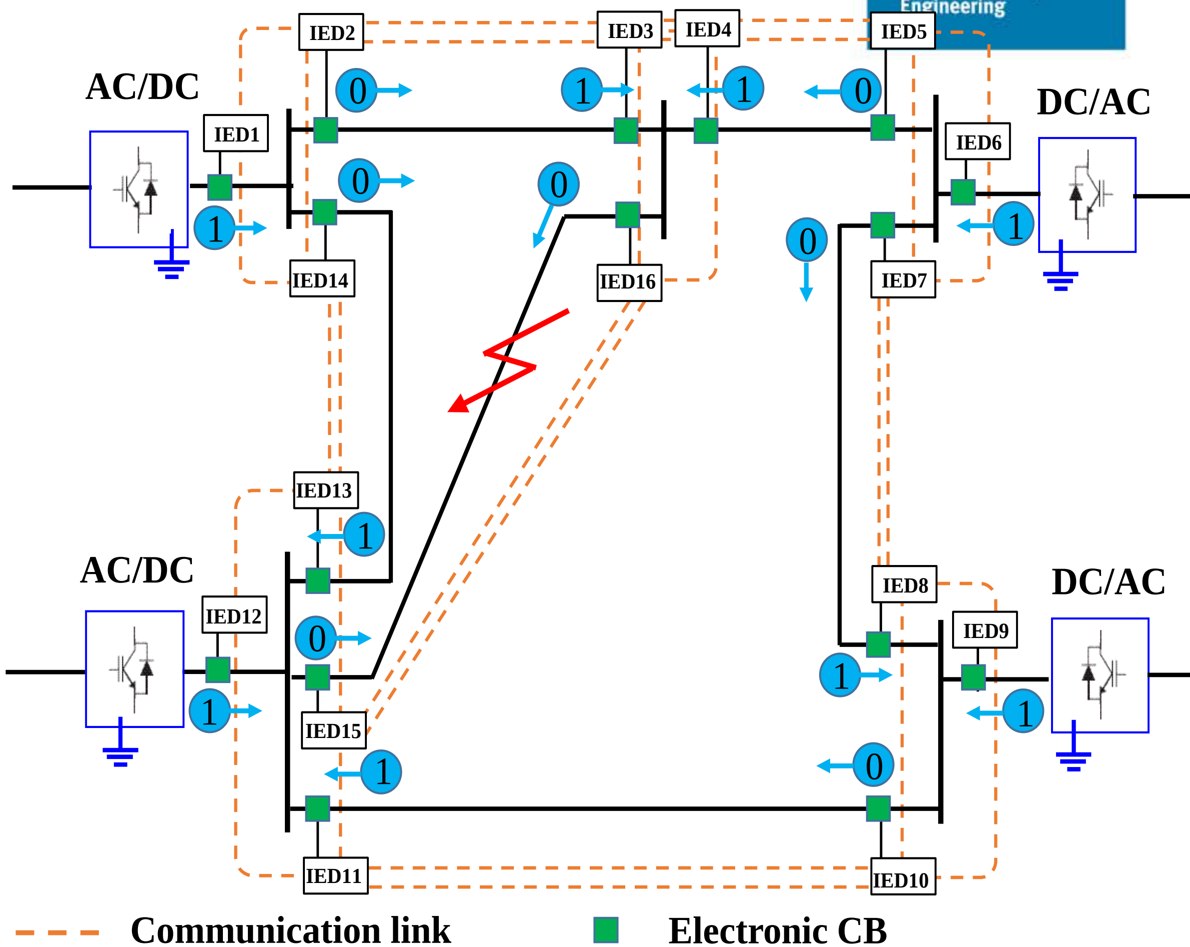




Protection solution

New DC current direction-based protection algorithm has been prototyped on radial last mile DC distribution network and is being investigated for MTDC





DC grid protected by current direction-based fast and selective protection scheme

Abdullah A S. Emhemed; Kenny Fong; Steven Fletcher; Graeme Burt,"Validation of Fast and Selective Protection Scheme for an LVDC Distribution Network", IEEE Transactions on Power Delivery, Vol. PP, No 99, Jul 2016.

Conclusions

- Large penetration of HVDC connections into power networks can significantly change the behaviour and response of existing power systems

- New controls and protection strategies will be required to maintain system stability and reliability

- The validated hybrid AC-DC grid model in RTDS (reduced AC dynamic model + MTDC) has provided a useful tool with greater flexibility which can potentially used to support
  - proof of concept where changes can be easily implemented
  - test the performance of other active control units such as FACTS, STATCOM, VSCs, and etc.
  - enabling a wider variety of studies (interaction between DC systems and converters and AC grid under different faulted locations)
  - investigate the impact of offshore wind generation to be carried out at reasonable accuracy level
  - quantify the impact of reduced inertia due to the integration of HVDC and high density of wind generation on the systems control and protection performance

- The new protection solution has the potential to provide fast detection of different DC faults, and fast interruption of the faults at low levels with a good

Thank you & Q?