Fast Frequency Response from HVDC Systems to AC grids Modelled using RTDS

Name: Dr. Oluwole Daniel Adeuyi

Date: September 15, 2016

Venue: RTDS European User Group Meeting.

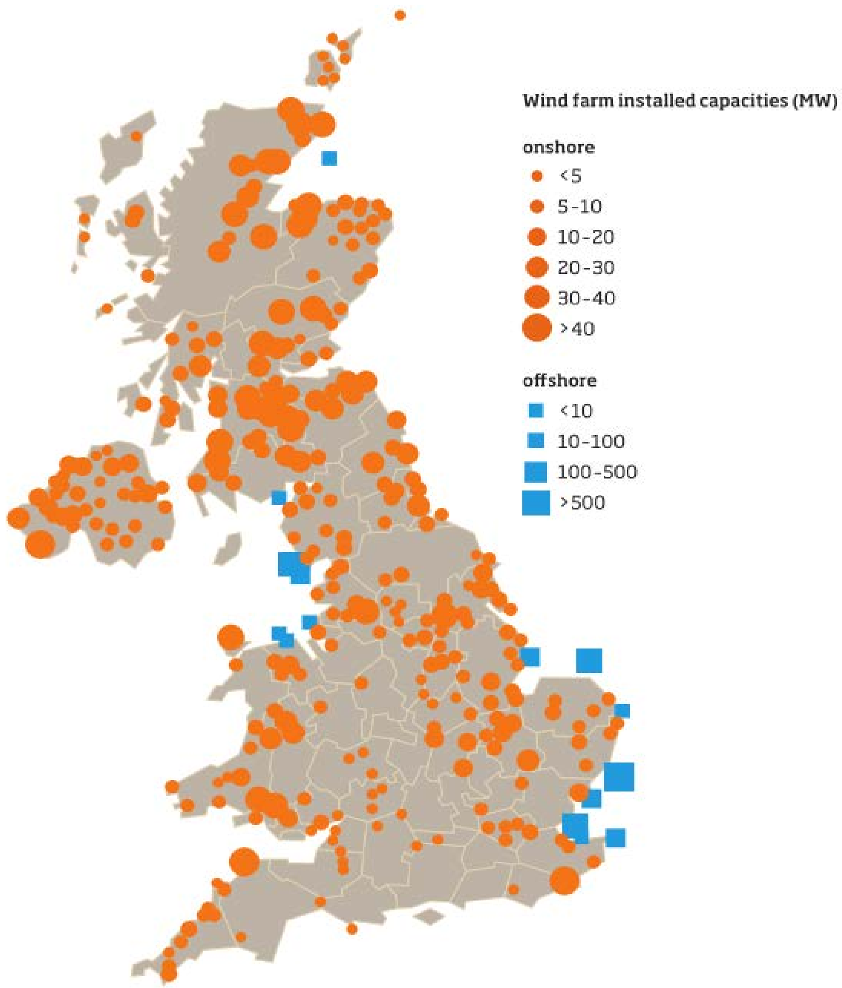
Cardiff University, UK

- Ranked 5th in the UK for the quality of our research and 2nd nationally for the impact of our research.

- The *HVDC* and *Power Electronics* research group has a focus on developing technology for HVDC grids.
- 20 academics/PhD students/ Postdocs/Visiting academics working in this area with
- Over £5.2 million of research grants for ongoing projects
- The main research topics are:
  - ✓ Fast Frequency support HVDC-connected offshore wind farms
  - ✓ Multi-Terminal VSC-HVDC (MTDC) Fault-ride-through Capability
  - ✓ Integration of offshore wind farms using MTDC grids
  - ✓ Flexible direct current flow control device in MTDC grids
  - ✓ Sub-Synchronous Resonance (SSR) damping through VSC & TCSC control

Introduction

- Drivers for development of Offshore Grids in the UK



- Renewable Energy Targets
  - Increasing wind capacity:
    - Operational in 2015
      - 7 GW Onshore
      - 5 GW Offshore
    - Planned to 2020
      - 5 GW Onshore
      - 4 GW Offshore
- Remote offshore wind farms will use VSC-HVDC transmission.

Fig. 1: Geographical distribution of installed wind capacity [1]

[1] RAEng, "Wind Energy - implications of large-scale deployment on the GB electricity system," London, 2014.

Introduction

❑ Drivers for development of Offshore Grids in the UK

Existing Interconnectors
1. IFA – 2GW
2. BritNed – 1GW
3. Moyle – 0.5GW
4. East-West – 0.5GW

Mature proposed interconnector
5. Eleclink – 1GW
6. NEMO – 1GW
7. IFA2 – 1GW
8. FAB – 1.4GW
9. NSN – 1.4GW
10. Northconnect – 1.4GW
11. Viking – 1.4GW
12. Greenlink – 0.5GW

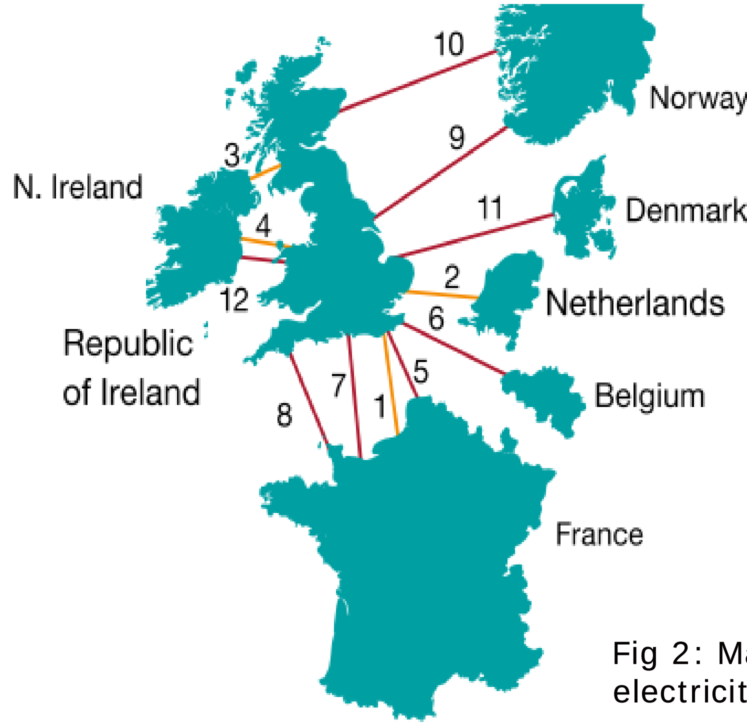


Fig 2: Map of existing and proposed GB electricity interconnection projects [2]

- ❑ Electricity Interconnection Targets
  - 4 GW Existing
  - 11 GW Planned to 2020

[2] DECC, "Delivering the UK Energy Investment: Networks," London, 2015.

❑ Key challenges:

- ❑ Lack of inertia from variable speed wind turbines & HVDC links
- ❑ 11 GW HVDC-connected generation capacity would replace 13 GW synchronous generation
- ❑ System inertia reduction increases risk of frequency control and system operation

❑ How to control frequency of AC grids with low inertia?

Fast Frequency Support from MTDC Systems

- Uses the energy transferred from:
  - Kinetic Energy stored in Wind Turbine rotating mass

$$\Delta E_{ko} = \frac{1}{2} J \omega_0^2 \left(1 - \frac{\omega_1^2}{\omega_0^2}\right) \qquad (1)$$

J – moment of inertia

ω_1, ω_0 – measured and synchronous rotor speed

  - Additional power from Other AC system (e.g. Norway grid)
  - Electrostatic Energy stored in MTDC Capacitance ***(Very small contribution)***

$$\Delta E_{MTDC} = \frac{1}{2} N_T . C_e V_{dc0}^2 \left(1 - \frac{V_{dc1}^2}{V_{dc0}^2}\right) \qquad (2)$$

C_e – capacitance of each VSC

N_T – number of terminals in the DC grid

V_{dc1}, V_{dc0} – measured and rated dc voltage

- Wind Turbine Inertia → Limits Rate of change of Frequency
- Active Power Transfer → Contains Frequency Deviation

3-Terminal VSC-HVDC System

- Normal Operation

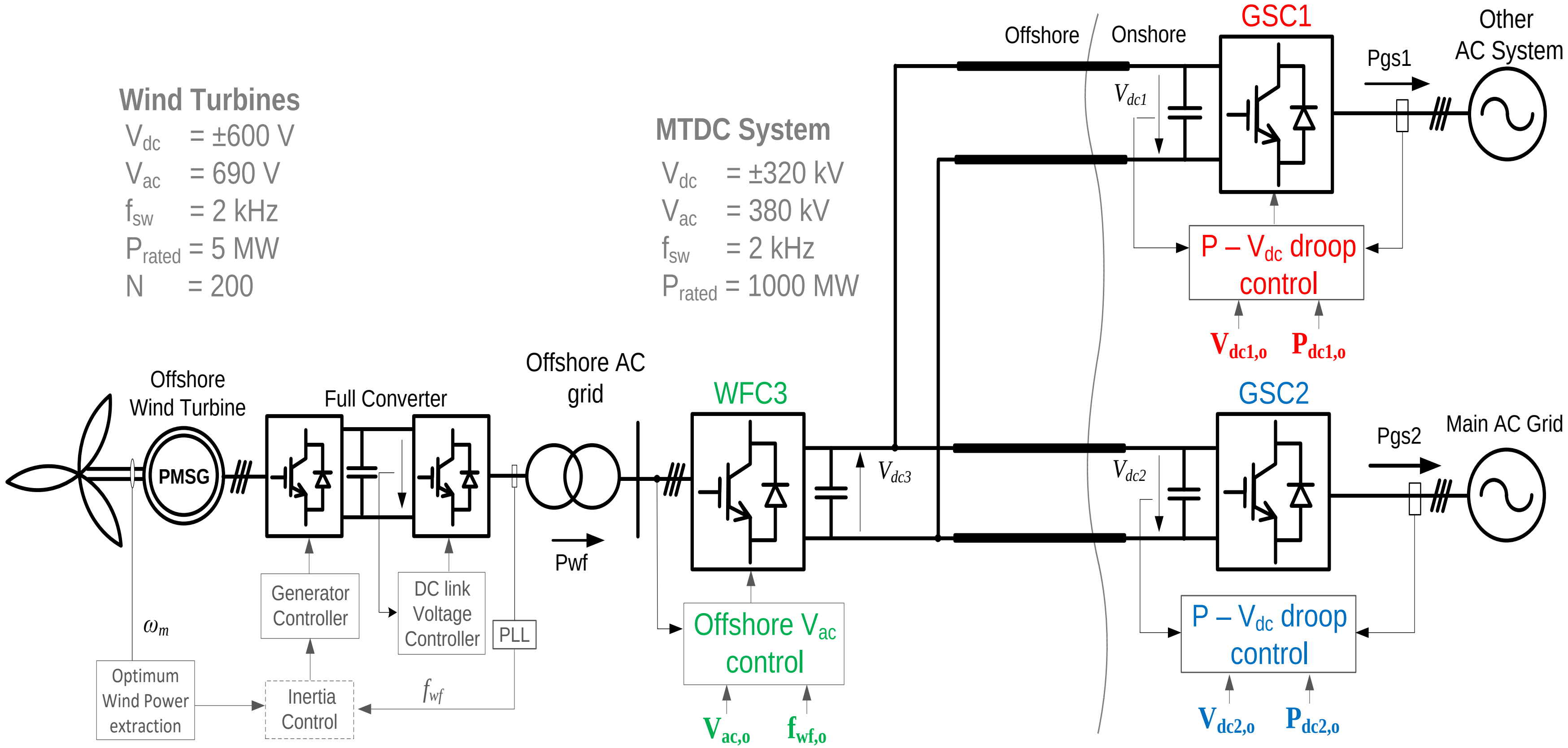


Fig 3: Control blocks and schematic diagram of a 3-Terminal VSC-HVDC System

- GSC1 regulates DC voltage and provides power balance to other AC system
- GSC2 regulates DC voltage and provides power balance to main AC Grid
- WFC3 extracts maximum power from wind farm

3-Terminal VSC-HVDC System

- **Coordinated Control**

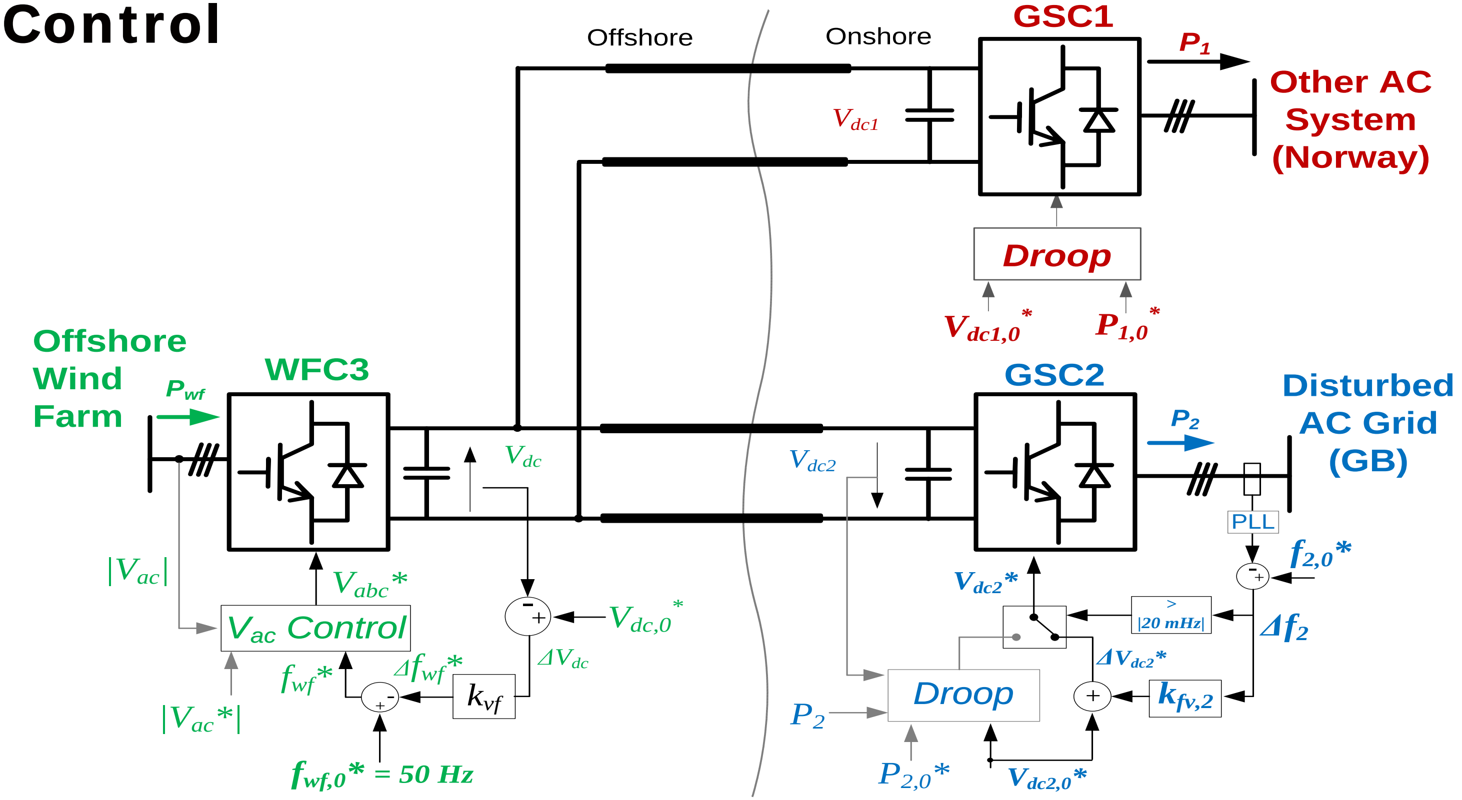


Fig 4: Control duties of the HVDC converters in the case of CC.

- **An *f* vs. V_{dc} droop regulates DC Voltage on GSC2 connected to disturbed AC grid**
- A ***P*** vs. V_{dc} droop on GSC1 connected to the other AC system.
- A V_{dc} vs. ***f*** droop is used in the offshore wind farm converter

3-Terminal VSC-HVDC System

Alternative Coordinated Control

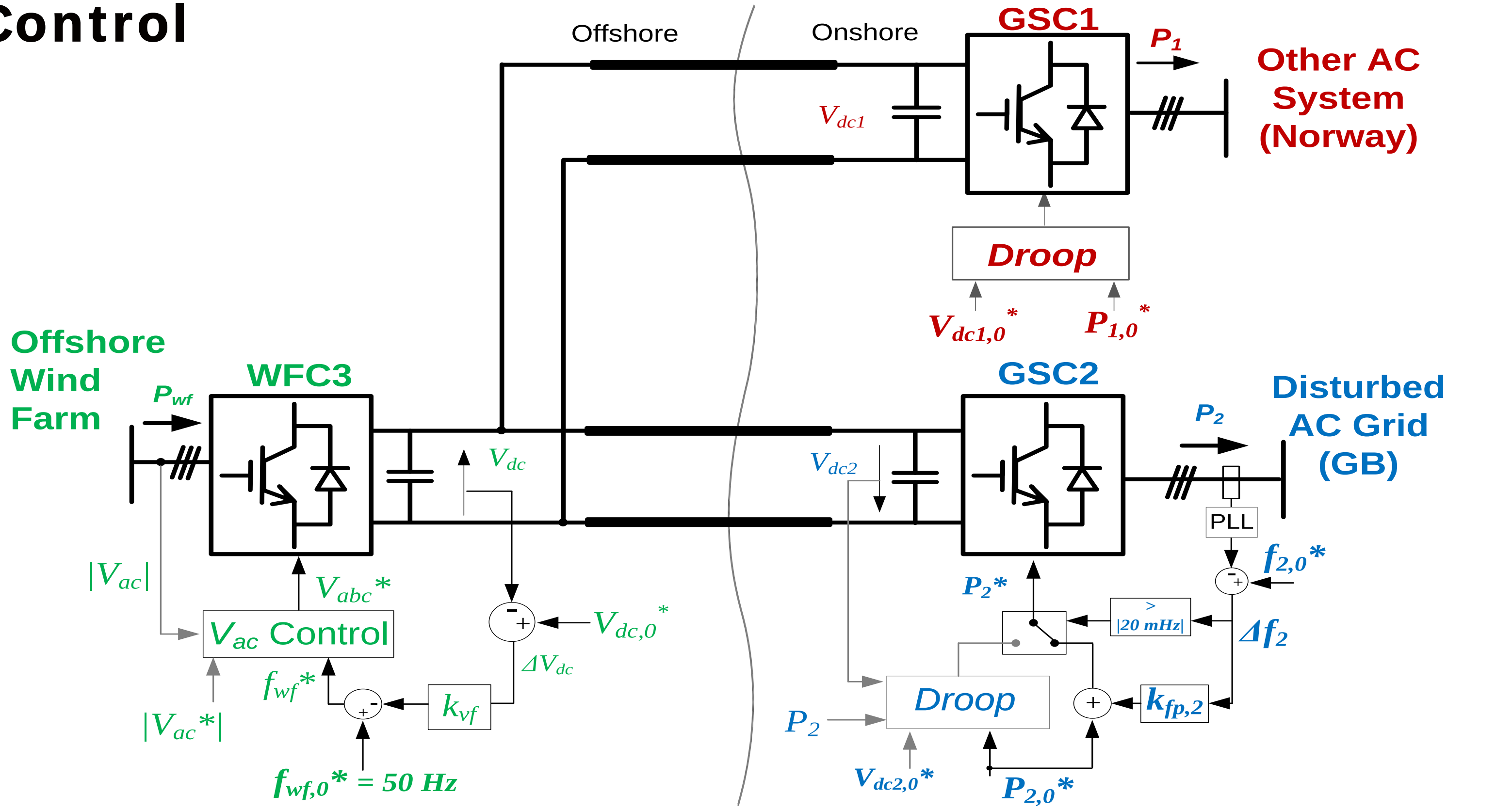


Fig 5: Control duties of the HVDC converters in the case of ACC

- **An *f* vs. *P* droop regulates Active Power from GSC2 to disturbed AC grid**
- A ***P*** vs. V_{dc} droop on GSC1 connected to the other AC system.
- A V_{dc} vs. ***f*** droop is used in the offshore wind farm converter

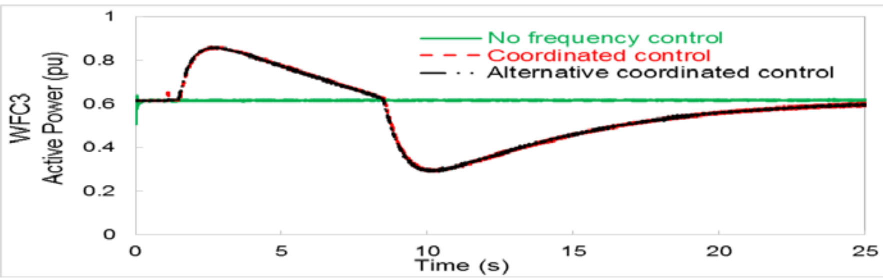
Simulation Results

- With 1 GW two-level VSC type & 1 GW Wind Farm
- Comparison of the two frequency control schemes:

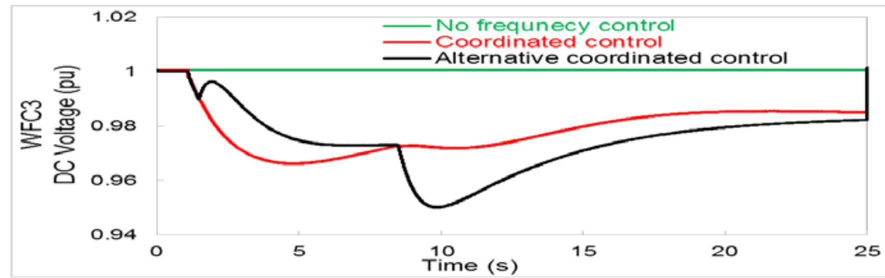
→ **Coordinated Control**

→ **Alternative Coordinated Control**

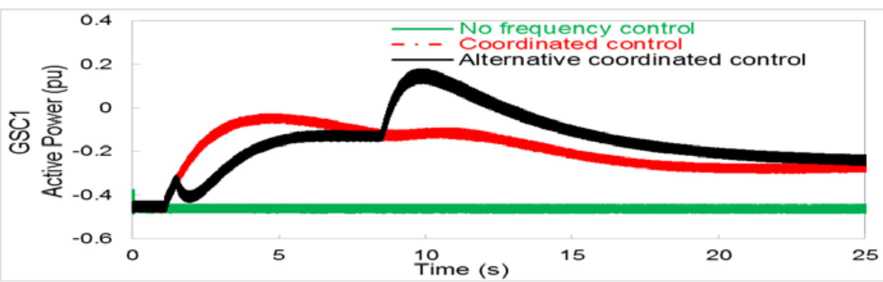
- Wind Farm Converter Active Power



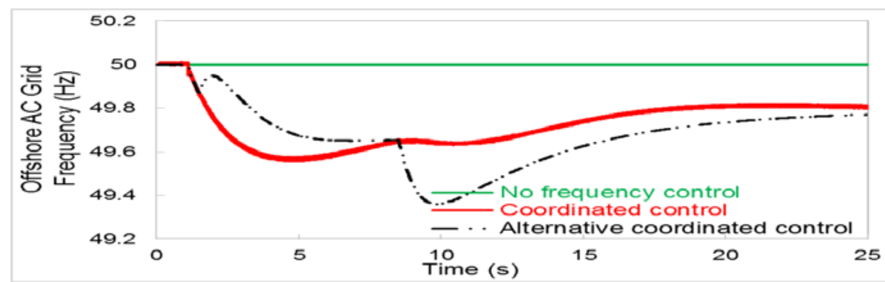
- Wind Farm Converter DC Voltage



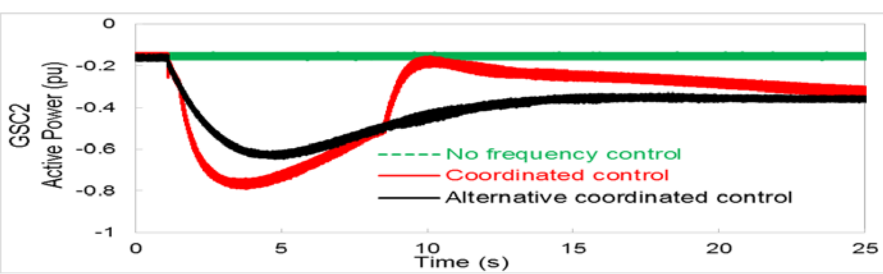
- Other AC System (Norway) Active Power



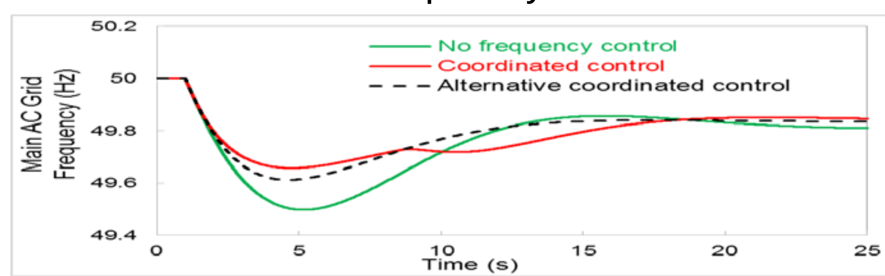
- Offshore AC Frequency



- Main AC Grid Active Power



- Main AC Grid Frequency



Experimental Test Rig

- Configuration

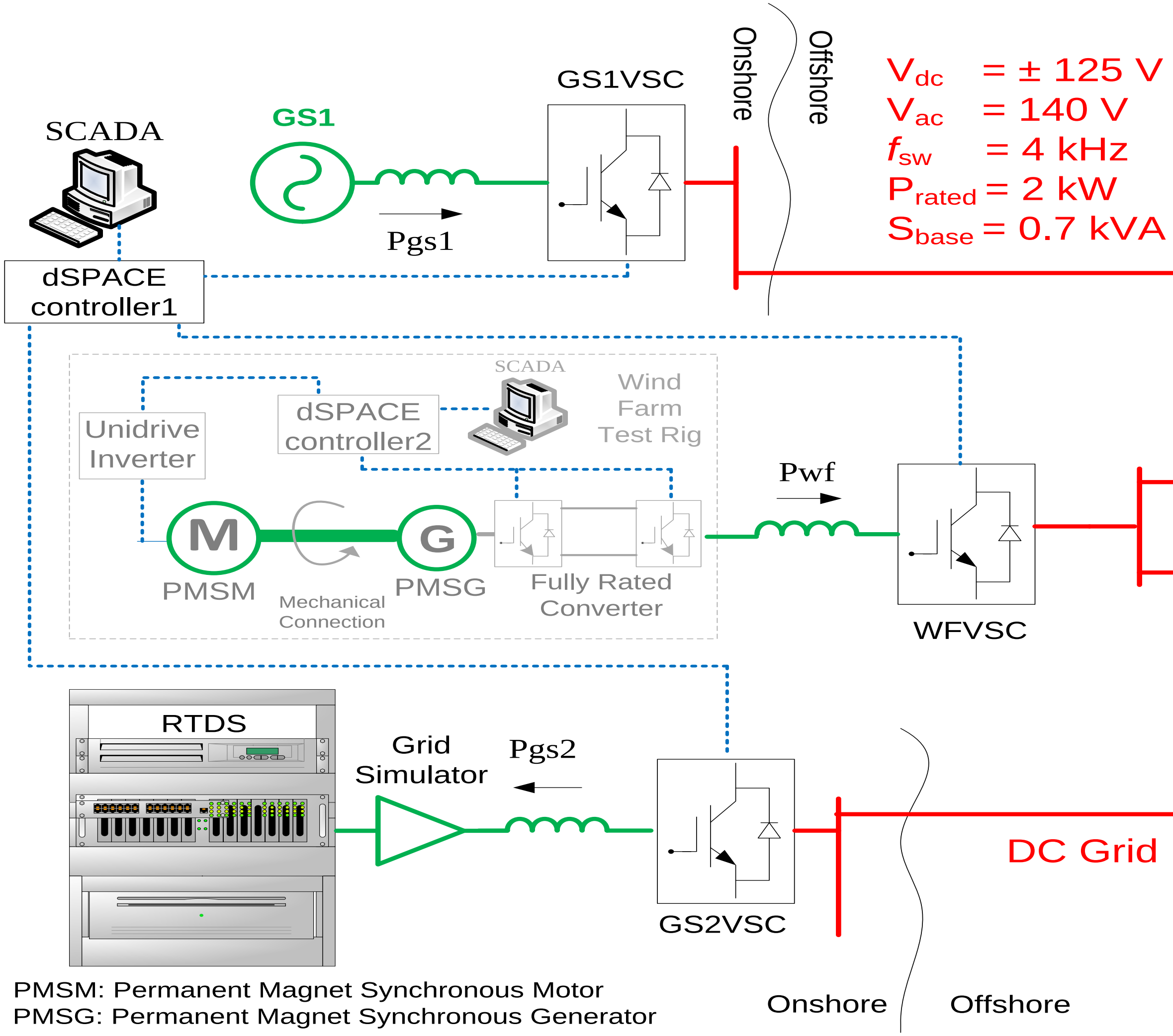


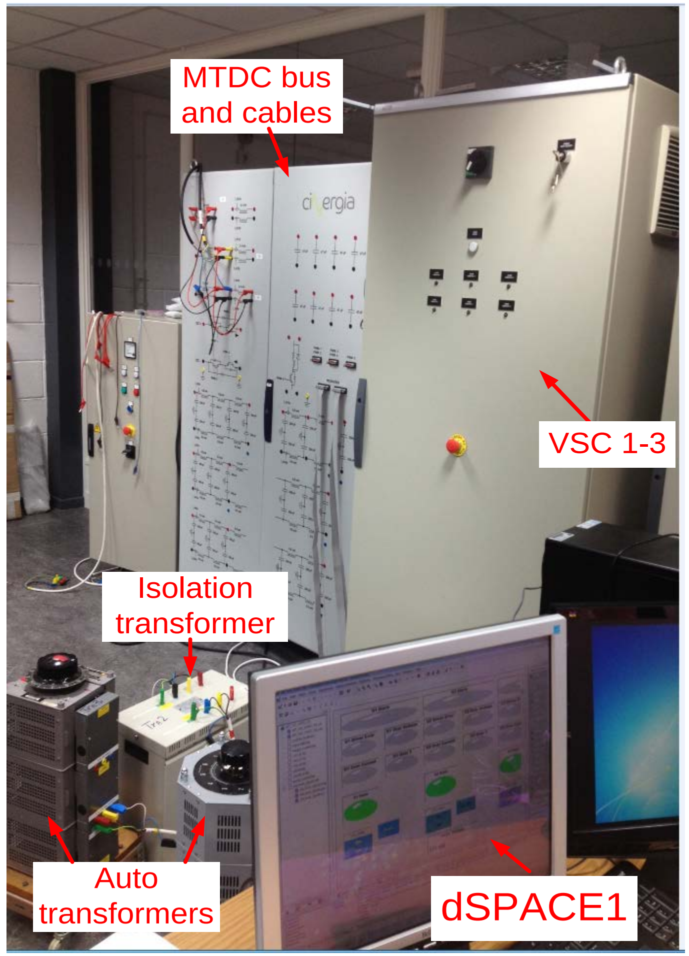
Fig 6: Configuration of the experimental platform

Experimental Test Rig

- Set-up

Main AC Grid Simulator

MTDC Test Rig



Wind Turbine Test Rig

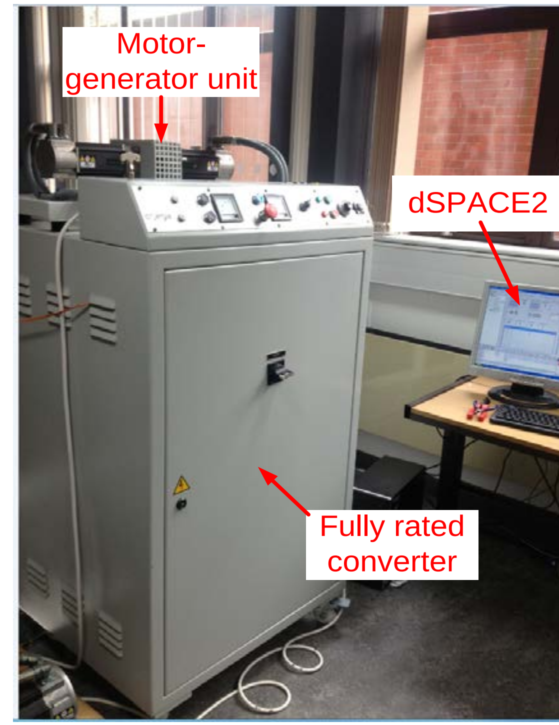


Fig 7: Setup of the experimental platform

Hardware in the Loop Test using RTDS

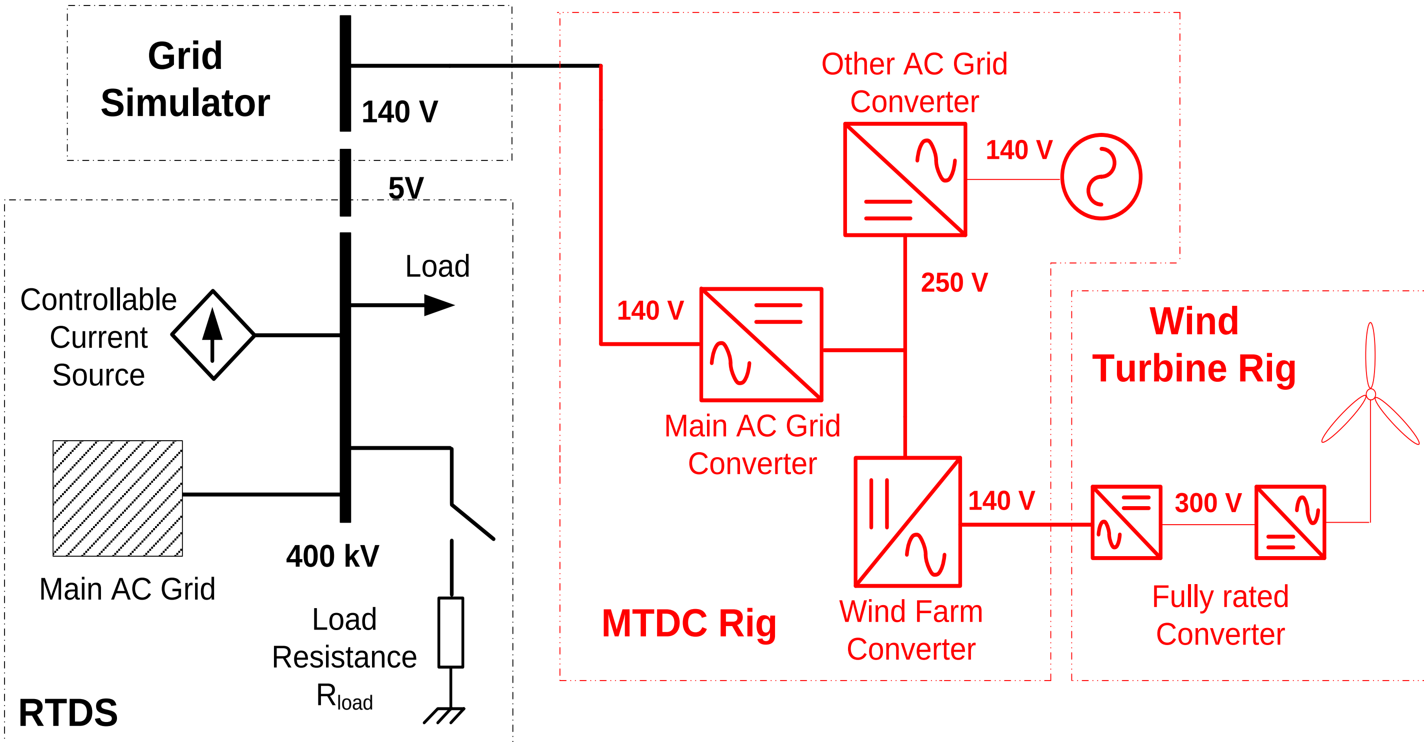


Fig 8a: Schematic diagram with operational voltages

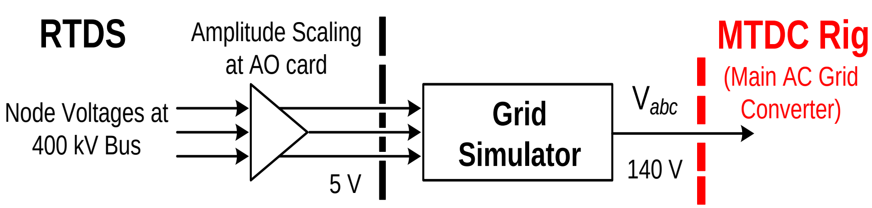


Fig 8b: AC Voltage signal transfer from RTDS to Grid Simulation to GSC2

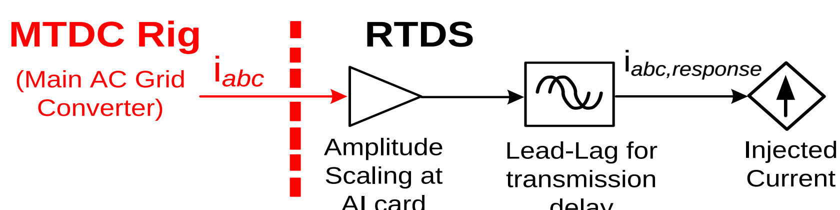


Fig 8c: Current signal transmitted from GSC2 to RTDS

Simplified AC Grid Modelled in RTDS

- Main AC Grid
  - **Frequency dependent load model**

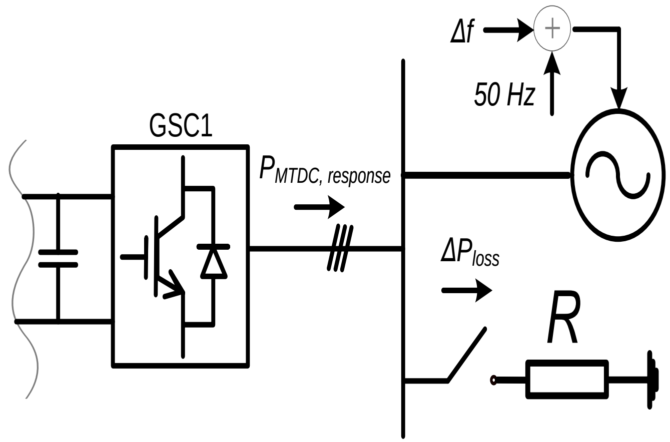


Fig 9: Controlled voltage source and load model

  - **Simplified GB Power System Model**

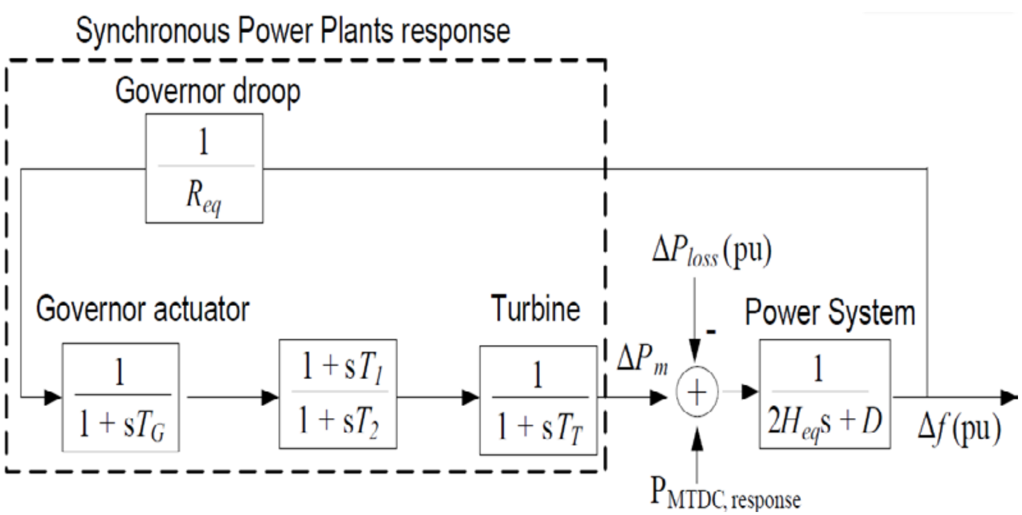
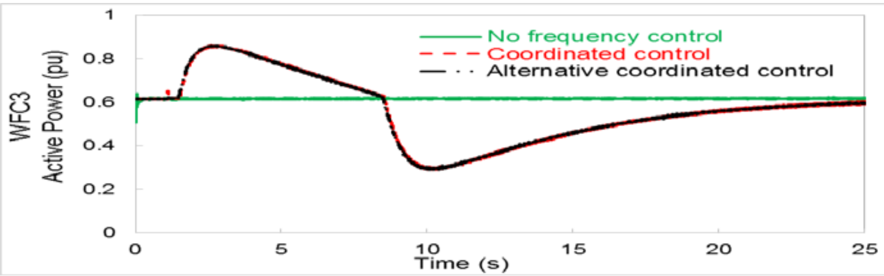


Fig 10: Transfer function blocks of the GB grid

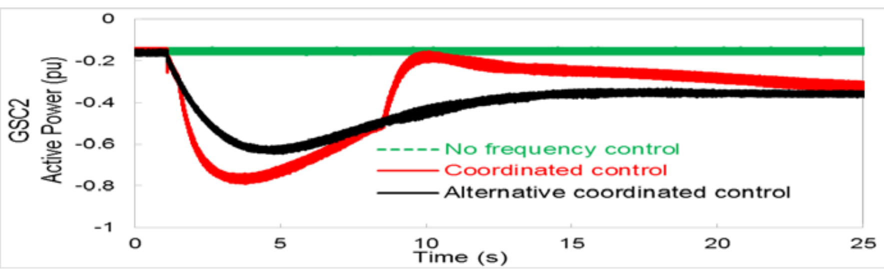
Simulation and Experimental Results

❑ Simulation

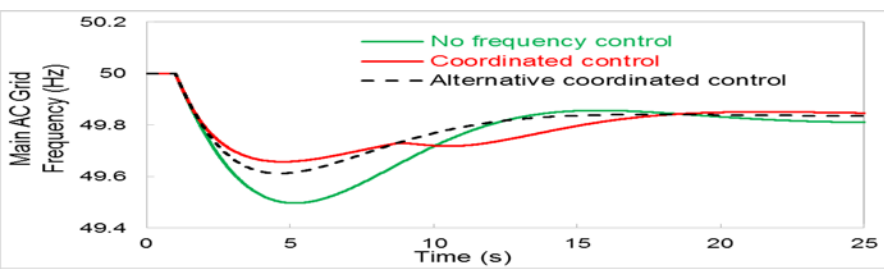
▪ Wind Farm Converter Active Power



▪ Main AC Grid Active Power

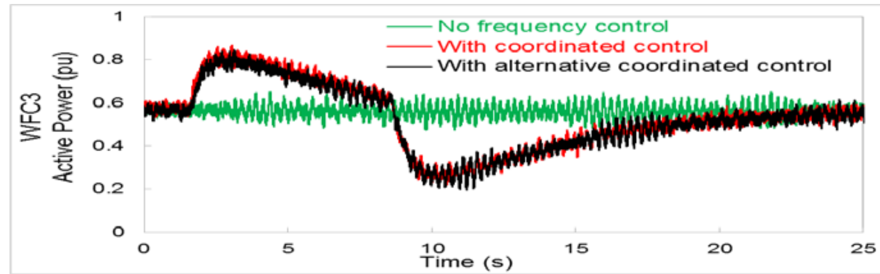


▪ Main AC Grid Frequency

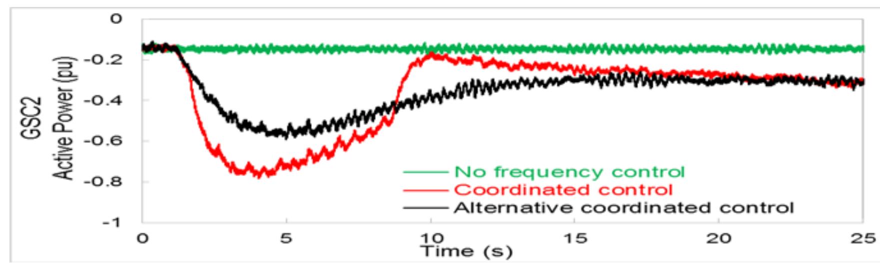


❑ Experimental

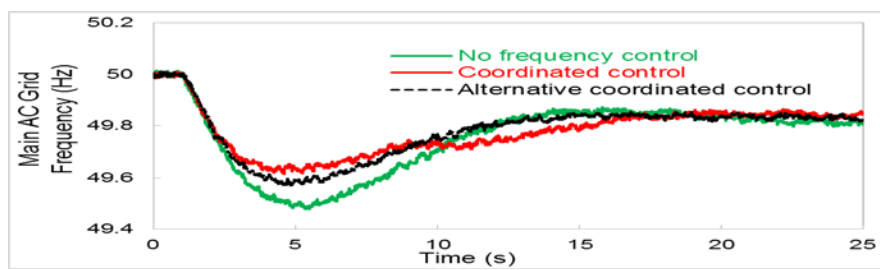
▪ Wind Farm Converter Active Power



▪ Main AC Grid Active Power



▪ Main AC Grid Frequency

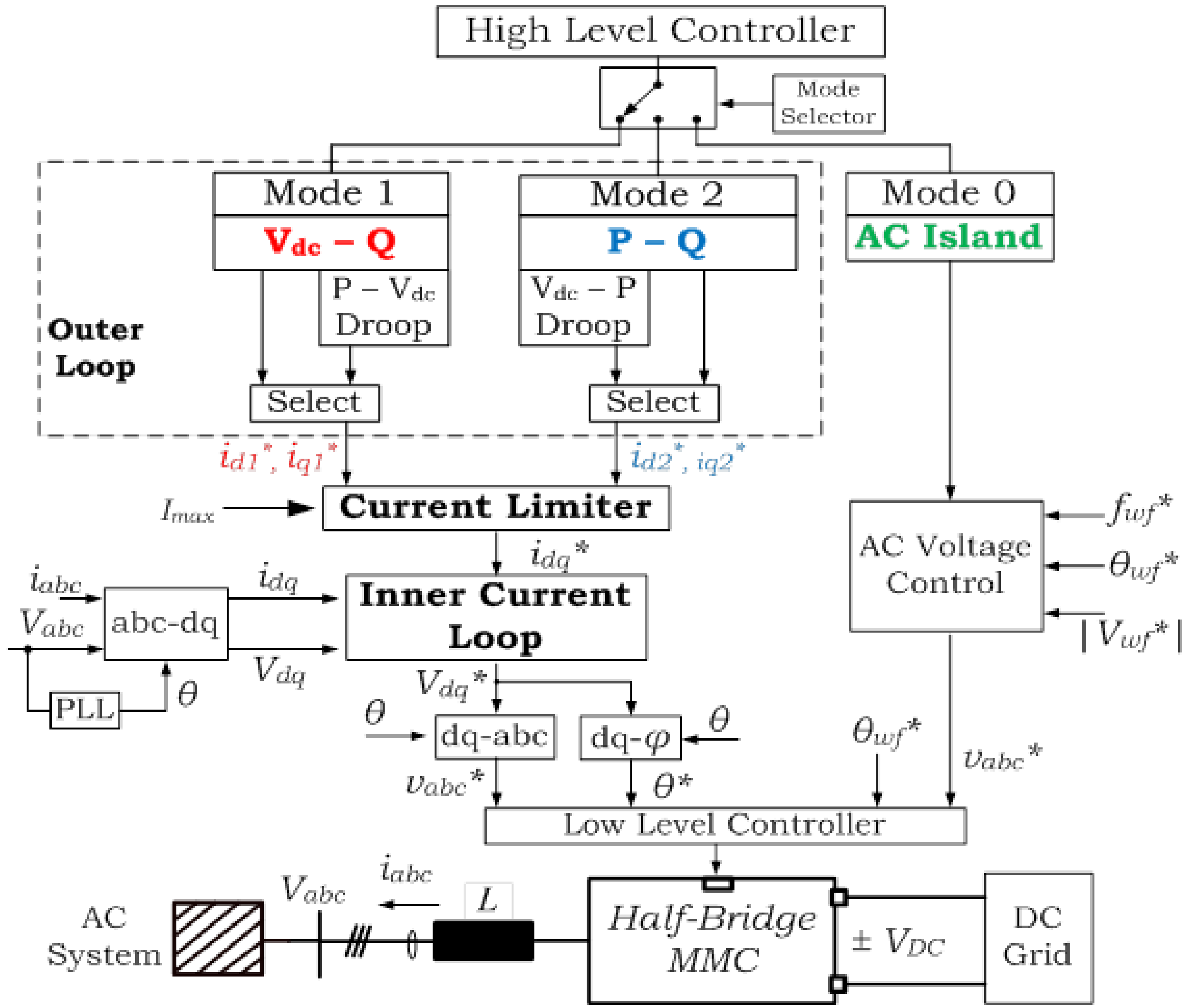


Conclusions

- **Fast Frequency response from MTDC limits RoCoF and contains frequency deviation on disturbed AC Grids.**
- **During the case of CC, the WT recovery period results in a further drop of system frequency**
- **In the case of ACC, the other AC system supplies the WT recovery power**
- **RTDS-connected power amplifier creates AC grid voltage with frequency disturbance for experimental VSC test rig.**

Current Work – BEST PATHS Project

- **Developed High Level Controller for VSC HVDC systems**
  - Mode 0: AC Voltage Control
  - Mode 1: Active & Reactive Power Control
  - Mode 2:DC Voltage & Reactive Power Control
- **Mode 1 fitted with active power versus DC voltage droop**
- **Mode 2 fitted with DC voltage versus active power droop**
- **Models fully functional in MATLAB**



Thank you for listening.

Any questions please?