HVDC challenges in meeting current GB Grid Code in a weak network

20th March 2020

Webcast

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The National HVDC Centre

CARDIFF UNIVERSITY
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Development of HVDC Connections in GB

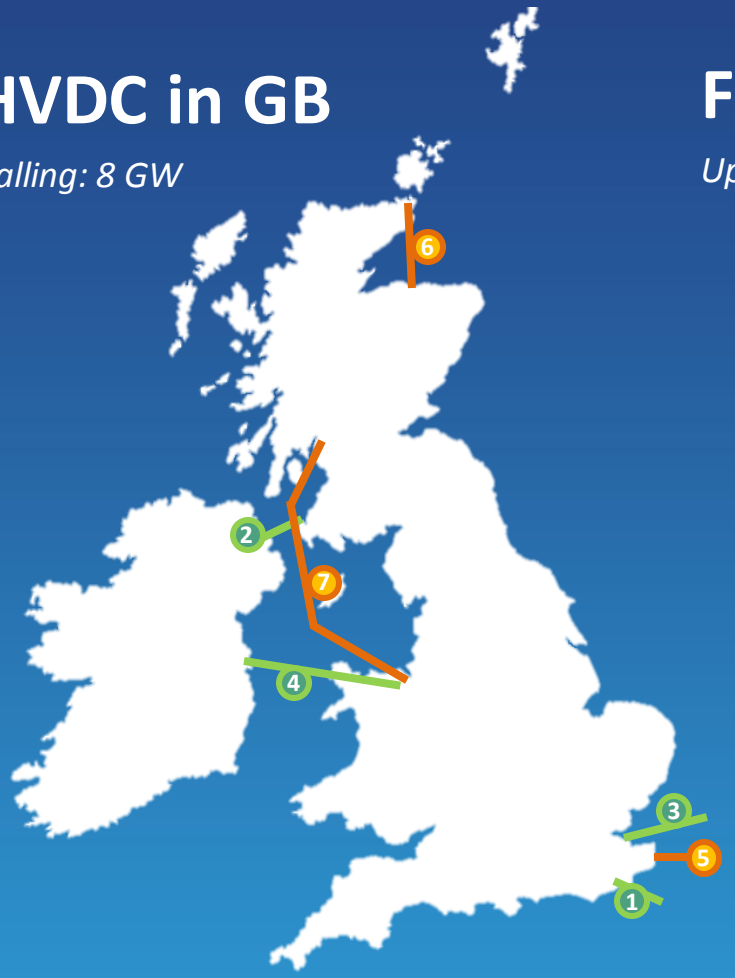
Current HVDC in GB

7 HVDC Links - Totalling: 8 GW

Interconnectors:
1) Cross Channel (IFA)
2) Moyle
3) BritNed
4) EWIC

New Interconnector:
5) Nemo

New Embedded Links:
6) Caithness – Moray
7) Western Link

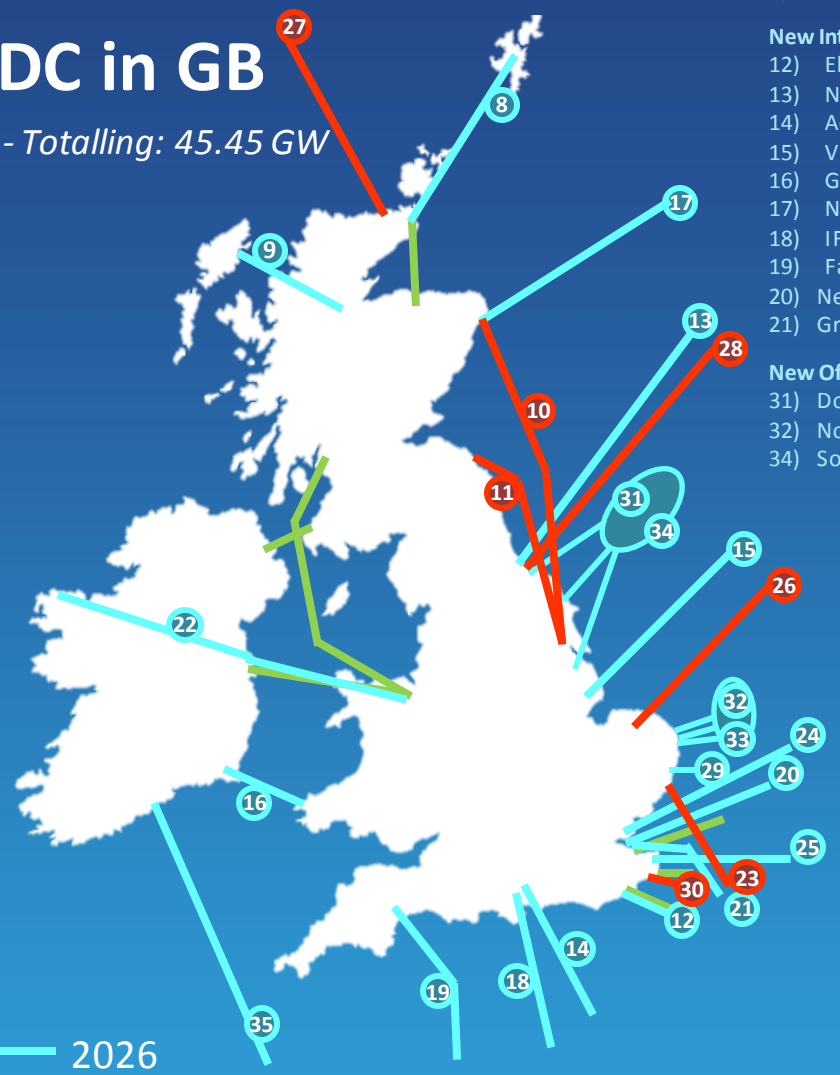


2018
2019

Source: National Grid Interconnector Register 01 08 2019

Future HVDC in GB

Up to 34 HVDC Links - Totalling: 45.45 GW



2026
2027+

New Island Links
8) Shetland
9) Western Isles

New Interconnectors
12) ElecLink
13) NSL
14) Aquind
15) Viking
16) GreenLink
17) NorthConnect
18) IFA2
19) Fablink
20) NeuConnect
21) Gridlink

New Offshore Wind Connections
31) Dogger Bank
32) Norfolk Vanguard
34) Sofia

New Embedded Links
10) Eastern Link 2
11) Eastern Link 1

Additional Interconnectors
26) Aminth
27) Atlantic Super Connection
28) Continental Link

The technical risks emerging…

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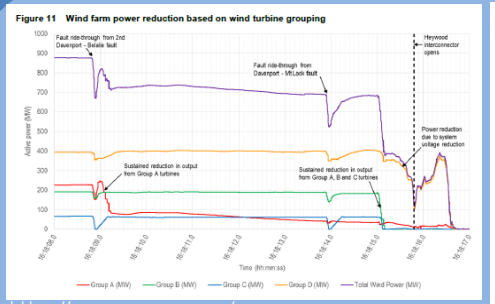
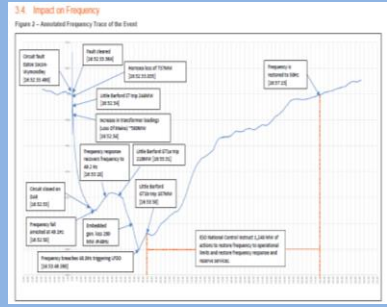
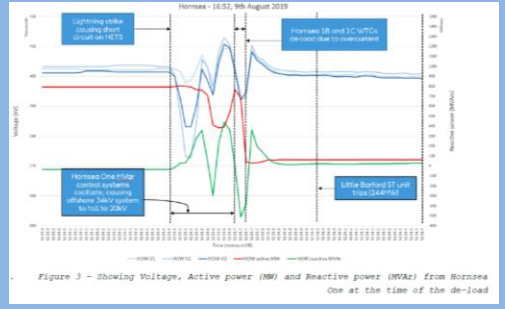
- Single point failure risks, as network conditions change-and more complex designs emerge
- Tracking and managing changes occurring over lifetime.
- Completeness of information and analysis possible ahead of connection



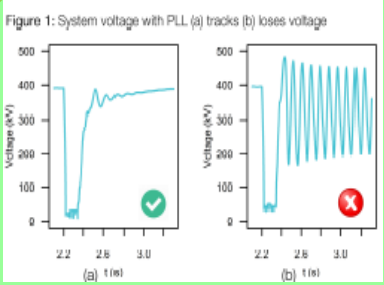
https://www.aemo.com.au/-/media/Files/Electricity/NEM/Market_Notices_and_Events/Power_System_Incident_Reports/2017/Integrated-Final-Report-SA-Black-System-28-September-2016.pdf



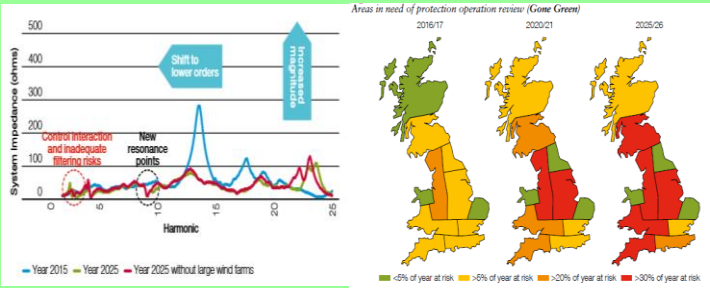
https://www.ofgem.gov.uk/publications-and-updates/investigation-9-august-2019-power-outage



- Hidden project interactions
- New vulnerabilities…



https://www.nationalgridso.com/publications/system-operability-framework-sof



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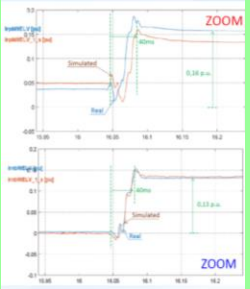
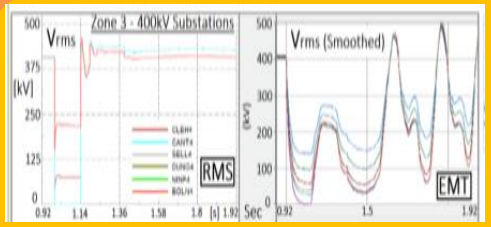


https://www.aanmelder.nl/ac-dc/wiki/470968/presentations

- Hidden project behaviours



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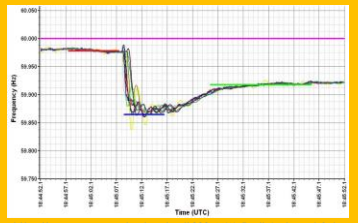
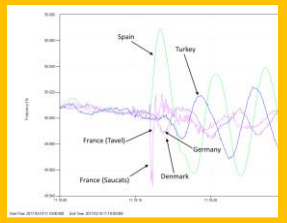
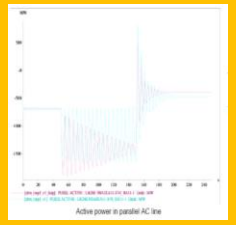


https://www.nerc.com/pa/rrm/ea/1200_MW_Fault_Induced_Solar_Photovoltaic_Resource_/1200_MW_Fault_Induced_Solar_Photovoltaic_Resource_Interruption_Final.pdf





https://www.wecc.org/Administrative/14_RTE-Interarea%20oscillations.pdf

- Completeness of codes & standards & Data Exchange

HVDC can be part of the problem, or part of the solution

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The Challenge for codes.

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❑ Risk environment is growing

The future will see a huge investment in HVDC schemes in GB; the most concentrated development of HVDC in the world. Other convertor technologies also growing at pace. Such extensive development poses significant risks to the reliable operation, control and resilience of the GB network.

❑ HVDC & convertor based performance is key to this risk

HVDC technologies are the largest individual examples of convertor technologies contributing to these risks, and can be designed to mitigate, rather than contribute to these risks.

❑ The pace of change.

Code requirements tend to evolve slowly as knowledge of the risk grows "after the fact" informing precise nature of changes needed. However the nature and visibility of risk is equally critical as informed by a more complete modelling and testing environment.

CONTENTS

Overview and Background

Method & structure of analysis

Testing to Grid Code Requirements

Gaps & Risks identified

Summary and Next steps

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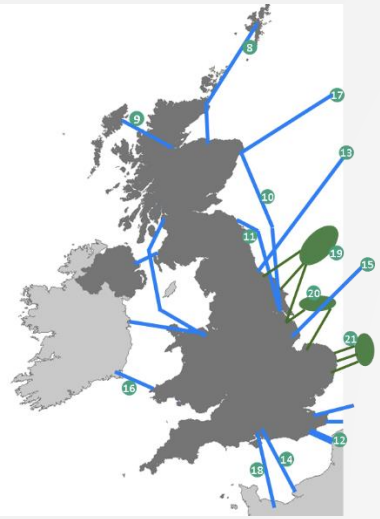
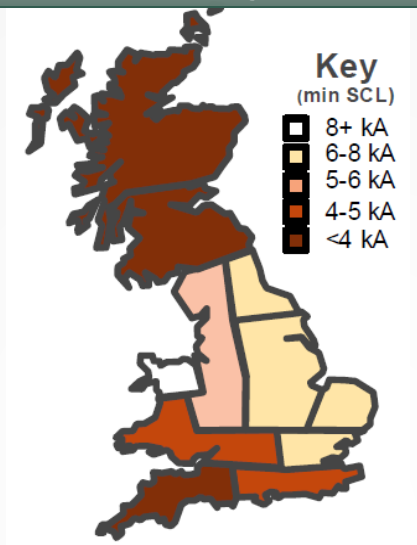
Overview and Background: Key Challenges

Increased Connections



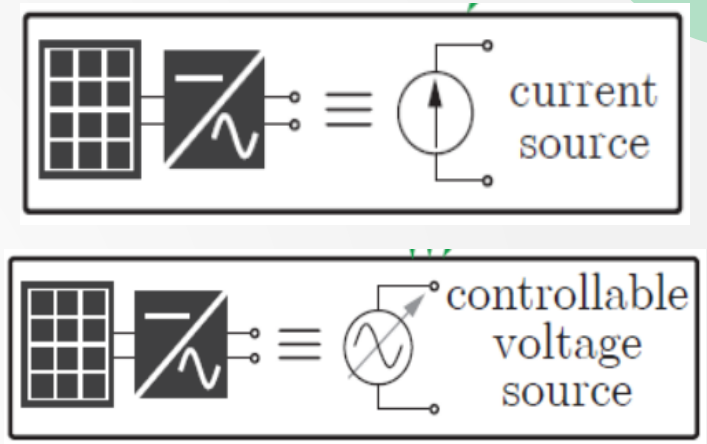
- HVDC capacity in the GB is expected to double by 2027
- Greater variety of HVDC and applications
- Largest single examples of power convertors connecting
- Flexibility for system services, potential risks from complexity.
- Codes look at each connection individually- how is total impact tracked?

Reduced System Strength



- Reduced system strength due to high penetration of power convertors
- Declining trend of system strength leads to stability and grid connection challenges
- New connections should be adaptable to present and foreseen future grid connections & conditions
- How are these best defined?

Control Challenges



- Operability challenges across the stages of grid connection, as designs are refined
- Grid Codes are experience-based- but the experience is changing
- New options for convertor control need effective design.
- Much of this is not visible in exchanged data-is it robust across its range of operation?

Overview & Background: Schedule & Purpose Of Work

- Task 1: Scoping of Grid Code challenges related to HVDC connection
  - Task 1.1. Identification of the key challenges faced by HVDC systems connected to weak grids
  - Task 1.2. Modelling and risk assessment – HVDC systems connected to weak grids.
- Task 2 Grid Code compliance tests – system operation with varying grid strength.
  - Task 2.1 Compliance tests for HVDC schemes with varying grid strength
  - Task 2.2 Validation of the tests using RTDS-Hardware-in-the-Loop (HiL).

- Looking "under the hood" of the convertor control of VSC-HVDC.
- Placing ourselves "in the shoes" of the convertor designer
- Understanding the decisions being taken, the control philosophies available.
- Understanding the "trade-offs".

- HVDC schemes need to be specified to support security of supply in a changing network environment
  - What do converter-based sources need to do to achieve this?
  - How well the current codes inform these design needs?
  - How well do we understand the impact of these decisions- as the environment changes?

Method and Structure of analysis

The analysis environment: key elements

The convertor model

- Representative MMC and control structures
- Key controls available to be tuned & modified
- Realistic control modes and system measurement
- Representing core areas of manufacturer design flexibility and capability with current VSC-HVDC designs.

The Network test model

- Capable of defining conditions of grid code test as presented to a manufacturer.
- Include other relevant simulation assumptions needed for the tests.

The Network test

- Different grid short circuit strength (SCL)
- Design of operating conditions for stable, marginal and unstable cases

Converter Sensitivity analysis

- **Different short circuit ratio (SCR)**
- **Different outer loop control modes**
- **Different Phase Lock Loop (PLL) types**
- **Different gains for Fast Fault Current Injection**

Experimental validation

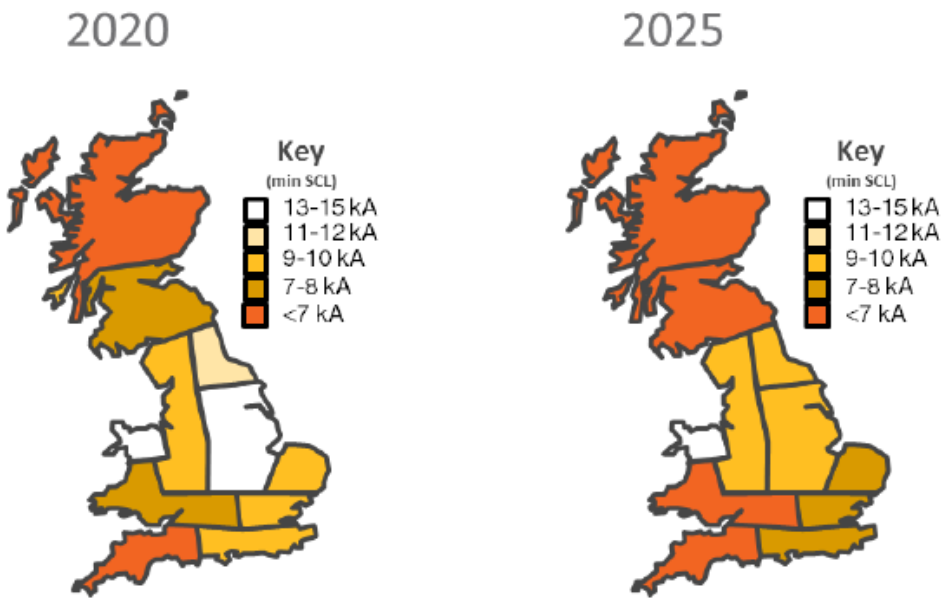
- Validation of simulation studies
- Comparison between offline and real-time operation
- Understand uncertainties not present in simulation

PSCAD/EMTDC

RSCAD/RTDS

Analysis assumptions: SCL

- The Short circuit strength (SCL) is a key factor provided to a network connection to inform analysis.
- The GB system operator National Grid (NG) has identified this scenario and identified the pattern of general decline of SCL in the network.
- This assessment has considered the effect of decline in the absolute magnitude of SCL, based on this data
- The assessment has similarly considered the effect of a lower inertia assumption within the test network
- Sensitivities have sought to test performance to the lowest levels of strength considered



National Grid, "The System Operability Framework", July 2018.

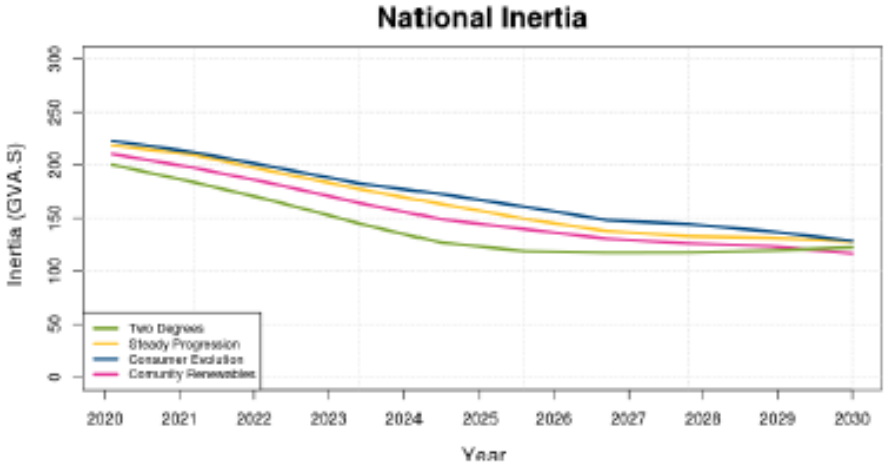


Figure 1: Inertia Trend to 2030

* Based of FES 2018 data

National Grid, "The System Operability Framework", February 2020.

Analysis measures: SCR, and other options

- In considering a convertor dominated, a range of measures can be used to defined network strength.
- Of these, only **SCR** can be defined from the data provided as standard at the time of any connection being a ratio between the short circuit power of the network and the power capability of the convertor.
- Our analysis has considered weak strength conditions to be at SCR= 3 and below.
- In such conditions, it is not clear that other convertors will contribute to system strength; or how this will be defined to a manufacturer.

Table 2.1: Comparison of SCR Methods

Metric		Simple calculation using short circuit program	Accounts for nearby inverter based equipment	Provides common metric across a larger group of VER	Accounts for weak electrical coupling between plants within larger group	Considers non-active power inverter capacity*	Able to consider individual sub-plants within larger group
SCR	Short Circuit Ratio	★★	X	X	X	X	X
CSCR	Composite SCR	★	★★	★★	X	X	X
WSCR-MW	Weighted SCR using MW	★	★★	★★	★	X	X
WSCR-MVA	Weighted SCR using MVA	★	★★	★★	★	★★	X
SCRIF	Multi-Infeed SCR	X	★★	X	★★	★★	★★

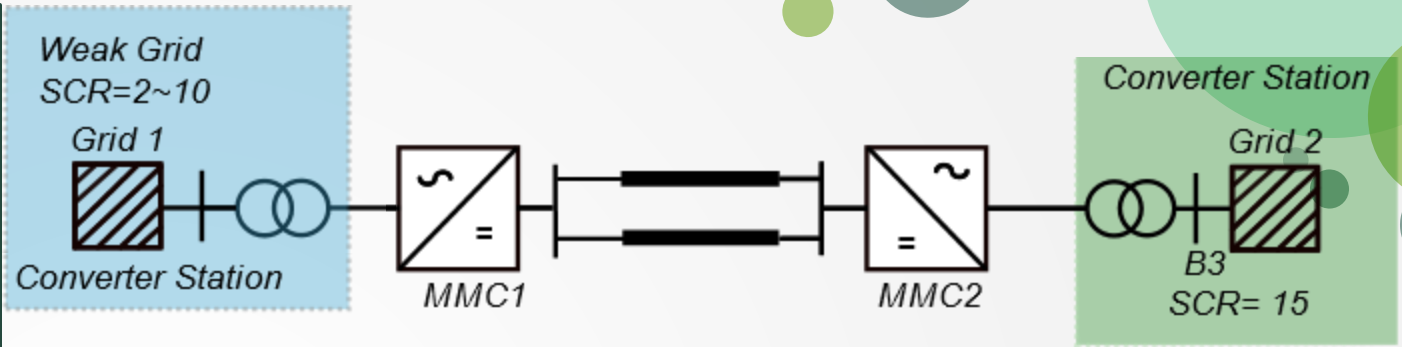
* e.g., STATCOMs or partial power inverter-based resources

Each metric has benefits and drawbacks in its application for assessing system strength and potential weak grid issues.

NERC guidelines, December 2017.

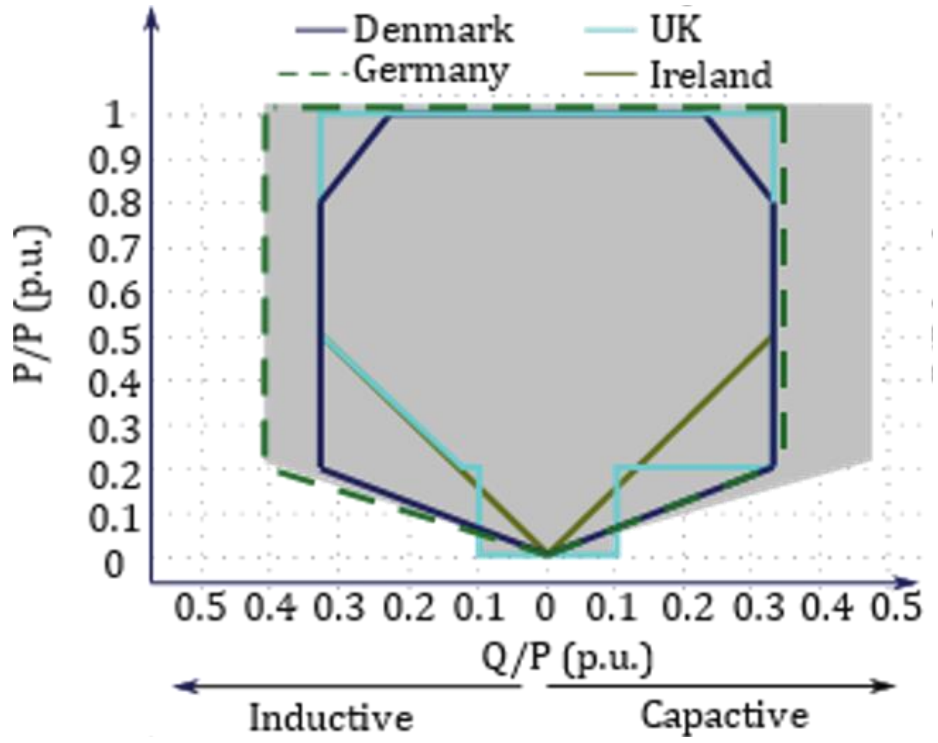
The test model considered.

- Capable of point-point and multi-terminal analysis
- Grid model is flexible to support investigation of:-
  - Voltage/reactive power requirements
  - Fault Ride Through requirements
- Code requirements investigated to GB specification.
- Voltage source Converter (VSC) technology with half-bridge modular multi-level convertors (MMCs)
- Grid 2 is modelled with varying network strength representation to study existing Grid Code requirements



Item	MMC1	MMC2
Rated Apparent Power (S)	840 MVA	1265 MVA
Rated Active Power (P)	±800 MW	±1200 MW
Convertor Nominal DC Voltage	640 kV (±320 kV)	640 kV (±320 kV)
AC Grid Voltage	275 kV	400 kV
SCR	2~10	15
Transformer Reactance	0.16 p.u.	0.16 p.u.
Control Modes (CM)	P and Q (CM1) P and Vac (CM2)	Vdc and Q

Task 1: Testing Grid Code Requirements



Mode	NC HVDC	NGESO
Power Factor	0.95 lead - 0.95 lag	0.95 lead - 0.95 lag
Voltage Range	1.1 p.u - 0.875 p.u. (0.225 p.u.)	1.1 p.u.– 0.875 p.u. (0.225 p.u.)
Maximum Q/P_{max}	0.95	0.95

REACTIVE POWER REQUIREMENTS

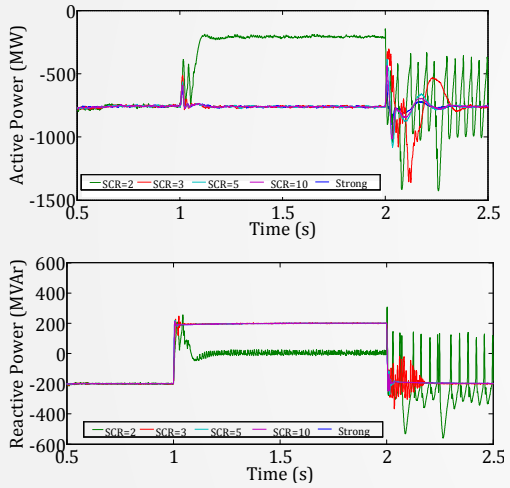
NC HVDC: Network Code for HVDC
NGESO: National Grid Electricity System Operator

Commission Regulation (EU) 2016/1447 of 26 August 2016 establishing a network code on requirements for grid connection of high voltage direct current systems and direct current-connected power park modules (Text with EEA relevance).

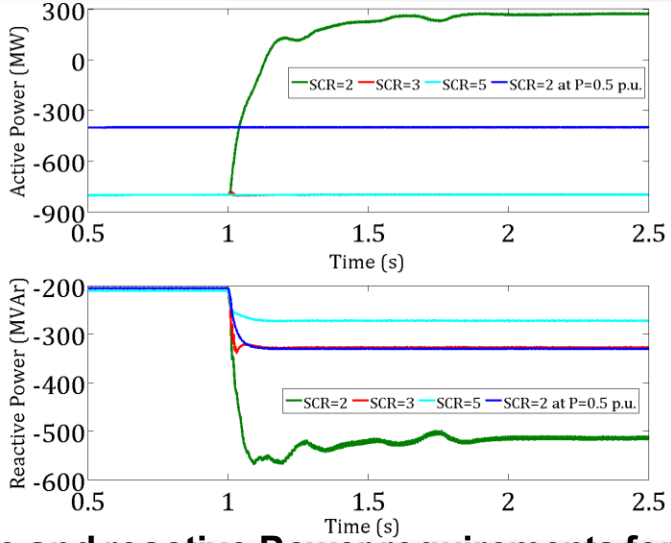
National Grid, "The Grid Code", Issue 5, revision 36, July 2019

System parameter requirements

- The AC voltage or reactive power control loop need to be tuned carefully across different SCRs
- At *t=1* s the power factor is changed from 0.95 lead to 0.95 lag and changed back at *t*=2 s
- The grid voltage deviation for this reactive power requirement case varies with SCR levels:
  - For SCR=5: 6%; SCR=3: 10% and for SCR=2: unstable

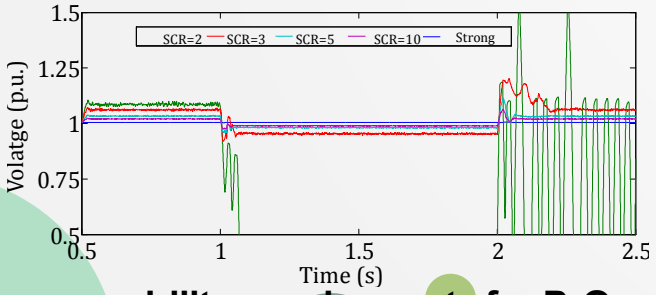


Active and reactive Power requirements for P-Q control mode



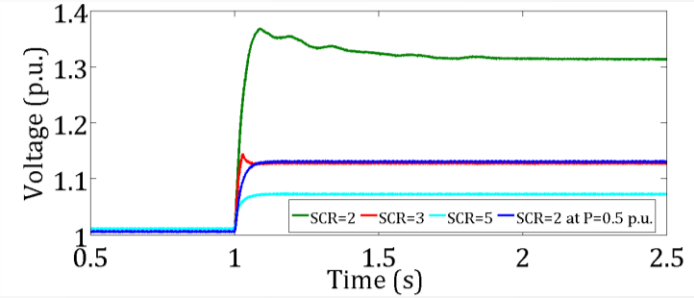
- At SCR=2 P-Vac control is unstable; but De-loading P to 0.5pu results in stable operation.

Active and reactive Power requirements for P-Vac control mode



- Voltage Step
- SCR=5: 6%;
- SCR=3: 10%
- SCR=2: unstable

Voltage capability requirements for P-Q control mode

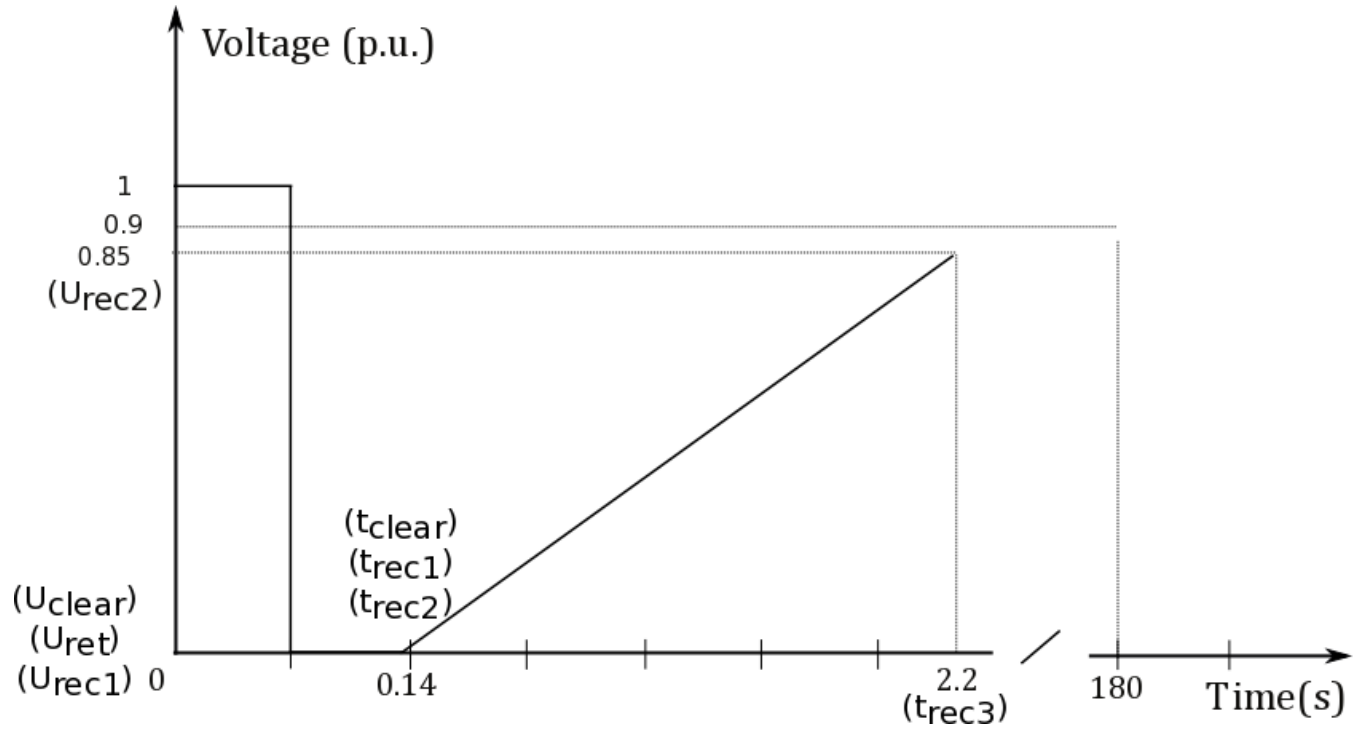


- Voltage Step
- SCR=5: 6%;
- SCR=3: 10%
- SCR=2: 30%

Voltage capability requirements for P-Vac control mode

Task 1: Testing Grid Code Requirements

Voltage parameters (p.u.)			Time parameters (seconds)		
Term	NC	NGESO	Term	NC	NGESO
U_{ret}	0-0.3	0	t_{ret}	0.14-0.25	0.14
U_{clear}	n/a	0	t_{clear}	n/a	0.14
U_{rec1}	0.25-0.85	0	t_{rec1}	1.5-2.5	0.14
U_{rec2}	0.85-0.9	0.85	t_{rec2}	t_{rec1}-10	2.2



FAULT RIDE THROUGH (FRT) REQUIREMENTS

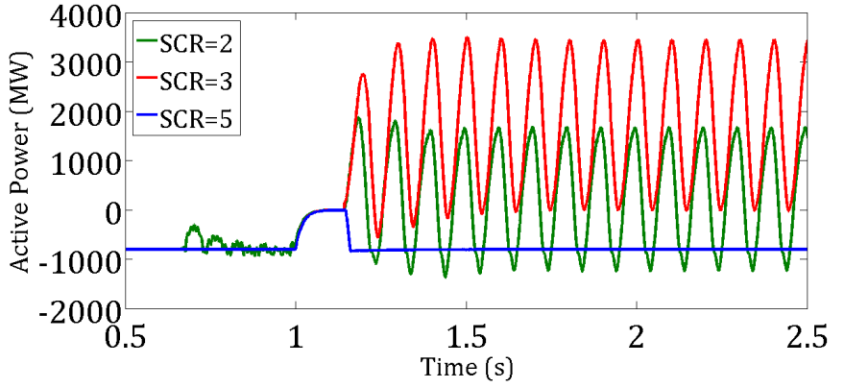
NC HVDC: Network Code for HVDC
NGESO: National Grid Electricity System Operator

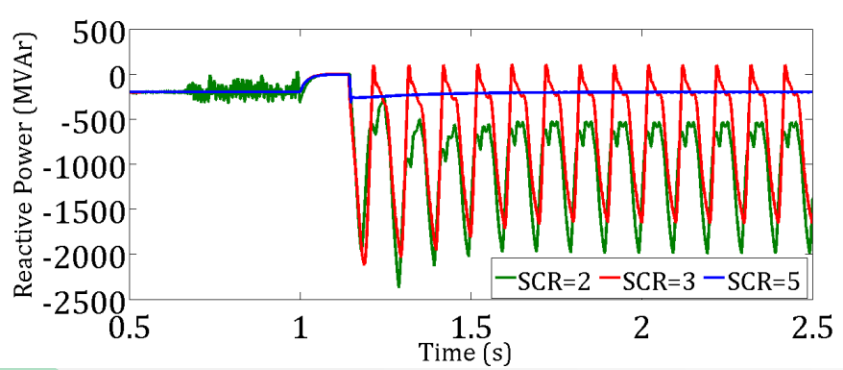
Commission Regulation (EU) 2016/1447 of 26 August 2016 establishing a network code on requirements for grid connection of high voltage direct current systems and direct current-connected power park modules (Text with EEA relevance).

National Grid, "The Grid Code", Issue 5, revision 36, July 2019

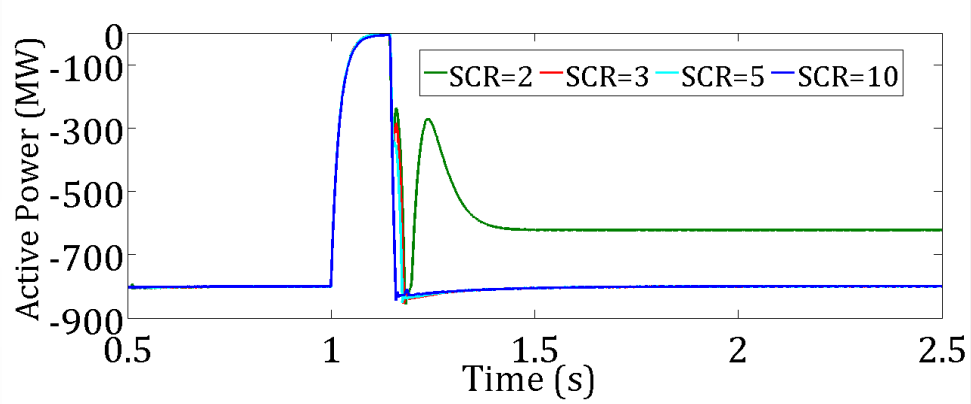
FRT requirements (1)

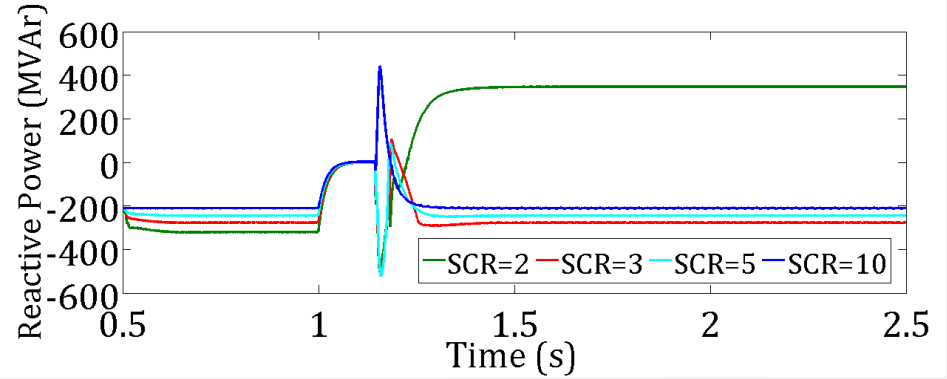
- Investigated the ability of the converter connected to weak grid to frt requirement Three-phase symmetrical fault applied at Grid 1 for 140 ms, with MMC1
- The SCR value of Grid 1 in changed from 10 to a different value at t = 0.7 s to emulate a weak grid
- However, the HVDC power oscillations are observed at reduced SCRs for P-Q control mode





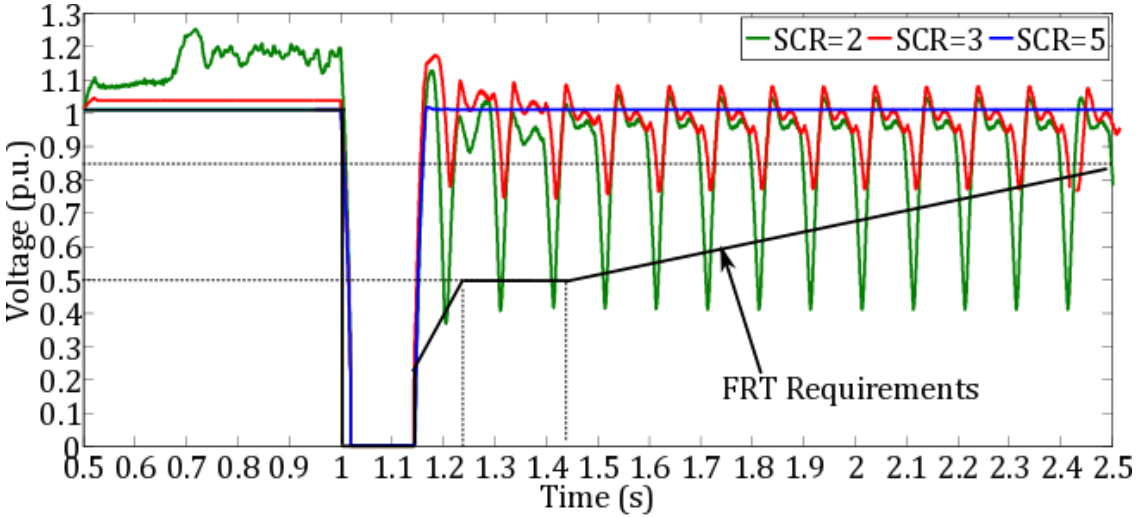
Active and reactive Power for P-Q control mode

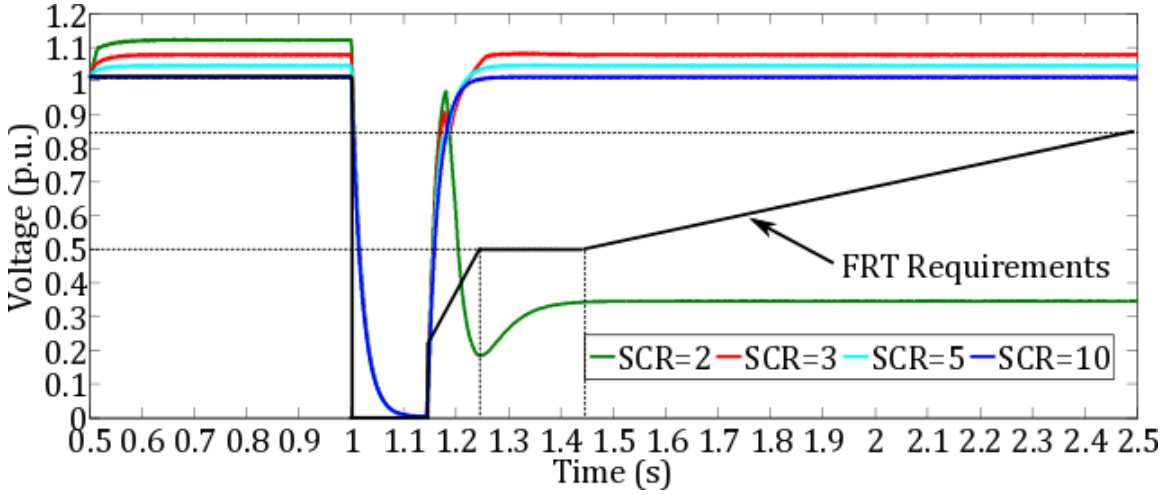




Active and reactive Power for P-Vac control mode

FRT requirements- impact of lower SCR on recovery by control mode





Voltage recovery for P-Q control mode

Unstable below SCR=5

Voltage recovery for P-Vac control mode

Unstable below SCR=3

- At lower SCRs de-loading P post-fault is an option to achieve stable operation.

Task 1: Summary and Recommendations

Connection challenges

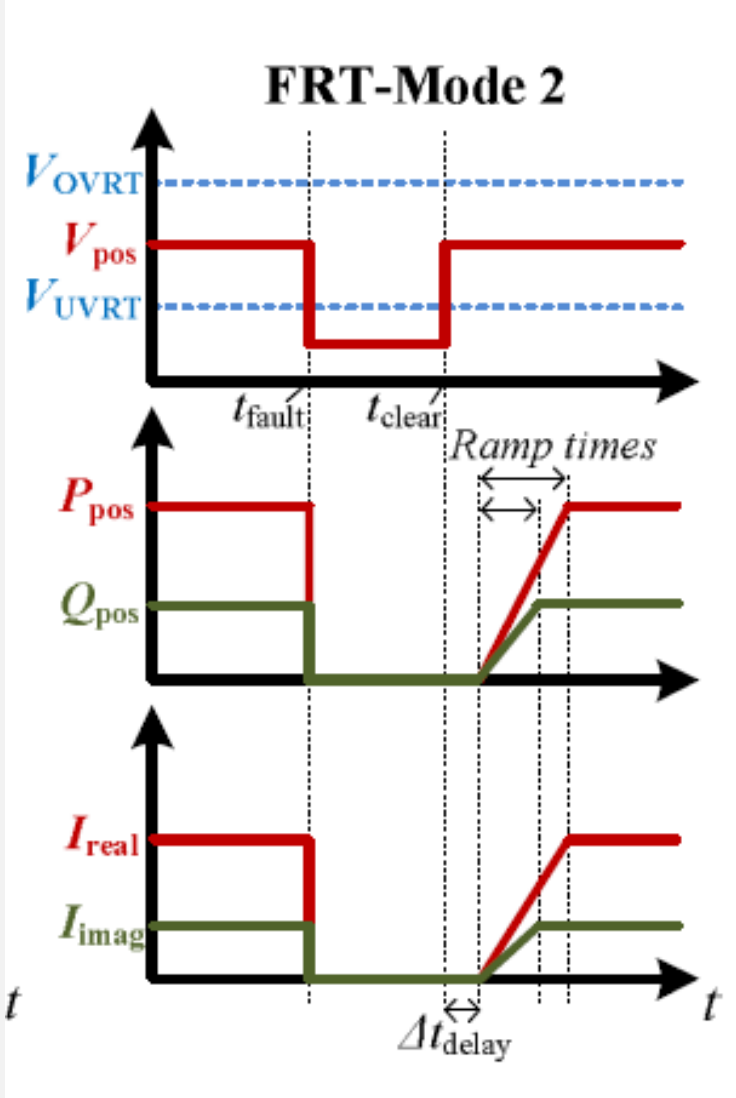
Min/max SCR at the PCC is key to stability during connection studies. However, SCL is declining and will change across operation, so stability is not assured.

Control tuning of the outer loop has the potential to improve system stability across lowers SCRs. This might include:

- Power de-loading post-fault
- Different outer loop control settings for different SCLs
- Different control modes for voltage regulation and fault ride through

Not clear how the issues are tracked, revised or modelled across the project's lifetime.

Transient stability can also be compromised in weak power grids during short-circuits- with oscillatory behaviour induced during a fault, impacting other controllers seeing that same voltage disturbance.



TASK 2: Fault ride through studies with different PLL, varying grid strength and P-Q control

The different PLL models-

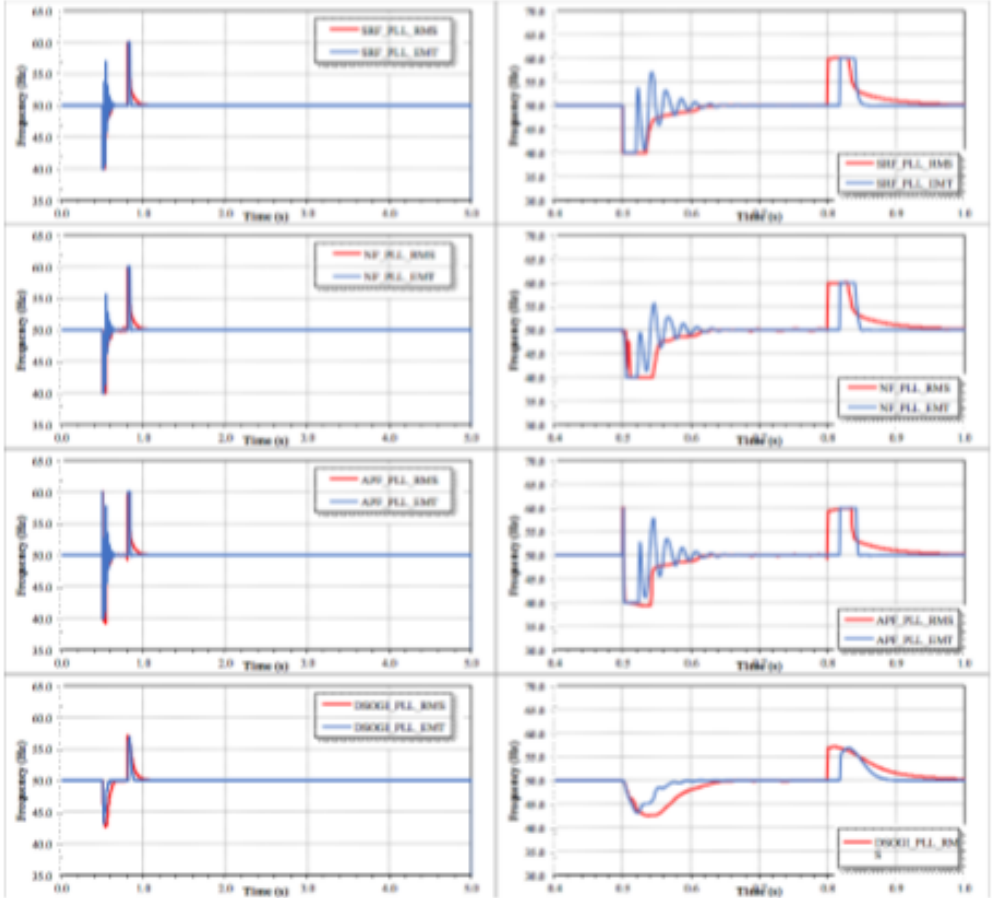


Table 2: PLL Designs

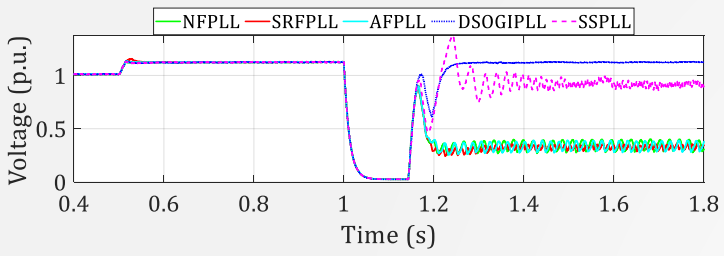
Description	Design	Expected Performance	Application
SRF-PLL	Simple	Poor	Small generators
NF-PLL	Average	Average	HVDC, Large Generators
APF-PLL	Average	Average	HVDC, Large Generators
DSOGI-PLL	Average	Good	Large Generators

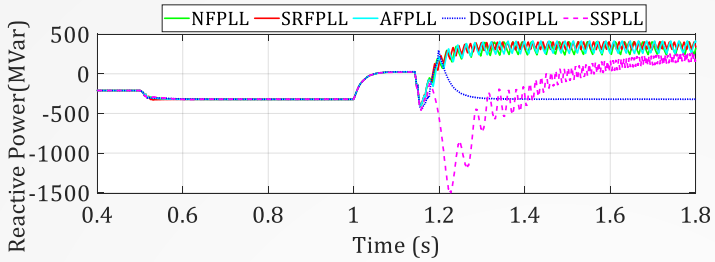
NGSO_0005- NIA considering 5 core types of PLL developed in PSCAD, with Digsilent equivalents available

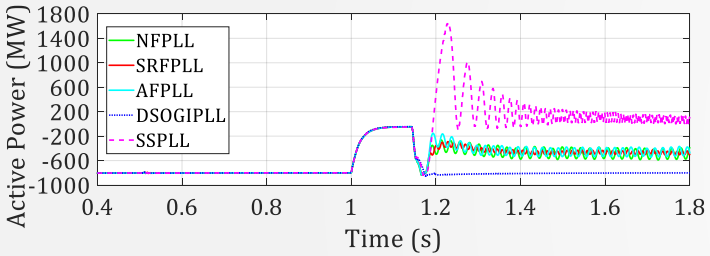
1) **Synchronous Reference Frame** (SRF-PLL)
   - classical/ standard approach
   - minimises balanced phase error
2) **Notch filter** (NF- PLL)
   - overcomes negative phase sequence limitations;
   - filter centred on 100Hz
3) **All Pass Filter**(APF-PLL)
   - alternate approach
   - tuned in alpha-beta frame.
4) **Double Second Order Generalised Integrator** (DSOGI-PLL)
   - doubly filtered; more complex,
   - inherently slowed and smoothed response
5) **State Space Optimised** (SS-PL) (not shown).
   - require complex definition of network
   - dynamic state space, normally not available

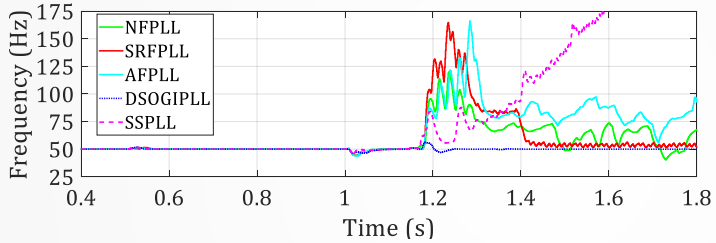
All require care in tuning via techniques captured in NIA project.
https://www.smarternetworks.org/project/nia_ngso0005/documents

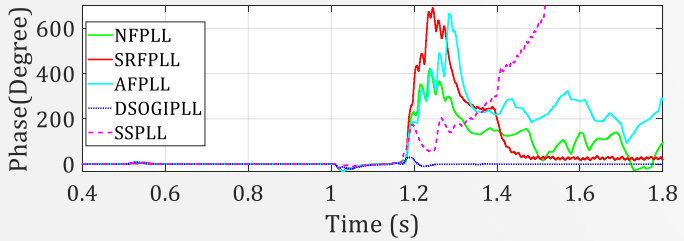
Case study: 3-phase fault at SCR=2 with five PLL types

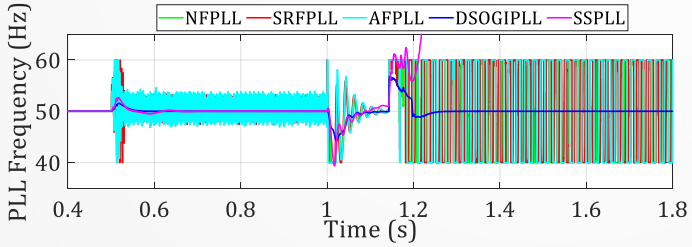






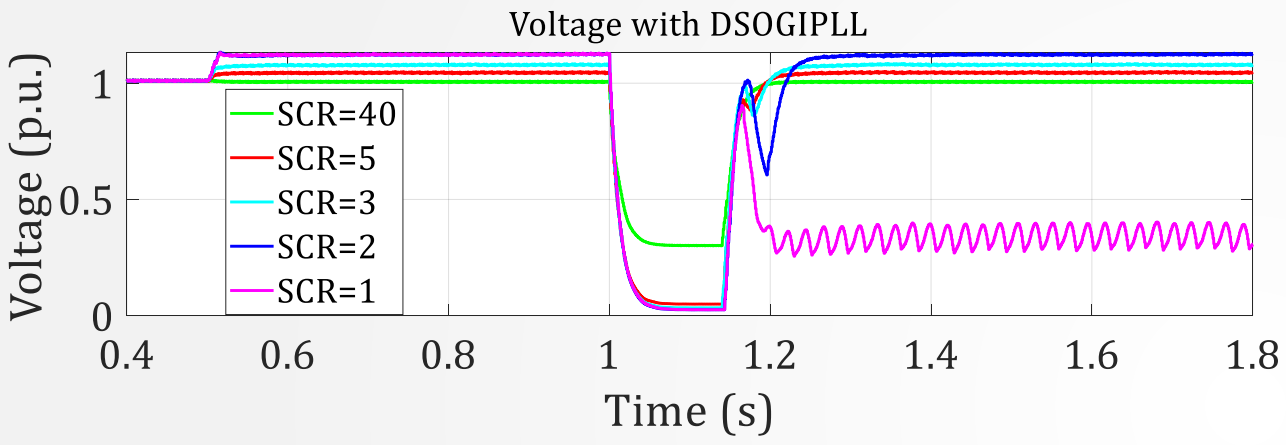


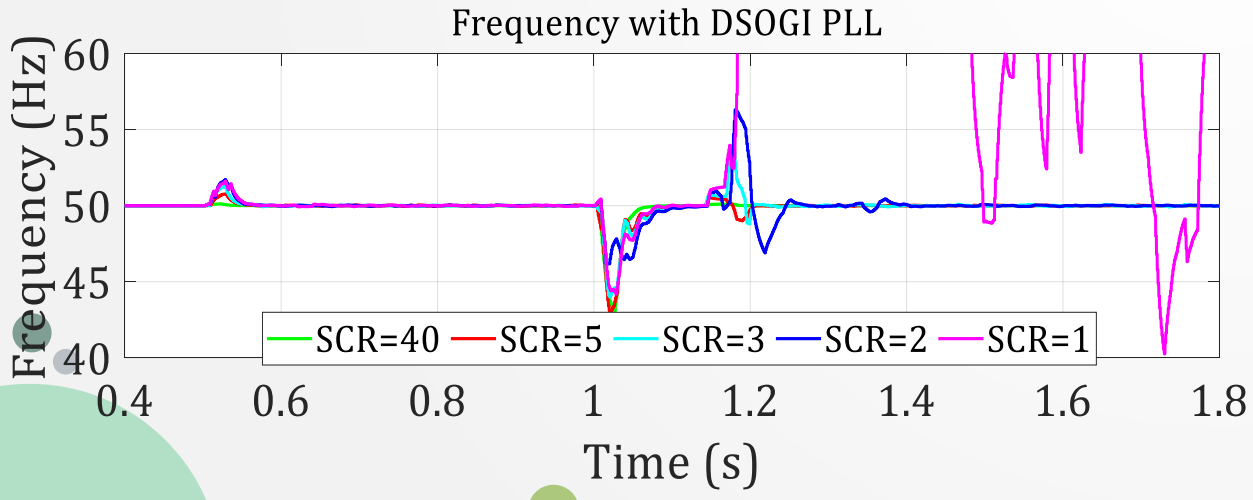




- At *t= 0.5 s* the grid impedance is changed to emulate SCR=2 operation and at *t=1s* a three-phase symmetrical fault is applied at AC grid 1 for 140ms
- Fault impedance is selected to retain 30% voltage at PCC during fault, however, can't retain the PCC voltage and stability
- Only DSOGI based PLL tracks the frequency during fault while others hit the limits and oscillates from the steady state
- No P/Q priority or fast fault current injection is considered which could improve the responses
- Voltage support can be provided with only DSOGI PLL in operation
- Phase angle jump during the impedance change and fault can be observed and is severe in all PLL types apart DSOGI

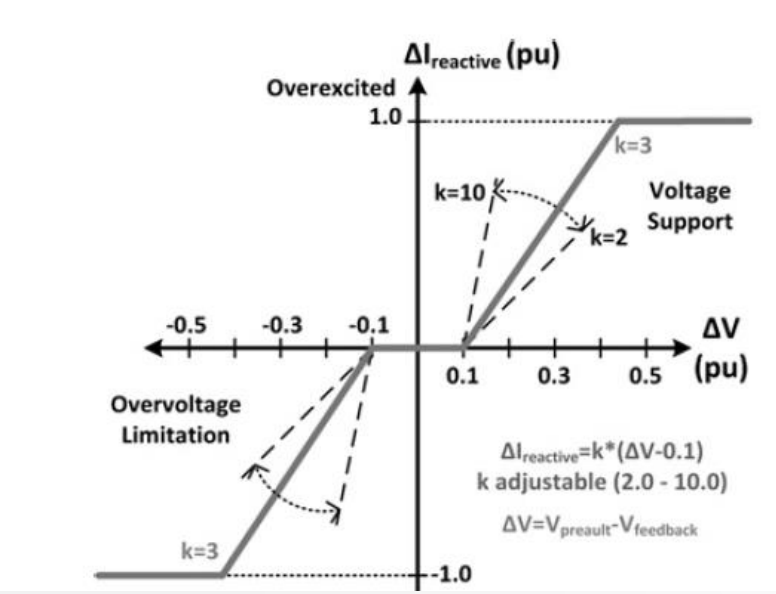
Case study: For DSOGI PLL with different SCR level

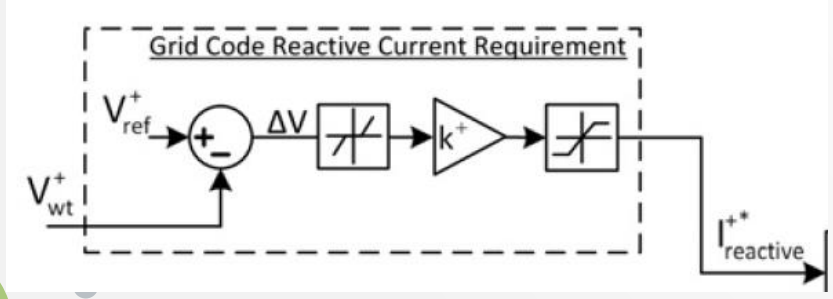




- MMC operation with DSOGI PLL is tested for different SCR (1~ 40)
- The PCC voltage starts oscillating for SCR=1 with low frequency component.
- The network frequency also shows similar trend with very low SCR
- Even though SCR=2 operation can be achieved with DSOGI very weak system operation is not possible and requires additional control modifications

Part 1: Fast Fault Current Injection (FFCI)





- The conventional method based on positive-sequence reactive current injection requirement of the grid code is analysed
- There is an additional outer loop control associated with FFCI, which modulates active and reactive current against the instantaneous retained voltage.
- A dead-band can be applied to voltage error, which is defined as 0.1 pu in certain grid codes
- The **proportional voltage control gain, K**, is adjusted based on the characteristics of the power system, and specified to be between 2 and 10

Göksu, Ömer, et al. "Impact of wind power plant reactive current injection during asymmetrical grid faults." *IET Renewable Power Generation* 7.5 (2013): 484-492.

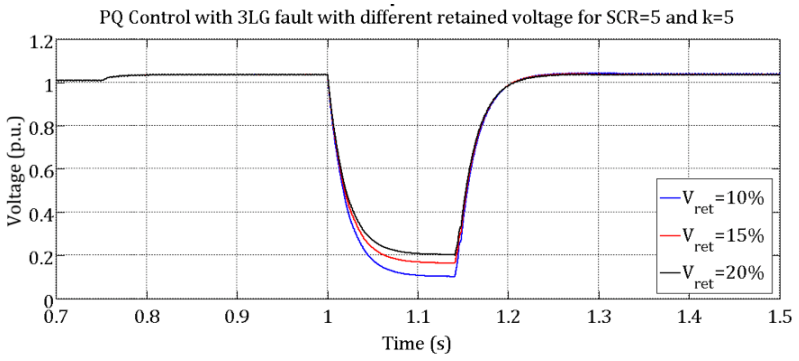
Part 1: Fault ride through studies for weak system and FFCI: Voltage Retained Level

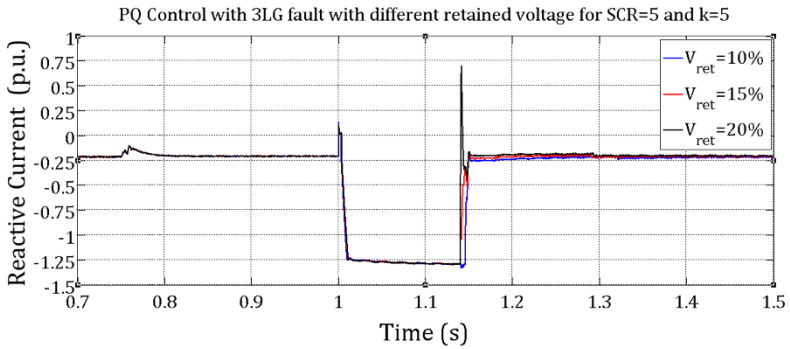
Case Study Scenario:

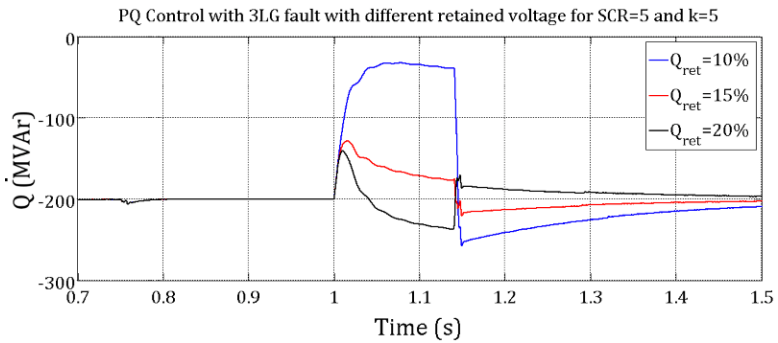
- At *t= 0.75 s* the grid impedance is changed to emulate weak grid operation and at *t=1s* a three-phase symmetrical fault is applied at Grid 2 for 140ms.
- SCR=5 and FFCI with K factor (k=5) is implemented to evaluate the test case. Varied the fault impedance to estimate the behavior of FFCI injection and support during fault.
- Tests were performed to evaluate what is the minimum level required to provide voltage support during reactive current injection with P-Q control mode implemented for MMCs

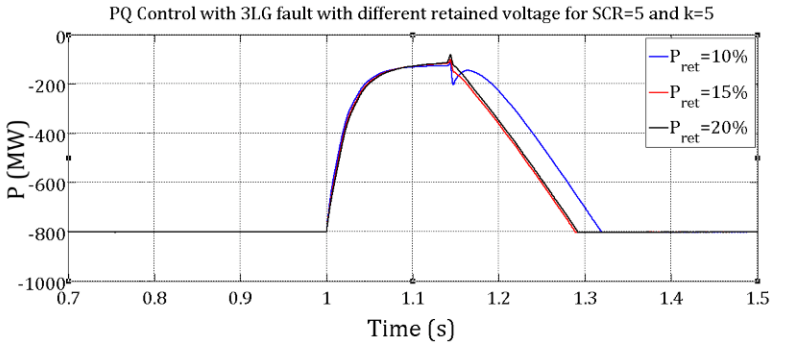
Part 1: Fast Fault Current Injection (FFCI) Case

- ➢ Voltage Response
- Slows decay in fault current
- Recovery rate similar
- ➢ Reactive Current Response
- Slow ramp avoids instability in deployment
- Fault clearance drives an instability – bigger phase jump= bigger instability
- ➢ Reactive Power Response:
- Uncertainty in reference drives slower recovery for lower strength condition
- Reactive power oscillating in angle
- ➢ Active Power Response:
- Slow recovery at low strength- reactive power utilization impacts convertor capacity to deliver active power









- Test cases revealed a counter intuitive relation between voltage retained level and FFCI support
- Active power reduction itself doesn't guarantee sufficient reactive current and voltage support during fault
- To enable sufficient support to PCC voltage through FFCI Q injection is also significant as it dictates the improved voltage support

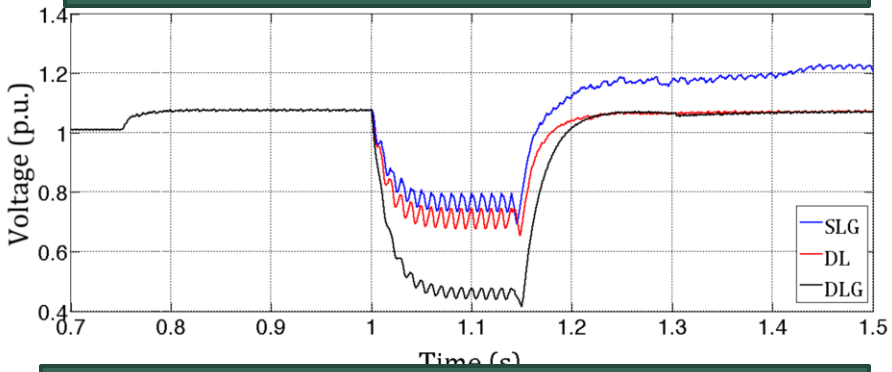
Part II: Unbalanced Fault Ride Through Requirements

Case Study Scenario:

- At *t= 0.75 s* the grid impedance is changed to emulate different SCR operation and at *t=1s* a asymmetrical faults are applied at weak AC grid for 140ms
- SCR=2 and FFCI with K factor (k=2) is implemented to evaluate the test case. Varied the fault impedance to estimate the behavior of FFCI injection and support during fault.
- Voltage retained level of 30% is implemented as in the case of three phase fault
- Tests were performed with single line to ground (SLG), double line (DL) and double line to ground (DLG) cases

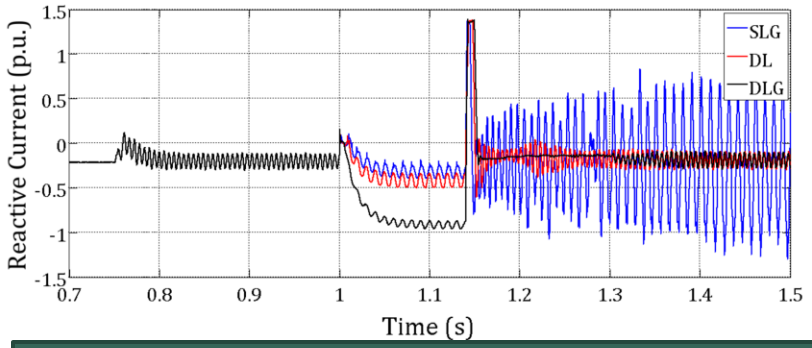
FFCI with different Fault Types, K=2 and 30% retained voltage at SCR=2

Voltage Response



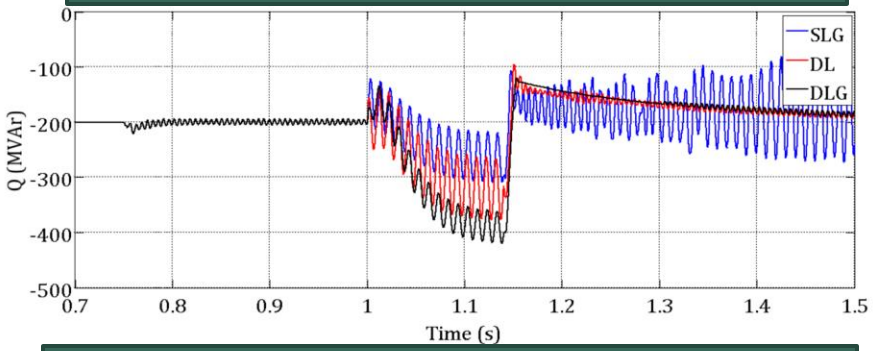
- Oscillation arises during fault and persists

Reactive Current Response



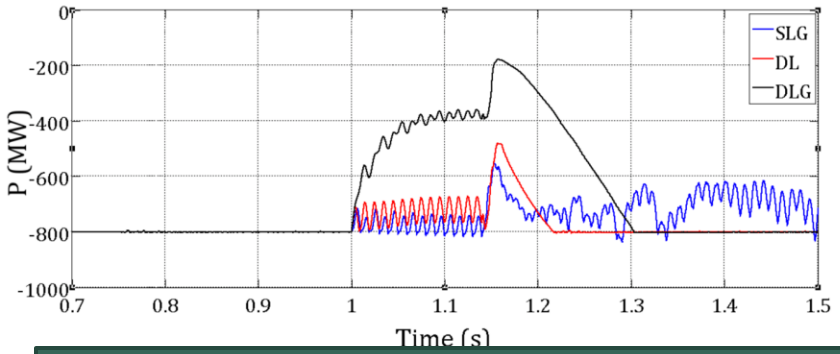
- Convertor induced disturbance increases post fault

Reactive Power Response



- Fault induced instability
- Could result in voltage instability.

Active Power Response



- Inability to respect power recovery requirements after 500ms of clearance

- SCR=2 oscillations with second order harmonics is present in the network variables
- The condition is most severe for SLG scenario and oscillations increases after post-fault condition requiring additional control strategies

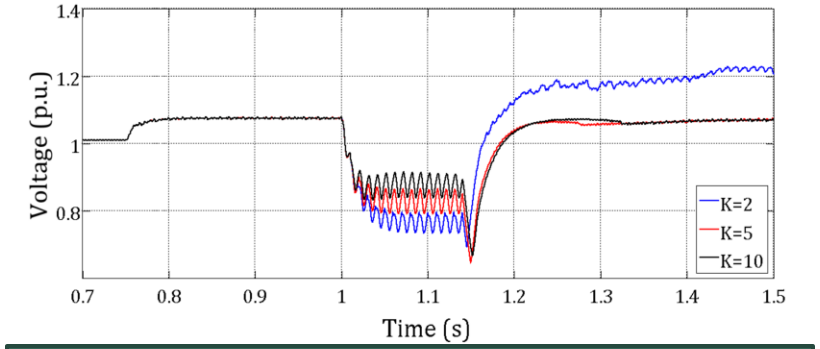
Part III: Fault ride through for weak system and FFCI: K-Factor sensitivity analysis

Case Study Scenario:

- At *t= 0.75 s* the grid impedance is changed to emulate different SCR operation and at *t=1s* a single line to ground fault is applied at AC grid 1 for 140ms
- SCR=2 and FFCI with different K factor (k=2 to 10) is implemented to evaluate the test case.
- Varied the fault impedance to estimate the behavior of FFCI injection and support during fault.
- Voltage retained level of 30% is implemented as in the case of three phase fault
- Tests were performed to see to performance enhancement using different FFCI injection level

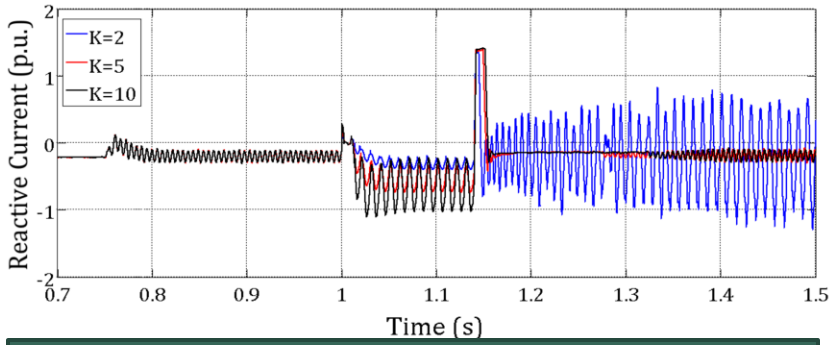
FFCI with different K values for P-Q Control and SLG fault at SCR=2

AC Voltage Response



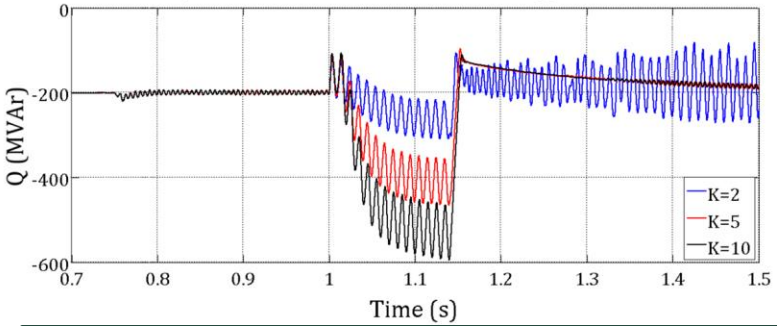
- High K factor:
- Results in reduced voltage recovery times
- Creates a double dip on voltage recovery.
- Highly sensitive on SCL

Reactive Current Response



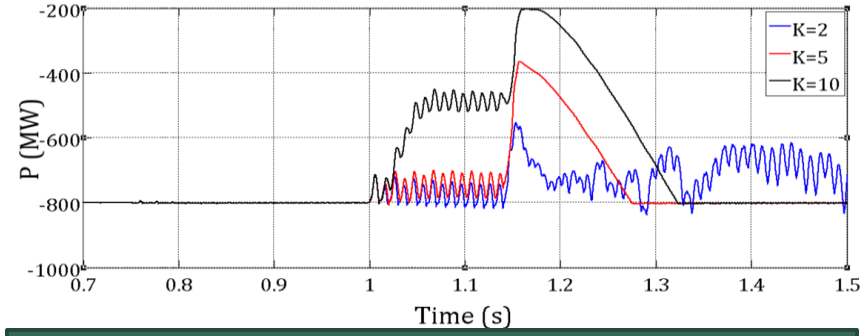
- Slower delivery with high K factor avoids out of phase response.
- However large reactive power absorption could result in voltage instability.

Reactive Power Response



- Slower control responses improve tracking and hence stability in weak system conditions
- Such controls delay post fault recovery and are sub-optimal in strong grids

Active Power Response



- High K factor leads to slower but more stable power recovery in a weak grid
- May be sub-optimal in a strong grid or in areas where widespread voltage depression occur.

- SCR=1 operation is compromised for the cases tested here, implying the inability to recover voltage for very weak system requiring additional control of specifications
- Voltage improvement with high level of FFCI injection is possible however, needs careful tuning and controller implementation

Summary: Case Study compliance performance between Fault types and SCR values

Type	SCR=5	SCR=3	SCR=2	SCR=1
Single Line-to-Ground	🔴	🔴	○	○
Double Line-to-Ground	🔴	🔴	🟠	○
Line-to-Line	🔴	🔴	🟠	○
Three-phase to ground	🔴	🟠	○	○

Ranking	
🔴	Fully Grid Code Compliance
🟠	Marginally Grid Code Compliance
○	Not Complaint with Grid Code

Fault Response and SCR Values

- Severe fault cases makes SCR=3 unstable
- Reduced power (0.5 p.u.) operation can be achieved at low SCR=2 under DLG faults
- Recovery of voltage after SLG fault is compromised for SCR=2 even with FFCI support

Conclusions – control optimization & FRT requirements

PLL types: different PLL choices and their tuning influence the performance and resilience of the converter- however it is not clear in current GC data exchange what choices are being made and what consequences these have.

Fault Types: Three phase to ground fault is more severe with weak grid operation, however, SLG faults are more challenging still- and data exchange of models for this not currently supported within Grid code.

K-factor: FFCI compounds voltage regulation and power recovery challenges after a fault and needs to be deployed with care. Different k-factor impacts the FFCI injection and thereby voltage support during fault and requires careful selection to comply with existing Grid Codes and not drive new or additional instability- requires a balance of factors, which may be different for different network areas.

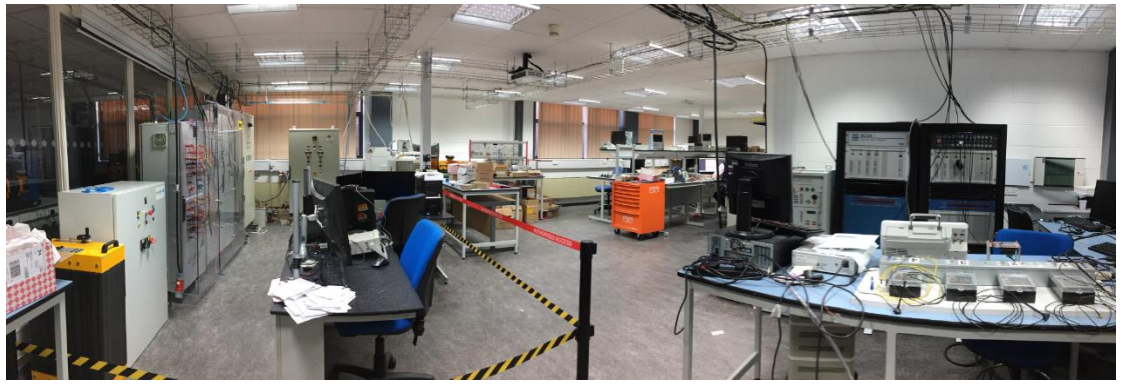
TASK 2.2 EXPERIMENTAL VALIDATION

Test Facility at Cardiff University

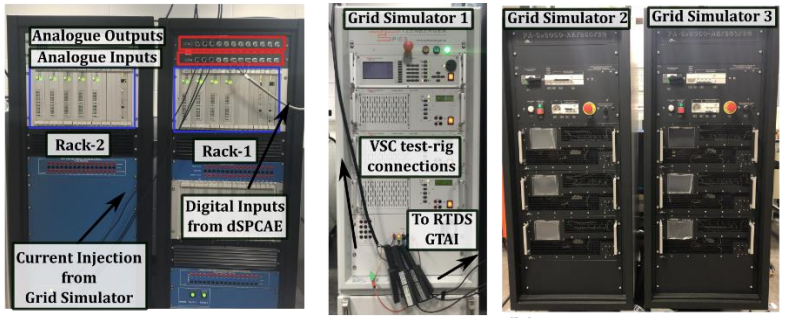
Voltage Source Converter HVDC Physical Test Rig and Real-time Simulator

To develop innovative technology/solutions in:

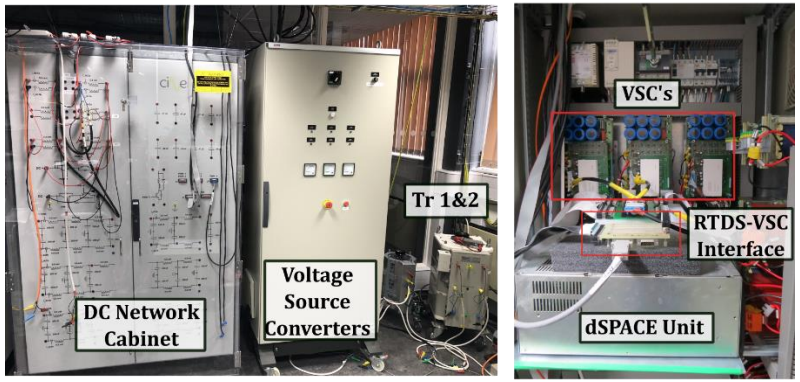
- MTDC grids
- Renewable energy and offshore wind networks
- Automatic control for power systems
- Industrial Power electronics



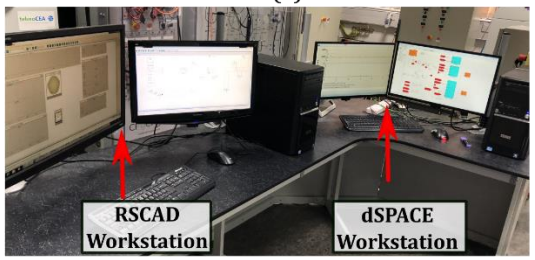
- Four 10kW VSCs, two 5kW PMSMs, Power system simulator (PSS), and Real Time Digital Simulator (RTDS)
- Three Grid Emulator
- TCSC Module
- dSPACE
- Unidrive



(a) (b)



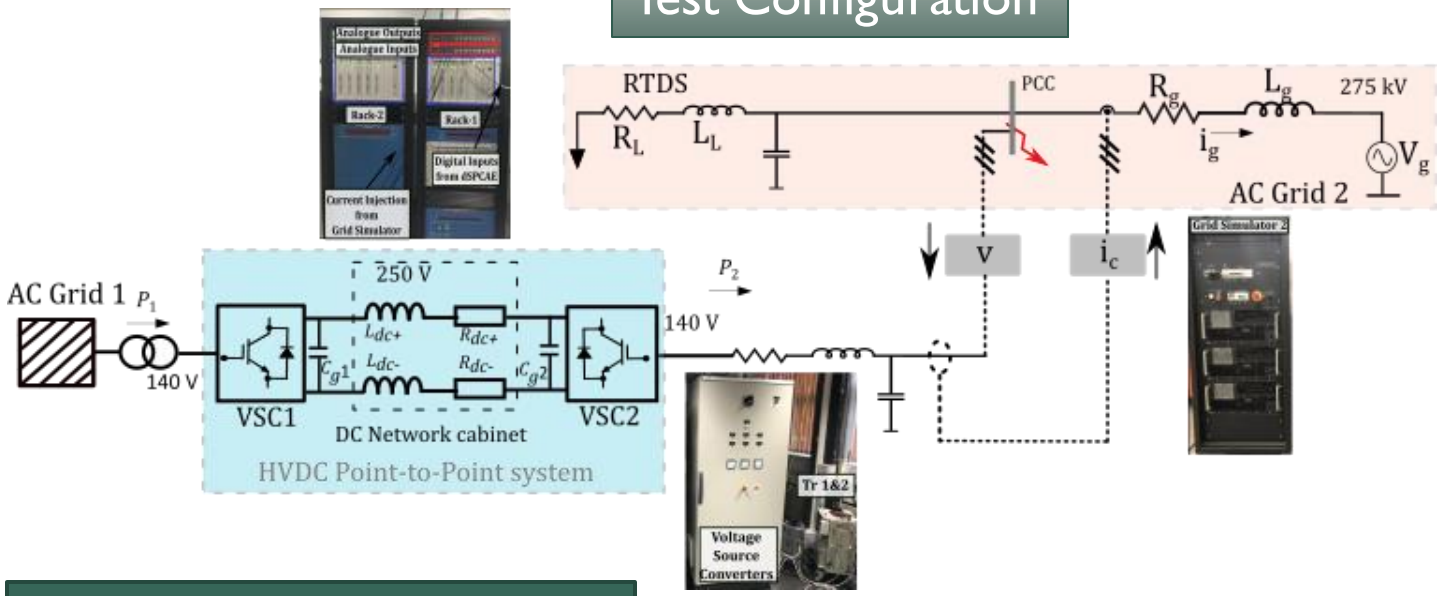
(c)



(d)

Real-time hardware-in-the-loop Experimental Set-up

Test Configuration



- Injected current is controlled by the Physical Test rig
- Grid 2 will be modelled as Weak Grid and is represented in the Real-time Simulator
- Real-time hardware-in-the-loop (RT-HiL) operation is devised to identify the impact of weak grid operation on the device under test and the AC system

Case Study Scenario:

- The AC grid is modelled in RSCD/RTDS to represents different grid strength by varying the impedance
- AC grid is modelled as weak before connecting the physical HVDC to see the changes in the voltage and current for different SCR levels.
- Voltage retained level of 50% is implemented as in the case of three phase fault
- Steady-state and three-phase to ground fault cases were tested and demonstrated

Experiment Test Cases

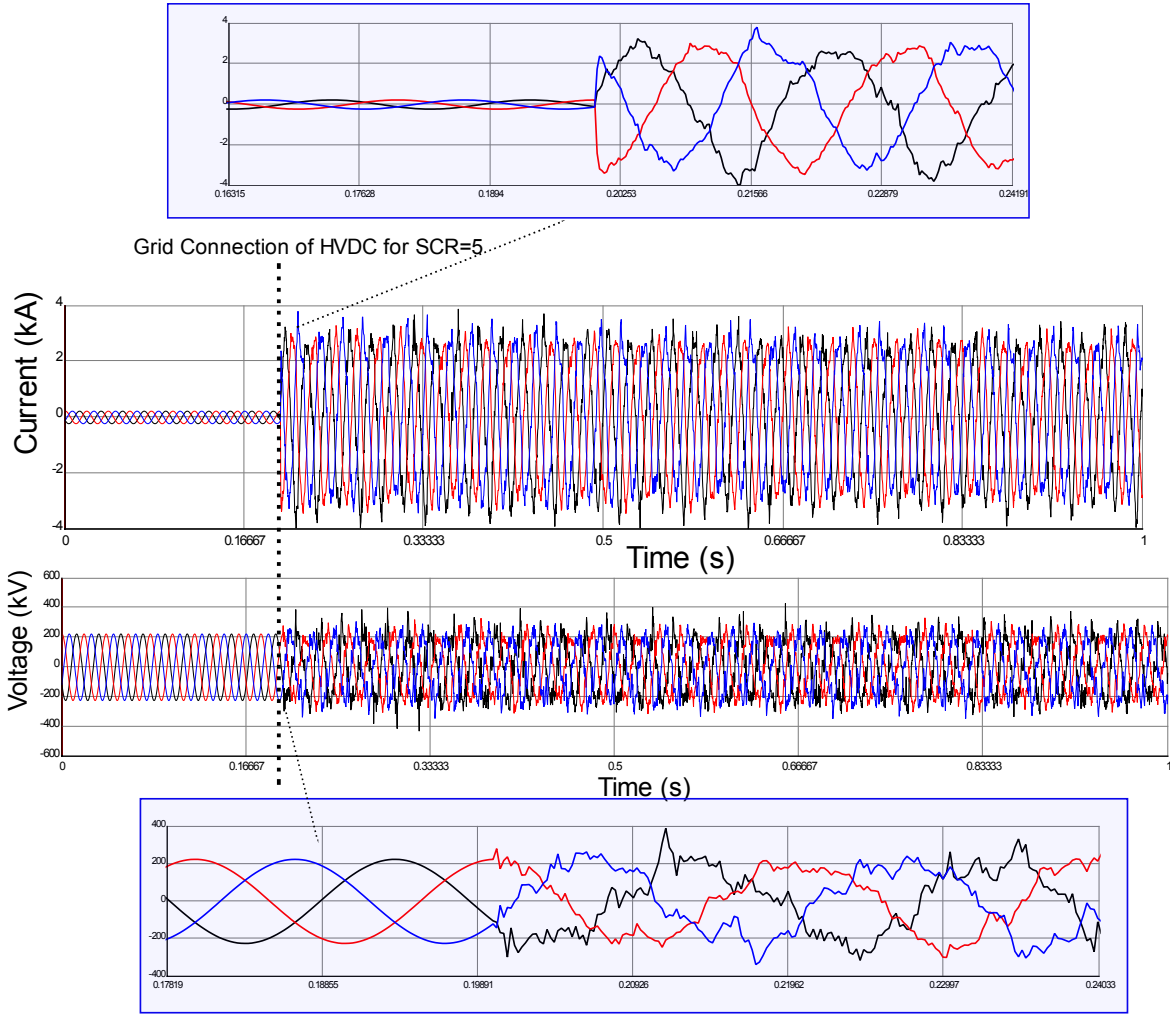
RT-HiL Set-up tested for Strong and Weak Grid operation under the following cases.

Control Modes: VSC1 operating in Vdc-Q Control mode and VSC 2 in P-Q with rated DC voltage =0.25kV; Active Power (p)= 1kW; reactive power= 0.2kVAr

Case1 : Weak Grid operation is emulated by reducing the grid strength into marginal case (SCR=5) and injected P =1kW (1 p.u.) scaled power into the AC grid.

Case 2 : Three-phase to ground Fault with fault impedance of 1 ohm and implemented for strong, marginal and weak grid cases(SCR=40, 5 and 2)

Experiment Results (1/2): Results for Weak Grid Connection



Case Study Scenario: Grid with SCR=5 is tested and at *t*=2*s* HVDC injection is enabled to the weak grid

➢ Grid Code Compliance

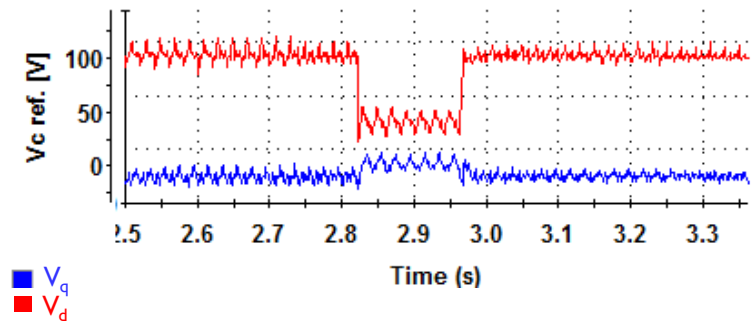
- Instability with reduced system strength
- Validates simulation studies
- Additional requirements needed to operate with system marginally stable

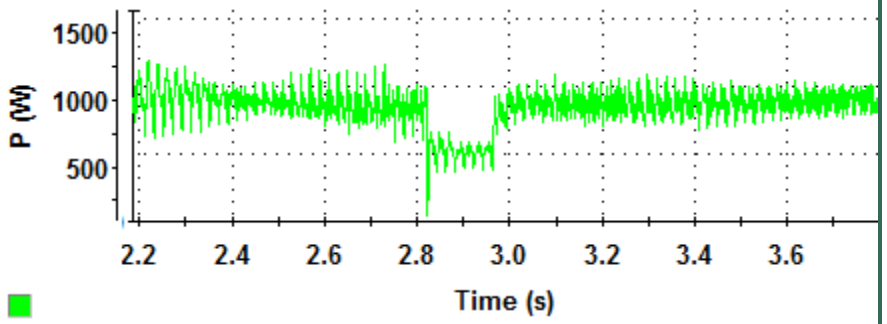
➢ Challenges

- HVDC connection further weakens the grid operation at SCR=5
- Large change in the grid current at PCC
- Voltage starts oscillating due to reduced impedance
- Marginally stable

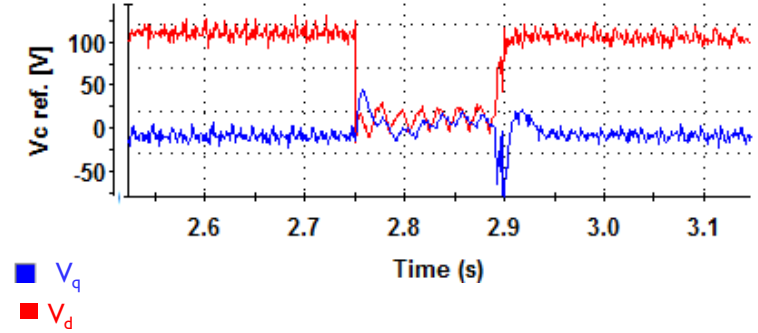
Experiment Results (2/2): FRT Test for three cases

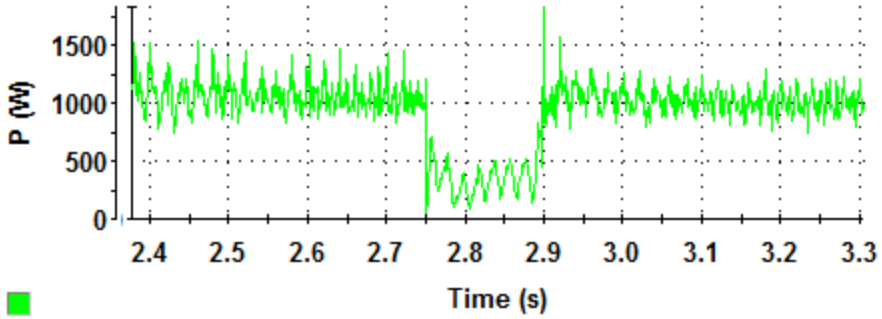
➢ Stable Case: Strong Grid (SCR=40)



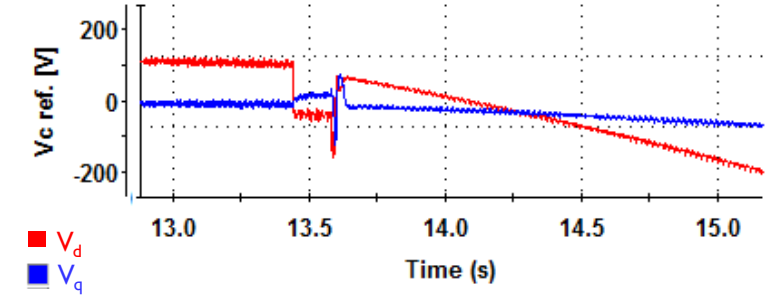


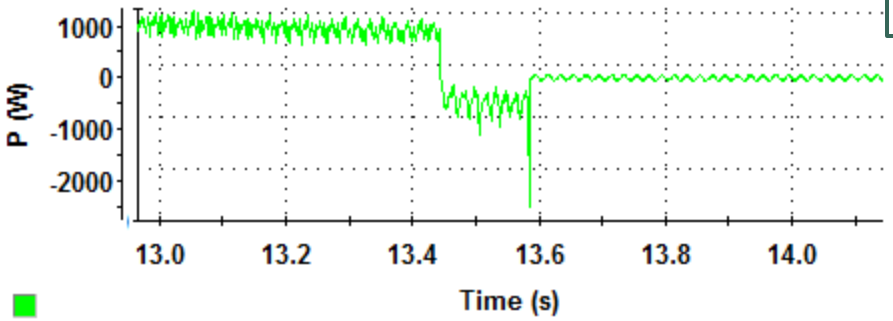
➢ Marginal Case: SCR=5





➢ Unstable Case: SCR=2





❑ Grid Code Compliance

- Three phase to ground fault will makes system unstable for low SCR values
- Marginal case recovers after severe fault without instability
- The RT-HiL result agrees well with simulation studies
- Careful consideration is required in connecting physical devices since the real impedance will vary with associated uncertainties.
- Further experimental work ongoing.

Task 2: Summary and Recommendations

Connection challenges

The GB Grid Code does not provide a limit for the min/max SCR at the PCC during Fault Ride Through. However, SCL is declining and will change across operation, so stability is not assured.

These challenges require different settings and different controls across different areas of performance. It is unclear how this is currently tracked and modelled across the project life within the Grid Code.

Control performance across different stages of convertor operation (pre-fault, during and post-fault) is not fully specified for weak grid connections in the Grid Codes

The post-fault recovery rate of active power and reactive power needs careful consideration as shown through our studies in weak grid connection

Conclusions

- As SCR and network conditions become more variable and convertor-dominated, solutions to achieve compliance become more complex, and potentially less robust to a wider range of stress tests.
- **AC System conditions** (changes in SCR, retained voltage during faults, fault types, scale of "phase jump" and specific characteristics of voltage recovery) impact performance. These are not signalled in data exchange or tested within the existing codes.
- The **Converter Controllers** used for HVDC systems (PLL, FFCI strategy, tuning of their speed and conditionality) play a vital role in the compliance of connection requirements but are neither visible nor adequately modelled in data exchange.
- RT-HiL provide additional validation to the simulation studies and improves the confidence of the system operator in connecting power converters to weak grids.

The Grid Code should apply not only at planning and commissioning stages, but also across the lifetime of the project. Developers and manufacturers will need to consider how best to do this.

Next steps: helping shape the future.

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Short term

- Improve data exchange in codes to inform new areas of analysis required
- Inform further compliance tests and requirements based on conclusions identified from work to date.
- Develop new techniques (e.g. multi-infeed small signal, protection validation) to support efficient analysis
- Identify required evolutions in tools to deliver the scale, volume and complexity of analysis needed.
- Develop reference modelling and assumptions for analysis.
- Identify mitigation options and changes to BAU activities.

Medium term

- Deploy new frameworks for composite system testing and simulation
- Deploy new control and protection approaches
- Further requirements and data exchange to optimise de-risking.
- New benchmark tests and processes
- In service tracking and active de-risking via focussed system and convertor monitoring.
- Complementary and seamless RMS, EMT and Real-Time Hardware in the loop analysis overcoming current information gap.

Longer term

- Realise net Zero objectives maintaining network resilience
- Proactive support implementing increasingly complex solutions; large scale Offshore
- Promote greater network insight to future control of convertors
- Manage and mitigate risk of convertor resilience.
- Fully realise opportunity convertors present with focussed control strategies.
- Support defining how risks & opportunity beyond GB can be managed across the wider European grid.

Feed through knowledge across Innovation Programmes

Knowledge sharing & solution deployment- effective cross-industry collaboration in de-risking

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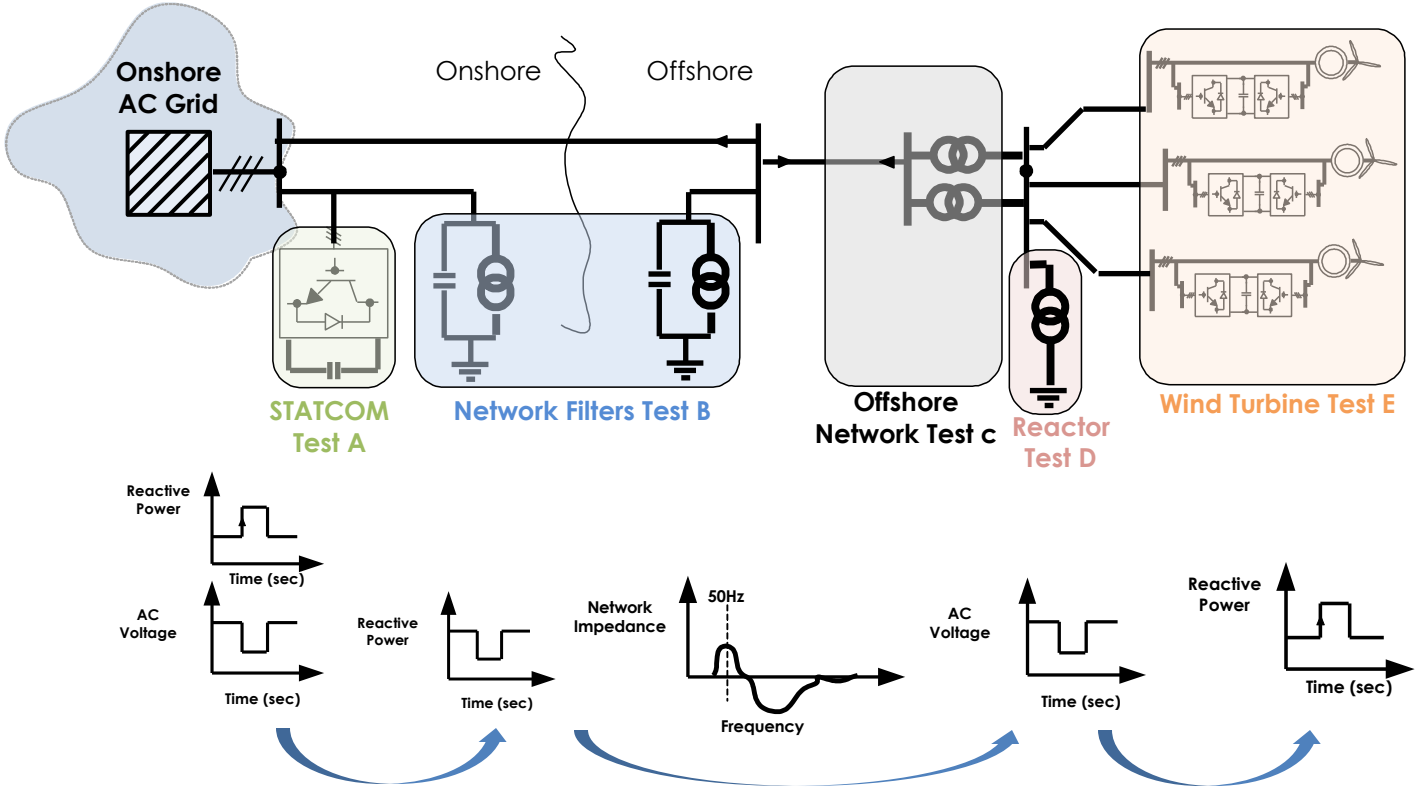
Offshore HVAC Design: Voltage Dip Example



- Coordinated Control Strategy needed – requires whole system testing

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Composite Testing of Complex Designs and New Technologies

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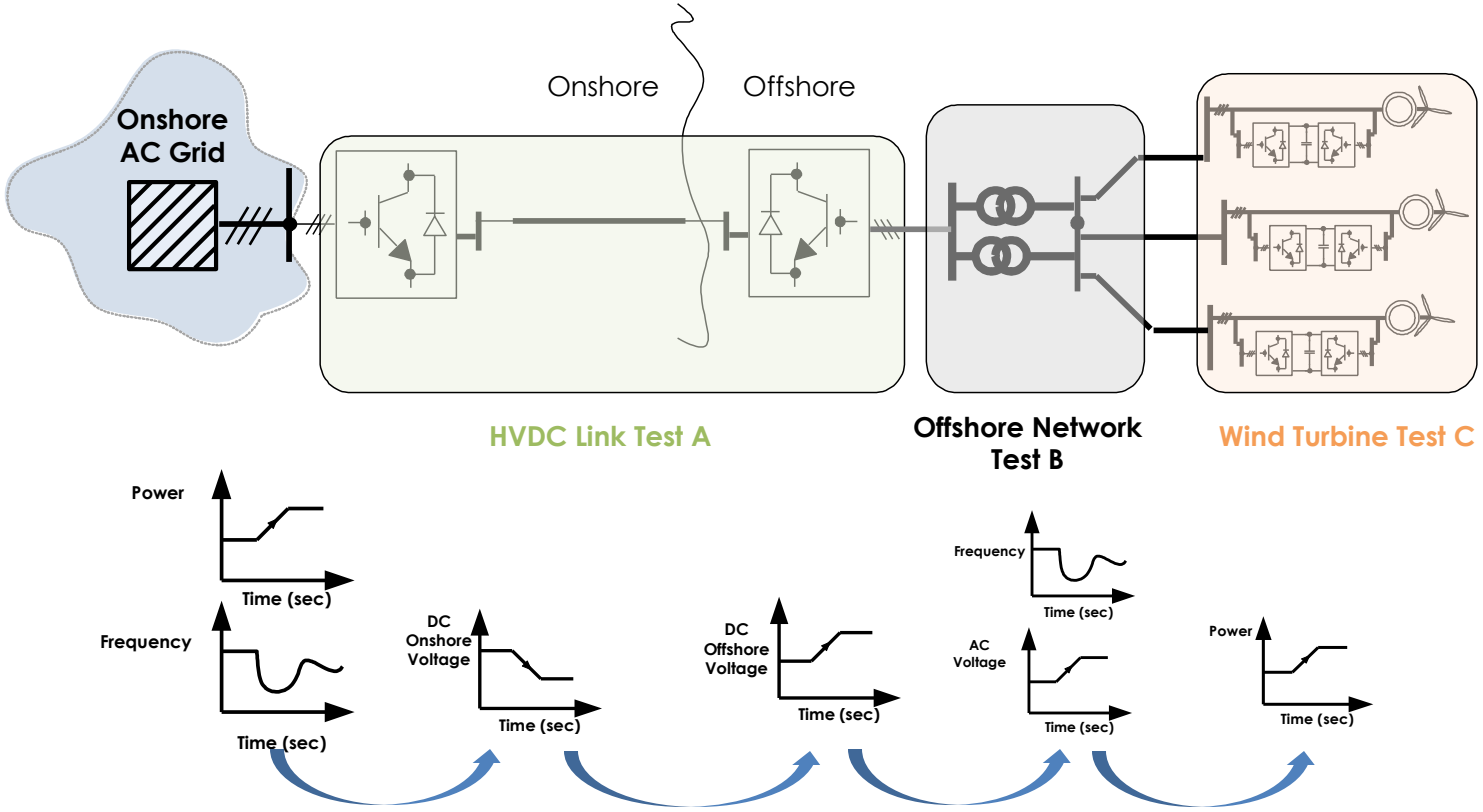
Offshore HVDC Design: Frequency Response Example



- Coordinated Control Strategy needed – requires whole system testing

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Plan for Composite Testing of Complex Designs & New Technologies

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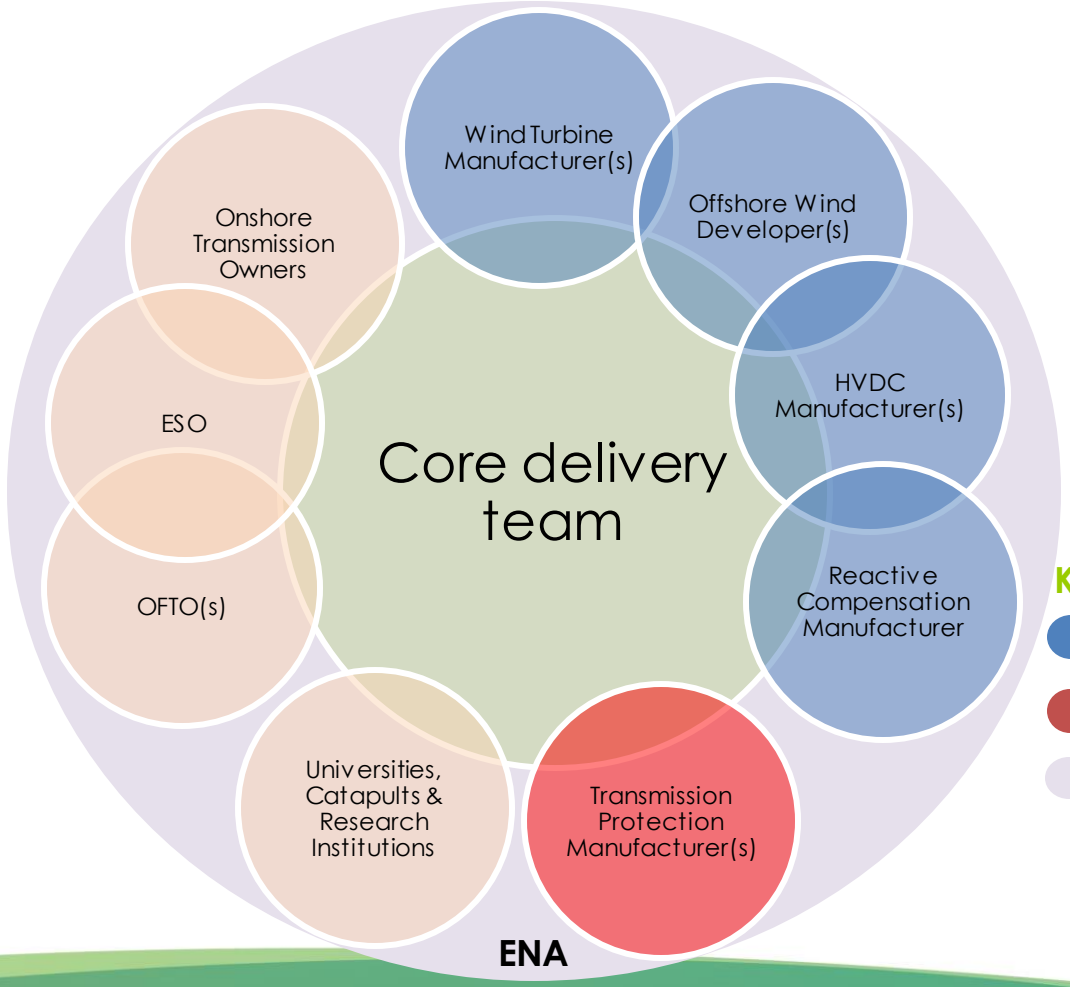
NIA- definition & scoping → *NIC- develop to implementation* → *BAU frameworks & tools*



- Defined simulation and testing milestones & criteria for composite system testing.
- Defining modelling needs & performance outcomes required across composite designs
- Defining the frameworks defining the who, what and when, and how.
- Techniques for analysing, testing, and tracking performance of individual elements and overall control performance and robustness.
- Tools for supporting range of analysis required and integrating with practical vendor processes.
- Identification of performance opportunities across the composite system to drive more efficient design and operation.

Key:

- Offshore Use Case
- Protection Use Case
- Shared Resource
- Core Partner
- Knowledge Sharing Partner

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Thanks for listening.

Any questions, please?

- **Summary of questions, answers and discussions from the webinar is available at:** https://www.hvdccentre.com/wp-content/uploads/2020/03/Webcast-Summary-20032020-Final.pdf
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