ACADEMIC ENGAGEMENT PROJECT:

Improving Grid Code compliance of HVDC schemes: Improve Requirements Specification of HVDC schemes

Prof. Jun Liang, Dr. Carlos Ugalde-Loo, and Dr. Tibin Joseph
Cardiff University, Wales, UK
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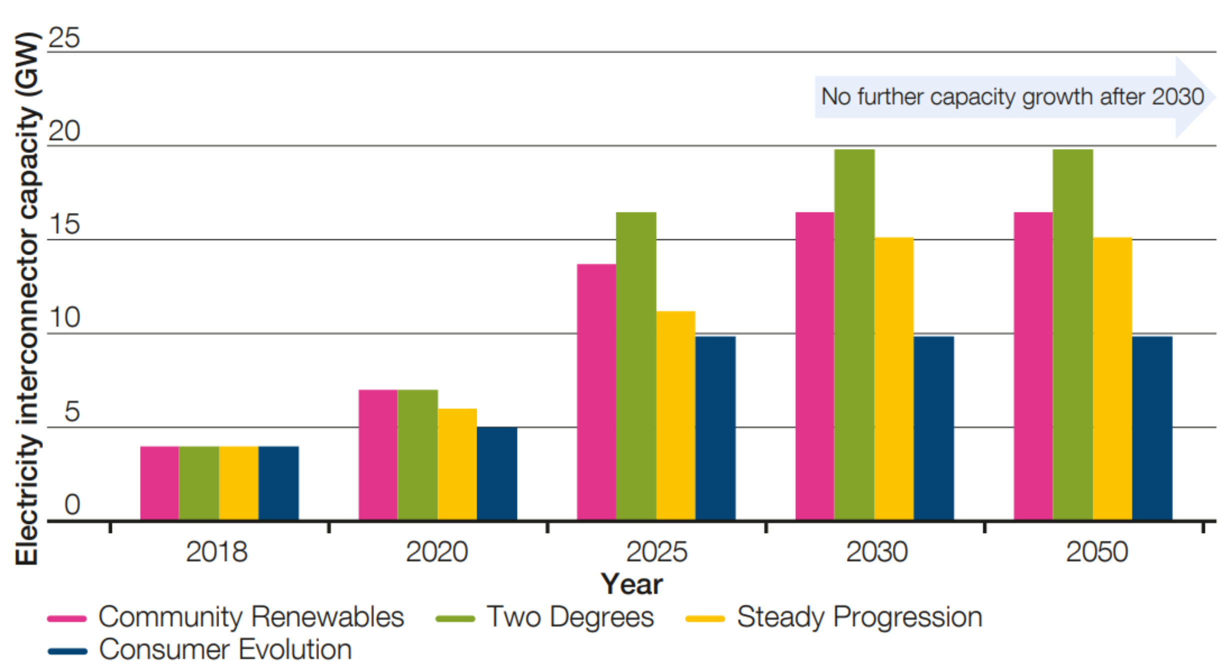
LiangJ1@cardiff.ac.uk

CONTENTS

Background of work: Growth in Interconnectors

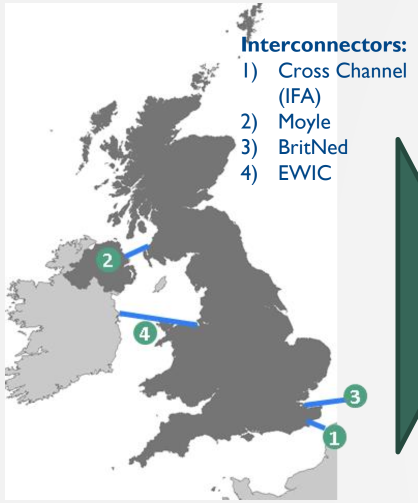
- Requirement for flexibility necessitates the need for interconnectors
- To facilitate balancing the intermittent renewable generation
- Reduced short circuit capability with more non-synchronous power flow through interconnectors
- Reliability and security of electricity network has become evermore significant
- Target to decarbonise electricity network by 2025:
  - Frequency management, inertia and short circuit infeed, and voltage management has been identified as challenges to meet this target



National Grid FES 2018

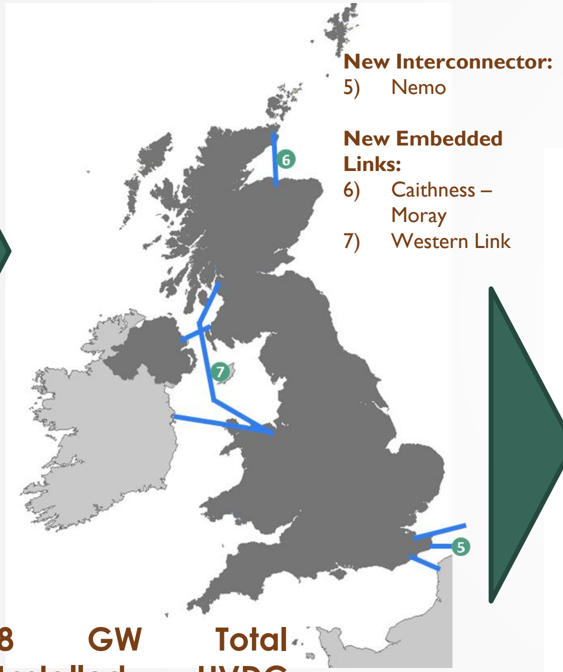
Background of work

2018



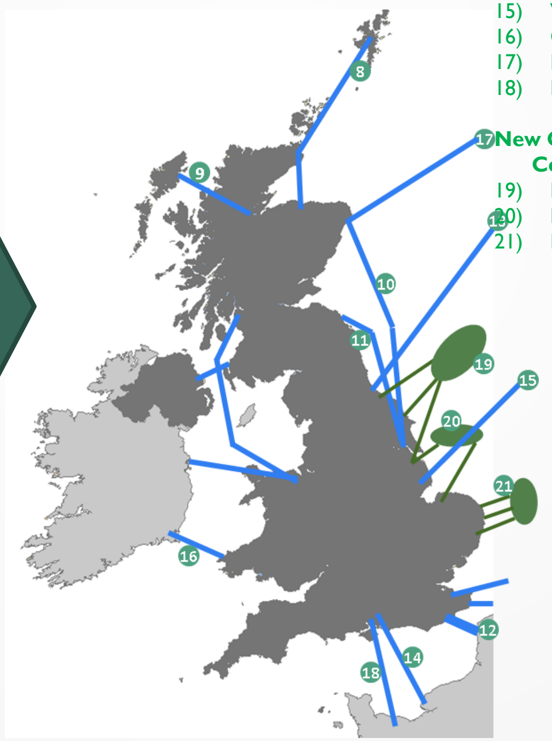
4 GW Total Installed HVDC Capacity

2019



8 GW Total Installed HVDC Capacity

2027



New Island Links
8) Shetland
9) Western Isles

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

New Interconnectors
12) ElecLink
13) NSL
14) Aquind
15) Viking
16) GreenLink
17) NorthConnect
18) IFA2

New Offshore Wind Connections
19) Dogger Bank
20) Hornsea
21) Norfolk Vanguard

> 16 GW Total Installed HVDC Capacity

- Transition from fossil-fuel based to HVDC-rich network
- Target to decarbonise electricity network by 2025
- With more HVDC schemes the potential issues could be:
  - Reduction of system strength and stability issues
  - Voltage issues
- Sufficient system strength is required for HVDC assets to function properly

Simon Marshall CM Project stake holder engagement event, National HVDC Centre, March 2019

COLLABORATION TOWARDS INNOVATION

Overview of collaboration

The National HVDC Centre is taking on the stewardship of Electricity Network Innovation and developed the MTTE facility to de-risk and support HVDC schemes in the GB.

The **Cardiff team**, consisting of 2 academics and 1 Research Associate will undertake the tasks for the **academic engagement** using their extensive experience of **power system operation, power electronics, control, HVDC and real-time experimental application**.

The Cardiff team will have access to other **relevant resources** (computer codes, models and know-how) that have been developed through a number of completed and on-going EU and EPSRC relevant funded research projects. The Cardiff team will use their extensive **professional and academic networks** through e.g. industry engagements, IEEE, IET, CIGRE and CIRED to **disseminate the outcomes** of this project.

Schedule Of Work

Task 1: Scoping of Grid Codes related to HVDC connections

- ✓ Task 1.1 Identification of key challenges faced by HVDC systems connected to weak grids
- ✓ Task 1.2 Modelling and risk assessment with HVDC systems connected to weak grids

Task 2: Grid Code compliance tests and system operation with varying grid strength

- ✓ Task 2.1 Compliance test for HVDC schemes with varying grid strength
- ✓ Task 2.2 Validation of the grid code compliance and safety regions using RTDS

Associated Tasks:

- ❖ **Knowledge capture and management**
- ❖ **Dissemination**
- ❖ **Open-source model**

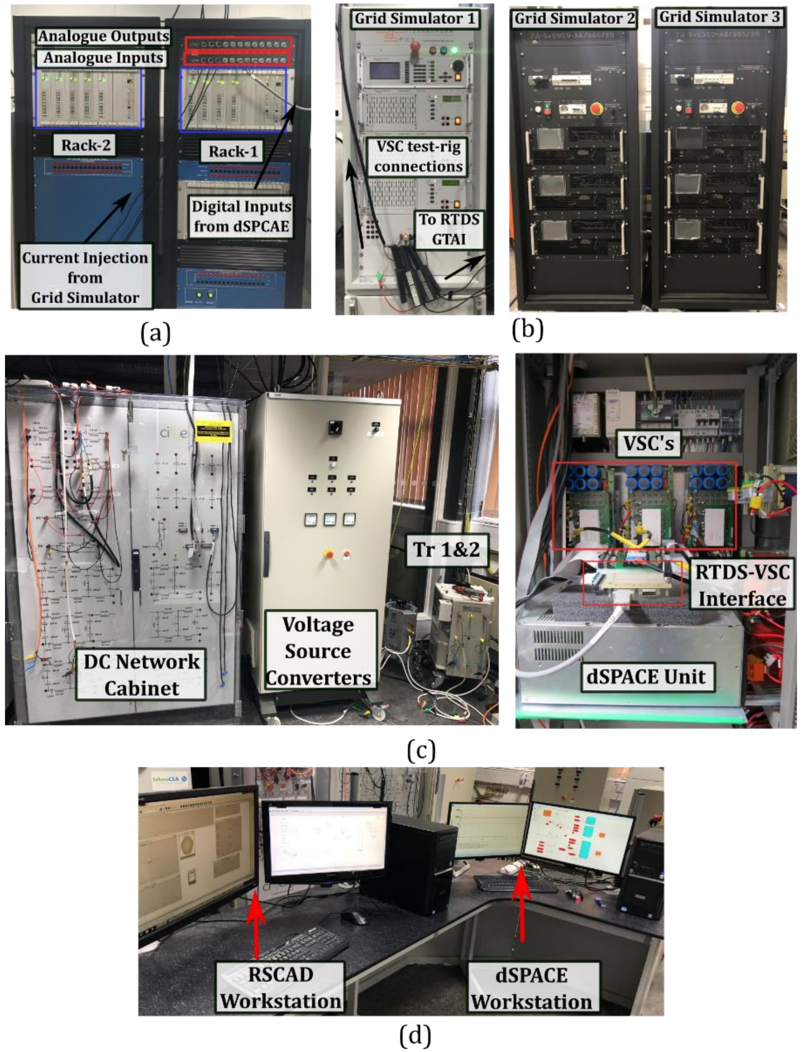
Test Facility at Cardiff University

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



Grid Code Requirements

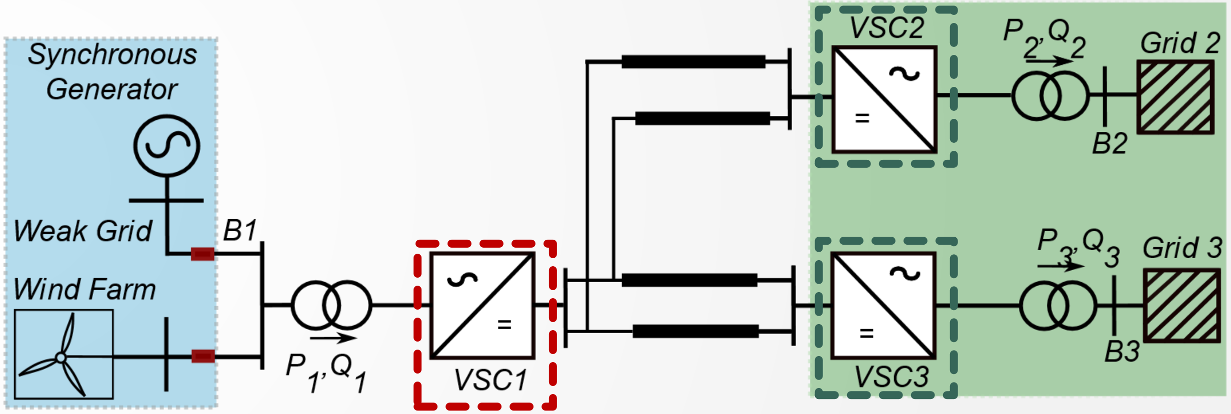
Grid Code requirements for HVDC

➢ Requirements to HVDC converters are set by:

- The ENTSO-E Grid code (GC)
- The National Grid (UK) Grid code

➢ The focus is on:

- Frequency requirements
- Voltage/reactive power requirements
- Fault Ride Through requirements



HVDC Converters to which requirements for grid connections mandate

DC Connected Power pack modules to which requirements for grid connections mandate

FREQUENCY REQUIREMENTS

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<tr><th>F (Hz)</th><th>UK</th><th>Spain</th><th>France</th><th>Germany</th><th colspan="2">Nordic</th></tr>
<tr><td>53</td><td></td><td rowspan="2"></td><td></td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="3">3 min</td></tr>
<tr><td>52</td><td>15 min</td><td></td></tr>
<tr><td>51.5</td><td>90 min</td><td rowspan="5">Unlimited</td><td>30 min</td><td rowspan="6">Unlimited</td><td>5 s</td></tr>
<tr><td>51</td><td rowspan="3">Unlimited</td><td rowspan="3">Unlimited</td><td colspan="2" rowspan="3">Unlimited</td></tr>
<tr><td>50</td></tr>
<tr><td>49</td></tr>
<tr><td>48</td><td rowspan="2">90 min</td><td rowspan="2">30 min</td><td colspan="2" rowspan="2">30 min</td></tr>
<tr><td>47.5</td><td>3s</td></tr>
<tr><td>47</td><td>20 s</td><td></td><td></td><td></td><td colspan="2"></td></tr>
</table>

OVERVOLTAGE/ UNDERVOLTAGE REQUIREMENTS

<table>
<tr><th>V (p.u.)</th><th>UK</th><th>Spain</th><th>France</th><th>Germany</th><th>Nordic</th></tr>
<tr><td>1.2</td><td rowspan="3"></td><td>0.05s-1s</td><td rowspan="3"></td><td></td><td rowspan="3"></td></tr>
<tr><td>1.15</td><td>15 min</td><td rowspan="2">30 min</td></tr>
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<tr><td>1.05</td><td rowspan="4">Unlimited</td><td rowspan="3">Unlimited</td><td rowspan="4">Unlimited</td></tr>
<tr><td>1</td></tr>
<tr><td>0.95</td></tr>
<tr><td>0.9</td><td rowspan="3">90 min</td><td>2 h</td></tr>
<tr><td>0.875</td><td rowspan="3"></td><td>3 h</td><td rowspan="3"></td><td rowspan="2">1 h</td></tr>
<tr><td>0.85</td><td>30 min</td></tr>
<tr><td>0.8</td><td></td><td>Variable</td><td></td></tr>
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Re-defining the understanding of Grid code requirements with HVDC schemes

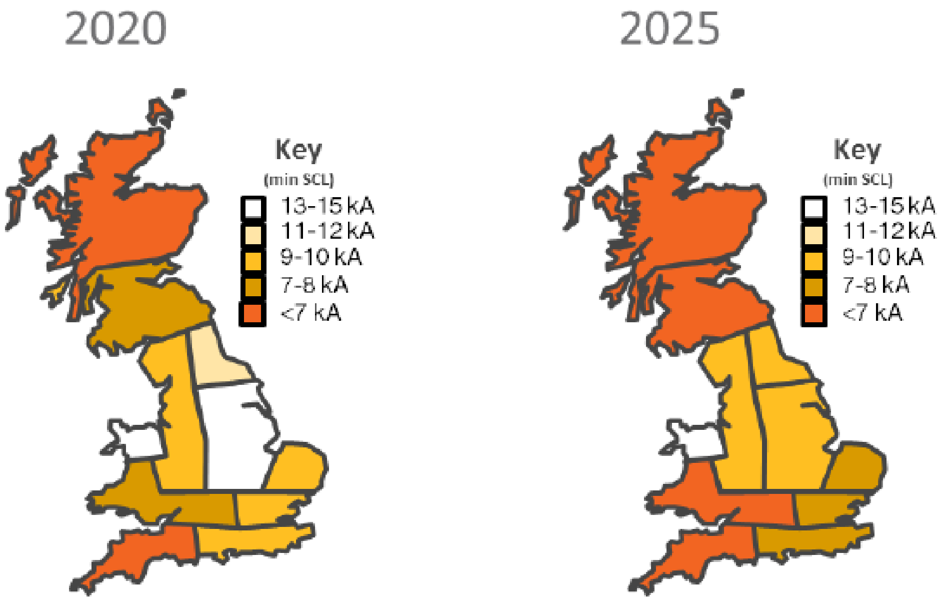
Short Circuit Level (SCL)

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

- **Given that the replacement of fossil-fuel based generation with HVDC-connected renewables will reduce the GB system strength (represented as short-circuit ratio, SCL)**

- **The GB system operator National Grid (NG) has identified this scenario and identified the pattern of general decline of SCL in the network**

- **And needs to be incorporated in the existing Grid Code provisions**



Regional short circuit level in the GB system

- ✓ To cope with this, stringent conditions are foreseen to be imposed on HVDC connections at weak areas or regions with declining SCL.
- ✓ On one hand, too negligent requirements may cause reliability or stability issues. However, on the other hand, too onerous requirements can prevent reaching energy policy targets.

Short Circuit Ratio (SCR) Based Metrics

With in the context of connecting HVDCs in an AC grid, the well documented and practiced aspects for system strength or "weakness" of the grid is short-circuit ratio

- How does HVDC performance change with lower SCL
- How to relate HVDC power flow to that of real-time declining SCL and measures to quantify the impacts
- Are factors other than SCR important in quantifying system strength while considering HVDC schemes
- How to specify safe operational zones of the network considering planned and future HVDC schemes
- Risk assessment of HVDC schemes providing additional services under varying grid strength and the criterion for safe operating zones needs t be specified.
- What are the current state-of-art in SCR based system strength quantification

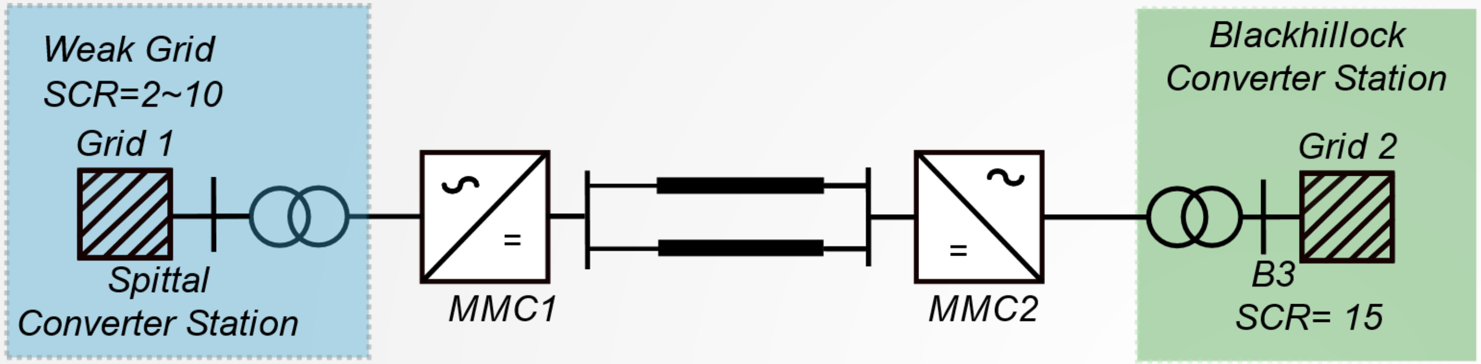
Comparison of SCR Methods

Metric		Simple calculation using short circuit program	Accounts for nearby Inverters	Provides common metric across large group of inverters	Accounts for weak electrical Coupling between larger plants	Considers non-active converters capacity (STACOM)	Considers individual inverters within a larger plant
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	★★	★★	★★

The ‘X’ represents that the metric cannot be applied for the described purpose. One star represents that the metric can be applied with some additional effort or processing, or can be applied to a limited extent, and two stars represents that the metric is easily or directly applied for these purposes.

PROGRESS AND CASE STUDY

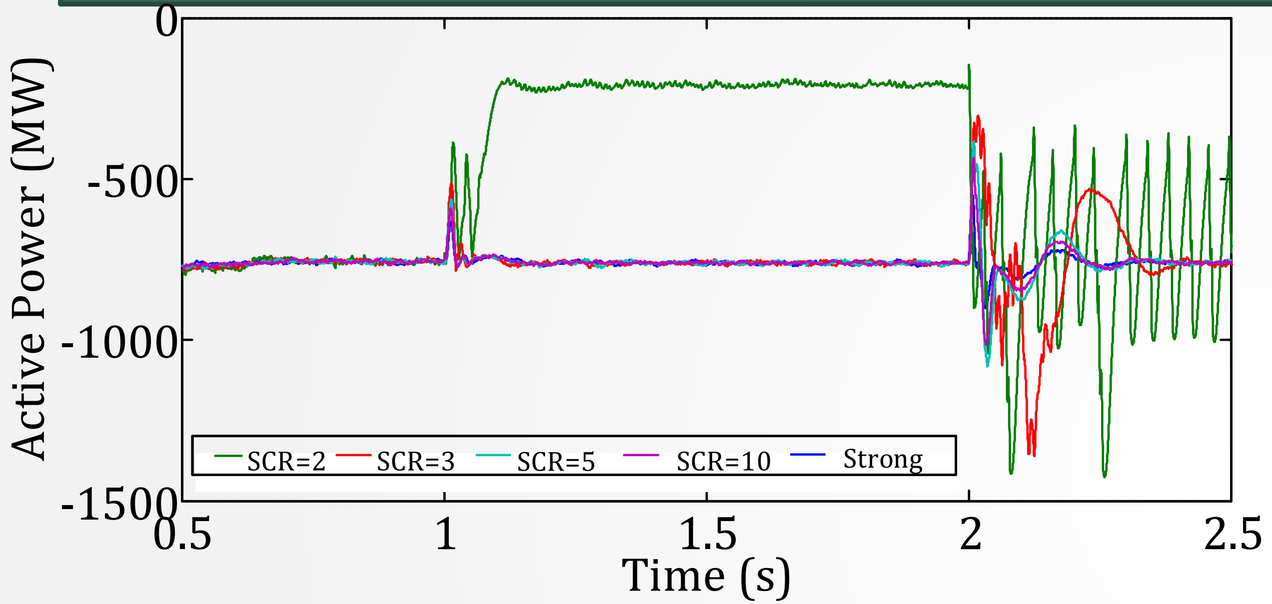
Point to Point Network representing CM HVDC link

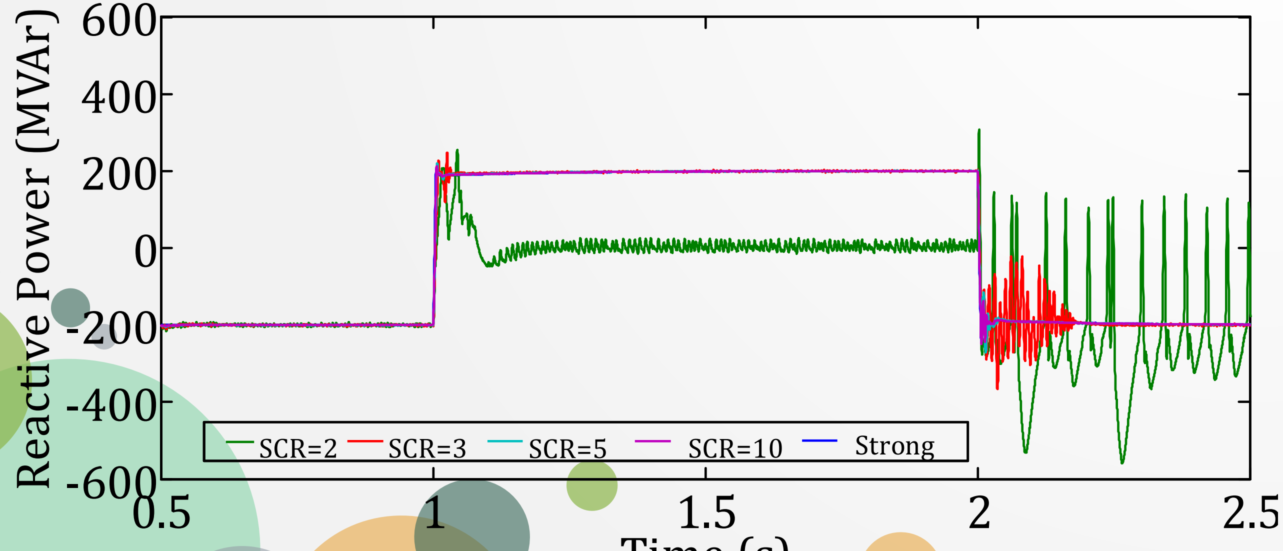


Item	MMC1	MMC2
Rated Apparent Power (S)	840 MVA	1265 MVA
Rated Active Power (P)	±800 MW	±1200 MW
Converter Nominal DC Voltage	640 kV (±320 kV)	640 kV (±320 kV)
AC Grid Voltage	275 kV	400 kV
SCR	2~10	15
Transformer Reactance	0.16 p.u.	0.16 p.u.

- Point-to-point HVDC link between Spittal (in Caithness) and Blackhillock (in Moray).
- Voltage source Converter (VSC) technology with half-bridge modular multi-level converters (MMC) were used
- Symmetrical monopole HVDC link operation is performed
- Spittal AC grid is modelled with varying network strength representation to study existing Grid Code requirements

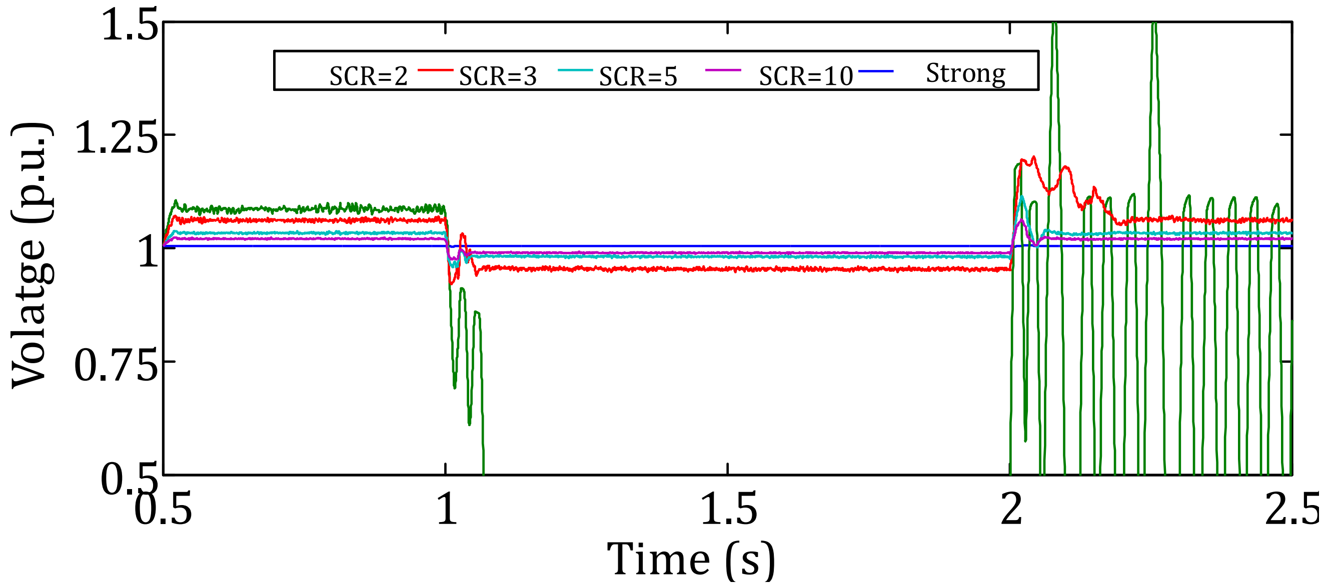
Case study: Voltage and Reactive power requirements





- Investigated the ability of the converter connected to weak grid to meet the reactive power requirement
- The operation is performed at Spittal AC grid
- 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 converter is capable to deliver the rated power without any difficulty within the specified range when the grid is strong
- However, the power flow through the HVDC link is compromised with reduced SCR's

- The ability of the VSC-HVDC system to regulate the reactive power independently is more useful for voltage control at PCC.
- HVDC converters rely on phase-locked loops (PLL) in converter control system to track the network changes
- Stable voltage at converter terminal is required to maintain PLL synchronism
- Voltage changes are directly linked to system strength and requires consideration in Grid Code to maintain system stability and security under weak grid operation



Case study: Voltage and Reactive capability requirements

Inferences: Connection of HVDC to Weak Grids

With the increasing number of converters connected, the transmission network could potentially suffer from low SCR and eventually instability issues;

Connection challenges

- Frequency and duration of unsafe situations in weak grids is much greater than in high performance strong grids
- This will lead to technical issues related to voltage and frequency regulation, and instability
- Weak power systems experience significant fluctuations in bus voltages, both in steady-state and dynamic events.
- Frequency regulation is primarily troublesome in weak power grids.
- Transient stability can also be compromised in weak power grids during short-circuits.

Summary

- There are synergies in a number of aspects between Grid Code requirements proposed by ENTSO-E and National Grid for HVDC schemes.
- The frequency bands in the interconnected case are strict and only allow 1 Hz or 2 Hz deviation for nominal value. However, the tripping times are much longer in interconnected cases.
- The voltage requirements specify a 10%–15% voltage band in which the systems operate all the time. Moreover, it allow shorter variations but wider trip times in interconnected grid codes.
- With system strength foreseen to decline impacting the stable connection requirements, solutions to cope with weak grid connections are required.

The frequency deviation and voltage bands are set for strong interconnected grids, however, with reduced system strength and larger power inflow through HVDC schemes, specification of grid code requirements needs revisit.

THANK YOU FOR YOUR TIME !

LiangJ1@cardiff.ac.uk

Prof. Jun Liang
Tel: +44 (0)29 2087 0666