SP Energy Networks

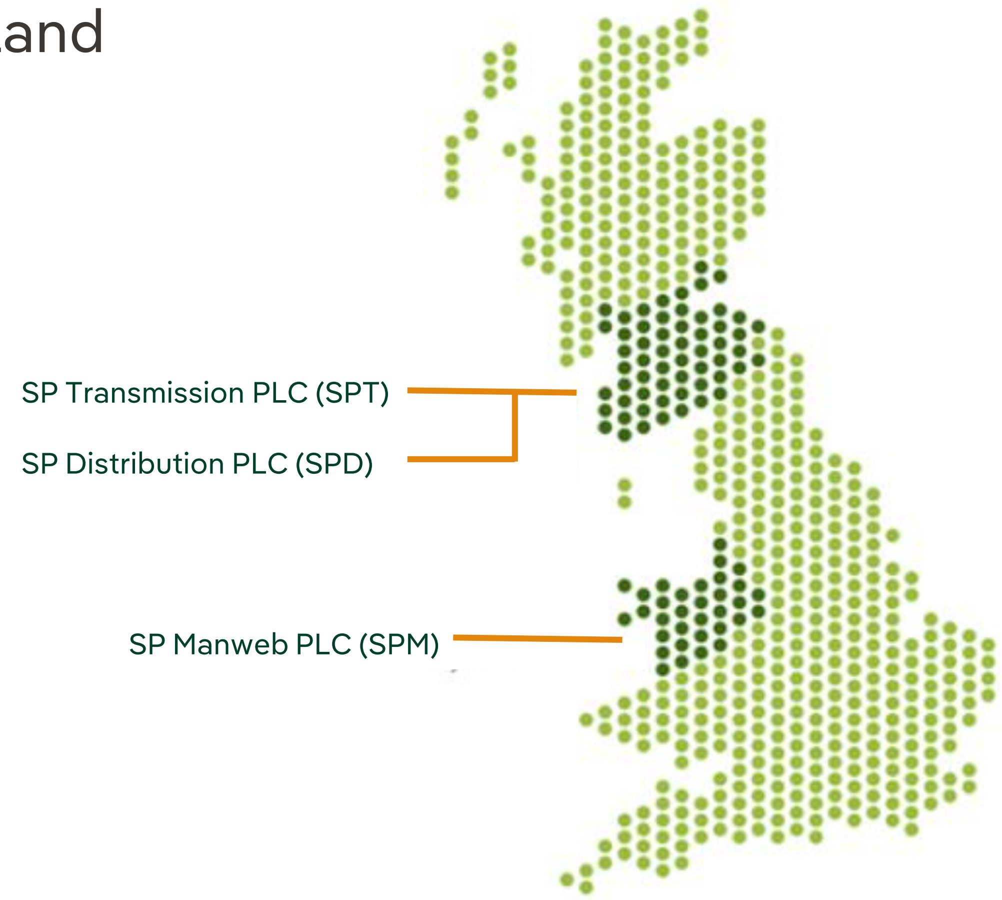
Angle – DC

Andrew Moon – Lead Innovation Engineer

Future Networks

SP Energy Networks

- TNO and DNO for Southern and Central Scotland
- DNO for Merseyside and North Wales
- 44,000km Overhead Lines
- 65,000km Underground Cables
- Over 3000 substations
- A Total of 3.5 Million Customers



Innovation Strategy

The Future Networks team are delivering our innovation strategy through;

- Industry leading expertise
- Concentrating on creating a positive and lasting impact on the future of distribution and transmission
- Two major fields of focus – black start and power electronics

Black Start

Black Start since 2015

Range of partners

Built expertise and capabilities

Power Electronics

Implementation across voltages on transmission and distribution networks

Transmission Network Reliability/Security

SP Energy Networks

VISOR

Greater visibility of network state and assets

FITNESS

Efficient and effective digital substation

Distributed Restart

DERs supporting the network and restoring power

Synthesis

Advanced analytics and real-time control enabling rapid response to system disturbances

£13.59m further **investment** for **SPT**, estimated **£40m** for other GB Transmission business

£54m investment in **RIIO-2** Business plan - digital substations - Westfield and Hunterston

£5m Green Recovery Fund: Synergy

2023-SIF: Black-start from the offshore

Power Electronics

Phoenix

Synchronous condensers + **static compensator** technologies - **manage reduced inertia** and **voltage control** on Transmission Network.

Angle-DC

Medium Voltage DC (**MVDC**) **link** to **Anglesey**, increased **renewable generation** integration.

LV Engine

Trial of innovative **Smart Transformers** for the connection of **LCTs**

£120m investment in **RIIO-2** Business plan **-** implementation of **synchronous condensers** at **Eccles**

3 further sites planned to roll out **LV Engine Technology** within **RIIO-ED2**

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- Increased Distributed Generation Hosting Capacity
- Reduced Losses

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Project Overview

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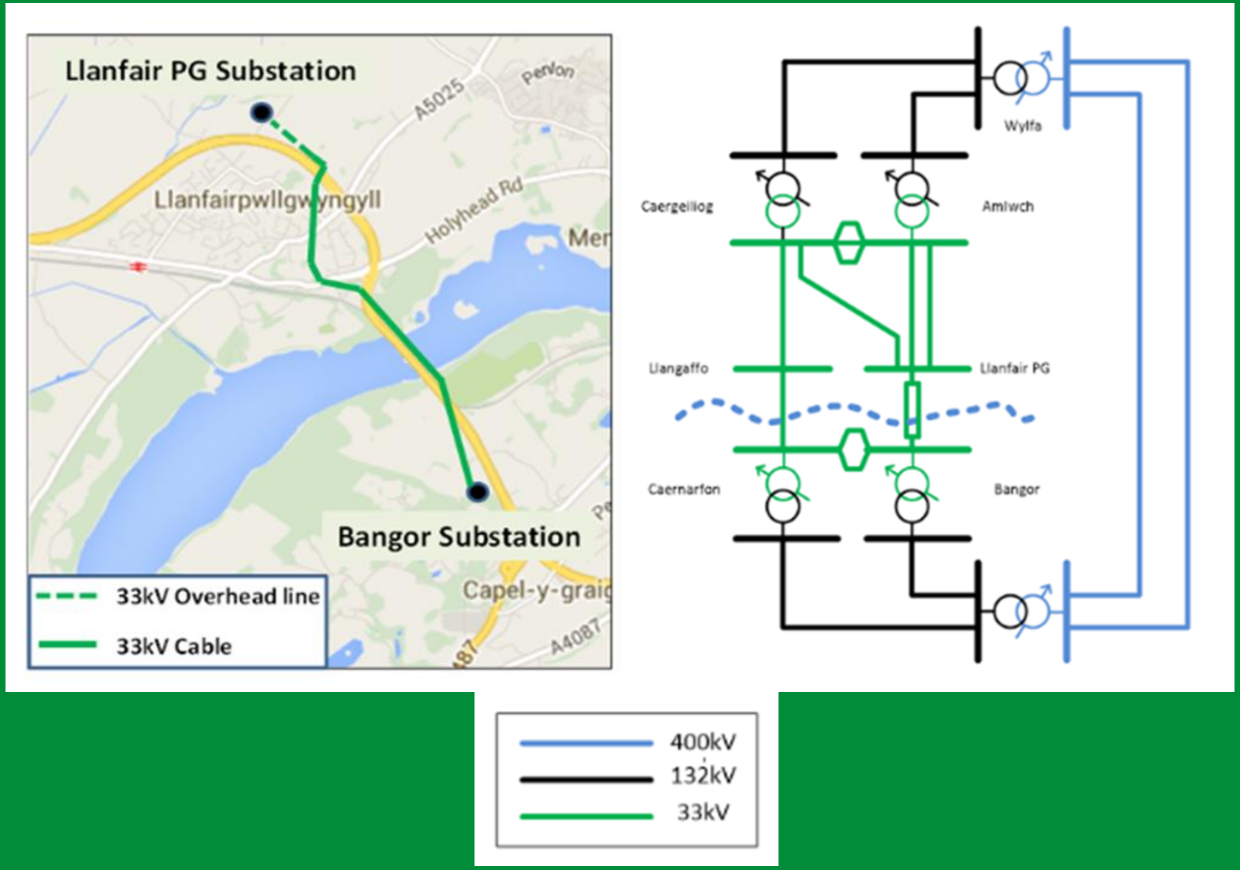
- **£14.8m Ofgem funded**
- Network Innovation
- Competition project (NIC).
- **Ground-breaking project,**
  - Improve network capacity and performance.
  - Forming a Medium Voltage Direct Current (MVDC) link
  - Converting an AC interconnector to DC
  - Provides Power flow control



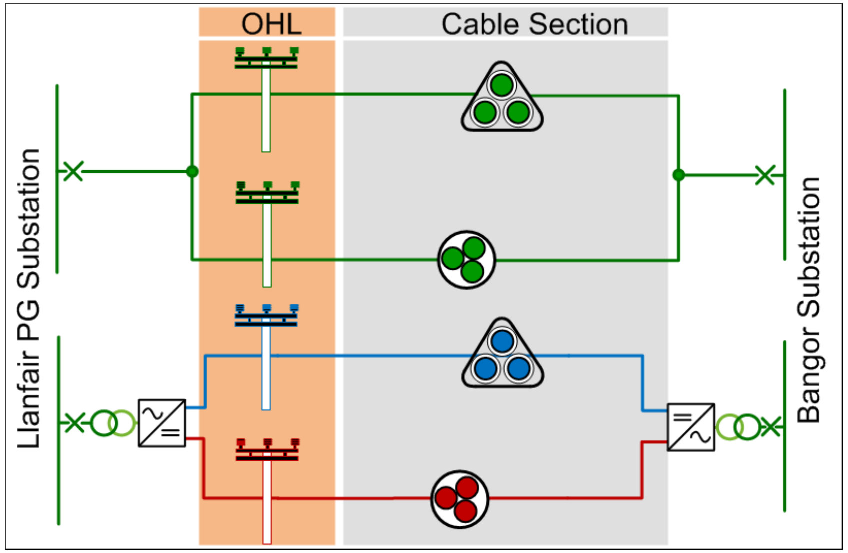
Project Aims

Concept

- 33kVAC cable/OHL circuit utilised for DC operation.
- Control real/reactive power flows, voltage
- Increase in DER capacity.
- Learning from AC to DC Conversion.
- Learning: install, operate and manage a MVDC link.

AC to DC Conversion

- Symmetrical monopole.
- Existing 2 x paralleled 33kV circuits AC (in green).
- AC-DC converters installed at both sub-stations.



MVDC Link System Design & Technical Information

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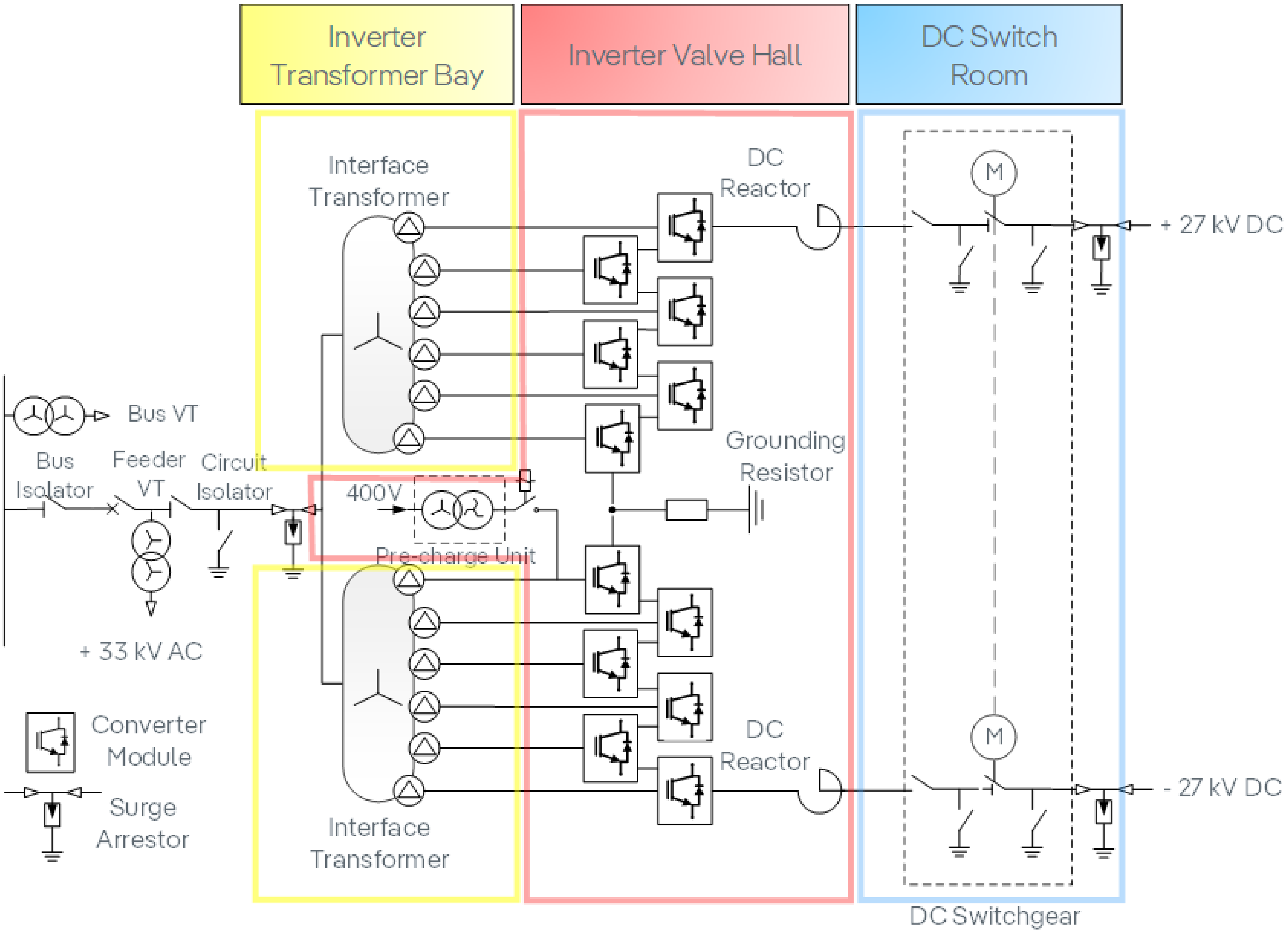
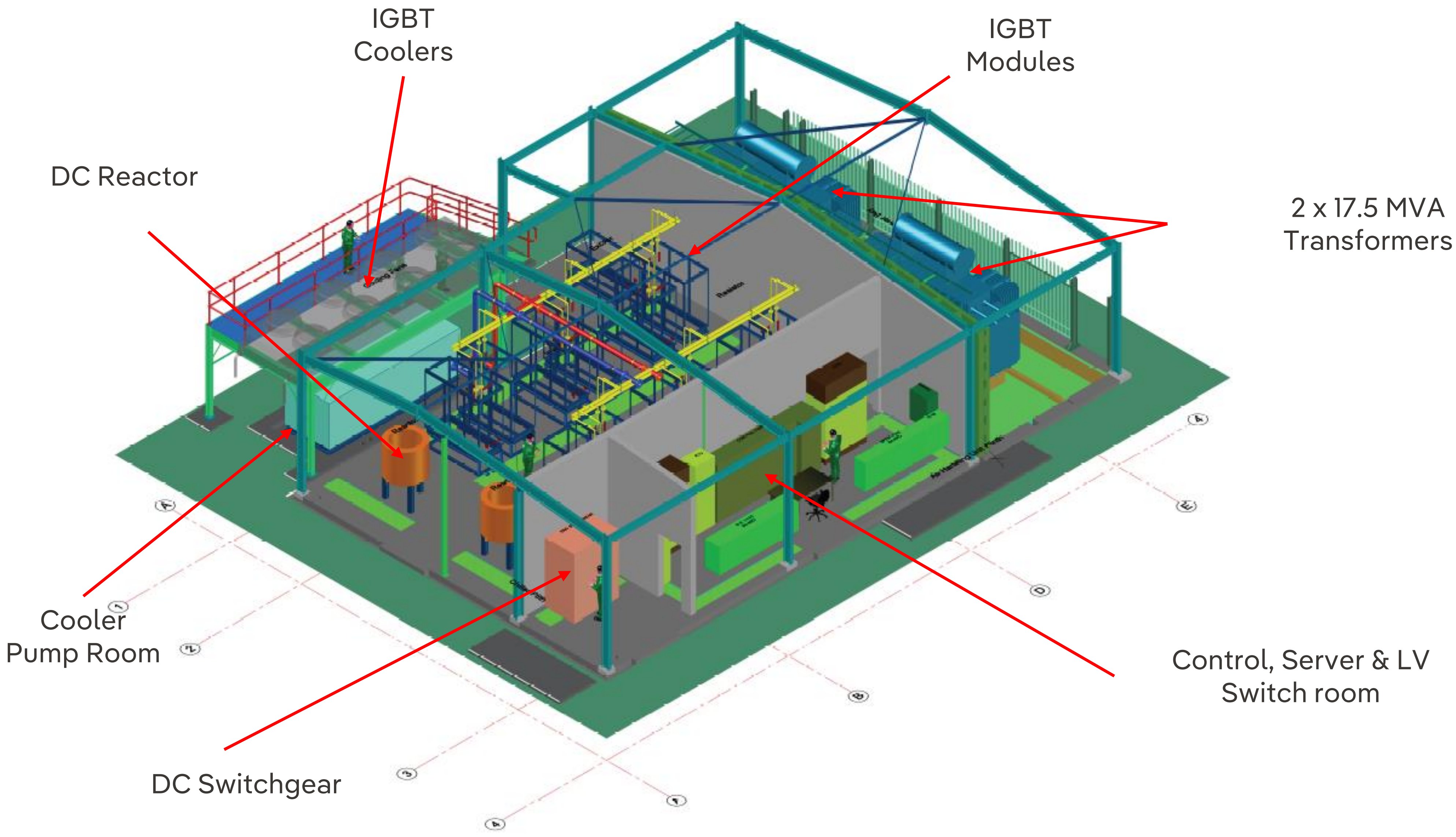
General Principle of Operation

- **Operating Voltage +/-27kVDC (54kVDC between poles)**
  - 33kVAC infeed -> 2.1kVAC and connected to each inverter module.
  - Inverter modules input = 2.1kVAC, output = 4.5kVDC.
  - 6 x inverter modules connected in series per pole (6 x 4.5kV = 27kV)
- **Power Transfer mode (30MVA) between substations**
- **STATCOM mode (+/-15MVAr) voltage support to the 33kVAC busbars.**
- **Inverters/circuit are "pre-charged" to overcome in-rush current.**
- **Poles are mid-point earthed. Earth fault return path.**

MVDC Station Electrical Layout

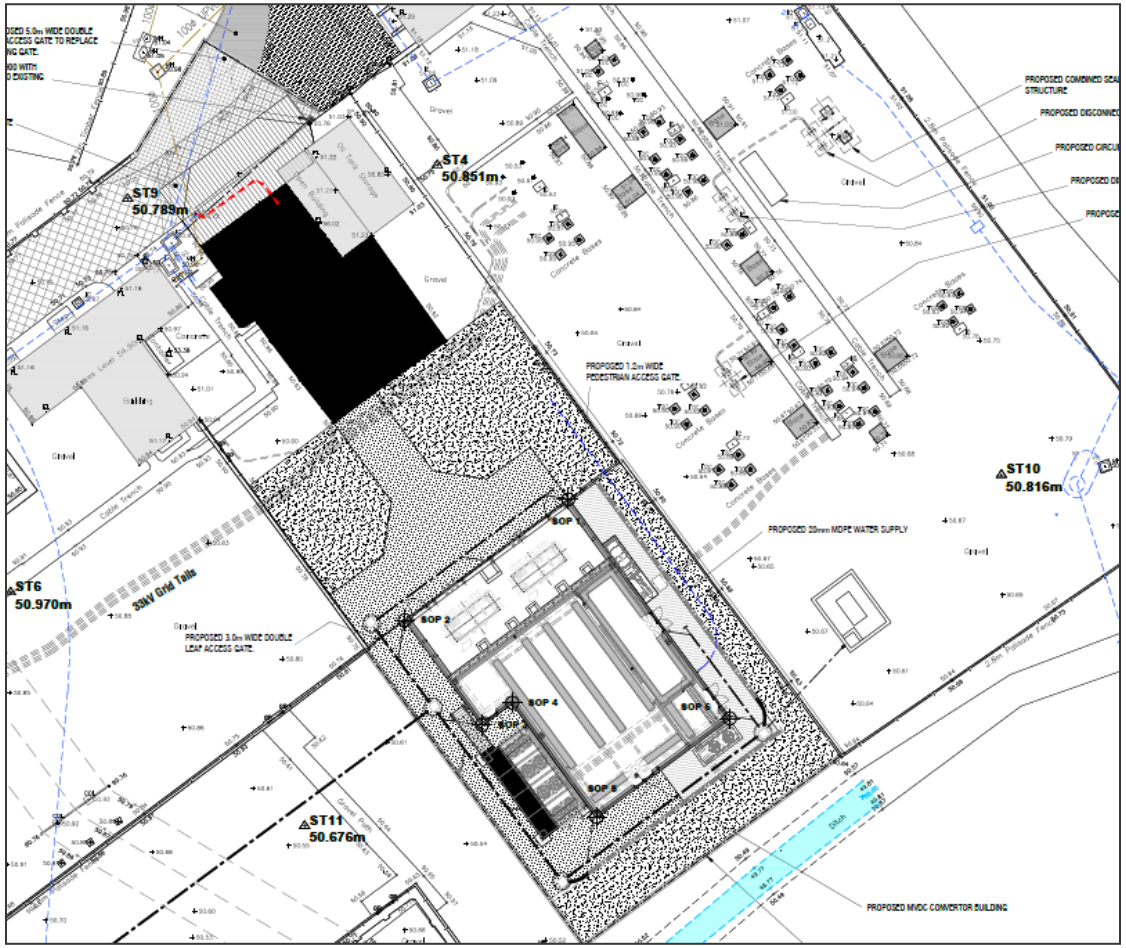


MVDC Station Physical Layout

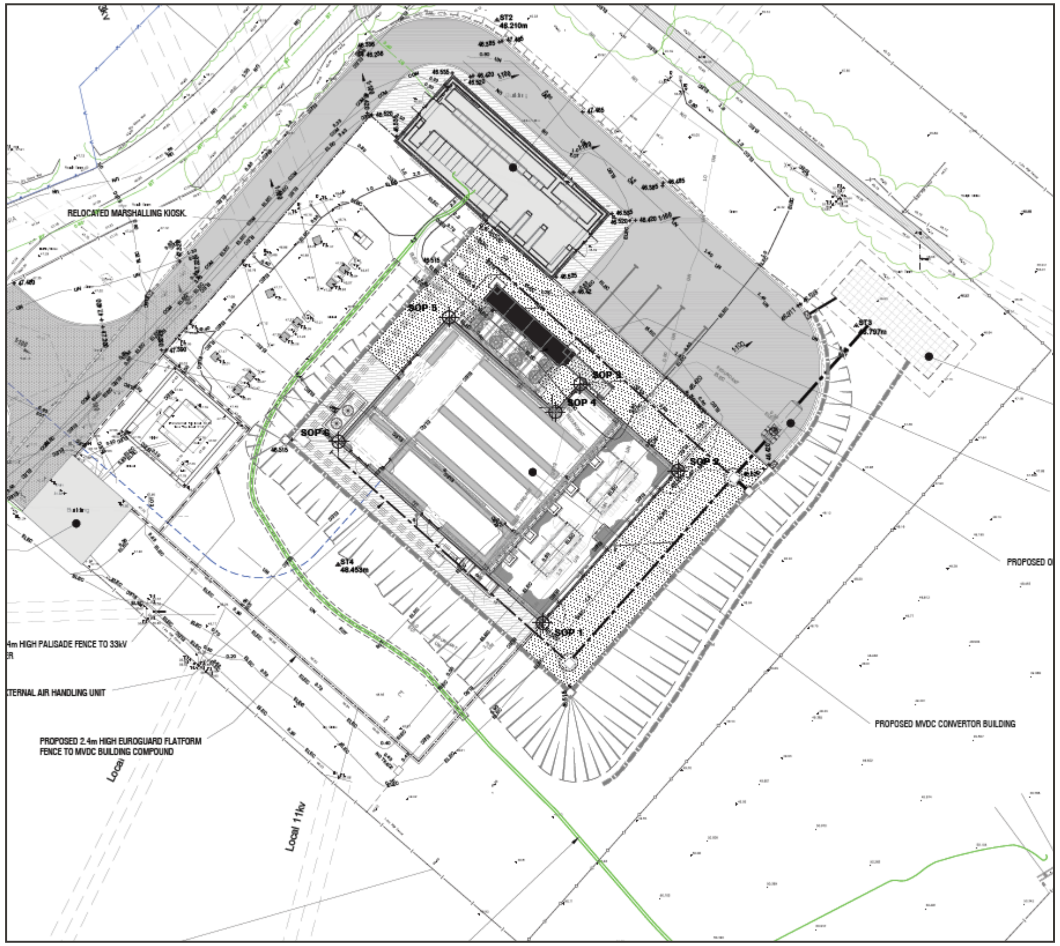


Converter Stations

Bangor Converter Station



Llanfair PG Converter Station



MVDC Converter Equipment

Converter Transformers

- 2 x 17.5 MVA Transformers
- Oil natural Air Natural Cooling
- 33kV AC Input.
- 2.1kV AC Output into Converter Modules

AC/DC Converters Modules

- 12 Modules Total (6 Pos leg, 6 Neg leg)
- 2.1kV AC Input
- 4.5kV AC Output
- IGBT power electronic switches

MVDC Converter Equipment

DC Reactor

- 10mH Rated Inductance
- Smoothing DC output current
- Space to protect from Electromagnetic field effects

Pre-Charge Unit

- Pre-charge transformer & disconnector
- 2.1kV AC pre-charge of the system
- Reduces mag-inrush currents during energisation of converter transformers

MVDC Converter Equipment

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DC Control Room

- Converter Controllers, enabling local operation
- LV Supplies
- Partial Discharge Monitoring
- Telecomms, RTU

Mid-Point Resistor

- 10Ω Banked Resistor, connected to Positive and Negative Legs of DC link
- Provides return path for current during faults.
- Sensor to detect current and operate protection

Technical Standards

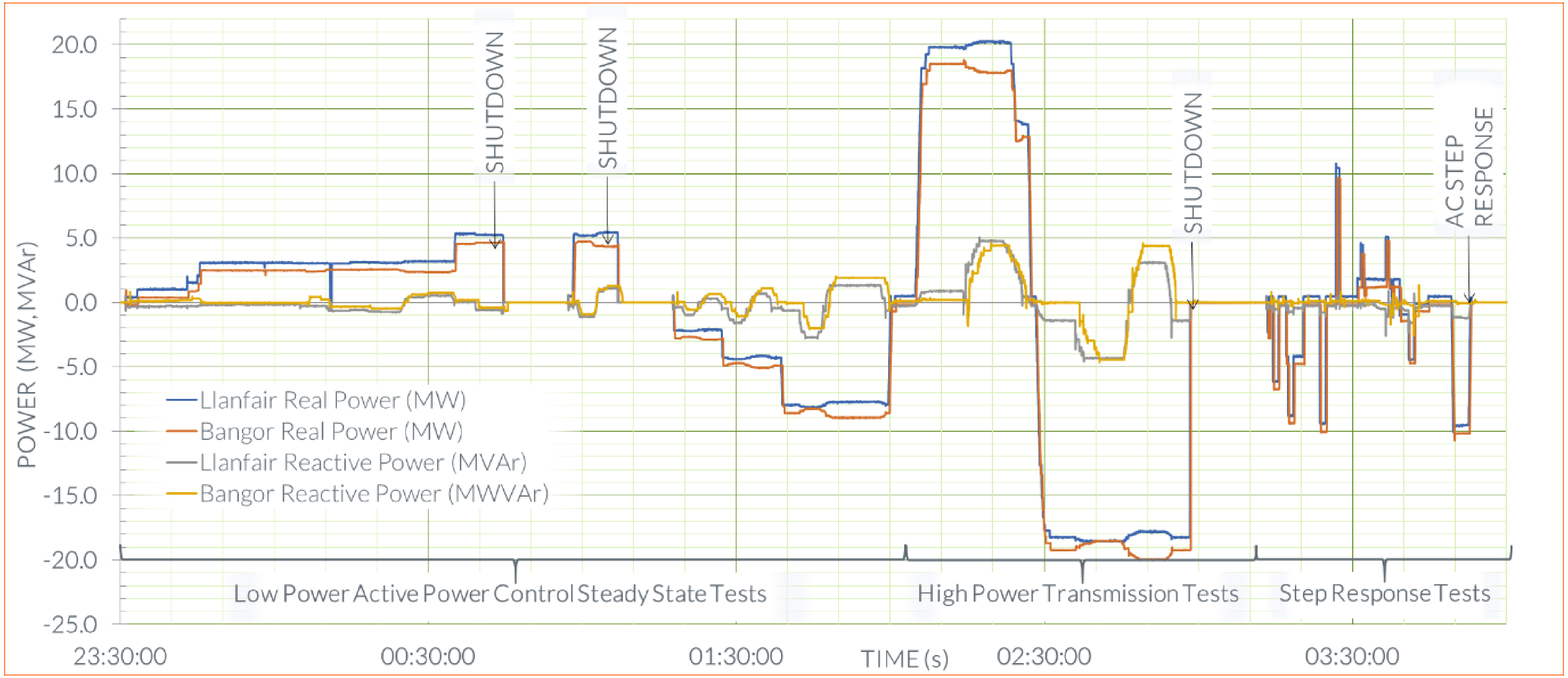
Item	Standard	Key Findings
Cable/OHL Conversion	IEC 61975	• HV pressure tested, cable/OHL intact. • MVDC Commissioning tests – High Power tests, cable/OHL performed well. • Partial Discharge results to follow.
Harmonics	G5	• MVDC Commissioning tests – THD below limits. • No impact above 6th Harmonic. Limited harmonic current below 6th harmonic.
Control	IEC 60870	• Control of both stations operating as expected. • Control of both converter stations from Bangor via fibre link. • RTU link back to Control Room for remote operation/start-up/shutdown.
EMC	EN 50121 IEC-TR 62543	• No EMC impact on Network Rail assets. • Monitoring continued through first 6 months of operation to detect any voltage issues.
Protection	IEC 60255	• Protection of both AC and DC systems. • During commissioning tests, protection operated as expected.

Common Safety Method – Risk Assessment

MVDC Link Commissioning

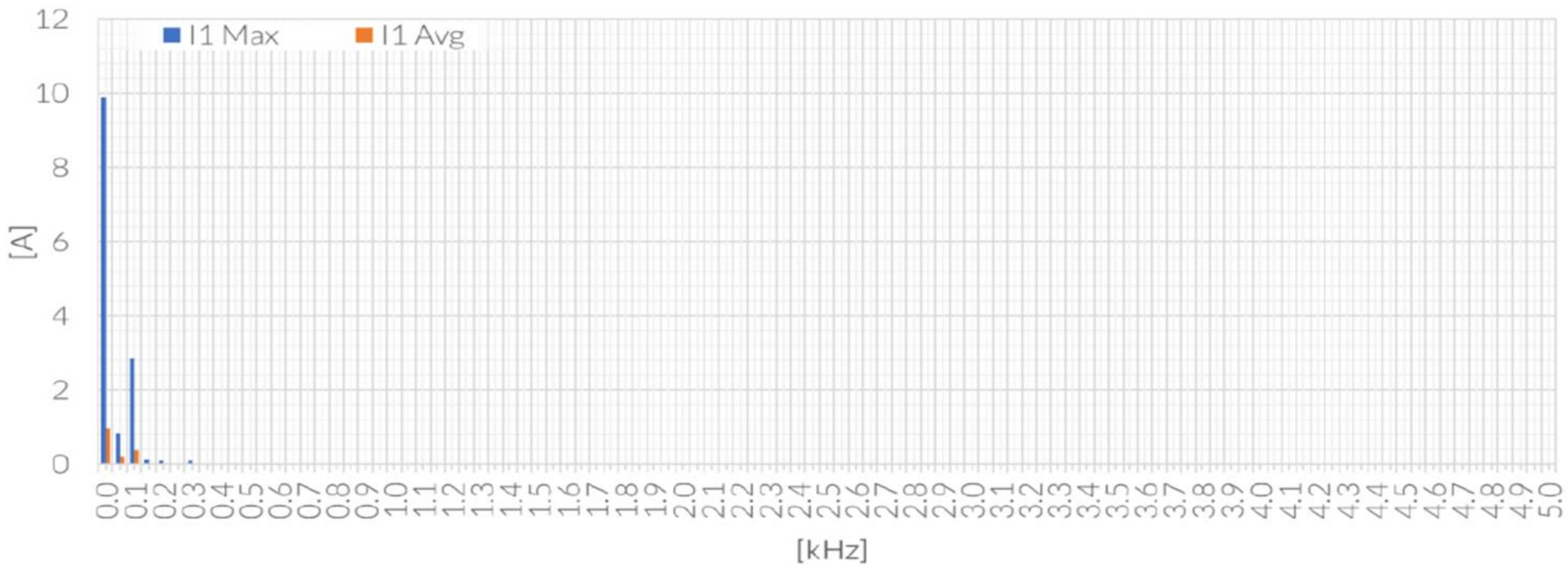
Results of initial commissioning tests shown below. Tests completed in 3 stages;

1) Low Power Steady State Tests
2) High Power Transmission Tests
3) Step Response Tests



MVDC Link Commissioning

- A Common Safety Method for Risk Evaluation and Assessment (CSM-RA)
- Evaluated the AC to DC conversion at commissioning
- Monitoring showed compliant DC harmonic and Electromagnetic Compatibility
- Negligible maximum harmonic currents above 6th harmonic were found



Project Benefits

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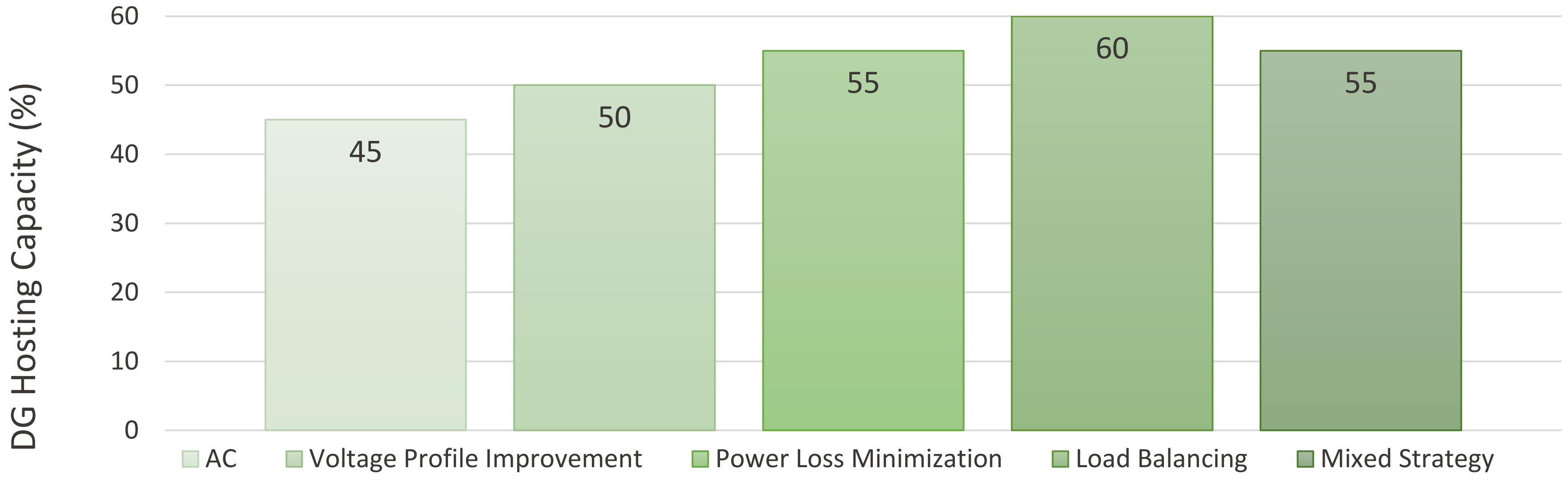
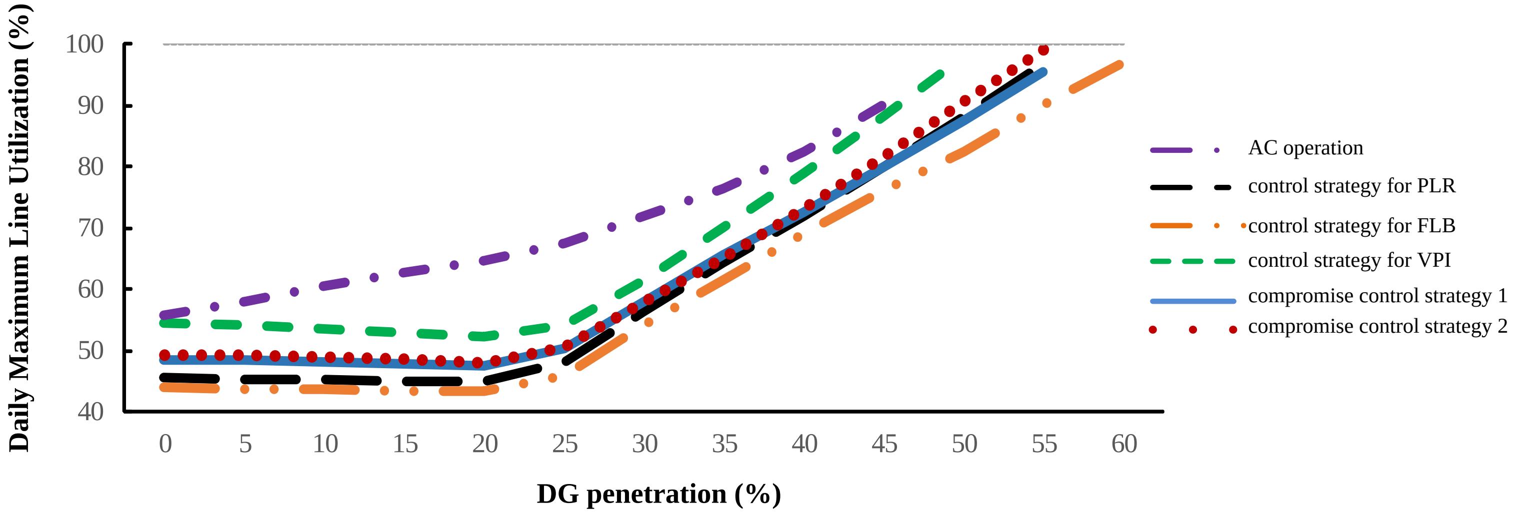
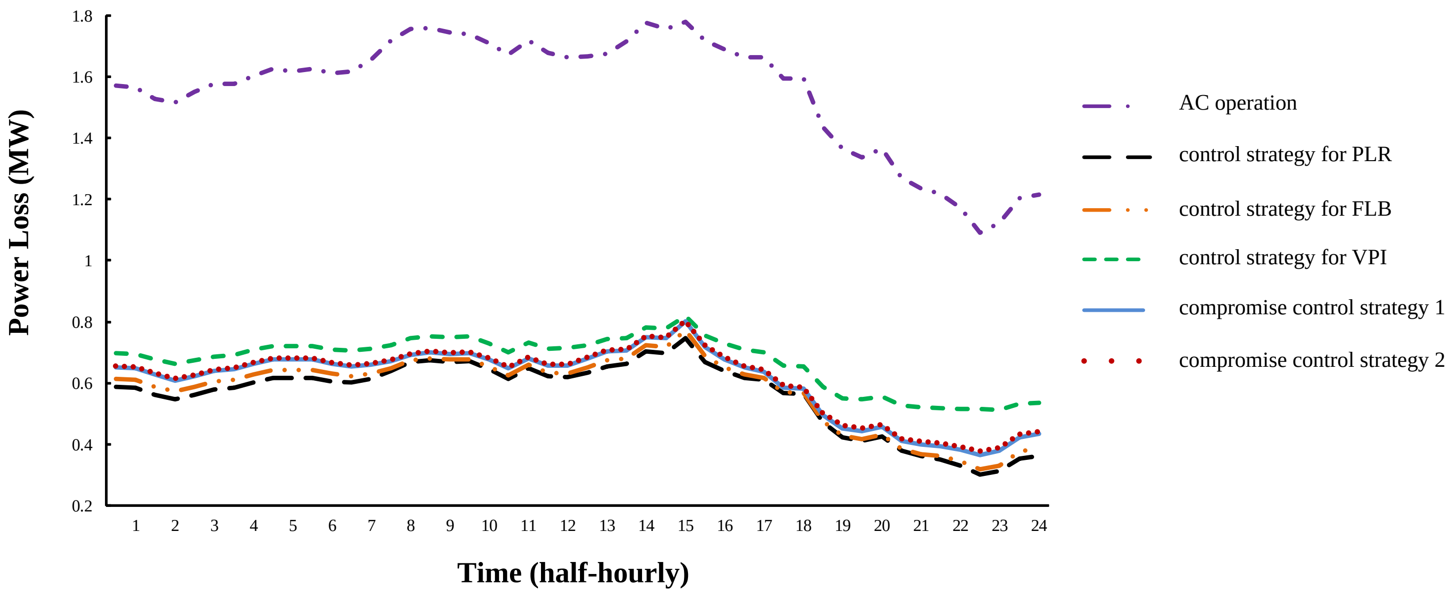
DG hosting capacity up to 15% can be achieved in the Anglesey network





Remote Operation



Power losses over a day of the network by using MVDC link and the original AC operation

Strategy	Daily Average Power Loss (MW)	Daily Energy Loss (MWh)
AC operation	1.556	37.35
Control strategy for PLR	0.562	13.49
Control strategy for FLB	0.578	13.87
Control strategy for VPI	0.673	16.15
Compromise control strategy 1	0.607	14.58
Compromise control strategy 2	0.613	14.72

Lessons Learned

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Lessons Learned

EMC Safety Case

- Complex and challenging study.
- Learning can inform future MVDC systems.

Cybersecurity

- Cybersecurity constantly changing.
- In-depth and rigorous cybersecurity requirements.

Station Cooling

- Building Environment is like a data centre.
- CAPEX vs OPEX costs for closed and open systems.
- Volume of Module housing.

DC Protection

- High Impedance pole to ground faults.

Questions

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