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

**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
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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- Reduced Losses

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Introduction

- **£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 substations.
MVDC Link System Design & Technical Information
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

- 2 x 17.5 MVA Transformers
- DC Reactor
- IGBT Coolers
- IGBT Modules
- Cooler Pump Room
- DC Switchgear
- Control, Server & LV Switch room
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
**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

**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
<table>
<thead>
<tr>
<th>Item</th>
<th>Standard</th>
<th>Key Findings</th>
</tr>
</thead>
</table>
| 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          | • No EMC impact on Network Rail assets.                                                                                                     |
|               | IEC-TR 62543      | • 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
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
DG hosting capacity up to 15% can be achieved in the Anglesey network.
Power losses over a day of the network by using MVDC link and the original AC operation

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Daily Average Power Loss (MW)</th>
<th>Daily Energy Loss (MWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC operation</td>
<td>1.556</td>
<td>37.35</td>
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<tr>
<td>Control strategy for PLR</td>
<td>0.562</td>
<td>13.49</td>
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<tr>
<td>Control strategy for FLB</td>
<td>0.578</td>
<td>13.87</td>
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<tr>
<td>Control strategy for VPI</td>
<td>0.673</td>
<td>16.15</td>
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<tr>
<td>Compromise control strategy 1</td>
<td>0.607</td>
<td>14.58</td>
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<tr>
<td>Compromise control strategy 2</td>
<td>0.613</td>
<td>14.72</td>
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</tbody>
</table>
Lessons Learned
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