Maximizing HVDC Support for GB Black Start and System Restoration

17th September 2019

Consultation Workshop

The National HVDC Centre

Scottish & Southern Electricity Networks

Safety

Fire Safety

- **Exits:** Familiarise yourself familiar with the nearest exits.
- **Assembly Point:** The fire assembly point is on the pavement outside the main gate.
- **Call points, extinguishers & blanket**.

Note: Weekly Fire Alarm Test is every Monday at 10:00am

First Aid

- There are there first-aid kits, a burns kit and a defibrillator on site.
- Simon Marshall & Ian Cowan are trained first-aiders, please contact them for assistance.

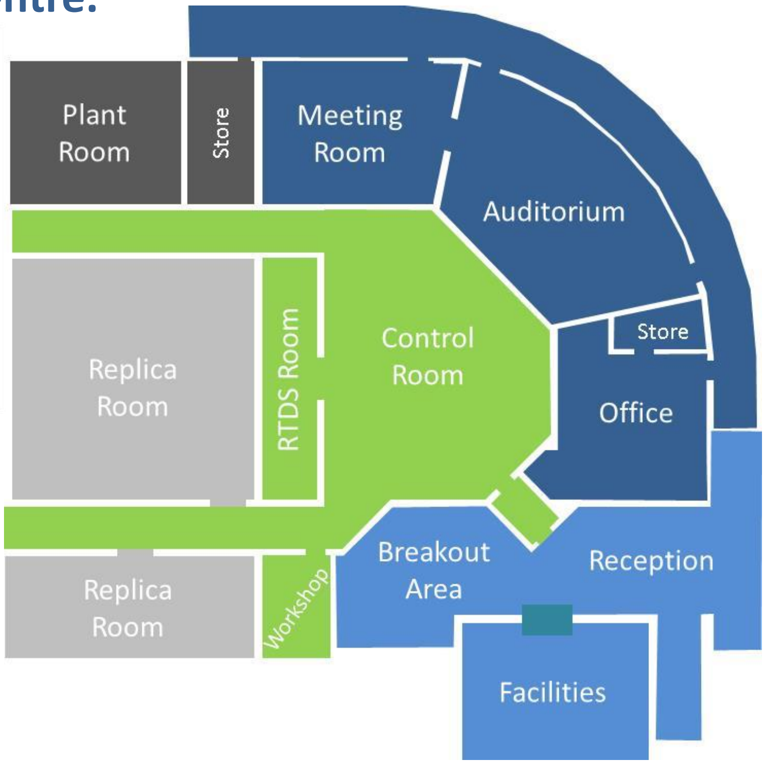
Safety Rules

- **Reverse Park**
- **Sign-In & Out**
- **Assess Risks**
- **Report All Incidents/Hazards**
- **Accept Challenges**
- **No jackets on chairs**

Security

For security, there are different access zones at the Centre.

- As a visitor, you will be given a red lanyard and access badge, which provide you access to the: Office, Auditorium, Meeting Room, Breakout Area and Facilities.
- Visitors may access the Control Room and RTDS Room while accompanied by their host.



Security Rules

- **Display your badge**
- **No Cameras**
- **Accept Challenges**
- **Report All Incidents**
- **Keep Information Safe**

At the end of your visit, please return your visitor's badge to reception and sign-out.

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The National HVDC Centre

The National HVDC Centre is an Ofgem funded simulation and training facility available to support all HVDC schemes.

Using state of the art simulators, we model and resolve potential issues in real-time before they impact delivery of your project or the Grid Network.

The National HVDC Centre *part of* Scottish & Southern Electricity Networks

together with

nationalgrid SP ENERGY NETWORKS

The National HVDC Centre is part of Scottish & Southern Electricity Networks and is funded through the Electricity Network Innovation Competition as the Multi-Terminal Test Environment (MTTE) Project. Scottish and Southern Electricity Networks is a trading name of Scottish Hydro Electric Transmission plc, Registered in Scotland No. SC213461, having its Registered Office at Inveralmond House, 200 Dunkeld Road, Perth, PH1 3AQ; and is a member of the SSE Group www.ssen.co.uk

Development of HVDC Links in Great Britain

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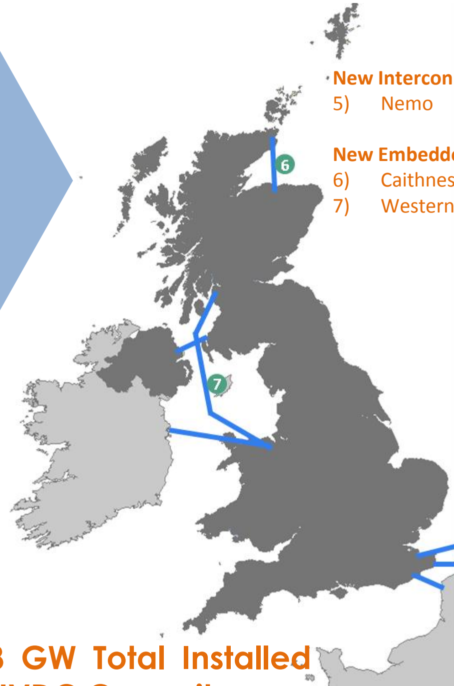
Past (2017)

4 GW Total Installed HVDC Capacity

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

Present (2019)

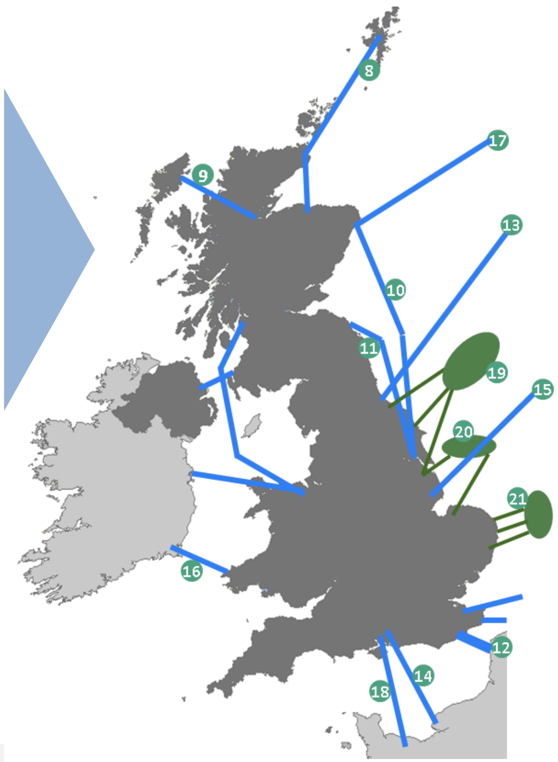


New Interconnector:
5) Nemo

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

8 GW Total Installed HVDC Capacity

Future (2027)



New Island Links
8) Shetland
9) Western Isles

New Embedded Links
10) Eastern Link 1
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

- **The National HVDC Centre is an Ofgem-funded simulation facility available to support HVDC schemes in GB.**
- **The Centre used real-time simulation with replica controls to support the Caithness-Moray HVDC Project.**

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Overview of Report

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This report:

- ❑ Reviews the key drivers for change in the GB electricity mix & development of HVDC schemes
- ❑ Outlines the capability of GB HVDC Schemes to provide BS and system restoration services
- ❑ Highlights opportunities for improving the system stability using HVDC schemes
- ❑ Identifies key enablers and considerations for HVDC technical performance across BS

Structure

- Introduction
- HVDC Applications in GB
- System Restoration Requirements with HVDC Capability
- Case Study of HVDC Schemes in Scotland and North of England
- Global Review of HVDC Contribution to Black Start and System Restoration
- International Black Outs Experience and GB Innovation Black Start Projects
- Recommendations and Conclusions
- References

Change in GB Generation Mix

	2012	2018	FES Range for 2025
Total generation capacity	94.4GW	107.4GW	116GW - 132GW
Of Which Coal	25.0GW	10.2GW	0GW
Of Which Wind	7.6GW	21.0GW	28GW - 41GW
Of Which Solar	0.4GW	12.7GW	13.9GW – 20.4GW
Synchronous Generation	82.2GW	65.1GW	45GW - 58GW
Non-synchronous generation	12.2GW	42.8GW	60GW - 84GW

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4 Main Applications of GB HVDC Schemes

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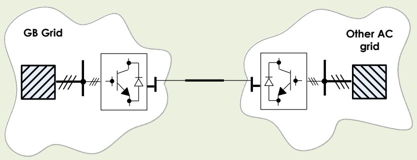
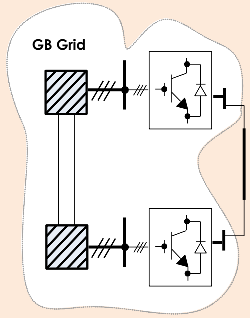
- **Interconnections**



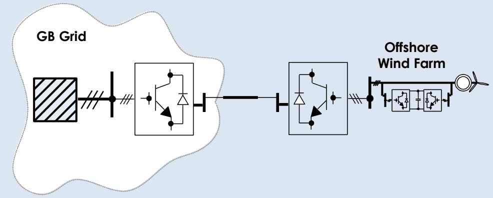
  - **VSC or LCC Option**
  - Typically built & owned by commercial / merchant operators

- **Embedded Links**



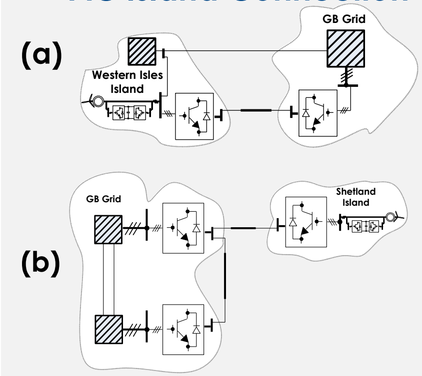
  - **VSC or LCC option**
  - Typically built & owned by Onshore Transmission Owners

- **Offshore Wind Connection**



  - **VSC Only**
  - Typically built by offshore wind farm developers & transferred to Offshore Transmission Owners

- **AC Island Connection**



  - **VSC Only**
  - Could be onshore TOs; competitively appointed TO; or alternative arrangements,

- **Other Considerations:**
  - It is assumed that **the DC link is energized from a far-end converter station** during provision of BS support;
  - Different GB HVDC ownership regimes could influence contribution to BS or system restoration phases; and
  - Testing of AC grid protection performance across HVDC Black Start energisation and system restoration is required.

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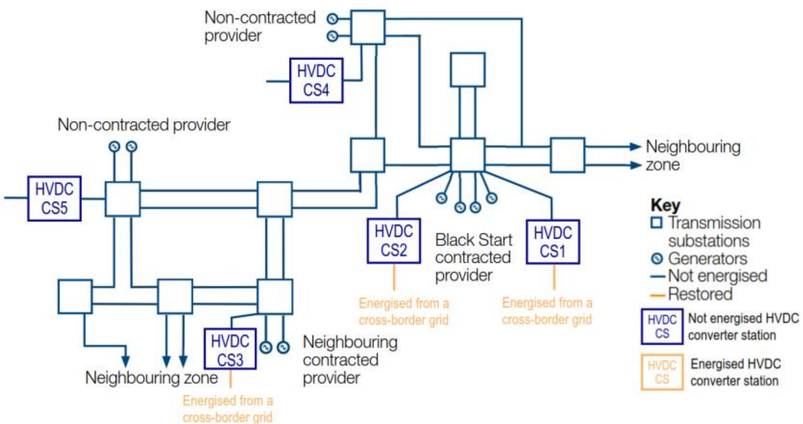
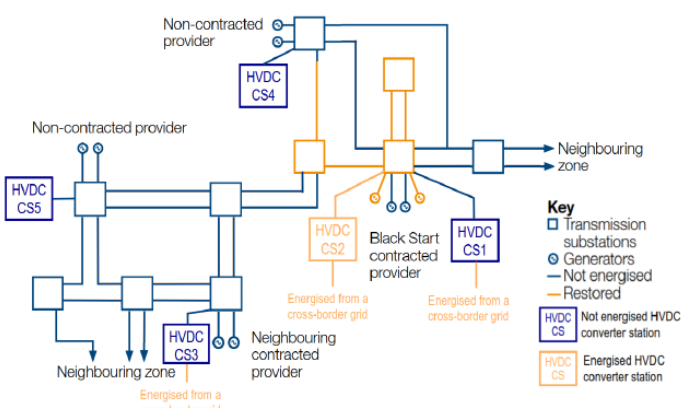
Stages: HVDC as part of Black Start

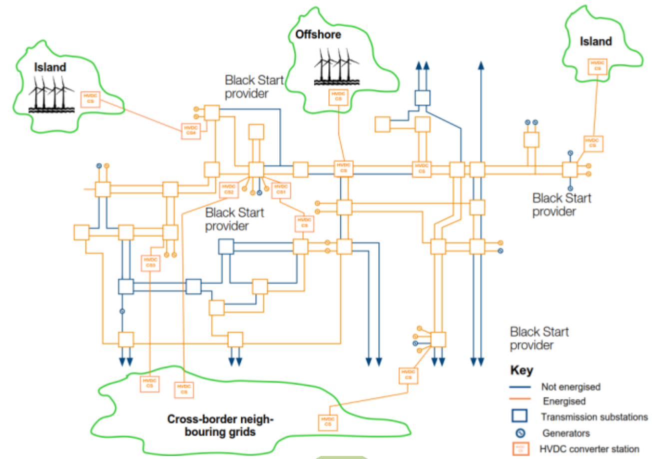
1. Review and Instruct:



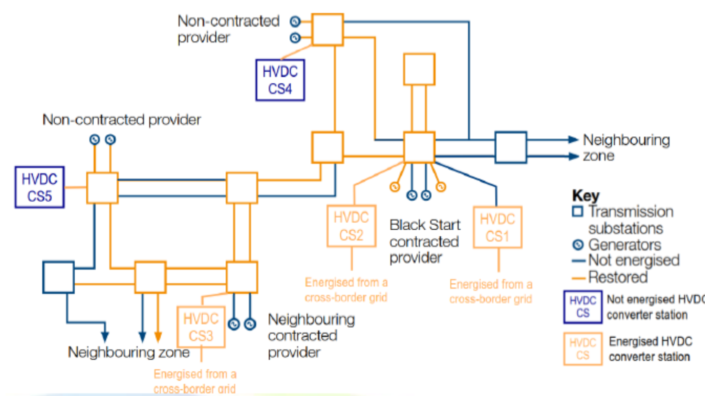
2. Start-up Stage:



4. Skeletal Network Stage:



3. Power Island Stage:



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Capability Analysis Table

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Category		Interconnections (with energised DC link)		Embedded Links		Offshore Wind Links	Islands Network interfaced to the GB mainland	
ESO BS Technical Requirements		VSC	LCC	VSC	LCC	VSC	Interfaced by a VSC-based multi-terminal HVDC link to the GB main land	Interfaced by a hybrid HVAC VSC-HVDC
		A	B	C	D	E	F	G
1	Time for the converter to start-up and energise part of the network (≤ 2hrs)	Self-commutated and can create an AC voltage [43].	Complementary technologies e.g. synch. compensation or equivalent are required to create a sufficient voltage & SCR to allow effective commutation [33] plus meeting the requirements B3-B9	During a complete blackout event, embedded HVDC links will be part of the dead network. Thus, they cannot provide Black Start services. However, they do have the capability to support the system restoration later stages as a part of the transmission system.		Limited by wind availability and requires synchronisation to an established AC terminal for self-start & back-energisation of HVDC link.	Existing local generation is not sufficient for back-energise a 600MW rated HVDC. With future wind generation, E1 is applicable.	Similar to F1
2	Service Availability ≥90% of Each Year of the Service	>95%	>95%			Offshore 90%, and onshore up to 95% [47][48]	Similar to E2	Similar to E2
3	Voltage Control Capability (within ±10%)	Inherent voltage control capability is available [46].	Requires synch. compensators to establish an AC voltage with sufficient SCR to ensure commutation is not lost [33]. Ability to withstand inrush currents & transient voltages during network energisation.			Maintaining stiff AC voltage for energising the offshore inter-array cables, offshore and onshore substations, and onshore AC transmission is a technical challenge [49].	Similar to E3	Similar to E3
4	Frequency Control Capability	Frequency control is available for 0MW to rated power if the transition to island freq. control mode is implemented [43][46].	Requires synch. compensators with enough inertia to slow RoCoF that the LCC can track and ramp up its power accordingly.			Requires power curtailing control for minimum production & fluctuating power due to wind speed variations. VSC needs to change from grid-following to grid-forming control mode, and BESS may be required for FFR.	Similar to E4	Similar to E4
5	Supply BS Service >10hrs	Applicable [46]	Applicable when B3, B4, B7 and B8 are met.			Requires 1-5% of its rated capacity power supply to energise yaw & pitch mechanisms for self-start plus HVDC converter auxiliary units [49].	Similar to E5	Similar to E5
6	Supply Auxiliary Units >72hrs	On-board backup supply normally installed	Similar to A6			Similar to A6	Similar to A6	Similar to A6
7	Block Loading Size (≥20MW)	Inherent fast active power response and control capability [43][46]	Sufficient reactive power is required to avoid commutation failure, and enable power import [33].			If E3 and E4 control requirements are met, aggregation of wind farms may deliver power up to 5 days [50].	Similar to E2	Similar to E2
8	Reactive Power Capability (≥100 MVAr leading)	Independent reactive power control capability	Requires synch. compensators and enough reactive power capacity to support the LCC commutation and system energisation [33].			Similar to A8	Similar to E8	Similar to E8
9	Sequential Start-up (≥3 attempts)	Multiple self-start up capability on dead and weak AC grids [43].	Possible when B3, B4 and B8 are met.			Possible with a strong AC voltage is established at the terminal & 1-5% of its rated capacity power supply to energise yaw & pitch mechanisms for self-start and emergency braking [49].	Similar to E9	Similar to E9
TRL*	GB system environment	6 (Pilot scale technology demonstration [24])	4 (Technology development with system validation in a laboratory environment)			3 (Research to prove feasibility and experimental proof of concept)	3 (Similar to GB system TRL in E)	3 (Similar to GB system TRL in E)
TRL*	International experience	9 (System operation over full range of conditions [24][43][46])	7 (System commissioning at full scale demonstration [33])			5 (Technology development with laboratory scale system validation in a relevant environment)	Not applicable	Not applicable

*Technology readiness level (TRL) definition adapted from [28].

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Case Study of Scotland and Northern England

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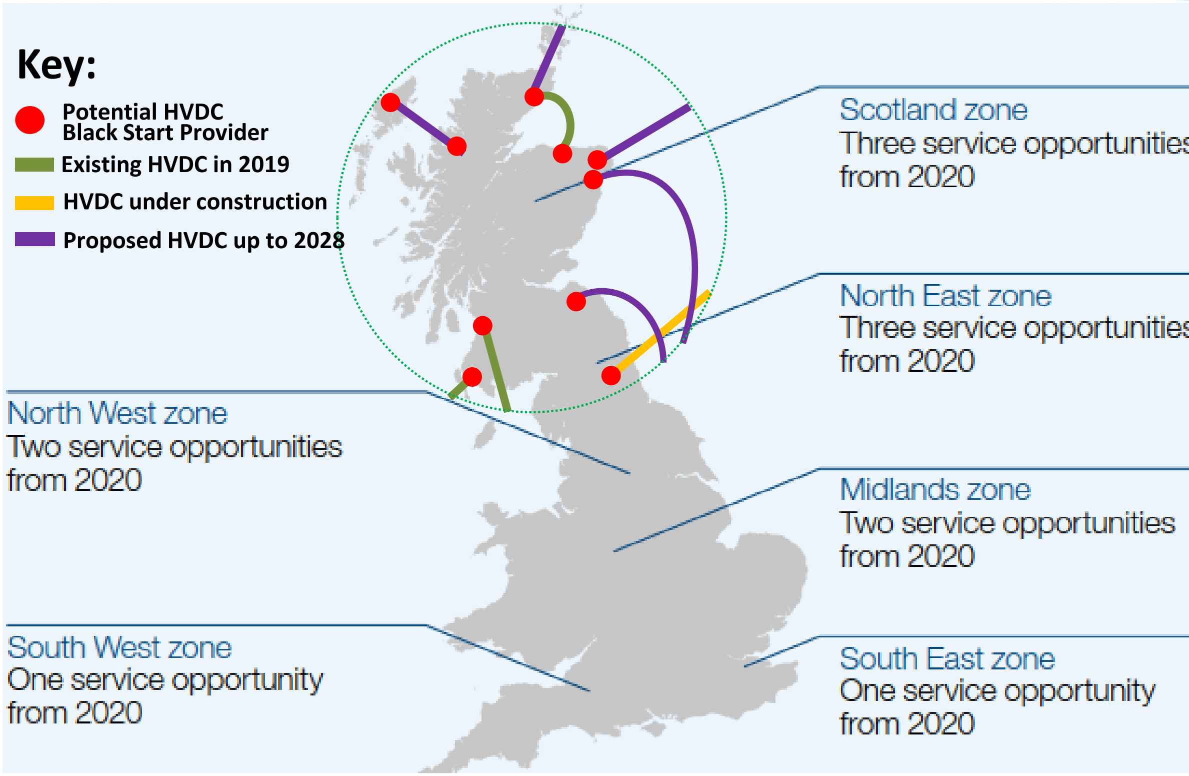

- ESO Stability Pathfinder identifies risk of system instability in Northern Britain;
- HVDC schemes in North Britain existing (Moyle, Wester Link, & Caithness-Moray) and future (NSL, North Connect, Eastern Links, Shetland & Western Isles) could provide BS support to the zone.
- The ESO are conducting a rolling BS tender programme in 6 zones including Scotland and North of England.

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Practical Recommendations for Maximising use of HVDC for BS and Restoration

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Opportunity	Recommendation
There is little guidance for HVDC Schemes on what Black Start services should be specified.	Define (and promote) the Black Start services that should be specified in all future schemes.
Black Start is a highly unusual situation, hence the AC network protection, or the HVDC system protection, may not act as expected during energisation.	The protection settings for both the AC system and HVDC system should be tested (as a combined system), for restoration scenarios.
During re-energisation; energised 'islands' need to be connected (and re-synchronised), requiring complex control and data exchange.	System studies are required to ensure the HVDC controllers transition as required during re-synchronisation.
The limited testing of HVDC Black Start functionality does not give the required level of confidence that it would act as expected on the real network.	Combine factory testing, real-time demonstration and field trials to build confidence in the robustness of Black Start operation.
The Black Start services that HVDC schemes provide could be significantly enhanced if combined with an synchronous condenser.	Investigate enhancing the Black-Start services by combining HVDC Converters with synchronous condenser.
The criteria to provide Black Start services are not appropriate for HVDC schemes.	Review the Black Start service criteria to ensure that HVDC schemes are not unnecessarily dis-qualified.
There are additional HVDC Black Start enhancements that merit further investigation.	Investigate further: o Using offshore windfarms (or island generation) to help energise the network, and o Reducing system voltage during restoration to speed-up the time-to-restore.

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Hands-on Workshops

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- A: Recommendations (Agree/Disagree)
  - Aim: To agree/disagree on all 7 recommendations
  - Activity 1: Discuss & Present Group report to attendees

- B: Any other recommendations?
  - Aim: To identify any missing recommendation(s) and why
  - Activity 2: Discuss and present suggested recommendation

- C: Next Steps
  - Aim: To plan next steps for 2/3 recommendations
  - Activity 3: Discuss in groups and present plans for next steps

- **Timeline and Collaboration Plan**
  - End of May: Agree and finalise scope;
  - End of June: Discussions with Transmission Owners and Kick-Off Meeting;
  - End of August 2019: Production of first draft of the report **(Face to face meeting)**;
  - **17 September 2019: Workshop with TO and ESO to agree recommendations; and**
  - **End of September 2019: Produce final report .**

Would you envisage any further engagement/ public stakeholder event?

Thank you for visiting The National HVDC Centre

- If you have any questions, or need anything during your visit, please contact one of the team.

- Should you see anything that can be improved, please talk to one of the team.

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