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This review is subject to the information made available from the Flemish administration in connection with this project and strictly represents the informed opinion of The National HVDC Centre based on this project information and the available supporting data as referenced at this time. This opinion has been provided for the sole purpose of further informing the review of the specifics of the project options provided and The National HVDC Centre should be contacted ahead of this material or opinion being used for any other purpose.

The opinions provided in this report, are solely the technical perspective of The National HVDC Centre, and do not necessarily represent the views of SSEN, SHE Transmission or SSE.

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The Ventilus Project: the technical maturity/ viability of alternate HVDC Options

The National HVDC Centre (hereafter “the Centre”) has been requested by Flemish administration to undertake an assessment of the technical options considered by Ellia, to provide its informed opinionas to whether such options are:

- Technically viable within the timeframes of the project (noting risks and considerations which influence this); and
- Whether the approach is technically mature in this time frame (i.e. where technologies and other solutions are available within the implementation timeframe of this project).

The Centre has been provided with the following 3 documents describing the project and its options:

1. {Elia Group} Study on the use if HVDC for the Ventilus Corridor;
2. {Manitoba Hydro} Technical Note - Technical Challenges & Risks of HVDC Transmission for Ventilus and Loop of Hainaut Corridors; and
3. {Ventilus} Context of the technology review for the Ventilus project.

The Ventilus project is intended to deliver against the following key principles. The table below summarises our opinion in these areas.

Principles	Key HVDC implementation factors	Key risk factors	Conclusion
Transmission Capacity of 6GW in normal conditions (N) **Transmission capacity of at least 3 GW during maintenance or incidents (N-1)**	Would require at least 3 distinct and separate circuits [1], not subject to common mode failure. This would require additional AC infrastructure to interface and additional separate HVDC infrastructure.	Technology not currently available for 2 x 3GW [2], possible for c. 3x 2GW around time of implementation [1].	Insufficient technical maturity for an exactly equivalent HVDC approach.
Route not yet known, length of 80 to 90 km per corridor	HVDC is not subject to a maximum distance consideration.	None.	HVDC solution available.

Principles	Key HVDC implementation factors	Key risk factors	Conclusion
Possibility of integration with the local transmission system to allow for regional development	HVDC project would need to be designed from the outset with new connections in mind [3], to ensure future control viability. Multi terminal solutions may require additional infrastructure (e.g. DC Circuit breakers & new protections) [4].	Use of discriminated protection DCCB Multi-terminal technology not mature in time to meet intended delivery programme [5].	Insufficient maturity and technical viability to consider in the available delivery timeline.
Very stable operation within the meshed backbone network	Given system weakness, new grid forming concepts [6], and/or synchronous condensers would be necessary [7].	HVDC control, network stability protection & control [8].	Insufficient viability and maturity- would be of high technical risk and first project internationally to attempt such a solution.

HVDC technology particularly in its application using Voltage Source Convertors is a mature and highly flexible technology, with examples of in delivery up to 1400MW [9]. The conventional control concept for this mature technology however relies up measurement of the system to complement its behaviour. In conditions of system weakness, as may be measured by regional inertia and short circuit level, these controls may be compromised and a range of risks may arise - which must be mitigated both at the design stage and effectively monitored and managed across the life of such solutions. Whilst there is precedent for doing this (The National HVDC Centre currently supports the operation of a parallel HVDC link, which is expected to evolve into the first multi-terminal HVDC project in Europe [10]) its connection context and network strength across operation presents a lesser challenge in design, operation and management than the intended function of the Ventilus project would represent.

Given the complexity of this design concept, particularly in its necessary control and protection combined with its intended capacity requirement, the Centre's opinion would concur with the Ellia conclusion that HVDC solutions are not yet at a position to fulfil the intended range of needs.

Were such proposals taken forward in some manner (e.g. several lower scale HVDC developments) to a later timeframe allowing for the necessary design considerations of the HVDC system to be addressed, the control concepts required would still continue be "first-in-generation". Whilst these would be more practicable with more time for their development and validation these solutions would still need to be carefully monitored and managed across the design and commissioning and project life. Such analysis would require a level of detail and completeness of the control and protection - of the Ventilus project, the existing NEMO link and the existing and future convertor based connections (offshore wind etc) in the area - which is not normally exchanged. Use of replica control and protection of each project in real time digital simulation, with Hardware-in-the-loop (RTDS-HiL) in combination with a detailed Ellia network model would be recommended to achieve the necessary standards of verification of performance needed.

Finally, we note that the Elia report does not mention the evolving challenges of protection performance upon the AC network for low system strength conditions [11]. We would additional recommend, were such HVDC solutions progressed for the Ventilus project, combining Interconnector, Wind and new HVDC control & protection replicas or models with the physical protections of the AC network, together with their recommended settings to ensure there is no risk of protection maloperation and the cascade losses of connections in this area that could result from such situations [12].

Regards,

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Appendix A: the Ventilus Project and its HVDC options (from {Manitoba Hydro} Technical Note - Technical Challenges & Risks of HVDC Transmission for Ventilus and Loop of Hainaut Corridors)

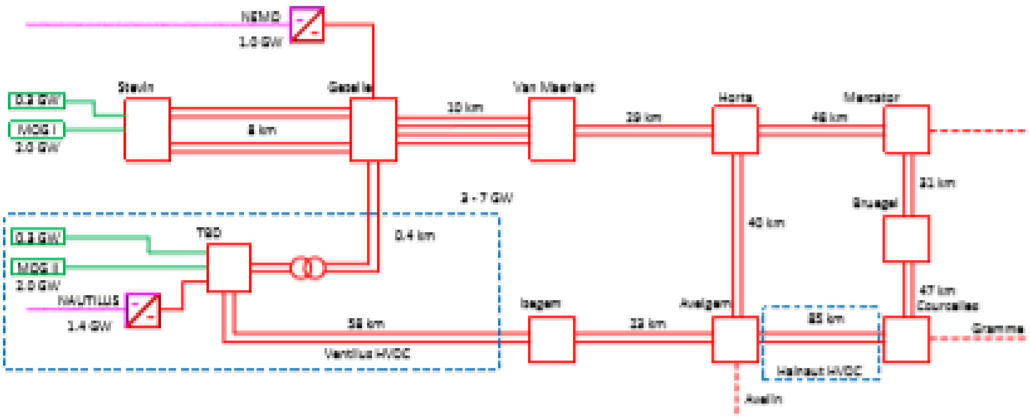

Figure 1: Proposed Ventilus and Hainaut project developments: HVAC Option

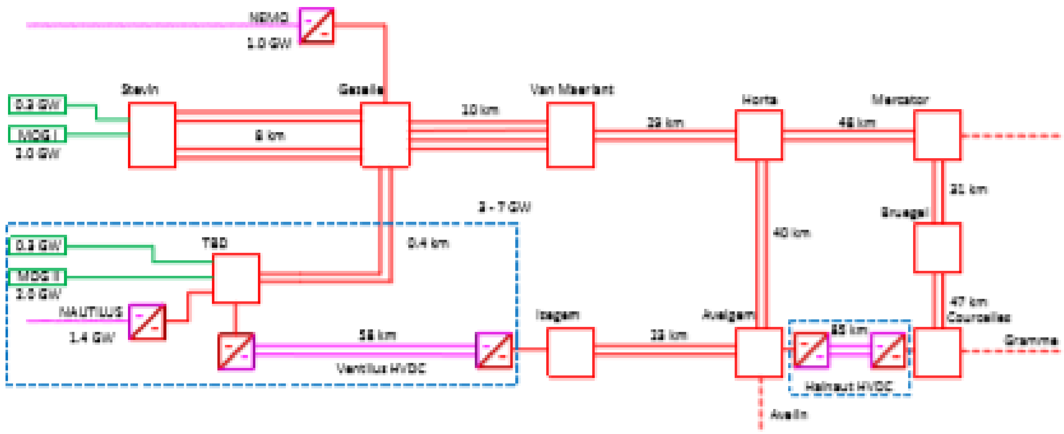

Figure 2: Proposed Ventilus and Hainaut project developments: HVDC Option

References (in addition to provided documents)

[1] submarine and onshore cable capabilities for HVDC https://www.europacable.eu/wp-content/uploads/2019/06/Joint-paper-HVDC-Cable-Reliability-ENTSO-E-Europacable_FINAL_13.06.2019.pdf

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[3] Requirements for the specification of multi-terminal DC grids https://www.promotion-offshore.net/results/deliverables/

[4] National HVDC centre webinar series https://www.promotion-offshore.net/news_events/news/detail/online-event-demonstration-of-dc-grid-protection/

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[6] ENTSO-e sub-group: grid forming convertor guidelines https://eepublicdownloads.blob.core.windows.net/public-cdn-container/clean-documents/Publications/SOC/High_Penetration_of_Power_Electronic_Interfaced_Power_Sources_and_the_Potential_Contribution_of_Grid_Forming_Converters.pdf

NERC requirements on high invertor dominated environments
https://www.nerc.com/comm/PC_Reliability_Guidelines_DL/Item_4a._Integrating%20_Inverter-Based_Resources_into_Low_Short_Circuit_Strength_Systems_-_2017-11-08-FINAL.pdf

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[7] National Grid ESO Stability pathfinder requirements, 2019 https://www.nationalgrideso.com/research-publications/network-options-assessment-noa/network-development-roadmap

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[9] National Grid ESO (2020). Interconnector Register. Accessed 15th June 2020.
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