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WHITE PAPER

Examining Meshed Interconnections and Their Impact on Offshore Wind Design

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Moving from radial interconnections of individual offshore wind turbines to a model with clusters of these facilities linked in a mesh is an idea whose time is rapidly approaching. The reliability and flexibility benefits will result in additional costs and complexity to develop "mesh-ready" designs.

Offshore wind facilities typically generate power independently and deliver it to onshore substations via a point-to-point interconnection. Several factors, such as outages and network congestion, may impact the supply of this energy to the onshore network. The January 2022 "Meshed Ready Technical Requirements" draft, issued as Appendix G of Draft ORECRFP22-1 by the New York State Energy Research and Development Authority, essentially mandates the utilization of HVDC links to connect to offshore wind areas.

The solution being put forward will provide flexibility in making the supply of energy from offshore wind farms available at the "right place at the right time" by developing a "mesh-ready" design for offshore substations. Meshed interconnections between the offshore plants will improve the utilization of high-voltage direct current (HVDC) links by providing an alternate path for the offshore wind energy to reach the onshore transmission network.

Given the complexities, cost and maturity level of technologies required to implement HVDC grids, alternating current (AC) connections appear to be the right choice to create such an offshore mesh. This paper discusses the concept without consideration of the commercial agreements that might be needed among the independent system operator (ISO), utility, developers and mesh network owner for successful implementation.

What Is a Meshed Offshore Grid?

In a meshed offshore network, the offshore substations of individual offshore wind projects would be linked. Such a configuration could offer numerous benefits, including reducing offshore wind curtailments; mitigating outages between the offshore wind generation tie and the point of interconnection; adding redundancy within the transmission system; and enabling ancillary services from HVDC technology.

A meshed configuration depends on the ability of individual plants to be incorporated into the mesh. The initial step is developing mesh-ready designs for offshore wind projects, including the capacity for radial connections even if such a concept will not be implemented immediately.

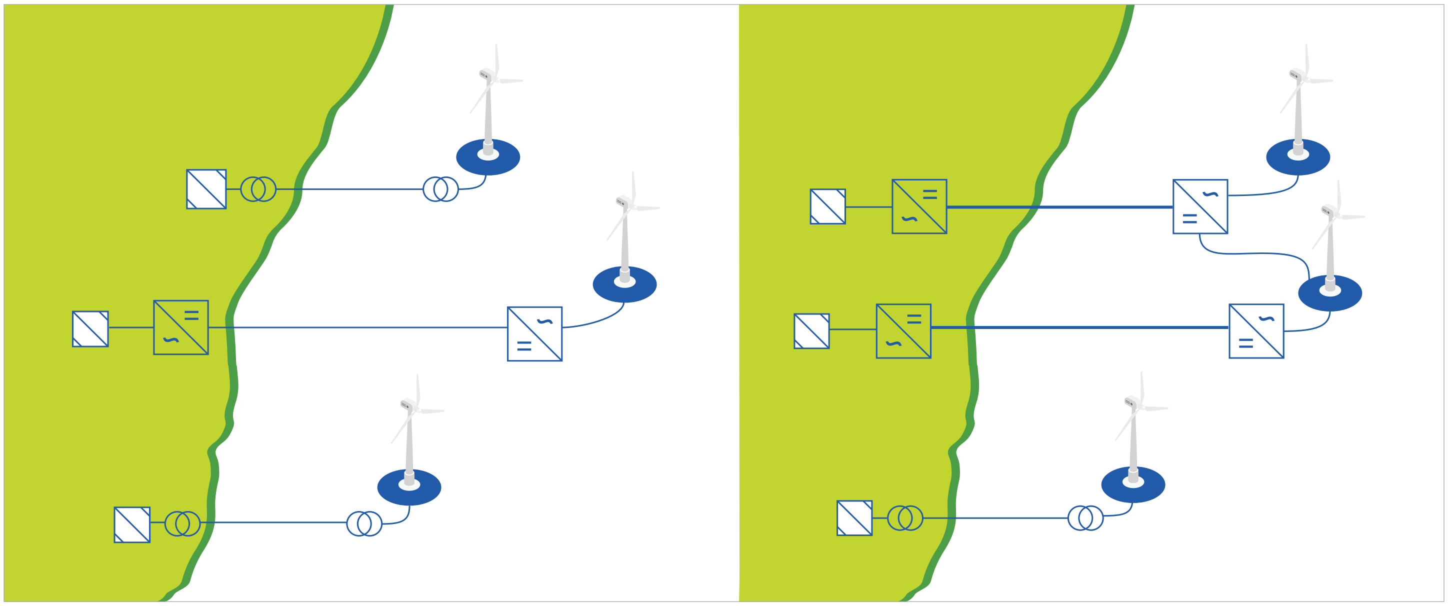

Figure 1: *Offshore wind configurations: traditional radial connections (left) and meshed interconnections (right).*

There will be additional costs associated with preparing the offshore substation to make it mesh-ready, and another round of expense to actually implement the links that connect the offshore substations, thereby creating a mesh. Developers will be investing in an anticipated future state by making sites mesh-ready, since the costs associated with doing so during the initial deployment would be significantly lower than retrofitting a site later. Once a site is ready to be interconnected as part of a meshed grid, the cables to interconnect the platforms would be installed.

Meshed Grid Coordinated Controller (MGCC)

A centralized control system performs control and monitoring functions across the meshed grid, HVDC links and individual offshore wind plants. The MGCC needs to be designed to be highly reliable — specifically the combination of dependability and security. Dependability relates to a degree of certainty that a system will perform correctly. Security relates to a degree of certainty that a system will not operate incorrectly. In this context, security differs from cybersecurity. In addition to designing the MGCC to be highly reliable, its performance requirements such as required speed of operation also must be carefully considered.

The MGCC has the potential to impact the power transfer of several HVDC links, so the MGCC must be designed for strong protection against misoperation, whether malign or unintended. It also needs to be highly dependable, since operators will rely on it to take the necessary actions when needed. This is critical to maintaining reliable operation. The communication network associated with the MGCC must be designed to support the high reliability and performance requirements. Additionally, failovers between MGCCs, whether planned or unplanned, must not impact the operation of the meshed network.

These strict standards for security and dependability must not compromise the performance of MGCC, another key factor in reliability. Finding the right balance among these essential requirements should be the subject of careful study.

HVDC Control System Enhancement

The HVDC control systems utilized in offshore wind designs would require enhancement with additional capabilities in a meshed grid. While this is achievable, it would increase the complexity of those systems.

Equally important, the added functionalities must be defined upfront in sufficient detail to avoid costly change orders during mesh implementation. Preparing those specifications will require additional studies, and those costs will need to be captured. These extensive studies should establish proper and effective coordination among the various wind power controllers, HVDC controllers and the MGCC. The potential need for remedial action schemes (RAS) would have to be analyzed, and integration into the overall HVDC control system would need to be considered.

The addition of an external controller, such as the MGCC, will add complexity to warranty processes associated with HVDC contracts. It also could complicate the root cause analysis in the event of a misoperation of the HVDC control system.

Those leading initial deployments should also bear in mind that the controls for early mesh-ready links might need modification as more HVDC links are added to the mesh and additional lessons are learned in the process.

Testing and Commissioning Requirements

Traditionally, factory acceptance testing (FAT) of the HVDC control system is performed to see that the DC link will perform as specified to meet the power transfer requirements of the individual generation interties. Factoring in the MGCC complicates matters.

Hardware-in-the-loop (HIL) testing attempts to verify that the actual hardware to be installed on-site will perform correctly when deployed. Since the MGCC needs to be included in the HIL testing along with the HVDC controls, the scope of that testing becomes larger.

Attention also should be paid to the FAT requirements when several HVDC links are part of the mesh system. There are several important questions to consider upfront:

- Do replica control systems of each HVDC link and offshore wind generation facility need to be procured to enable future integration of additional mesh-ready HVDC links?
- Will replicas have to be made available in the HVDC vendors' facilities to test the integrated system?
- It could be awkward and challenging to have one vendor's control system present in another vendor's facilities for that purpose. If the replicas have to be kept at a neutral facility, where will that location be so they are readily available for testing when needed?
- Who will develop and retain the necessary knowledge to perform the testing utilizing the replicas?

Finally, upon integration, commissioning of the meshed HVDC links will need to take into consideration the potential impacts to the in-service links.

Primary Equipment

The mesh-ready requirements do not require the rating for the HVDC link to be increased to allow for 300 MW to be transmitted between platforms. However, the additional equipment required to be installed on the offshore platform for it to be considered mesh-ready will have a significant impact on the platform design. Mesh-ready designs might be achieved by expanding the size of the converter platform if the inter-array cabling from the wind farms is also terminated there. An alternative might be to terminate the inter-array cabling at an intermediate platform and install the additional equipment on that platform. A cost-benefit analysis would be needed to identify an optimal solution for a given instance.

Thought also needs to be given to redundancy requirements for the primary equipment. The availability targets for the mesh network will have to be clearly defined at the initial stages, since they will have a significant impact on the design of the platform. Does the design require spare GIS bays to allow for redundancy in cable connections to adjacent platforms? How should the shunt compensation be sized in the absence of availability of locations on the adjacent platforms?

Ratings of the primary equipment also need to consider the additional pass-through current that may be seen on the AC bus of an offshore substation.

Conclusion

The meshed grid concept is an intriguing one. It trades off the incremental upfront costs to make offshore wind platforms mesh-ready against the costs of not being adequately prepared to realize the benefits of this future state. The changes that would be required in the designs of offshore wind platforms and controls should not be trivialized. While the idea merits close consideration, evaluation of the concept's application must be informed by due consideration of the numerous design changes, equipment ratings and testing needs that would accompany an implementation.

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27621-0522