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NREL Response to RFI on deep-water HVDC substations for offshore wind

Additional submitted attachment is included below.

Request for Information
Deep-Water High-Voltage Direct Current (HVDC) Substations for Offshore Wind

Docket # 23-ERDD-01

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This document provides NREL's response to the RFI on Deep-Water High-Voltage Direct Current (HVDC) Substations for Offshore Wind. The questions are repeated in black, and NREL's response is provided in blue.

General:

1. What information or analysis is needed to inform timely and cost-effective development and deployment of deep-water substations and associated offshore electrical infrastructure in existing and future California WEAs? How can publicly funded research and development (R&D) address technological, economic, and environmental uncertainties and better inform strategic technology advancement, feasibility, standards development, and component selection and procurement?

Comparison of substation and array cable topology alternatives

Substation position and array cable topology choices can strongly affect costs, risks, installation and maintenance processes, and environmental impacts. Substations can be floating or subsea. Array cables can take a variety of topologies (from parallel strings of turbines to multiple radial clusters) and in deep water there are serious choices about how each array cable is structured: (1) dynamic cable sections at each turbine with a static cable section along the seabed, connected by subsea joints, (2) a continuous dynamic cable spanning the whole distance, partially laying along the seabed, or (3) a fully suspended dynamic cable that does not touch the seabed. These choices result in major differences in required components, degree of seabed disruption and water column obstruction, costs, and failure modes. A comparative study of the technical feasibility, costs, risks, logistical requirements, and environmental impacts of these alternatives would provide much-needed information for substation and electrical infrastructure choices.

2. What key metrics or factors are required to inform systems integration of offshore wind components, deep-water substations, associated electrical infrastructure, communication networks, data collection, environmental monitoring, and ancillary services such as secondary generation, hydrogen production, and storage?

From an environmental perspective, remote data collection will be key to understanding impacts of these substations on marine life. Key sensors employed could include camera systems and oceanographic sensors (e.g., conductivity, temperature, depth [CTD]). Platforms hosting these sensors may be fixed (attached to the substation or the nearby seafloor) or mobile (e.g., AUVs, ROVs). The collection of eDNA around these structures may also be of interest. To make data transmission reliable and efficient, any environmental sensors deployed will likely require specific infrastructure/hardware/software (and environmental permits) to accommodate them.

3. What specific technical, economic, or other factors are crucial for understanding the viability and success of offshore electrical infrastructure technologies for FOSW development in California? What key performance characteristics and metrics are anticipated to be challenging for California's existing and future WEAs?

The viability of the required electrical components offshore California depends on how they are integrated into deep-water floating systems. For floating substations, the onboard equipment would not have different requirements based on water depth. However, subsea substations would face strong dependencies on the ability to withstand the higher pressures at the water depth. These high pressures are also a key factor for the power cables, where cables at the seabed need to withstand the maximum amount of pressure without water ingress.

Dynamic power cables, which run from the floating platforms and need to accommodate their motions, will be different for California offshore wind projects. In deep water, dynamic power cables will have much larger lengths than previous applications. For dynamic cables that run to the seabed, the cable weight will be of increased importance and may result in larger than typical cable structural loads, while the motions may be less significant relative to shallower sites. For dynamic cables that run fully suspended between turbines, there is little prior experience in these configurations and their sensitivity to sea currents may be a key design factor. For both configurations, accumulation of marine growth may cause significant additional weight and sea current drag forces due to the long cable lengths.

Expected marine growth on subsea dynamic power cables in Californian waters is not well characterized. It is a crucial factor for designing dynamic cable configurations. For example, marine growth caused dynamic cables to sink and hit the seabed in one of the floating wind projects in Fukushima, Japan. Existing design work for dynamic power cables for California typically uses generic marine growth assumptions from DNV guidelines due to lack of site-specific data. Site-specific characterization of marine growth levels—as a function of water depth—in California offshore wind areas is a key knowledge gap.

4. What environmental, ecosystem, health, and social impacts, including, both direct and indirect impacts, should be evaluated in deep-water substation and offshore electrical component design, procurement, and deployment for California’s existing and future WEAs? How should knowledge about these impacts be used to better inform more sound design, procurement, and deployment of deep-water substation and offshore electrical components?

There have been few studies investigating the environmental effects of HVDC substations, and none in deep water (e.g. > 60 m) that we are aware of. The two main environmental/ecosystem concerns related to HVDC substations that we know of are 1) effluent temperature effects and 2) entrainment/impingement risks to marine organisms.

- The AC to DC conversion process creates heat, so HVDC substations are often cooled using open-loop systems, which withdraw seawater, pump it through a heat exchanger, and discharge it back to the sea. This creates a warmed plume of water above ambient temperature. Heated effluent has shown to alter sea turtle movements, for example.

- Because the cooling system withdraws seawater from the HVDC system, these withdrawals have potential to *entrain* organisms through the cooling system, or *impinge* organisms against the intake opening screens/bar racks. (Entrainment = unwanted passage of marine organisms through a water intake, generally caused by an absent or inadequate screen surrounding the water intake; Impingement = physical contact of an organism with such a barrier structure (e.g., screen) due to intake velocities which are too high to allow escape.)

- It would be beneficial to have more empirical data on the effects of HVDC substations on plankton (things that can't swim against the current like eggs, larvae, amphipods and copepods) and nekton (fish, turtles, marine mammals), particularly in deep water environments. Data collection, or a white paper on recommendations along these lines would be beneficial.

Marine growth on dynamic power cables, which will traverse the full water column, is not well characterized for California locations. Cables can provide new habitat for organisms but their current flow makes for elevated temperatures and maintenance procedures could remove marine growth at points in the project life. The quantity and types of marine growth over time and water depth needs to be better understood.

5. Are there other pressing needs or challenges relating to FOSW electrical infrastructure or transmission R&D that EPIC should consider?

Increase reliability and reduce cost of fully suspended subsea power cables

Currently, subsea power cable failures lead to 80% of fixed-bottom offshore wind farm insurance costs (DNV 2024). It is therefore of the utmost importance to increase the reliability of subsea cables, including array as well as export cables.

California's Wind Energy Areas are located in deep water, which means that one way to reduce the associated cable costs is to suspend the cables in the water column, resulting in floating cables at a certain water depth. This leads to additional challenges as the cables are more exposed to environmental loadings and external threats. The failure of an array cable can lead to the loss of the electrical connection to several turbines, while the failure of the export cable system can shut down the entire wind farm.

Research endeavors related to the following topics would decrease the costs and increase the reliability of floating subsea power cables:

- Cable protection system: Development of technologies to further protect floating subsea cables and improve their reliability.
- Cable risk assessment: Development of methods for assessing risks associated with suspended power cables. This is especially important to allow co-use of floating offshore wind farms.

- Array cable layout (electrical collector system): Investigate possible alternatives to "classical" array cable layouts to reduce costs, risks and enable co-use
- Thermal and electromagnetic analysis of HV power cables, floating at a certain depth below the water surface

DNV. 2024. "80% of Insurance Claims in Offshore Wind Are Related to Subsea Cable Failures – How Can the Industry Manage These Risks?" 2024. https://www.dnv.com/article/80-percent-of-insurance-claims-in-offshore-wind-are-related-to-subsea-cable-failures-how-can-the-industry-manage-these-risks/.

HVDC Technology and Cost:

6. What technical barriers will have the largest impact on development of deep-water HVDC substations in California? How could publicly funded R&D be most effectively applied to help increase timely and cost-effective deployment of new offshore deep-water HVDC substations in existing or future California WEAs?

Participation Development of

Development is needed of operational models that integrate modular multi-level converter (MMC) HVDC into unit commitment and dispatch models to increase the flexibility of renewable energy allocation across regions with distinct resource profiles. Adding these approaches to existing operational simulation capabilities and demonstrating the added value of new flow control and coordination for large systems is important. Overall, the power balance flexibility in a MMC HVDC system is a critical capability that enables power coordination across interconnected systems and will reduce supply risks posed by renewable energy variability.

Development and testing is needed of novel HVDC MMC control approaches that enhance the capability of HVDC meshed grids to provide stability and increase the participation of renewables in the system. This work would focus on the scalability and design of novel control techniques that have the potential to overcome the limitations of existing control methods to unlock more value from HVDC.

7. What key cost factors are critical to the timely deployment of deep-water HVDC substations and associated offshore electrical infrastructure that could be addressed through technology advancement or analysis?

HVDC substation supply chain analysis

The global HVDC substation market is limited; there are only a few manufacturers that can supply the required equipment. Whereas HVAC systems have good interoperability, and thus hardware from different vendors can be integrated, HVDC systems will require all hardware to be supplied by the same manufacturer. It would therefore be beneficial to carry out an HVDC system supply chain analysis as soon as possible, to assess the availability of the HVDC systems for specific U.S. projects, considering the global offshore wind market. The availability of HVDC systems is key to ensuring that floating offshore wind farms can be commissioned at the planned COD.

8. What novel technologies or design concepts proposed for HVDC substations have been successfully demonstrated in a physical or simulated dynamic offshore environment and can provide economic benefits and costs savings for California ratepayers? Are there any specific substation platforms, mooring systems, HVDC electrical components, or other substation technologies that provide clear benefits and advantages for use in the existing or future California WEAs? How could R&D funding be

most effectively applied to improve and optimize these technologies further to reduce cost and improve their technical suitability for California's WEAs?

Floating platforms and mooring systems for substations (whether HVDC or HVAC) in deep water is an under-researched topic. These floating support structures could likely have many similarities to the floating wind turbine support structures. However, the criticality of the substations could call for higher levels of redundancy in the mooring systems, and greater safety factors, particularly for failure modes related to extreme waves and earthquakes. These issues could be explored through design-exploration and techno-economic studies of floating substation support structures.

9. What key technologies or capabilities are needed in-state, regionally, and nationally to facilitate supply chain, manufacturing, installation, and operations and maintenance needs for deep-water HVDC substations and associated electrical infrastructure? What are the environmental, ecosystem, health, and social impacts associated with these technologies or that should be evaluated for these technologies?

10. What technologies or processes can monitor the condition and performance of deep-water HVDC substations and offshore electrical infrastructure? What are the current resolution capabilities of these technologies? Are these technologies or processes adequate for application in existing or future California WEAs? What are additional operations and maintenance needs for deep-water HVDC substations?

11. Are there any other questions or information the CEC should consider for research on deep-water HVDC substations for offshore wind that is not otherwise covered by the questions above?

To address the issues of stability and grid strength when interconnecting large amounts of offshore wind power to the onshore grid, it makes sense to consider the integration of offshore wind power plants (HVAC and HVDC) with onshore energy storage and synchronous condensers to operate the systems as an integrated hybrid system for energy, reliability and stability services, and resiliency. Multi-terminal HVDC can be added to this. The system can provide increased flexibility since storage components can be dispatched as a system level asset when needed, or as a plant level asset in some other cases. It can also be used as a black start asset for both offshore wind and onshore grids.