OCS Study
BOEM 2022-023

Supporting National Environmental Policy Act Documentation for Offshore Wind Energy Development Related to High Voltage Direct Current Cooling Systems

U.S. Department of the Interior
Bureau of Ocean Energy Management
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List of Abbreviations and Acronyms

AC	Alternating Current
BOEM	Bureau of Ocean Energy Management
DC	Direct Current
EPA	Environmental Protection Agency
GW	Gigawatt
HVDC	High Voltage Direct Current
MW	Megawatt
NPDES	National Pollutant Discharge Elimination System
OCS	Outer Continental Shelf
U.S.	United States

Executive Summary

Offshore wind development on the Atlantic Outer Continental Shelf is moving further offshore, and with the distance, comes the challenge of effectively transporting the power to users onshore. Alternating current (AC) generated from wind turbines may be transported onshore when the wind farm is within about 30 miles (50 kilometers). When a wind farm is located further than 30 miles from shore, additional equipment is required to effectively move this energy onshore without encountering significant losses of power during transmission. A high voltage direct current (HVDC) system is used to convert AC power to direct current (DC), which is capable of being transported longer distances without significant power losses. The conversion process from AC to HVDC generates heat as a byproduct, and the systems require cooling to protect the equipment from damage and breakdown. Concerns have been raised to the Bureau of Ocean Energy Management (BOEM) about how HVDC systems are cooled and the impacts of the cooling systems to the environment. As of 2022, innovations in cooling systems are being studied and developed, but so far, no new systems are tested and available for use on a commercial scale.

1 Introduction

Offshore wind development on the Atlantic Outer Continental Shelf (OCS) is growing as the United States (U.S.) expands renewable energy generation. As wind energy development moves further offshore, transporting the energy back to land and the communities that will use the electricity is an integral part of the offshore wind farm. When a wind farm is located about 30 or more miles (50 kilometers) from shore, additional equipment is used to more effectively move this energy onshore to the electrical grid. A high voltage direct current (HVDC) system is used in an offshore wind farm to convert alternating current (AC) to direct current (DC) for transport to shore. Because of the large amount of heat generated during the conversion of AC to DC, these systems must be cooled when operating. Concerns have been raised about how HVDC systems are cooled and the impacts of the cooling systems to the environment. Additionally, there are inquiries about alternative cooling systems that could be applied to HVDC systems.

This paper provides a brief overview of the HVDC system, how the systems are presently cooled, the effects of current cooling systems, and any feasible options for cooling HVDC systems.

2 Background

The electricity generated by wind turbines and other power plants is AC, which is the current used in American homes. Larger quantities of electricity can be made from an AC generator, which is one of the reasons why AC is generated by wind turbines. Onshore, when electricity is transported from where it is generated to where it is used, AC can be moved across high voltage electrical lines for relatively long distances. This is achieved by the aboveground configuration of power lines and transformers.

Offshore wind farms transmit high voltage AC electricity when distances from shore do not result in significant losses of voltage. Many offshore wind projects in the U.S. opt to use AC power due to proximity to shore, the amount of power being produced, and higher cost of investment in an HVDC system. AC power does not travel as effectively through underwater cables over longer distances, limiting AC cable lines to about 30 miles (50 kilometers) offshore before power losses and cost make AC increasingly prohibitive (Breseti, Kling, Hendriks, & Vailati, 2007).

Converting high voltage electricity from AC to DC for long-range bulk transmission from offshore wind farms reduces losses of power experienced on AC transmission lines and becomes cost effective within 37 to 60 miles from shore (BVGassociates, 2019; ICF, 2018). When electricity is generated offshore, it is converted from AC to DC for transmission from the offshore wind farm, then converted back to AC onshore for distribution and use by consumers. The offshore conversion from AC to DC is accomplished through an HVDC system located in the wind farm. The HVDC system converts AC to DC, creating a byproduct of heat in the process. For the system to operate continually, the portion of the conversion equipment that emits heat, called the thyristor, must be cooled (Fisher, et al., 2021).

3 Cooling Systems

HVDC systems increase in size commensurate with the amount of power being converted. A sample of Atlantic OCS offshore wind projects in development and operation show an average of 520 megawatts (MW) of energy expected to be produced, with future offshore wind farms expecting up to 1 to 2 gigawatts (GW) of production (Orsted, 2022). Presently, HVDC system structures for an offshore wind farm range from about 200 to 400 feet long, 140 to 350 feet wide, 80 to 300 feet high, and weigh several thousand tons (Mayflower Wind Energy, LLC, 2021; Sunrise Wind, LLC, 2021; Siemens, 2015; Kirchgeorg, et al., 2018). These structures are likely to get larger as offshore wind farms grow and move further offshore.

3.1 Open Loop System

The most effective way to cool large HVDC systems is by using deionized water in a closed system. The deionized water is then cooled by sea water pumped through a heat exchanger, absorbing heat from the deionized water. This open loop cooling process allows continual operation of the HVDC converter. Sea water is filtered to remove small particles, sand, and other elements to about 500 microns. Chemicals, such as sodium hypochlorite may be added to prevent growth in the system, with an estimated concentration of 10-200 parts per million as proposed for the Mayflower Wind project (Mayflower Wind Energy, LLC, 2021) The filtered, heated water is then discharged back into the ocean (Figure 1).

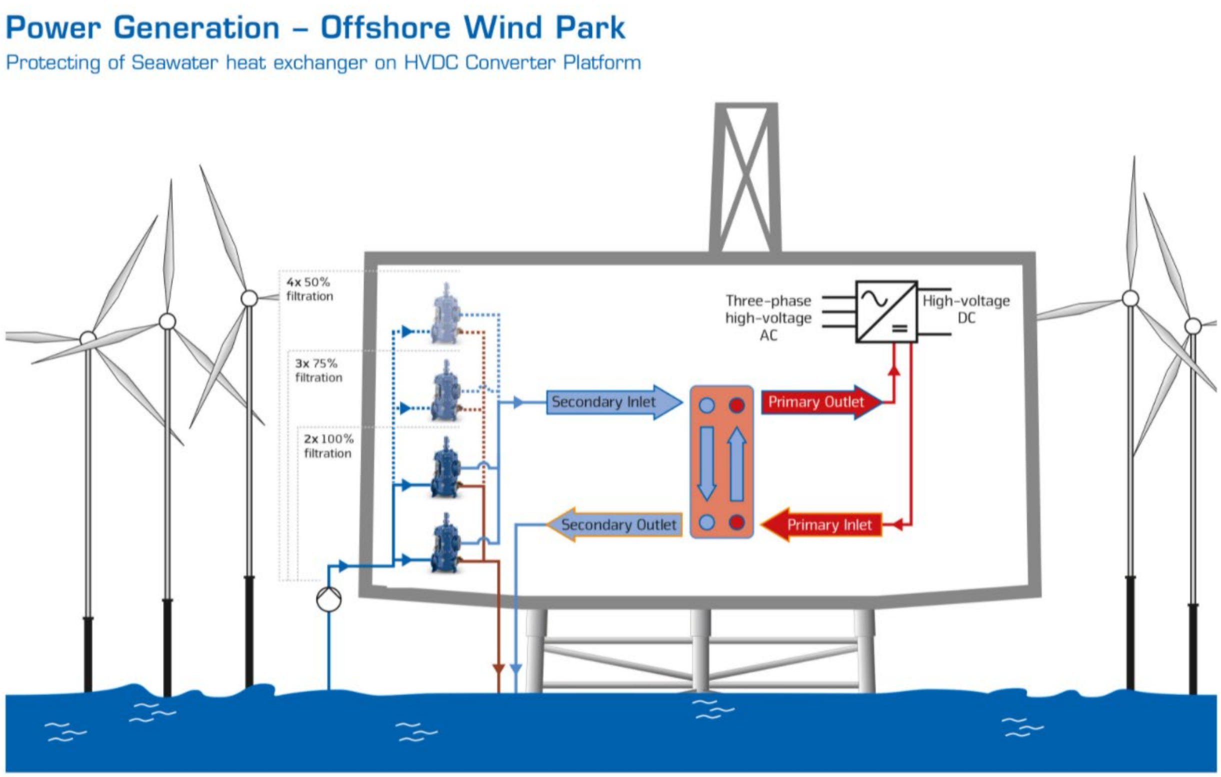

Figure 1. Diagram of an Open Loop HVDC Filtration System

(Bollfilter, 2022)

HVDC systems are used across the globe where electricity is moved over long distances on land or offshore, in cases where energy is transferred across borders with different electrical grid systems, or where renewable energy is connected to an existing electrical grid. Purified water is the cooling source for these systems, and open loop systems, where cold water is pumped in for cooling and heated water is discharged back into the ocean or other water bodies is the standard design of these systems. Open loop systems are used for cooling many types of power generation, including coal, natural gas, thermoelectric, and nuclear (U.S. Energy Information Administration, 2011).

3.2 Other Cooling Systems

The wind farm size and offshore location of the HVDC dictates the requirements of the cooling systems. Additionally, platform/enclosure size, weight, and cost are factors in system designs. The corrosive nature of the offshore location requires the HVDC equipment be enclosed, which limits air cooling capabilities (Kirchgeorg, et al., 2018). The amount of heat is a factor in cooling requirements, and water can transfer the most heat away from the system. In a common closed loop system, air is used to cool the water, generally by a large bank of electric powered fans. Other closed loop air cooling systems use refrigerant gasses (such as chlorofluorocarbons and hydrochlorofluorocarbons) to pull heat from water, then dissipate the heat with fans into the ambient air. Refrigerant systems require power for operation and the refrigerant gasses must be replenished over time. Presently, refrigerant systems are not used for cooling HVDC systems offshore due to capacity limitations. Adiabatic systems are semi-closed loop fan systems designed to use water to increase cooling capacity through evaporation. Some adiabatic systems may operate as closed loop systems when temperatures allow the fans to cool the internal systems without the evaporative systems being engaged. These systems require a supply of freshwater on site, and it must be replenished regularly to ensure uninterrupted service. (ABB, 2016)

In other systems, chemicals are combined with water in certain circumstances. Glycol is added to water where temperatures are consistently below 32 degrees Fahrenheit to prevent freezing, although pure water has a larger cooling capacity in these systems. If glycol is required, an air-cooled, closed loop system is used. These systems have yet to be applied offshore because most offshore wind farm locations do not reach freezing temperatures frequently. These systems are less effective from a cooling standpoint, and the weight and size constraints are a concern offshore. (Stomberg, Abrahamsson, & Saksvik, ND)

The required number of fans to cool heated HVDC water within a platform facility is space and cost prohibitive, in addition to the electrical requirements to power a large bank of cooling fans. Weight is a factor in cooling water within a facility. One gallon of sea water is approximately 8.56 pounds. If a cooling system circulates 343,424 gallons an hour, the weight of the water alone would be nearly 3 million pounds (1,500 tons), making air cooling water on an offshore platform prohibitive solely from a weight perspective.[1]

4 Effects of Current HVDC Systems

HVDC systems are used in a range of electrical transmission systems around the world. In the U.S., as of early 2022, only two federal offshore wind projects are proposing to use these systems. The remainder of the wind farms are using or have proposed to use AC due to their proximity to shore. BOEM has identified cumulative impacts from electromagnetic effects from the HVDC transmission cables and notes an Environmental Protection Agency (EPA) National Pollutant Discharge Elimination System (NPDES) permit requirement for the cooling system discharge (BOEM, 2019). However, some effects to marine species from the HVDC system may occur from the intake pipes and discharge outflow. NEPA analysis for offshore HVDC systems is in progress, but comparisons may be made to other sea water intake systems, such as desalinization plants, to assess effects from intake pumping and filtration systems.

Filtration systems on intake pipes capture small particles, such as sand grains, but also filter larvae of marine species and plankton that other marine species consume. For one proposed U.S. offshore wind project, the filter removes particles larger than 500 microns (Mayflower Wind Energy, LLC, 2021). Most

[1] Filter circulation based on the Siemens BorWin2 HVDC Platform (Siemens, 2015).

filtration systems backflush filters to allow for continuous use, so the collected filtrates will eventually return to the ecosystem; however, larval species will be lost and will not grow to maturity. The number of larval fish and invertebrates lost in the process is difficult to measure. Losses of larval food sources for other species is notable, in addition to the larval species that do not survive to maturity. It is unclear how many marine species do not mature to reproduce and provide fish and shellfish for human and animal consumption.

For the same offshore wind project, the intake pipes are planned to be located about 30 feet above the seafloor where the proposed project depth is about 164 feet, approximately 130 feet below the surface (Mayflower Wind Energy, LLC, 2021). Depending on the species, many juvenile fish grow in shallower water, closer to shore; but this is not true for all species of fish or shellfish. Some small and young fish may be caught in the inflow system and become injured or expire. The velocity of the pump determines the pull of inflow and which species may be vulnerable. Screens and other systems can protect small marine life from intakes to prevent damage or mortality.

Placement of the intake pipe opening depth and velocity of the pump system can mitigate effects to fish and marine species. The depth of the intake opening can be placed where fewer marine species are found, reducing the risk of harm to smaller fish or invertebrates. Studies on mitigation measures for desalination plants considered screening that essentially deflects small species away from intakes. Pre-filtering processes for larval and small organisms have been studied in desalination intakes to help protect these organisms and return them to the ocean unharmed. As advances in engineering are available, mitigation to reduce harm to plankton, larval species, and small marine species may be applied. (Jenkins, 2008)

Temperatures of the discharge water have not been documented for the proposed wind farms on the OCS to date. The warmer outflow from HVDC is generally accepted as a minimal effect that will be absorbed and transition to ambient temperature over time (Sunrise Wind, LLC, 2021). Studies have shown that some localized effects could occur in the area surrounding the outlet pipe until mixing or equilibrium of the water temperature is achieved. Within this localized area, some species may move to cooler water; however, other species could find the warmer temperature more desirable (Natural Resources Defense Council, 2014). Given the single point outlet within the large mass of surrounding ocean, effects from the warm water are likely to be extremely minimal. Similar conclusions have been made for any chemicals added to prevent growth within the seawater system. Both potential impacts to surrounding sea water are required to be permitted through EPA’s NPDES system (Mayflower Wind Energy, LLC, 2021).

5 New Technology

Research on other HVDC cooling systems is being conducted to identify alternative cooling mechanisms. A study, called COOLWIND, funded by a grant agreement with the European Union, is considering the feasibility and effectiveness of placing a heat exchanging system within the ocean, using the ambient temperature of the sea to cool the water within a closed loop system. This could be a novel solution to filtering sea water, removing plankton, diatoms, and other nutrients used by marine animals, and discharging sterile, warm water into the ocean. Additionally, little to no new equipment would be added to the converter platform structure allowing a standard HVDC assemblage to be used. This research began in 2019 and is scheduled to be complete in 2023. COOLWIND is a technology to monitor as a future option for locations with cooler sea temperatures. (European Commission, 2021)

Another study by Fischer, et. al., is considering closed-loop cooling systems using alternate fluids to absorb heat. The study team is testing heat transfer fluids using phase change dispersion. The subject fluid has low viscosity, which induces isothermal cooling as it melts. Study results show that the phased change dispersion fluids are more effective coolants than pure water. While only in the early stages of research, it is possible that this or other advances in cooling technology may rise to commercial production in the coming decades. (Fisher, et al., 2021)

These and other cooling technology could provide meaningful alternatives in the future to reduce the effects of open loop cooling systems offshore. Presently, open loop cooling systems are the only commercially available and demonstrated reliable systems available for AC to DC conversion offshore and provide the most effective and cost-efficient solutions for cooling offshore HVDC converter stations.

6 Summary

As offshore wind development moves further away from shore and increase in size and energy output, use of HVDC systems is likely to continue. Cooling these systems using current technology requires open loop seawater systems. Potential effects from using the cooling systems include the discharge of heated water, use of chemicals, and trapping of fish larvae. Mitigation techniques, such as engineered screens and filters may help protect small marine life from filtration systems. Ultimately, innovations for cooling HVDC systems to a form of closed loop technology shows the most promise in reducing or preventing the effects of current open loop systems. In the meantime, HVDC systems with open loop cooling play an important role in providing low carbon footprint, renewable energy along the OCS.

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