OFFSHORE WIND FACTS

Deeper Dive: Electromagnetic Fields (EMFs) and Offshore Wind

Electromagnetic Fields (EMFs)

An electric field is the physical field that surrounds electrically charged particles and exerts force on all other charged particles in the field, either attracting or repelling them. Magnetic fields are an invisible force field created by a magnet from the movement of electric charges through a conductor. Together, electromagnetic fields (EMFs) are invisible areas of electrical and magnetic energy that are associated with electrical power and various forms of natural and anthropogenic sources, such as the Earth's geomagnetic field, thunderstorms, power cables, and common household electronics.

EMFs are measured in levels of frequency. Frequency is the number of times per second that a field completes a full cycle (or oscillates), and is expressed in units of cycles per second, or Hertz (Hz).

EMFs are typically grouped into one of two categories (Figure 1) by their frequency (National Institute of Environmental Health Sciences [NIEHS], 2022).:

- Non-ionizing EMF includes low-level radiation, which is generally considered harmless to humans and occurs in the form of extremely low frequency (ELF) waves, radio frequency (RF) currents, microwaves, and visual light. Examples of non-ionizing EMF sources include microwave ovens, computers, home energy smart meters, wireless (wi-fi) networks, cell phones, Bluetooth devices, power lines, and MRI machines.

- Ionizing EMF includes high-level radiation which has the potential to cause cellular and DNA damage and occurs in the form of ultraviolet (UV) rays (e.g., like those in sunlight), X-rays, and gamma rays.

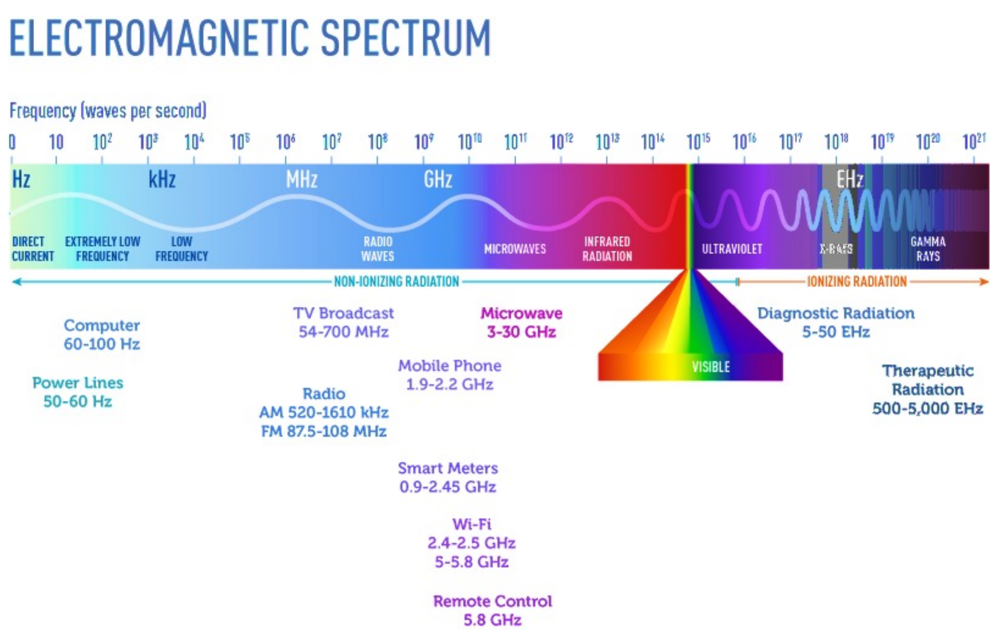


Figure 1: Electromagnetic Spectrum - Illustrative Table (National Cancer Institute, n.d.).

EMFs in the Marine Environment

EMFs also occurs naturally in the oceans. The most common naturally occurring direct current (DC) field in the marine environment is the Earth's 0-Hz geomagnetic field, while alternating current (AC) fields that occur at frequencies of less than 10 Hz are naturally produced by marine organisms. Undersea telecommunications and power cables on the ocean floor, which form the critical infrastructure for modern day internet connectivity and power distribution, also generate AC and DC EMFs.
A number of species can detect various levels of EMFs in the marine environment.

- Marine mammals are capable of detecting magnetic field gradients of 0.1 percent of the Earth's magnetic field (Kirschvink, 1990).
- Sea turtles can sense magnetic fields and use the earth's magnetic field (as well as other cues) for long range navigation, migration, and orientation. Multiple studies have demonstrated magnetosensitivity and behavioral responses to field intensities (Normandeau Associates et al., 2011).
- Some species of fish and invertebrates have been found to be able to detect electric fields and make use of either electric (electrosensitive) or magnetic (magnetosensitive) signals (along with other senses) to locate food, habitats, and spawning areas. These include species such as salmon, eel, sturgeon, tuna, sharks, skates, rays, and lobster (CSA Ocean Sciences Inc. & Exponent 2019).

EMFs from Offshore Wind and Mitigation Measures

Offshore wind farms use a variety of subsea power cables for intra-turbine, array-to-transformer, and transformer-to-shore transmissions (Ohman et al., 2007). These subsea power cables induce EMFs that may add to and interact with other sources of electric and magnetic radiation already present in the environment. These subsea power cables are typically grounded and shielded to block electric field emissions to the surrounding environment using conductive sheathing (SEER, 2022a). In the onshore environment, the transmission cables are laid underground to deliver electricity to the onshore converter stations, which is then connected into existing substations to supply electricity to the grid.
Depending on the type and amount of electrical current a cable carries, the cable design, and the proximity of an organism to a cable, EMF emitted by a submarine power cable can have variable effects on marine life that occupy habitats along a cable route. Alternating-current (AC) and direct-current (DC) power cables that may be used in offshore wind projects produce EMF at different magnitudes and frequencies (Normandeau Associates et al., 2011).
During the offshore wind permitting process, EMFs that can be generated by a project are evaluated through a combination of existing research, new data collected from surveys, and modeling exercises. Three major factors determine the levels of exposure to magnetic and induced electric fields from power cables and substation infrastructure:

- the amount of electrical current being carried by the cable;
- the design of the cable, and;
- the distance between an organism and the cable.

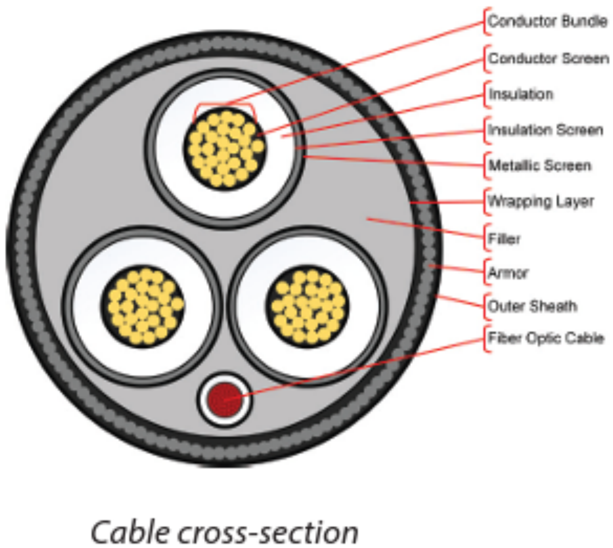
EMFs associated with offshore wind power lines and onshore transmission infrastructure are of the non-ionizing, extremely low frequency (ELF) category.

Results from a modeling study conducted by Normandeau Associates et al. (2011) for the Bureau of Ocean Energy Management (BOEM) has shown that the magnetic fields and induced electric fields from operational offshore wind AC cables quickly diminish with increasing distance from the cables. For DC cables, the intensity of the magnetic field produced was observed to increase as a direct function of the current flow (ranging from 75 to 500 kV), and the configuration of the cables. With the exception of cables that use sea electrodes, undersea cables will not generate direct electric fields. However, similar to AC cables, DC cable magnetic field strength was highest directly over the cables and decreased rapidly with vertical and horizontal distance from the cables.

In an assessment of the effects of EMF from renewable energy cables and devices on the marine environment, Gill and Desender (2020) concluded that biological or ecological effects associated with subsea power cables range from weak to moderate at the EMF intensities associated with marine renewable energy, though further research is still necessary.

While research on EMF in the marine environment continues to progress, EMF detection ranges are not well known for many species (SEER, 2022b). As such, EMF detection or exposure thresholds for marine organisms cannot be established by regulatory agencies. However, consensus based on the available research referenced above generally concludes that any potential effects from EMF generated by offshore wind farms would be minor to negligible at the individual and population levels. To minimize any potential effects of EMF on marine organisms, best management practices adopted by offshore wind developers during export and inter-array cable installation include cable burial, the use of cable protection (rock or concrete blankets) when cable burial is insufficient, and industry standard cable shielding. These measures reduce the amount of EMF that enters the surrounding environment to very minimal levels that individuals may detect, but that are unlikely to affect the health of individuals or population status of marine species.

Offshore wind projects typically target a cable burial depth of 3 to 7 ft (1 to 2 m) for their inter-array cables and offshore export cables, wherein the cable specifications (e.g. Figure 2a) are determined in consultation with and approved by the U.S. Army Corps of Engineers (USACE) on a project-specific basis. The target burial depth is also determined based on an assessment of seabed conditions, seabed mobility, the risk of interaction with external hazards such as fishing gear and vessel anchors, onshore conditions, and a site-specific Cable Burial Risk Assessment (Exponent Engineering P.C., 2022b). Calculations from a baseline assessment study on EMF (Center for Marine and Coastal Studies [CMACS], 2003) showed that burying a cable at a depth of one meter would already reduce the emitted electric field at the seabed (Figure 2b). In the onshore environment, as cables exit the landfall points towards substations, they are buried beneath town roads and generally encased in concrete. This is comparable to installation standards of other utilities beneath public roadways, as required. Hundreds of miles of cable beneath public roadways in dozens of towns in Massachusetts and existing submarine cable connection sites on Cape Cod in Falmouth, Harwich, and Barnstable have already been installed while successfully following these mitigation measures.



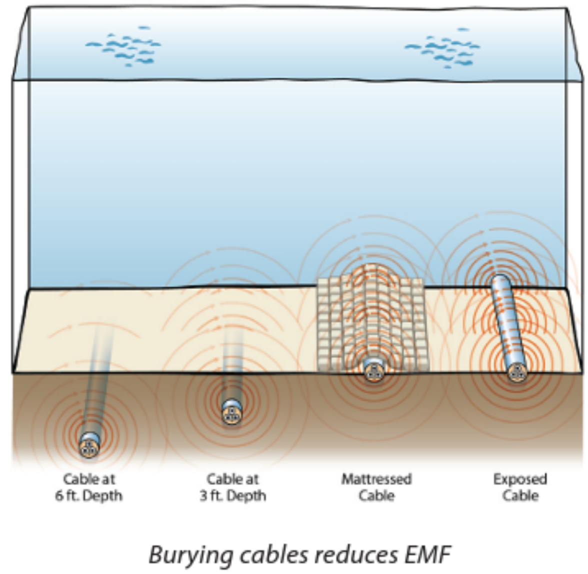


Figure 2. (BOEM, 2023): (a) cross-section of an undersea power cable (b) diagram of reduced EMF associated with cable burial

Where hardbottom seafloor conditions or existing infrastructure is encountered during offshore wind cable installation, the power cables are often covered with 6- to 12-inch-thick concrete rock berms, or other measures such as cable insulation, grounded metallic sheaths, conductive sheathing, and steel armoring to protect the cable. While this covering does not achieve the same level of EMF reduction as burial and distance, EMF levels and the rate of dissipation for buried and mattress-covered cables are quite similar at a distance beyond 10 feet from the cable.

Power cables can also be installed with conductive sheathing. The undersea cables produce a 60-Hz AC magnetic field around each cable. The 60-Hz AC magnetic field induces a weak electric field in the surrounding ocean that is unrelated to the voltage of the cable, but instead is related to the amount of current flowing through the cable (Snyder et al., 2019). However, previous research has found that as the conductivity of the sheath and armor increased, the resultant EMF strength outside the cable decreased (CMACS, 2003). This indicates that using thicker sheaths or materials with higher conductivity for the sheathing and armoring power cables can help reduce the strength of EMFs generated.

Marine Mammals & Sea Turtles

Marine mammals are likely able to detect minor changes in magnetic fields (Walker et al., 2003) and may react to local variation in geomagnetic fields associated with cable EMFs. These variations could result in short-term effects on swimming direction or migration detours (Gill et al., 2005). Exposure to EMF ultimately depends on the animals' proximity to the subsea power cables. This means that benthopelagic-feeding marine mammals would have a greater potential for exposure than those that forage throughout the water column (Normandeau Associates et al., 2011). Laboratory and field studies have shown that sensitive marine species may exhibit altered behavior in the presence of EMFs, but the level of disturbance appears to be too limited to affect migration patterns or to keep animals from their preferred habitats. In other words, the ability to detect or respond to the presence of EMFs does not necessarily mean there will be impacts to a species or life stage (Copping & Hemery, 2020). Currently, conclusive evidence of impacts is insufficient and additional research is needed.

Exposure to subsea power cable EMFs could potentially affect a sea turtle's migratory behavior and navigational cues. However, any deviations are expected to be minor (Normandeau Associates et al., 2011), and any increased energy expenditure due to these deviations would not be biologically significant. Export cables, as they route back to shore, may be in the vicinity of sea turtle nests or hatchlings, thus, additional research on the potential impacts on these early life stages is needed and should be included in the spatial planning of each offshore wind project. Buried subsea cables can warm the surrounding sediment and could affect benthic organisms that serve as prey for benthic-feeding sea turtles. However, based on the weakness of expected thermal radiation and the required cable burial depths, impacts on benthic organisms are not expected to be significant (Taormina et al., 2018) and would be limited to a small area around the cable.

Fish & Invertebrates

As some species of fish and invertebrates have been found to detect electric fields up to 25 Hz, detection of an EMF from a DC cable operating at a frequency of 10 Hz is possible. The detection of an EMF from an AC cable, typically operating at a frequency of 60 Hz, is much less likely (SEER, 2022b). Potential effects of EMF on benthic and demersal fish and invertebrate species can include behavioral responses, altered movement patterns, and physiological effects (Taormina et al., 2018). Temporary alterations in behavior and movement patterns in response to undersea DC power cable EMFs have been observed in sturgeon, skates, and lobster (Wyman et al., 2023; Hutchison et al., 2018). Wyman et al. (2023) noted varied evidence of green sturgeon behavioral responses to EMF from a subsea DC cable, however, no strong negative effects on migratory behavior or success were found. Similarly, Hutchison et al. (2018) reported that biologically significant alterations in movement patterns of both the American lobster and little skate occurred within the cable EMF zone, but that the cable did not act as a barrier to the movements of either species. For marine invertebrates, a synthesis by Albert et al. (2020) reported that temporary behavioral and physiological effects from both AC and DC EMF exposure can occur in crustaceans, echinoderms, molluscs, and polychaetes, but any impacts from these changes at the population level are unidentified. In a review of potential EMF impacts from undersea power cables on commercial and recreational fish species, CSA Ocean Sciences Inc. and Exponent (2019) found that bottom-dwelling fish were more likely to encounter EMF, with skates having the greatest potential for exposure. However, no evidence of negative impacts from EMF was found for any of the fishery species studied.

Human Health

For offshore wind energy, human exposure to EMF is mostly limited to the onshore cable landing points, substation, and existing transmission networks. Onshore export cables are placed in shore areas that are carefully selected for minimizing disruption and avoiding environmentally sensitive areas and housing. These cables are laid and buried within duct banks ranging in depths of 3-80 feet as conditions require. As in the case of Sunrise Wind, with onshore cables in Long Island, NY, the highest magnetic-field levels occur right over the duct banks at peak electricity flow and decrease rapidly with distance (Exponent Engineering P.C., 2022a, 2022b).

For onshore substations, the strongest EMF around the outside of a substation comes from the power lines entering and leaving the substation. EMF from equipment within the substations, such as transformers, reactors, and capacitor banks, also decreases rapidly with increasing distance. Beyond the substation fence or wall, the EMF produced by the substation equipment is typically indistinguishable from background or existing levels (NIEHS, 2022).

Overall, research has not shown that long-term exposure to low-level, low-frequency EMFs emitted by offshore wind cables has detrimental effects on human health (International Commission on Non-Ionizing Radiation Protection [ICNIRP], n.d.). WHO recommends that countries follow limits on human exposure to electric and magnetic fields, such as those developed by two international organizations: the International Committee on Electromagnetic Safety (ICES) and the International Commission on Non-Ionizing

Radiation Protection (ICNIRP). An overview of the recommended exposure limits (from: ICNIRP 2009; ICES 2019; ICNIRP 2010; ISO 2019; CENELEC 2016) compared against expected EMF emitted at 10 meters above seabed (Normandeau Associates et al. 2011) for offshore wind cables and at 10 ft from the onshore wind cables duct bank is presented in Table 2 and Table 3. These illustrate that the EMF generated from the offshore and onshore cable infrastructure is significantly lower than the recommended limits.

Table 2: Recommended EMF Exposure Limits for General Public Compared against Offshore Wind EMF

Organization	Recommended Limit	Cable/ EMF Type	Comparison with offshore cable generated EMF at 10 m above seabed	Comparison with onshore cables EMF at 10 ft from buried location
International Commission on Non-Ionizing Radiation Protection (ICNIRP)	4,000,000 mG for general public	DC	870,000 times lower than recommended limit	57,000 times lower than recommended limit
International Committee on Electromagnetic Safety (ICES)	9,040 mG of 60-Hz EMF for general public	AC	11,300 times lower than recommended limit	452 times lower than recommended limit
International Commission on Non-Ionizing Radiation Protection (ICNIRP)	2000 mG of 60-Hz EMF for general public	AC	2,500 times lower than recommended limit	100 times lower than recommended limit

Table 3: Recommended EMF Exposure Limits for Implanted Medical Device Users Compared Against Offshore Wind EMF

Organization	Recommended Limit	Cable/ EMF Type	Comparison with offshore wind generated EMF at 10 m above seabed	Comparison with onshore cables EMF at 10 ft from buried location
Association for the Advancement of Medical Instrumentation (AAMI)	10,000 mG for implanted medical device users	DC	2,200 times lower than recommended limit	143 times lower than recommended limit
European Committee for Electrotechnical Standardization (CENELEC)	1,000 mG for implanted medical device users	AC	1,250 times lower than recommended limit	50 times lower than recommended limit

These proposed limits are the result of extensive review and evaluation of relevant research on health and safety issues and are designed to protect the health and safety of persons in an occupational setting and for the general public. While land-based exposure to AC EMFs from transmission and distribution lines is relatively common, marine-based underwater cables provide very limited opportunities for persons to come in close proximity to them. Limited exposure to submarine cables is possible for those who may be scuba diving in the direct vicinity of offshore wind structures and cables, but otherwise people will not be exposed to any EMFs generated by the underwater cables associated with offshore wind.

Future Considerations

As the number of offshore wind projects is anticipated to increase in the coming decades it is important to consider the cumulative effects resulting from large-scale offshore wind development. As can be learned from studies in the Dutch North Sea, where some offshore wind farms have been in operation for the last two decades, the calculated magnetic field levels have been steadily increasing due to the increasing magnitude and size of offshore wind farms (Hermans & Schilt, 2022). However, while magnetic field levels can be measured, the induced electrical fields coupled with variable field strengths due to cable length, design, and placement are difficult to measure in the marine environment (Hermans & Schilt, 2022; Tasker et al., 2010). Therefore, drawing conclusions on significant ecological effects on marine animals from the overall input of energy from EMF remains a challenge. To date, no significant negative impacts have been observed on electro- or magnetosensitive species after exposure to EMFs from subsea cables (SEER, 2022a). Continued research and monitoring is needed, both to compare findings from U.S. and non-U.S. habitats with subsea EMF cables, and to better understand the ecological impacts from EMF exposure including short-term, long-term, and cumulative effects from offshore wind development.

In the interim, offshore wind developers are required to implement mitigation measures to reduce any potential effects from EMF and heat from subsea cables. For example, siting strategies include avoiding areas of special ecological interest when planning cable routes. Permit conditions require that cables be buried to an appropriate burial depth, between three to six feet, which reduces the magnetic field at the seafloor approximately four-fold (BOEM, 2020). In areas where sufficient cable burial is not feasible, power cables will be covered with 6- to 12-inch-thick concrete mattresses, rock berms, or other measures to protect the cable and reduce emission of EMF. Other potential measures include helically twisting AC cables in order to have parts of the EMF cancel each other out, resulting in an overall lower EMF emission, or grouping DC power cables, which can also reduce the effect of EMF as it remains more localized and limited (Hermans & Schilt, 2022).

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