OCS Study
BOEM 2023-007

Supporting National Environmental Policy Act Documentation for Offshore Wind Energy Development Related to Electromagnetic Frequencies from Buried Transmission Cables

U.S. Department of the Interior
Bureau of Ocean Energy Management
Office of Renewable Energy Programs

OCS Study
BOEM 2023-007

Supporting National Environmental Policy Act Documentation for Offshore Wind Energy Development Related to Electromagnetic Frequencies from Buried Transmission Cables

February 2023
Revised, April 2023

Authors:
Pamela Middleton
Bethany Barnhart

Prepared under BOEM Call Order #140M0122F0004
By
Booz Allen Hamilton
8283 Greensboro Ave
McLean, Virginia

U.S. Department of the Interior
Bureau of Ocean Energy Management
Office of Renewable Energy Programs

DISCLAIMER

Study concept, oversight, and funding were provided by the US Department of the Interior, Bureau of Ocean Energy Management (BOEM), Office of Renewable Energy Programs, Sterling, VA, under Call Order 140M0121F0012. This report has been technically reviewed by BOEM, and it has been approved for publication. The views and conclusions contained in this document are those of the authors and should not be interpreted as representing the opinions or policies of the US Government, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

REPORT AVAILABILITY

To download a PDF file of this report, go to the US Department of the Interior, Bureau of Ocean Energy Management website and search on 2023-007. The report is also available at the National Technical Reports Library at https://ntrl.ntis.gov/NTRL/.

CITATION

Middleton, P., Barnhart, B. 2023. Supporting National Environmental Policy Act Documentation for Offshore Wind Energy Development Related to Electromagnetic Frequencies from Buried Transmission Cables. Washington (DC): U.S. Department of the Interior, Bureau of Ocean Energy Management. OCS Study BOEM 2023-007. 17 p.

Contents

List of Figures

List of Tables

List of Abbreviations and Acronyms

AC	Alternating Current
BOEM	Bureau of Ocean Energy Management
CFR	Code of Federal Regulations
DC	Direct Current
EMF	Electromagnetic Field
EMR	Electromagnetic Radiation
FDA	Food and Drug Administration
HVAC	High Voltage Alternating Current
HVDC	High Voltage Direct Current
ICD	Implantable Cardioverter Defibrillator
ICNIRP	International Commission on Non-Ionizing Radiation Protection
MRI	Magnetic Resonance Imaging
NEPA	National Environmental Policy Act
OCS	Outer Continental Shelf
U.S.	United States
WHO	World Health Organization

Executive Summary

Concerns and questions have been raised by the public regarding electric transmission cables making landfall from offshore wind farms and the electromagnetic frequencies associated with the transport of electricity through the onshore cables. Specifically, if frequencies from cables are dangerous to people using the beach and other public spaces, especially for those individuals with implanted pacemakers and/or implantable cardioverter defibrillators.

Electromagnetic frequencies are present continually throughout daily life, from the Earth's geomagnetic force to non-ionizing radiation from radio waves and cell phones. Electromagnetic frequencies are also emitted from appliances, electronic devices, and transmission lines which are commonly found throughout our environment. Common electronics, the Earth's geomagnetic radiation, and transmission lines are generally proven safe with appropriate distance from the source. This paper provides a high-level overview of electricity, electrical transmission, electromagnetic frequencies associated with electrical transmission, how electromagnetic frequencies affect humans, and the electromagnetic frequencies present with offshore wind energy transmission.

This paper was revised in April 2023, to add milligauss measurements for magnetic fields and to include modeled measurements of magnetic fields for additional onshore cable infrastructure, joint bays and duct banks.

1 Introduction

The Bureau of Ocean Energy Management (BOEM) facilitates the development of offshore wind energy on the Outer Continental Shelf (OCS) of the United States (U.S.). With numerous offshore wind farms in various phases of planning and analysis under the National Environmental Policy Act (NEPA), interest in offshore wind and specific aspects of offshore wind farms is also increasing. Concerns and questions regarding electric transmission cables making landfall from offshore wind farms have been raised. Specifically, if the electromagnetic frequencies associated with the transport of electricity from offshore to onshore are dangerous to people using the beach and other public spaces, particularly those individuals with implanted pacemakers and/or implantable cardioverter defibrillators.

This paper provides basic information about electricity, electrical transmission, electromagnetic frequencies associated with electrical transmission, how electromagnetic frequencies affect humans, and the electromagnetic frequencies present with offshore wind energy transmission. Links to more in-depth resources can be accessed in the References Section at the end of the document.

2 Background

Electric current is the movement of electrons through a wire or other conductive material. The pressure used to push electric current through a wire is called voltage. An electric field is produced by the voltage and increases in strength as the voltage increases. As electric current flows through a wire, a magnetic field is also generated as a result of the electrical flow. As the electric current increases, so does the magnetic field. Electric fields are measured in volts per meter (V/m), and magnetic fields are measured in units of tesla (T) or gauss (G)[1]. (National Institute of Environmental Health Sciences, National Institutes of Health, 2002)

The potential for electricity to do work, or the electrical pressure, is measured in volts (V), and electrical current is measured in amps or amperes (A), which is the movement of electric charge (National Institute of Environmental Health Sciences, National Institutes of Health, 2002). The level of amps in an electrical current is what poses the greatest danger to humans when an electrical source is not properly protected. Power cords in the home are wrapped, generally in a plastic, non-conductive material, to ensure the current-carrying elements within are not exposed. Electrical fields can be weakened or shielded by materials that conduct electricity, such as structures, vegetation, and even human skin (National Institute of Environmental Health Sciences, National Institutes of Health, 2002). Magnetic fields are able to pass through most materials and are more difficult to shield or weaken when compared to electrical fields (National Institute of Health, National Cancer Institute, 2022). Both electric and magnetic fields rapidly decrease in strength with distance, thereby reducing exposure to the fields (U.S. Environmental Protection Agency, 2021). Insulation surrounding transmission cables protects the cables within from external elements and damage but also provides protection from electric fields and prevents external contact with the current. Because of the prevalence and utility of electricity, it is often discussed separately from

[1] Gauss (G) is the common measure for magnetic fields used in the U.S. while tesla (T) is used internationally and in the scientific community. A measure of 10,000 G is equal to one (1) T. The full unit measures of G and T are used for large electromagnetic fields, smaller units of T, microtesla (μT) and G, milligauss (mG) are more commonly used. In this document, μT is used throughout the text and mG is also provided since it is more commonly used in the U.S. A μT is 1/1,000,000 of a T and a mG is 1/1,000 of a G. To convert a μT to a mG, multiply the unit of μT by 10, so 1 μT is 10 mG. (National Institute of Environmental Health Sciences, National Institutes of Health, 2002)

electromagnetic frequencies; however, magnetic fields are present when electricity is actively flowing through a power cord or transmission cable (U.S. Environmental Protection Agency, 2021).

Nearly all electrical transmission is conducted through alternating current (AC) in U.S. homes and businesses. The frequency of the electrical source, measured in Hertz (Hz), is one electrical cycle (a change in the flow of electrical current over time) per second (Iowa State University of Science and Technology, 2022). Alternating current is aptly named due to the electrical current reversing direction. In the U.S., the AC current frequency reverses 60 times a second, and most AC power in the U.S. is 60 Hz. In Europe and other countries, AC is 50 Hz (U.S. Department of Energy, 2014). The alternating property is what allows AC electricity to be converted to different voltages through the use of a transformer (U.S. Department of Energy, 2015).

The use of direct current (DC) is not as prevalent in the U.S. for transmission but is growing as larger volumes of energy are being transmitted over longer distances. DC current flows in one direction, which is not as easily converted to lower or higher voltages (U.S. Department of Energy, 2014). DC electricity can be transformed to AC current and is commonly used this way in both electrical transmission and household applications. A laptop computer runs on DC power when it is not plugged in; the black box on the power cord transforms the AC power transmitted through an electrical outlet into DC to power the computer. The frequencies differ between AC and DC currents due to the oscillating wavelengths of the AC electricity and the constant, static nature of the wavelengths of DC electricity (Tetra Tech, 2021).

2.1 Electromagnetic Fields and Radiation

The term electromagnetic field (EMF) refers to the electric and magnetic fields surrounding an electrical device and other manufactured or naturally occurring sources (National Institute of Environmental Health Sciences, National Institutes of Health, 2002). EMFs are present throughout the natural environment, such as within thunderstorms and in the Earth's magnetic field generated within the Earth's core, also known as a geomagnetic field (Tetra Tech, 2021). The Earth's geomagnetic field, which is a DC current, is strong enough to influence compasses, migrating avian species, and fish (U.S. Environmental Protection Agency, 2021). The Earth's DC geomagnetic field varies by latitude from 30 to 70 microtesla (µT) (300 to 700 mG), with the U.S. at approximately 50 µT (500 mG) (ICNIRP, 2009). EMFs are found everywhere, near electrical wires, overhead powerlines, electrical appliances and devices, radio waves, mobile phones, microwaves, and remote controls (U.S. Environmental Protection Agency, 2021). As long as household electrical appliances are plugged in, there are electric fields present (National Institute of Environmental Health Sciences, National Institutes of Health, 2002). Magnetic fields are only present when electric appliances are turned on and operating (National Institute of Environmental Health Sciences, National Institutes of Health, 2002). Power lines are continuously transmitting current; therefore, EMF is present as long as the power is flowing through the cable (U.S. Environmental Protection Agency, 2021).

Waves of electric and magnetic energy moving through space together are also known as electromagnetic radiation (EMR) (U.S. Environmental Protection Agency, 2021). EMR is found in the natural world in visible light, ultraviolet radiation, and lightning during a thunderstorm (U.S. Environmental Protection Agency, 2021). EMR wavelengths vary in frequency, from low to high with corresponding long to short wavelengths, generally classified as ionizing and non-ionizing radiation (U.S. Environmental Protection Agency, 2021). Examples of low frequency EMR are radio waves and microwaves, which are measured in Hz (Butcher, 2016). High frequency and ionizing radiation examples are X-rays and Gamma waves, measured in energy as electron volts (Butcher, 2016). Ionizing radiation can be harmful to human cells (U.S. Environmental Protection Agency, 2021). Low frequency, non-ionizing radiation is associated with the electromagnetic fields from electricity, and this EMR has not been shown to damage human cells

(U.S. Environmental Protection Agency, 2021). Figure 1 displays examples in the electromagnetic spectrum with the associated frequencies in Hz.

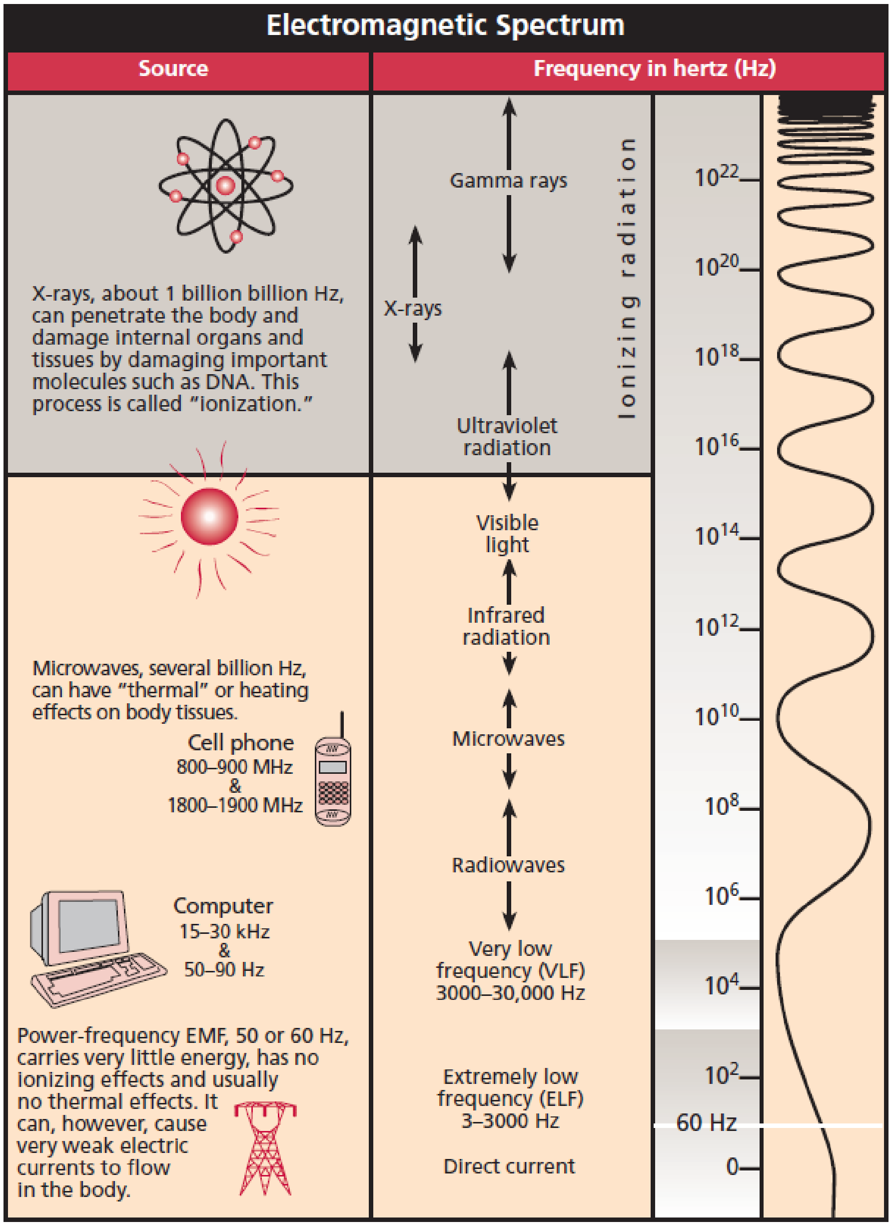

Figure 1. Characterization of Electromagnetic Frequencies

(National Institute of Environmental Health Sciences, National Institutes of Health, 2002)

2.1.1 Human Health and Electromagnetic Fields

Characterizing exposure to EMF and the effects to human health poses challenges due to the various aspects to consider when quantifying exposure, such as length of exposure, field strength, source, and even time of day (National Institute of Environmental Health Sciences, National Institutes of Health, 2002). The International Commission on Non-Ionizing Radiation Protection (ICNIRP), a non-governmental organization of experts in the field of non-ionizing radiation, conducted a thorough review of scientific literature from around the world to determine standards for exposure to electromagnetic fields (ICNIRP, 2010). These recommended standards are used as guidelines in many countries. The U.S. federal government is not presently applying the guidelines for low-frequency or static frequency exposure, nor are there standards limiting residential or occupational exposure to 60 Hz EMF (Iowa State University of Science and Technology, 2022; National Institute of Environmental Health Sciences, National Institutes of Health, 2002). Some states do have standards or guidelines for electric and magnetic fields, primarily for transmission lines, and some federal agencies regulate certain aspects of radiation emitting products, such as the U.S. Food and Drug Administration (FDA), which regulates electronic product radiation performance standards under 21 Code of Federal Regulations (CFR) 1010-1050 (Iowa State University of Science and Technology, 2022; U.S. Food and Drug Administration, 2018).

The standards recommended by the ICNIRP for low frequency EMF for the general public are shown in Table 1. The standards for exposure limits for the general public for static (DC) frequencies should not exceed 400 millitesla (mT) (0.4 T/4,000 G) (ICNIRP, 2009). However, exposures of up to 8 T (80,000 G) have shown no evidence of long-term, major, adverse effects to humans (ICNIRP, 2009). The ICNIRP also developed exposure guidelines for general EMF exposure for occupational and the general public, as shown in Table 2. These guidelines are intended to prevent effects from very high magnitude exposures, which are usually not found under normal circumstances in homes or businesses (National Institute of Environmental Health Sciences, National Institutes of Health, 2002).

Table 1. Standards for Low-Frequency AC Magnetic Frequencies— Exposure Limits for the General Public

Frequency Range	Internal Electric Field (Vm^{-1})
1 Hz – 3 kHz	0.4
3 kHz – 10 MHz	1.35×10^{-4}

(ICNIRP, 2010)

Table 2. ICNIRP Guidelines for EMF Exposure[1]

Exposure (60 Hz)	Electric Field	Magnetic Field
Occupational	8.3 kV/m	420 μT/4,200 mG
General Public	4.2 kV/m	83.3 μT/833 mG

[1] Taken from Electric and Magnetic Fields Associated with the Use of Electric Power, measures were modified for ease of understanding (National Institute of Environmental Health Sciences, National Institutes of Health, 2002).

Studies have been conducted to investigate effects of human exposure to EMF. Most reported symptoms to short-term exposure from 2 to 8 T (20,000 to 80,000 G) are vertigo, moderate visual disruption, nausea, dizziness, and a metallic taste (ICNIRP, 2009). Human tissue is far more vulnerable to damage from electric fields, which is why electric sources are shielded from human contact. Long-term exposure studies have yet to show conclusive evidence of acute effects from EMF (National Institute of Environmental Health Sciences, National Institutes of Health, 2002; ICNIRP, 2009). See ICNIRP Guidelines on Limits of Exposure to Static Magnetic Fields (ICNIRP, 2009), Extremely Low Frequency Fields (World Health Organization, 2007), and EMF: Electric and Magnetic Fields Associated with the Use of Electric Power, Questions and Answers (National Institute of Environmental Health Sciences, National Institutes of Health, 2002) for additional details about EMF and the effects of EMF to human health.

The World Health Organization (WHO) provides documents and websites with information regarding safety of radiation and electromagnetic fields. The table below is from a German source (Federal Office for Radiation Safety, 1999) and provides examples of typical magnetic field strength of household appliances at various distances. Because the measurements were taken in Germany, the listed appliances are powered at an AC frequency of 50 Hz rather than 60 Hz used in the U.S., making the comparison slightly different with frequencies measured in U.S. homes. The examples are shown to illustrate the levels of EMF present in daily life within most homes. Operating distance measurements for common use scenarios in the table are shown in bold. For most household appliances, the recommended guideline for magnetic fields is 100 µT (1,000 mG) at 50 Hz or 83 µT (830 mG) at 60 Hz. (WHO, 2016)

Table 3. Magnetic Field Strength from Common Household Appliances

Electric Appliance	Distance – 1.18 in (µT)	Distance – 1.18 in (mG)	Distance – 11.81 in (µT)	Distance – 11.81 in (mG)	Distance – 3.28 ft (µT)	Distance – 3.28 ft (mG)
Hair Dryer	**6 – 2,000**	**60 – 20,000**	0.01 – 7	0.1 – 70	0.01 – 0.03	0.1 – 0.3
Electric Shaver	**15 – 1,500**	**150 – 15,000**	0.08 – 9	0.8 – 90	0.01 – 0.03	0.1 – 0.3
Vacuum Cleaner	200 – 800	2,000 – 8,000	**2 – 20**	**20 – 200**	0.13 – 2	1.3 – 20
Fluorescent Light	40 – 400	400 – 4,000	**0.5 – 2**	**5 – 20**	0.02 – 0.25	0.2 – 2.5
Microwave Oven	73 – 200	730 – 2,000	**4 – 8**	**40 – 80**	0.25 – 0.6	2.5 – 6
Electric Oven	1 – 50	10 – 500	**0.15 – 0.5**	**1.5 – 5**	0.01 – 0.04	0.1 – 0.4
Dishwasher	3.5 – 20	35 – 200	**0.6 – 3**	**6 – 30**	0.07 – 0.3	0.7 – 3

(WHO, 2016)

Research and literature studies have determined that normal interactions with EMF present in homes, overhead transmission lines, and buried transmission cables show no adverse impacts to human health (ICNIRP, ND; ICNIRP, 2009; ICNIRP, 2010; Exponent, 2021; Gradient, 2021; National Institute of Environmental Health Sciences, National Institutes of Health, 2002; Trigano, Blandeau, Souques, Gernez, & Magne, 2005; U.S. Environmental Protection Agency, 2021).

2.1.1.1 Implanted Pacemakers and Cardioverter Defibrillators

Although most people will not sustain adverse effects from EMFs in day-to-day life, those with implanted pacemakers and/or implantable cardioverter defibrillators (ICD) are more vulnerable to magnetic fields due to the sensors in their devices that monitor heart activity and generate shocks or electrical pulses if heart activity becomes abnormal (MedlinePlus, 2017). Many cardiac devices will switch into “magnet mode” if levels of over 9,000 µT (0.009 T/9.0 G/90,000 mG) are detected near a device, causing the device to temporarily cease operation (FDA, 2021). This safety feature is used during a medical procedure where electromagnetic frequencies, such as magnetic resonance imaging (MRI), are present in order to prevent unintended sensing of irregularities and subsequent responses of the device (Seidman, Guag, Beard, & Arp, 2021). Most sources of electromagnetic fields that people are typically in contact with will not come close to or exceed 9,000 µT (90,000 mG). This is usually limited to medical or lab equipment using very powerful magnets. However, an implanted cardiac device’s “magnet mode” can also be triggered by strong electromagnetic fields up to 1,000 µT (10,000 mG) from electronics, such as a cell phone or smart watch, within very close proximity, such as within 0.4 to 0.8 inches of the device (Seidman, Guag, Beard, & Arp, 2021). This has led to recommendations to keep these electronics at least 6 inches away from implanted defibrillators and ICDs (FDA, 2021). If a device were to switch into “magnet mode” accidentally, a person with the device could be at risk if they experience a cardiac event during that time (Seidman, Guag, Beard, & Arp, 2021). The “magnet mode” safety feature will automatically switch off and the device should resume normal operation once the triggering EMF is no longer in range of the device (FDA, 2021).

As a result of the potential interference of EMFs with pacemakers or ICDs, individuals with these cardiac devices need to be aware of magnetic frequencies in their surroundings, including cell phones, welding equipment, and some rail transportation (National Institute of Environmental Health Sciences, National Institutes of Health, 2002). A standard recommendation for workers with pacemakers or ICDs who may come in contact with EMF more often than those in a standard office or household setting is to avoid being exposed to 60 Hz magnetic fields exceeding 100 µT (1,000 mG) (National Institute of Environmental Health Sciences, National Institutes of Health, 2002).

3 Wind Energy

3.1 Background

A wind turbine generates electricity when the force of moving air causes the turbine blades to move by changing the air pressure on one side of the blade (U.S. Department of Energy, ND). The moving blades spin a rotor, collecting the kinetic energy, which is transformed to electricity through a generator within the turbine (U.S. Energy Information Administration, 2021). Wind turbines generate AC electricity, which is collected through inter-array cables from the turbines to an offshore platform, substation, or converter station. These inter-array cables can range from 33 to 72.5kV and may be buried or suspended in the water column. Cables transmitting power from an offshore platform, substation, or AC to DC converter station to an onshore substation range from about 200 to 420kV for AC and from 320 to 600 kV for DC (Tetra Tech, 2021). Cables buried offshore for wind transmission are typically located between 5 and 6.5 feet under the seafloor, but this can vary depending on substrate composition and seafloor topography (Sharples, 2011). Figure 2 shows the cable array from offshore to onshore along with associated infrastructure.

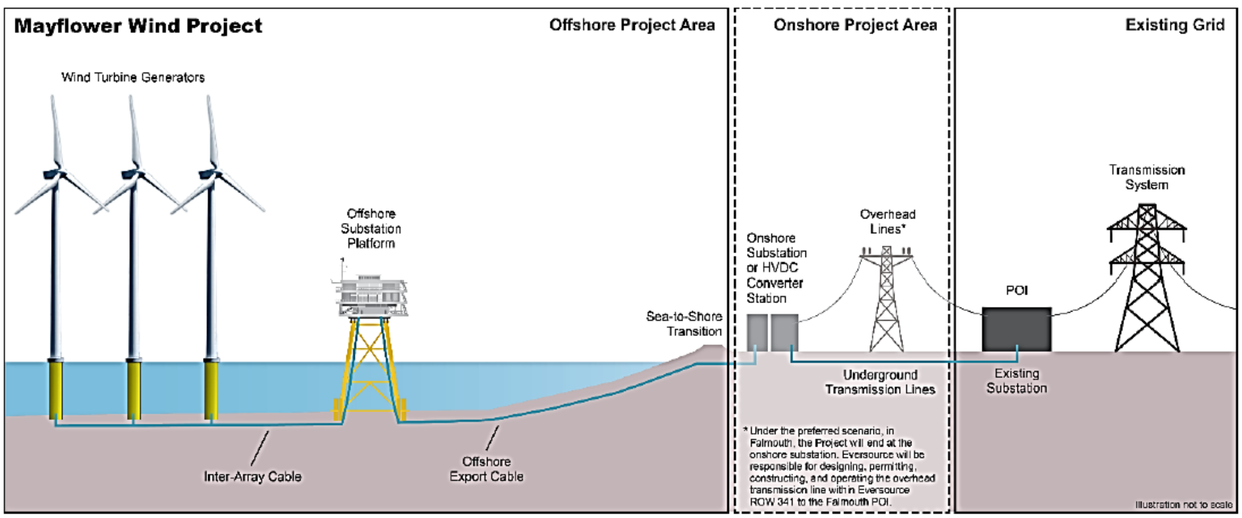

Figure 2. Turbines, Cables, Substations, and Other Associated Infrastructure for Offshore and Onshore Facilities

(Mayflower Wind Energy, LLC, 2021)

3.2 Magnetic Frequencies and Transmission of Wind Energy Onshore

Some offshore wind projects transmit power onshore through high voltage AC (HVAC) cables due to their proximity to land, the amount of power being produced, and higher cost of investment in a high voltage DC (HVDC) system. As windfarms are developed further offshore, HVDC cables are becoming more prevalent in U.S. offshore wind farm designs for transporting power onshore. Both AC and DC transmission cables are surrounded with a conductive metal sheath that prevents the generation of external electric frequencies when the cables are grounded, leaving the possibility of magnetic frequencies being present near HVAC and HVDC transmission cables (Mayflower Wind Energy, LLC, 2021).

Magnetic frequencies will vary depending on the configuration of cables, and whether they are AC or DC (Sharples, 2011). If HVAC is transmitted onshore in a three-phase system, which is most often used for onshore transmission, rather than a single cable, the sum of the phases when transmitting equally among the cables will nearly to completely cancel out the magnetic fields around the cable (Bureau of Safety and Envirnmental Enforcement, 2014; Hutchinson, et al., 2018). If HVDC is transmitted through a single (monopolar) cable, magnetic fields will be present (Bureau of Safety and Envirnmental Enforcement, 2014). Most often, two (bipolar) DC cables are used, and the magnetic fields from both cables nearly to completely cancel each other out, resulting in low to no magnetic field within a short distance from the cable (Bureau of Safety and Envirnmental Enforcement, 2014). Because monopolar DC cables generate larger magnetic fields, they are not generally used for offshore wind transmission. (Sharples, 2011). As ocean currents and marine species move through the sea and the Earth's DC magnetic field, weak DC electric fields are generated (CSA Ocean Sciences Inc. and Exponent, 2019). These induced fields may increase or decrease when in proximity to AC or DC cables (Hutchinson, et al., 2018).

Each offshore wind project develops cable landfalls differently according to the shoreline geology, volume of energy produced, cables used, equipment used for burial, and other factors such as water depth and sensitive resources. Cable landfalls are buried at ranging depths (approximately 6 to over 50 feet), and most use conduits or ducts to enclose the cables from a point offshore through the onshore environment and to an onshore substation or converter station; although some cables are buried directly in the environment without being enclosed in conduit (Tetra Tech, 2021). In general, if magnetic frequencies are generated from a buried AC or DC cable, the point where the strongest magnetic force is present will be directly above the cable, and the field decreases rapidly with distance from either side of the center line (National Grid, ND).

Modeled magnetic fields for onshore landfall cables from the Mayflower Wind and Revolution Wind projects are provided in Table 4 as an example of magnetic fields above and adjacent to onshore 60 Hz AC cables operating at 275 kV (Gradient, 2021; Exponent, 2021).

Table 4. Magnetic Fields from Cable Landfalls

Project	Cable Depth	Directly Above* (μT/mG)	Approx. 10 feet* (μT/mG)	Approx. 25-30 feet* (μT/mG)
Revolution	3.3 feet	3.9 / 39	3.8 / 38	0.52 / 5.2
Mayflower	9.8 feet	3.93 / 39.3	2.05 / 20.5	0.62 / 6.2
Mayflower	52.8 feet	0.38 / 3.8	0.34 / 3.4	0.28 / 2.8

*Horizontal distance above cable (three-phase AC)
(Exponent, 2021; Gradient, 2021)

Once onshore, the landfall cables are connected into onshore transmission cables within an underground transition vault or joint bay. The vault or joint bay may be located under a parking lot following construction, or within another accessible area near the landfall cables. The onshore cables are combined into groups termed as "duct banks" that transmit AC or DC electricity underground to an onshore substation or converter station. Duct banks encase the transmission cables within polyvinyl chloride (PVC) or high-density polyethylene (HDPE) pipes surrounded by concrete (Epsilon Associates, Inc., 2022). Most offshore wind projects propose to place the cable duct banks underground, usually within existing corridors along roadways, although some new corridors may be constructed as well. As with the landfall cables, the onshore cables emit magnetic fields. The strength of the magnetic fields will vary based on the voltage of power transmitted and the configuration, number of circuits, and spacing of the cables, as well as if the power is HVAC or HVDC. Table 5 displays examples of modeled predicted magnetic fields for joint bays in two locations from the Mayflower Wind project. The examples in Table 5 are comprised of three cables buried 6.6 feet deep, AC 60 Hz, 300 kV and maximum current of 1,200 amperes (A) but have different spacing distances between the cables.

Table 5. Magnetic Fields from Joint Bays, Mayflower Wind

Cable Separation	Directly Above* (µT/mG)	Approx. 10 feet* (µT/mG)	Approx. 25 feet* (µT/mG)
16.4 ft	7.72 / 77.2	3.68 / 36.8	1.03 / 10.3
90 ft	8.6 / 86	2.88 / 28.8	0.68 / 6.8

*Horizontal distance above cable (three-phase AC)
(Gradient, 2021)

The modeled predicted magnetic fields for duct bank examples in Table 6 are comprised of a varying number of circuits, each circuit is composed of three cables, buried 6.6 feet deep, and the cables conduct AC 60 Hz, 300 kV and 1.200 A. The configuration of circuits is described by the number of circuits arranged by depth (D) and width (W), with depth being a stacked formation and width being positioned side-by-side.

Table 6. Magnetic Fields from Duct Banks, Mayflower Wind

Duct Bank Config.	Directly Above[1] (µT)	Directly Above[1] (mG)	Approx. 10 feet[2] (µT)	Approx. 10 feet[2] (mG)	Approx. 25 feet[2] (µT)	Approx. 25 feet[2] (mG)
2D by 5W	18.70	187.0	8.40 / 8.69	84.0 / 86.9	1.83 / 1.86	18.3 / 18.6
3D by 2W	22.34	223.4	9.30 / 9.11	93.0 / 91.1	2.16 / 2.15	21.6 / 21.5
2D by 2W	22.00	220.0	8.08 / 7.84	80.8 / 78.4	1.80 / 1.77	18.0 / 17.7
1D by 4W	40.33	403.3	15.67 / 12.81	156.7 / 128.1	3.24 / 2.90	32.4 / 29.0

[1] Horizontal distance above cable (three-phase AC)
[2] Distances are measured horizontally to the left and right from the center line of the duct bank, respectively.
(Gradient, 2021)

Direct measurements were taken from offshore transmission cables, the Cross Sound (dipole HVDC), Neptune (dipole HVDC), and sea2shore (3-phase HVAC). The Cross Sound (330 MW capacity) and Neptune (660 MW capacity) measurements were compared to the Earth's background DC magnetic field and the increase or decrease of the magnetic field. The deviation of the DC magnetic field from background ranged from 0.4 to 18.7 µT (4 to 187 mG) for Cross Sound and 1.3 to 20.7 µT (13 to 207 mG) for Neptune. An unexpected measure of AC electric and magnetic fields occurred for both HVDC cables, which were measured from a baseline of zero. Maximum AC values for Cross Sound for magnetic field were 0.15 µT (150 mG) and electric maximum of 0.7 mV/m, Neptune's maximum AC values were 0.04 µT (0.4 mG) and electric maximum of 0.4 mV/m. The sea2shore AC cable (32 MW capacity) directly measured the magnetic field produced, ranging from 0.05 to 0.3 µT (0.5 to 3 mG) and the AC electric fields were 1 to 2.5 mV/m. The research conducted and collected for these measurements is part of a larger study to investigate effects of EMF on marine species, *Electromagnetic Field Impacts on Elasmobranch (shark, rays, and skates) and American Lobster Movement and Migration from Direct Current Cables* (Hutchinson, et al., 2018).

The recommended limit of magnetic frequencies from household appliances is 83 µT (830 mG) at 60 Hz, and pacemaker and ICD "magnet mode" is 9,000 µT (90,000 mG). All modeled frequencies above or adjacent to onshore cables shown in Table 4, Table 5, and Table 6 fall below these thresholds. There is no evidence or research showing adverse health effects from EMF exposure from underground AC or DC powerlines. Even if a person wearing a pacemaker or ICD were to sit, sunbathe, walk along, or live near buried transmission cables, the strength of the magnetic field is unlikely to reach any threshold for danger to their device or the health of the person with the device. Exposure to EMF from buried onshore transmission lines will not cause short-or long-term health effects to those who are in proximity of the buried cables. (Trigano, Blandeau, Souques, Gernez, & Magne, 2005; ICNIRP, ND)

4 Summary

Electromagnetic frequencies are present continually throughout daily life, from the Earth's geomagnetic force to non-ionizing radiation from radio waves and cell phones. Characterizing exposure to EMF and the effects to human health poses challenges due to the various aspects to consider when quantifying exposure, such as length of exposure, field strength, source, and even time of day (National Institute of Environmental Health Sciences, National Institutes of Health, 2002). However, the frequencies from appliances, devices, and transmission lines are generally proven safe with appropriate distance from the source.

Both AC and DC transmission cables used with offshore windfarms to transmit power onshore are surrounded with a conductive metal sheath that prevents the generation of external electric frequencies when the cables are grounded, leaving the possibility of magnetic frequencies being present near HVAC and HVDC transmission cables (Mayflower Wind Energy, LLC, 2021). Magnetic frequencies will vary depending on the configuration of cables, and whether they are AC or DC (Sharples, 2011). However, all modeled frequencies above or adjacent to onshore cables shown in Table 4, Table 5, and Table 6 fall well below the recommended thresholds. There is no evidence or research showing adverse health effects from EMF exposure from underground AC or DC powerlines. Even if a person wearing a pacemaker or ICD were to sit, sunbathe, walk, or reside along a buried transmission cable, the strength of the magnetic field is unlikely to reach any threshold for danger to their device or the health of the person with the device. Exposure to EMF from buried onshore transmission lines will not cause short-or long-term health effects to those who are in proximity of the buried cables. (Trigano, Blandeau, Souques, Gernez, & Magne, 2005; ICNIRP, ND)

5 References

Bureau of Safety and Envirnmental Enforcement. (2014). *Offshore Wind Submarine Cable Spacing Guidance.* U.S. DOI, BSEE. Retrieved November 30, 2022, from https://www.boem.gov/sites/default/files/renewable-energy-program/Studies/TAP/722AA.pdf

Butcher, G. (2016). National Aeronautics and Space Administration - Tour of the Electromagnetic Spectrum. Washington, DC, USA. Retrieved October 14, 2022, from https://smd-prod.s3.amazonaws.com/science-pink/s3fs-public/atoms/files/Tour-of-the-EMS-TAGGED-v7_0.pdf

CSA Ocean Sciences Inc. and Exponent. (2019). Evaluation of Potential EMF Effects on Fish Species of Commercial or Recreational Fishing Importance in Southern New England. Sterling, VA, USA. Retrieved January 26, 2023, from https://espis.boem.gov/final%20reports/BOEM_2019-049.pdf

Epsilon Associates, Inc. (2022). *New England Wind 1 Connector, Barnstable, Massachusetts - Development of Regional Impact.* Barnstable: Cape Cod Commission. Retrieved April 6, 2023, from https://www.capecodcommission.org/resource-library/file?url=%2Fdept%2Fcommission%2Fteam%2Fmember%2FProject+Documents%2FVineyard+Wind+II+aka+New+England+Wind%2FApplication_Materials%2F2022-06-10+New+England+Wind+1+DRI+App.pdf

Exponent. (2021). *Revolution Wind Farm Offshore Electric- and Magnetic- Field Assessment.* Bowie: Revolution Wind, LLC. Retrieved November 28, 2022, from https://www.boem.gov/sites/default/files/documents/renewable-energy/state-activities/App_Q1%20RevolutionWind_Offshore_EMF_Assessment_880MW.pdf

FDA. (2021, May 13). *Magnets in Cell Phones and Smart Watches May Affect Pacemakers and Other Implanted Medical Devices*. Retrieved from U.S. Food and Drug Administration: https://www.fda.gov/radiation-emitting-products/cell-phones/magnets-cell-phones-and-smart-watches-may-affect-pacemakers-and-other-implanted-medical-devices

Gradient. (2021). *Electric and Magnetic Field (EMF) Assessment for the Proposed Mayflower Wind Project.* Boston: Mayflower Wind Energy. Retrieved November 30, 2022, from https://www.boem.gov/sites/default/files/documents/renewable-energy/state-activities/Appendix%20P1_EMF%20Assessment%20Report.pdf

Hutchinson, Z., Sigray, P., He, H., Gill, A., King, J., & Gibson, C. (2018). Electromagnetic Field (EMF) Impacts on Elasmobranch (shark, rays, and skates) and American Lobster Movement and Migration from Direct Current Cables. Sterling, VA, USA. Retrieved January 26, 2023, from https://espis.boem.gov/final%20reports/5659.pdf

ICNIRP. (2009). ICNIRP Guidelines on Limits of Exposure to Static Magnetic Fields. *Helath Physics, 96(4)*, 504-514. Retrieved November 23, 3033, from https://www.icnirp.org/cms/upload/publications/ICNIRPstatgdl.pdf

ICNIRP. (2010, November 1). Fact Sheet on the Guidelines for Limiting Exposrue to time-Varying Electric and Magnetic Fields (1Hz - 100kHz), Published in Health Phys 99(6):818-836; 2010. Munich, Germany, European Union. Retrieved November 12, 2022, from https://www.icnirp.org/cms/upload/publications/ICNIRPFactSheetLF.pdf

ICNIRP. (ND). *Power Lines*. Retrieved December 20, 2022, from ICNIRP: https://www.icnirp.org/en/applications/power-lines/index.html

Iowa State University of Science and Technology. (2022, November 12). Electromagnetic Fields Factsheet. Ames, Iowa, USA. Retrieved from https://www.ehs.iastate.edu/sites/default/files/uploads/publications/manuals/emf.pdf

Mayflower Wind Energy, LLC. (2021). *Construction and Operations Plan.* Sterling: Bureau of Ocean Energy Management.

MedlinePlus. (2017, February 28). *Pacemakers and Implantable Defibrillators*. Retrieved December 27, 2022, from MedlinePlus: https://medlineplus.gov/pacemakersandimplantabledefibrillators.html

National Grid. (ND). *Underground Power Cables*. Retrieved July 13, 2022, from EMFs.info: https://www.emfs.info/sources/underground/

National Institute of Environmental Health Sciences, National Institutes of Health. (2002, June). EMF: Electric and Magnetic Fields Associated with the Use of Electric Power - Questions and Answers. Research Triangle Park. Retrieved July 7, 2022, from https://www.niehs.nih.gov/health/materials/electric_and_magnetic_fields_associated_with_the_use_of_electric_power_questions_and_answers_english_508.pdf

National Institute of Health, National Cancer Institute. (2022, May 30). *Electromagnetic Fields and Cancer*. Retrieved from NIH - National Cancer Institute: https://www.cancer.gov/about-cancer/causes-prevention/risk/radiation/electromagnetic-fields-fact-sheet

Seidman, S., Guag, J., Beard, B., & Arp, Z. (2021). Static Magnetic Field Measurements of Smart Phones and Watches and Applicability to Triggering Magnet Modes in Implantable Pacemakers and Implantable Cardioverter-Defibrillators. *Heart Rythm*, 1741-1744. Retrieved December 20, 2022, from heartrhythmjournal.com/action/showPdf?pii=S1547-5271%2821%2901859-2

Sharples, M. (2011, November 1). Offshore Electrical Cable Burial for Wind Farms: State of the Art, Standards and Guidance and Acceptable Burial Depths, Separation Distances and Sand Wave Effect. (BOEM, Ed.) Retrieved from https://www.bsee.gov/sites/bsee.gov/files/tap-technical-assessment-program/final-report-offshore-electrical-cable-burial-for-wind-farms.pdf

Tetra Tech. (2021, April 2). Offshore Wind Submarine Cabling Overview, Fisheries Technical Working Group, Final Report. Albany, NY, USA. Retrieved March 15, 2022, from https://www.nyserda.ny.gov/-/media/Files/Programs/offshore-wind/21-14-Offshore-Wind-Submarine-Cable-Report.pdf

Trigano, A., Blandeau, O., Souques, M., Gernez, J. P., & Magne, I. (2005). Clinical Study of Interference With Cardiac Pacemakers by a Magnetic Field at Power Line Frequencies. *Journal of the American College of Cardiology*, 896-900. Retrieved July 7, 2022, from https://www.researchgate.net/publication/7967468_Clinical_study_of_interference_with_cardiac_pacemakers_by_a_magnetic_field_at_power_line_frequencies

U.S. Department of Energy. (2014, November 18). *The War of the Currents: AC vs. DC Power.* Retrieved from Energy.gov: https://www.energy.gov/articles/war-currents-ac-vs-dc-power

U.S. Department of Energy. (2015, August 31). *Current Obsession: AC/DC.* Retrieved from Office of Energy Efficiency and Renewable Energy: https://www.energy.gov/eere/articles/current-obsession-acdc

U.S. Department of Energy. (ND). *How Do Wind Turbines Work?* Retrieved July 18, 2022, from U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Wind Energy Technologies Office: https://www.energy.gov/eere/wind/how-do-wind-turbines-work

U.S. Energy Information Administration. (2021, March 17). *Wind Explained: Electricity Generation from Wind*. Retrieved from EIA: Independent Statistics and Analysis: https://www.eia.gov/energyexplained/wind/electricity-generation-from-wind.php#:~:text=Wind%20turbines%20use%20blades%20to,which%20produces%20(generates)%20electricity.

U.S. Environmental Protection Agency. (2021, August 30). *RadTown-Electric and Magnetic Fields from Power Lines*. Retrieved from EPA: https://www.epa.gov/radtown/electric-and-magnetic-fields-power-lines

U.S. Food and Drug Administration. (2018, March 22). *Performance Standards: Radiological Health Program*. Retrieved from Radiation-Emitting Producs: https://www.fda.gov/radiation-emitting-products/getting-radiation-emitting-product-market-frequently-asked-questions/performance-standards

WHO. (2016, August 4). *World Health Organization*. Retrieved from Radiation: Electromagnetic Fields - Q&A: https://www.who.int/news-room/questions-and-answers/item/radiation-electromagnetic-fields

World Health Organization. (2007). *Extremely Low Frequency Fields.* Geneva: WHO.