Electrical Engineering and Computer Science Practice

Ecological and Biological Sciences Practice

US Wind Maryland Offshore Wind Project

Onshore Magnetic-Field Assessment

Exponent®

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Offshore Magnetic-Field Assessment

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Acronyms and Abbreviations

µT	Microtesla
A	Ampere
AC	Alternating current
BOEM	Bureau of Ocean Energy Management
Exponent	Exponent, Inc.
FEA	Finite elemental analysis
ft	Feet
HDD	Horizonal directional drilling
Hz	Hertz
ICES	International Committee on Electromagnetic Safety
ICNIRP	International Commission on Non-Ionizing Radiation Protection
IEEE	Institute of Electrical and Electronics Engineers
km	Kilometer
kV	Kilovolt
Lease Area	Renewable Energy Lease Area OCS-A 0490
m	Meter
mG	Milligauss
mi	Mile
OCS	Outer Continental Shelf
OSS	Offshore substations
POI	Point of interconnection
Project	MARWIN Offshore Wind Project
ROW	Right-of-way
TRC	TRC Environmental Corporation
US Wind	U.S. Wind, Inc.
WTG	Wind turbine generator

Limitations

At the request of TRC Environmental Corporation (TRC), on behalf of US Wind, Inc. (US Wind), Exponent modeled the alternating current magnetic-field levels associated with the operation of the onshore underground cables proposed to transport electricity generated by the Maryland Offshore Wind Project (the Project).

This report summarizes the analysis performed to date and presents the findings resulting from that work. In the analysis, we have relied on cable design geometry, usage, specifications, and various other types of information provided by US Wind, TRC, and K2 Engineering, the engineering company contracted by US Wind to support development of the Project. We cannot verify the correctness of these input data and rely on US Wind, TRC, and K2 Engineering for the data's accuracy. Although Exponent has exercised usual and customary care in the conduct of this analysis, the responsibility for the design and operation of the Project remains fully with the client. US Wind and TRC have confirmed to Exponent that the data contained herein are not subject to Critical Energy Infrastructure Information restrictions.

The analyses presented herein are made to a reasonable degree of engineering and scientific certainty. Exponent reserves the right to supplement this report and to expand or modify opinions based on review of additional material as it becomes available, through any additional work, or review of additional work performed by others.

The scope of services performed during this investigation may not adequately address the needs of other users of this report, and any re-use of this report or its findings, conclusions, or recommendations presented herein for purposes other than intended for Project permitting are at the sole risk of the user. The opinions and comments formulated during this assessment are based on observations and information available at the time of the investigation. No guarantee or warranty as to future life or performance of any reviewed condition is expressed or implied.

Executive Summary

At the request of TRC Environmental Corporation (TRC), on behalf of US Wind Inc. (US Wind), Exponent, Inc. (Exponent) calculated the alternating current magnetic fields associated with the operation of the Maryland Offshore Wind Project (the Project), an offshore wind energy project of up to approximately 2,000 megawatts of nameplate capacity within Lease Area OCS-A 0490. Electricity generated by offshore wind turbine generators (WTG) is proposed to be carried on submarine cables to up to four Offshore Substations. Offshore submarine Export Cables will transmit the power to a landfall location at the 3R's Beach in the Delaware Seashore State Park and then through Indian River Bay to the point of interconnection (POI) with the Delaware electric grid adjacent to the existing Indian River Generating Station. The onshore transmission lines between Indian River Bay and the POI will be installed underground in two double-circuit duct banks.

This report summarizes the magnetic fields associated with the operation of the terrestrial duct banks. Magnetic-field levels were calculated for currents projected for long-term average and short-term peak electricity generation (i.e., average and peak load) for a configuration of the proposed onshore cables representative of that to be installed in the two underground duct banks between Indian River Bay and the POI. Magnetic-field calculations were performed for an optimized arrangement of phase conductors to minimize the magnetic-field levels generated by the duct bank, a method discussed by the World Health Organization for reducing magnetic-field levels.[1] The magnetic-field levels associated with the operation of the Project's onshore cables in the modeled duct bank configuration at both average and peak load were calculated to be far below the limits developed by the International Committee on Electromagnetic Safety and the International Commission on Non-Ionizing Radiation Protection,[2] which were designed to protect the health and safety of the general public and workers.

[1] World Health Organization (WHO). Environmental Health Criteria 238: Extremely Low Frequency (ELF) Fields. Geneva, Switzerland: WHO, 2007.

[2] International Committee on Electromagnetic Safety (ICES). IEEE Standard for Safety Levels with Respect to Human Exposure to Electromagnetic Fields 0 to 300 GHz. IEEE Std C95.1-2019 (Revision of IEEE Std

Note that this Executive Summary does not contain all of Exponent's technical evaluations, analyses, conclusions, and recommendations. Hence, the main body of this report is at all times the controlling document.

C95.1-2005/Incorporates IEEE Std C95.1-2019/Cor 1-2019). New York: IEEE, 2019.; International Commission on Non-Ionizing Radiation PI. ICNIRP Statement - Guidelines for Limiting Exposure to Electromagnetic Fields (1 Hz to 100 kHz). Health Phys 99:818-836, 2010.

Introduction

Project Description

US Wind Inc. (US Wind), proposes to construct and operate the Maryland Offshore Wind Project (the Project), an offshore wind energy project of up to approximately 2,000 megawatts (MW) of nameplate capacity. The Offshore Substations (OSS), Wind Turbine Generators (WTG), and Inter-array Cables will all be located in federal waters on the Outer Continental Shelf (OCS) in the Bureau of Ocean Energy Management's (BOEM) Renewable Energy Lease Area OCS-A 0490 (Lease Area). The roughly 80,000-acre Lease Area is located approximately 11.5 miles (mi) (18.5 kilometers [km]) off the coast of Maryland. The Project includes MarWin, a wind farm of approximately 300 MW; Momentum Wind, consisting of approximately 808 MW; and build out of the remainder of the Lease area to fulfill ongoing, government-sanctioned demands for offshore wind energy. Up to four offshore Export Cables will transmit the electricity from the wind farm's substations to a landfall location near 3R's Beach in Delaware Seashore State Park. From there the cables will continue through Indian River Bay to a point near the Indian River Generating Facility.

Where the four Export Cables reach the west side of Indian River Bay near the proposed and existing onshore substations, the Project cables will transition from water to land via HDD ducts. Along the short terrestrial portion of the Project's cable route between the HDD ducts and the connection to the US Wind substations the Onshore Export Cables will be installed in a pair of underground double-circuit duct banks. These duct banks will be more than 2,000 feet (ft) (600 meters [m]) from the nearest residence. For the portion of the onshore route installed by HDD, the calculated magnetic fields will be still lower.

Both 230-kV and 275-kV designs are currently within the project design envelope. For the same power flow, a higher electrical current and hence higher magnetic fields will result for operation at 230 kV, and hence all calculations in this report assume an operating voltage of 230 kV.

This report summarizes the calculated alternating current (AC) magnetic-field levels along the route of the Onshore Export Cables duct bank in the terrestrial portion of the Project. An assessment of magnetic-field and induced electric-field levels generated by offshore portions of the Project (offshore in federal and state waters as well as in Indian River Bay) is provided in a companion report titled *US Wind Maryland Offshore Wind Project: Offshore Electric and Magnetic Field Assessment*.

Technical Background

The Project will transmit AC electricity from the offshore turbines to the POI at a frequency of 60 Hertz (Hz), which means that both the electrical current and the magnetic fields generated by this current change direction and intensity in a continuous cycle that repeats 60 times per second (i.e., they oscillate at this rate). This is the same as the electricity typically carried over distribution and transmission lines in our communities and that is used throughout modern life in our homes and businesses. For context, Figure 1 (below) shows typical 60-Hz magnetic-field levels measured in residential and occupational environments along with typical magnetic-field levels from overhead transmission lines both within the edge of the right-of-way (ROW) and at the ROW edge. In general, magnetic-field levels from all common sources decrease rapidly with distance from the source, which is also the case for underground Export Cables that are part of this Project, as noted below.

Magnetic Fields

Magnetic fields from the Project are reported as magnetic flux density in units of milligauss (mG), which is the unit of measure commonly used in North America. Elsewhere in the world, magnetic-field levels often are reported in units of microtesla (µT), where 1 µT is equal to 10 mG. The magnetic field created by the flow of electric current on the Project's cables will be highest above the Onshore Export Cables' underground installation, and like magnetic fields from other sources, the fields will decrease rapidly with distance.

Since the current (i.e., the load) carried by the cables depends on the speed of the wind, magnetic-field levels also will vary as windspeed varies. Exponent therefore calculated magnetic fields for estimated annual average load to provide typical field levels for average operating conditions, as well as for peak load, which provides a conservative representation of the maximum magnetic-field levels expected for short periods of time when all wind turbines are generating electricity at their maximum capacity).

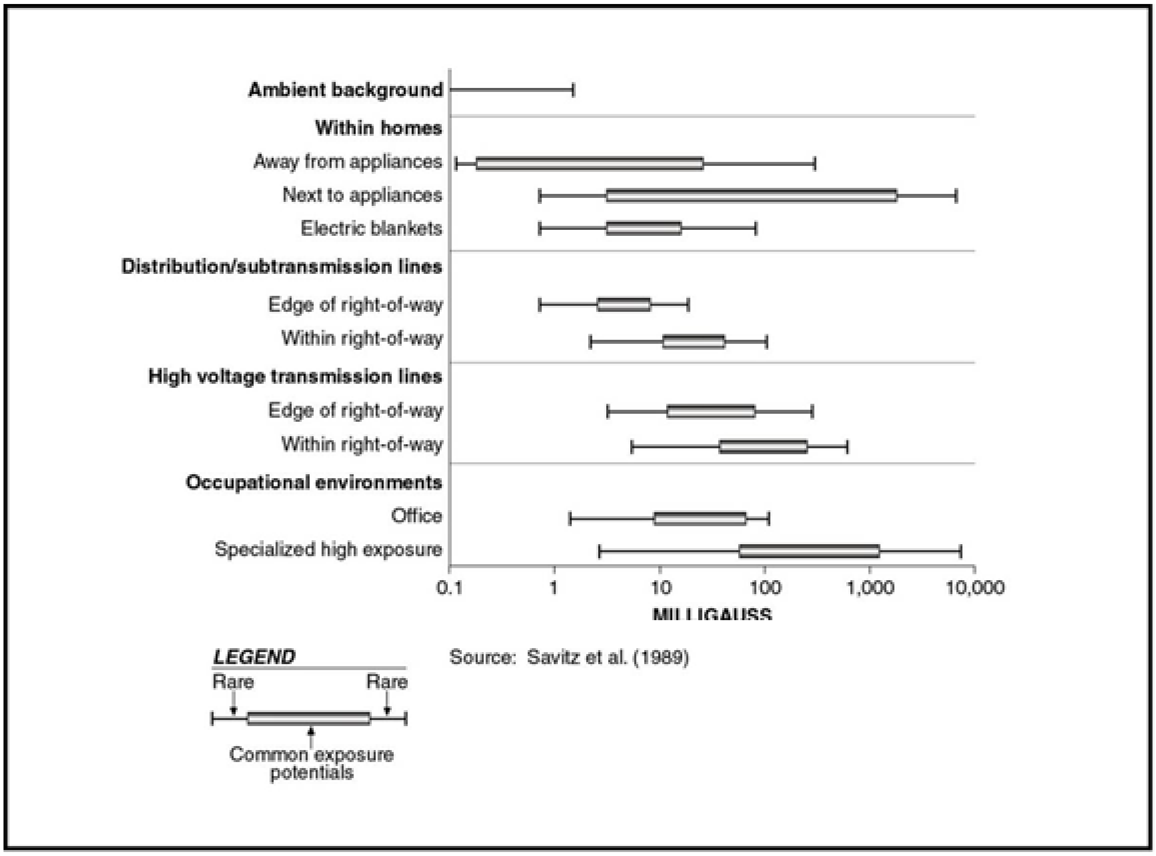

Figure 1. 60-Hz magnetic-field levels in the environment

Relevant Standards

The states of Maryland and Delaware do not have any laws, regulations, or guidelines that limit 60-Hz magnetic field from any type of electric transmission or distribution cables, either above ground, or underground, or offshore. Similarly, the federal government has no such laws, regulations, or guidelines regarding 60-Hz magnetic fields.

Since there are no governmental regulatory guidelines, magnetic-field levels were assessed in the context of the relevant health-based exposure limits developed by scientific organizations based on reviews and evaluations of relevant health research. Both the International Commission on Non-Ionizing Radiation (ICNIRP) and the Institute of Electrical and Electronics Engineers' (IEEE) International Committee on Electromagnetic Safety (ICES) have conducted extensive reviews of the relevant research related to magnetic-field exposure and developed guidance for exposure based on that research.[3]

ICNIRP is an independent, non-profit scientific organization with the stated aim "… to protect people and the environment against adverse effects of non-ionizing radiation … To this end, ICNIRP develops and disseminates science-based advice on limiting exposure to non-ionizing radiation"[4] The Commission consists of international experts in fields such as biology, epidemiology, medicine, physics, and chemistry. These experts "… work together with and within ICNIRP to assess the risk of [non-ionizing radiation] exposure and provide exposure guidance,"[5] which is periodically published in guidelines, reviews, and statements, that are publicly available.

ICES, operating under the oversight of the IEEE's Standards Association Board, is "… responsible for development of standards for the safe use of electromagnetic energy in the range of 0 Hz to 300 GHz [Gigahertz] relative to: the potential hazards of exposure of humans …, standards for products that emit electromagnetic energy by design or as a by-product of their operation, and standards for environmental limits." The Committee "strives to achieve consensus among all the stakeholders in the safe use of electromagnetic energy, thereby producing practical science-based standards that are readily accepted and applied."

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3 International Commission on Non-Ionizing Radiation PI. ICNIRP Statement - Guidelines for Limiting Exposure to Electromagnetic Fields (1 Hz to 100 kHz). Health Phys 99:818-836, 2010; International Committee on Electromagnetic Safety (ICES). IEEE Standard for Safety Levels with Respect to Human Exposure to Electromagnetic Fields 0 to 300 GHz. IEEE Std C95.1-2019 (Revision of IEEE Std C95.1-2005/Incorporates IEEE Std C95.1-2019/Cor 1-2019). New York: IEEE, 2019.

4 https://www.icnirp.org/en/about-icnirp/aim-status-history/index.html

5 *Ibid*.

The ICNIRP reference level for 60-Hz magnetic fields is 2,000 mG for the general public, while the ICES exposure reference level for the general public is 9,040 mG.[6] There will be no electric fields above ground from the Onshore Export Cables because these fields will be shielded by cable construction and the ground itself. Thus, above-ground electric-field levels were not calculated as part of this assessment and are not discussed further.

The World Health Organization recommends compliance with limits such as those proposed by the ICES and ICNIRP standards, and also encourages practical options to reduce magnetic-field levels such as optimal phasing.[7]

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6 International Commission on Non-Ionizing Radiation PI. ICNIRP Statement - Guidelines for Limiting Exposure to Electromagnetic Fields (1 Hz to 100 kHz). Health Phys 99:818-836, 2010; International Committee on Electromagnetic Safety (ICES). IEEE Standard for Safety Levels with Respect to Human Exposure to Electromagnetic Fields 0 to 300 GHz. IEEE Std C95.1-2019 (Revision of IEEE Std C95.1-2005/Incorporates IEEE Std C95.1-2019/Cor 1-2019). New York: IEEE, 2019.

7 World Health Organization (WHO). Environmental Health Criteria 238: Extremely Low Frequency (ELF) Fields. Geneva, Switzerland: WHO, 2007.

Modeling Configuration and Methodology

Description of Onshore Duct Banks

Where the four Export Cables reach the west side of Indian River Bay near the proposed and existing onshore substations, the Project cables will transition from water to land via HDD ducts. Along the short terrestrial portion of the Project's cable route between the HDD ducts and the connection to the US Wind substations, each three-core 230-kV Export Cable in Indian River Bay will be spliced to three individual single-core Export Cables (three for each circuit for a maximum of 12 cables in total). The 230-kV Onshore Export Cables will be installed in a pair of underground double-circuit duct banks, as shown in Figure 2, where the three conductors of each circuit are horizontally aligned with one another. Each duct bank will be installed to a minimum burial depth of 3 ft (1 m) from the surface to the top of the duct bank, as illustrated in Figure 2. The center-to-center spacing between the two duct banks will be approximately 20 ft (6 m). As noted above, these Onshore Export Cables will be more than 2,000 ft (600 m) from the nearest residence.

Each of the four circuits in the Onshore Export Cable duct bank operate at 230 kV. Three of the four circuits were modeled with an average current of 480 Amperes (A) and a peak current of 1,200 A, and one circuit was modeled with an average current of 348 A and a peak current of 870 A. As shown in Figure 2, the circuit with lower current was placed in the bottom-right of the duct bank model. This placement was selected to generate the most conservative (i.e., highest) calculated magnetic fields.

Note that the phasing of the cables (designated A, B, and C) within the duct bank has been optimized to minimize the calculated magnetic-field levels at a horizontal distance of 25 ft (7.6 m) from the center of the two circuits, as shown in Figure 2.

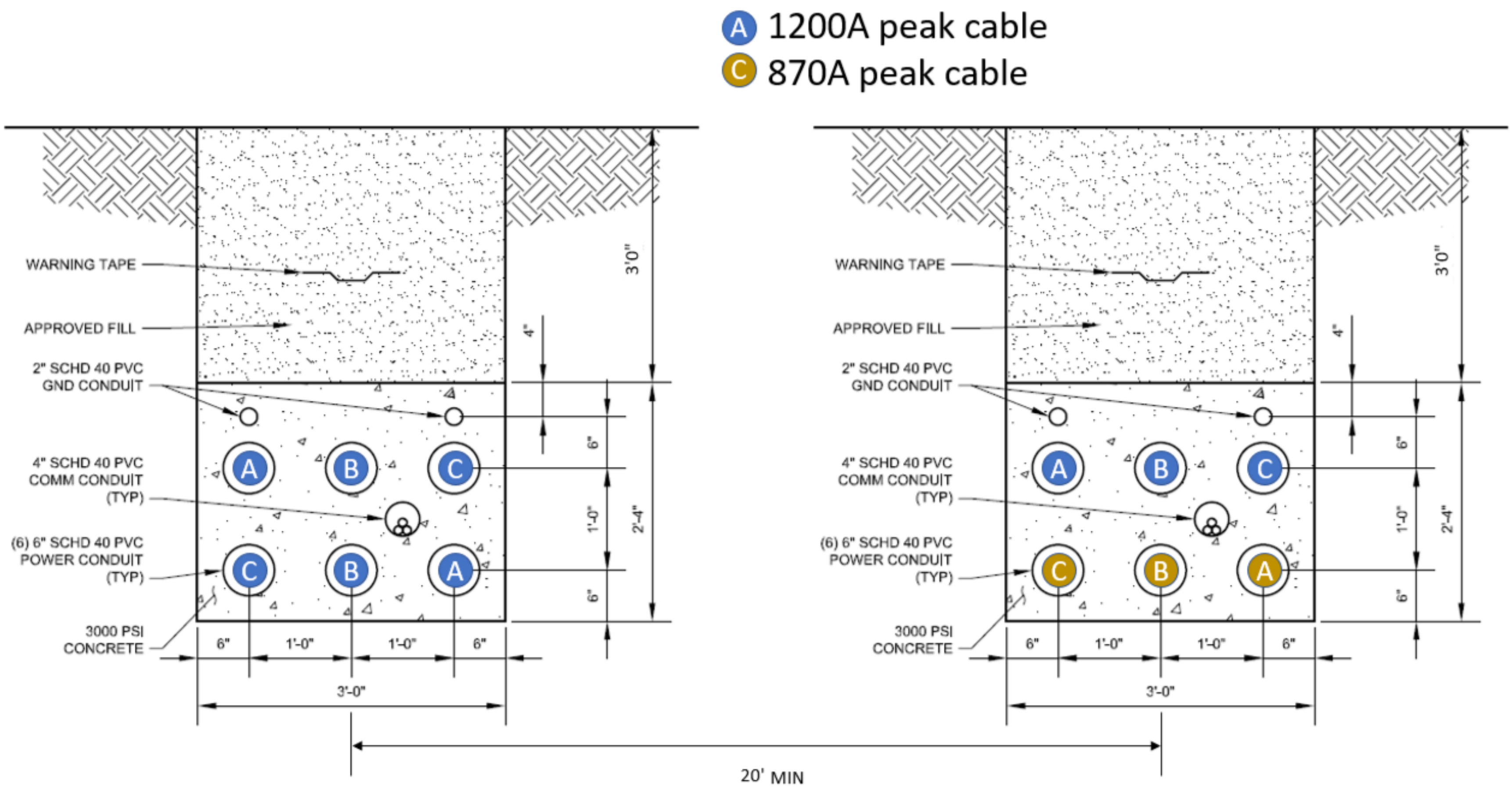

Figure 2. Representative cross-section of the Onshore Export Cables in two underground duct banks before the Project cables connect to the Indian River Bay Substation.

The 1,200 A in blue-colored cables and 870 A in brown-colored cables are representative of peak loading. Average loading is estimated to be approximately 40% of peak (i.e., 480 A and 348 A).

Modeling Methodology

Magnetic-field levels were calculated using 2D Finite Elemental Analysis (FEA) in COMSOL Multiphysics (version 6.0). These simulations employed the magnetic-field physics interface of COMSOL to solve the time-harmonic Maxwell-Ampere's Law for magnetic fields generated by the Onshore Export Cables.

Inputs to the FEA model included the duct bank geometry (e.g., the duct bank conduit diameter, conductor spacing, and the burial depth of the duct bank). In accordance with IEEE Std. C95.3-2021 and IEEE Std. 644-2019, the magnetic-field levels were calculated at a height of 3.3 ft (1 m) above ground and reported in units of mG as the maximum root-mean-square flux density value.[8]

The models additionally assume that the load on the phase conductors is balanced and that there is no attenuation of magnetic fields by any surrounding material.

8 Institute of Electrical and Electronics Engineers (IEEE). IEEE Standard Procedures for Measurement of Power Frequency Electric and Magnetic Fields from AC Power Lines (ANSI/IEEE Std. 644-2019). New York: IEEE., 2019; Institute of Electrical and Electronics Engineers (IEEE). IEEE Recommended Practice for Measurements and Computations of Electric, Magnetic and Electromagnetic Fields with Respect to Human Exposure to Such Fields, 0 Hz-300 GHz (IEEE Std. C95.3-2021). New York: IEEE, 2021.

Modeling Results and Discussion

Using the methods described above, Exponent calculated the 60-Hz AC magnetic field from the proposed Onshore Export Cables in underground duct banks at both peak (i.e., maximum) loading and average loading, which are estimated as 40% of peak loading. A summary of the results of these calculated magnetic-field levels is provided below.

Results

The calculated magnetic field above ground from the Onshore Export Cables in underground duct banks is shown in Figure 3, and a summary of the magnetic-field levels in the terrestrial segment of the Project's cable route between Indian River Bay and the US Wind substation is provided in Table 1.

As shown in Table 1, the magnetic-field levels generated by the Onshore Export Cables in the underground duct bank configuration were calculated to decrease rapidly with distance from the two double-circuit duct banks. The highest magnetic-field level at peak loading was above the cables (52 mG), decreasing to 3.9 mG at +25 ft (+8 m) and 9.5 mG at a distance of –25 ft (–8 m) from the midpoint of the two duct banks. The highest magnetic-field level at average loading similarly occurred nearly directly above the cables (21 mG), decreasing to 1.6 mG at +25 ft (+8 m) and 3.8 mG at a distance of –25 ft (–8 m) from the midpoint of the two duct banks. The asymmetry in the magnetic field levels, i.e., higher magnetic fields on right side of Table 1 and Figure 3 reflects the differences between the currents flowing on cables within the two duct banks.

Table 1. Calculated magnetic-field levels (mG) of the Onshore Export Cables at 3.3 ft (1 m) above ground level*

Configuration	Current Load	–75 ft (–23 m)	–25 ft (–7.6 m)	–12.5 ft (–3.8 m)	Max	+12.5 ft (+3.8 m)	+25 ft (+7.6 m)	–75 ft (–23 m)
Two Double-Circuit Duct Banks	Average	0.3	3.8	13	21	17	1.6	0.1
	Peak	0.7	9.5	33	52	42	3.9	0.4

* The two duct banks are separated by a distance of approximately 20 ft (6 m). Distances are referenced to the center point between the two duct banks.

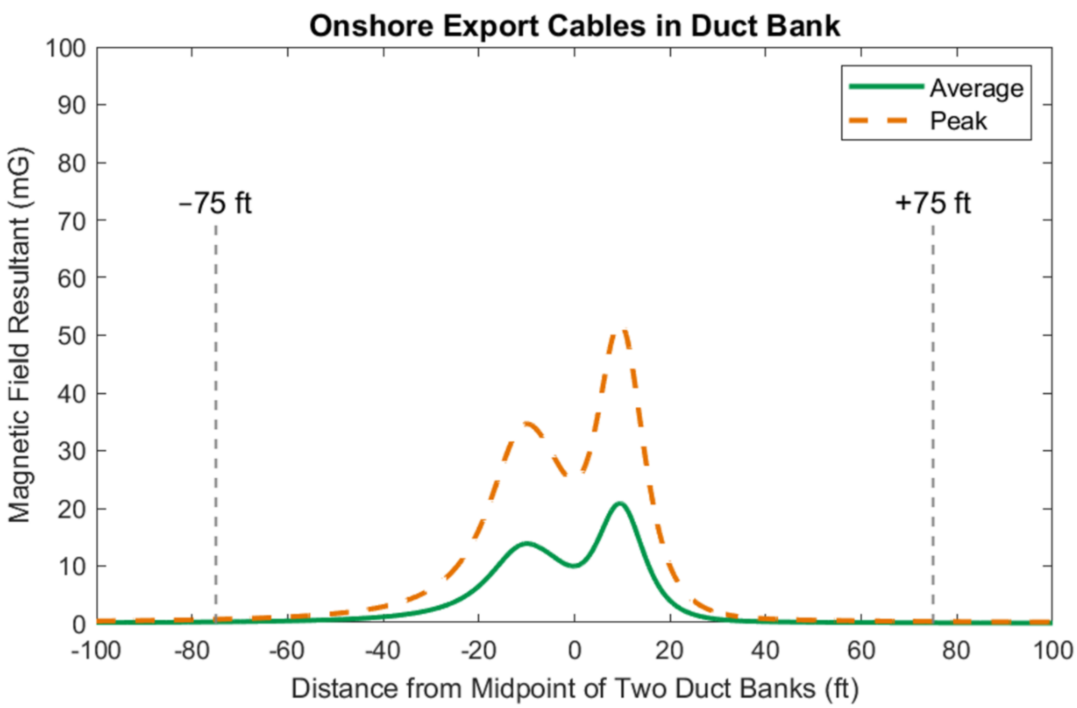

Figure 3. Calculated magnetic-field levels (mG) of the Onshore Export Cables in the duct bank configuration, evaluated at 3.3 ft (1 m) above ground level.

The asymmetry in the magnetic field above the two duct banks is due to the different loading in the duct bank on the right compared to the duct bank on the left.

Discussion

Along the terrestrial portion of the Project route, between the exit point of the HDD on shore and the POI, the Onshore Export Cables are proposed to be constructed as a pair of double-circuit underground duct banks with a phase-optimized arrangement of conductors. The Onshore Export Cables are proposed to be installed far (more than 2,000 ft [600 m]) from any existing residential areas or areas where the general public will spend any significant time. Additionally, the calculated magnetic-field levels within ±25 ft (±8 m) of the duct banks, for both average and peak loading, are within the same range of magnetic-field levels generated by low-voltage power distribution lines typically found throughout communities in the United States (as shown in Figure 1).

Calculated magnetic-field levels also are assessed with respect to standards and guidelines for magnetic-field exposure levels that have been developed by scientific and health agencies, based on reviews and evaluations of relevant health research, in order to protect health and safety. The magnetic-field levels calculated above the underground duct bank configuration for the Onshore Export Cables, as discussed above, are more than 38 times lower than the guideline levels set by international health organizations (2,000 mG and 9,040 mG) even directly above the duct bank installation. As noted above, magnetic-field levels at average loading decrease rapidly with distance to 1.6 mG at +25 ft (+8 m) and 3.8 mG at –25 ft (–8 m) from the midpoint of the two duct banks, and decreases still further at greater distances.

Conclusions

Exponent modeled the Onshore Export Cables proposed to be installed in underground duct bank configurations and used this model to calculate the magnetic-field levels associated with this portion of the Project at both peak and average loading. The design of the Project incorporates features to reduce magnetic-field levels. Chief among these are the construction of the lines in a pair of double-circuit underground duct banks and the use of optimal phasing to further minimize magnetic-field levels.

The calculations show that the long-term average magnetic field over the Onshore Export Cables in duct banks is 21 mG and less than 4 mG at 25 ft from the centerline between the duct banks, which is indicative of exposure on any selected day. For those short periods during the year when the wind blows hardest and generates the maximum current, the magnetic field will reach peak values of 52 mG or less.

All the values above are far below the ICNIRP reference level of 2,000 mG and the ICES maximum permissible exposure limit of 9,040 mG for the general public.[9] Magnetic-field levels at greater distances from the duct bank or at less than peak loading would be still lower. Magnetic fields from the US Wind substations are expected to reach background levels within a short distance from the substation property and thus were not modeled as part of this assessment.[10]

The electric fields generated by electricity transmitted on the Onshore Export Cables installed in underground duct banks will be blocked by the cable insulation and the sheathing, as well as the ground, and thus, these cables will not contribute a significant source of electric fields above ground in the vicinity of the duct bank.

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9 Institute of Electrical and Electronics Engineers (IEEE). IEEE Standard Procedures for Measurement of Power Frequency Electric and Magnetic Fields from AC Power Lines (ANSI/IEEE Std. 644-2019). New York: IEEE, 2019; Institute of Electrical and Electronics Engineers (IEEE). IEEE Recommended Practice for Measurements and Computations of Electric, Magnetic and Electromagnetic Fields with Respect to Human Exposure to Such Fields, 0 Hz-300 GHz (IEEE Std. C95.3-2021). New York: IEEE, 2021.

10 Institute of Electrical and Electronics Engineers (IEEE). IEEE Guide for the Design, Construction, and Operation of Electric Power Substations for Community Acceptance and Environmental Compatibility. IEEE Std 1127-2013 (Revision of IEEE Std 1127-1998):1-50, 2014; National Institute of Environmental Health Sciences (NIEHS). EMF Questions & Answers. NIH Publication 02-4493. Research Triangle Park, NC: NIEHS, 2002.