Appendix K – Magnetic Fields from Submarine Cables

Electrical Engineering and Computer Science Practice

Virginia Offshore Wind Technology Advancement Project

Magnetic Fields from Submarine Cables

Virginia Offshore Wind Technology Advancement Project

Magnetic Fields from Submarine Cables

Prepared for

Tetra Tech, Inc.
160 Federal Street, 3rd Floor
Boston, MA 02110

Dominion
5000 Dominion Boulevard
Glen Allen, VA 23060

Prepared by

Exponent, Inc.
17000 Science Drive, Suite 200
Bowie, MD 20715

December 2013

Contents

List of Figures

Executive Summary

This report provides a summary of the calculated magnetic-field levels associated with the transport of wind-generated electricity on the submarine Export and Inter-Array Cables from the proposed Virginia Offshore Wind Technology Advancement Project to an existing ancillary onshore facility. The Project is proposed by Virginia Electric and Power Company, a wholly-owned subsidiary of Dominion Resources, Inc. (Dominion)". The Inter-Array Cable is modeled for one target burial depth and the Export Cable is modeled for two key sections of the cable route: 1) a submarine section from the generating site to shore; and 2) within a horizontal directional drilling (HDD) submarine-to-shore cable conduit.

The average magnetic field at the surface of the seabed over the Export Cable is quite low (1.6 milligauss [mG]). At a distance of 3 meters (m) (10 feet) to either side of the cable, the magnetic-field level at the seabed diminishes to 0.5 mG, and to 0.1 mG at 10 m to either side. The average magnetic field calculated above the more shallowly-buried Inter-Array Cable is 3.1 mG. At distances of 3 m and 10 m to either side of the Inter-Array Cable, the magnetic-field level at the seabed diminishes to 0.3 mG and less than 0.1 mG, respectively. The calculated average magnetic-field levels associated with the onshore-HDD portion of the route are still lower due to a greater burial depth. At ground level, the average magnetic field is less than 0.1 mG at all locations. Although not anticipated, should portions of the Inter-Array and/or Export Cable not achieve the minimum target burial depth they may be covered, as necessary, with protective materials, such as concrete mattresses, sandbags, rocks, or articulated split pipe protection, at least 0.2 meters thick. Should this occur, the magnetic-field levels at these discrete locations would be higher.

These magnetic-field levels are well below limits for human exposure and are also below a theoretical detection level for magnetite-based systems (e.g., mammals, turtles, fish, and invertebrates) except at potential discrete locations along the Inter-Array and/or Export Cable where protective material of at least 0.2 meters may be required.

Introduction

Virginia Electric and Power Company, a wholly-owned subsidiary of Dominion Resources, Inc. (Dominion) proposes to construct, own, and operate the Virginia Offshore Wind Technology Advancement Project (VOWTAP or Project). The VOWTAP consists of i) two offshore, 6-megawatt (MW) wind turbine generators (WTG) separated by 1,050 meters (m) and orientated in a north-south configuration; ii) a submarine transmission cable (Inter-Array Cable) interconnecting the two 6 MW WTGs ; iii) a submarine transmission cable (Export Cable) that will convey electricity from the WTGs to the landfall site; and iv) a horizontal directional drilling (HDD) of the Export Cable to its proposed onshore landfall site at the Camp Pendleton State Military Reservation (Camp Pendleton) in Virginia Beach, Virginia.

The proposed VOWTAP transmission system Export Cable is a 34.5-kilovolt (kV) alternating current (AC) cable that will extend approximately 44 kilometers (km) from the VOWTAP WTGs to the landfall site at an existing parking lot adjacent to Camp Pendleton Beach in Virginia Beach, Virginia. The target burial depth for the offshore portion of the Export Cable is 2 meters (m) to 4 m and modeled at a minimum target burial depth of 2 m while the Inter-Array Cable will be buried to a target depth of 1 m. The burial depth for the HDD portion of the Export Cable will range from a maximum depth of 24 m offshore to 11 m beneath the sand dunes, and is modeled at a burial depth of 10 m to provide a more conservative estimate.

The current carried by the Export and Inter-Array Cables generates an AC magnetic field, which is reported as magnetic flux density in units of Gauss or milligauss (mG)—1 Gauss = 1,000 mG—with a frequency of 60 Hertz (Hz), that is the current (and thus magnetic field) varies in direction and magnitude at a rate of 60 times per second. On a given day, throughout a week, or over the course of months and years, the load current—expressed in units of amperes (A)—may change depending upon the power generated by the WTGs, which depends on wind speed and operational status. The offshore and HDD portions of the Export Cable modeled in this report are expected to carry a peak (maximum) load current of 12 MW, while the Inter-Array Cables will carry a peak load of 6 MW.

This report summarizes the calculated magnetic field along transects perpendicular to the Inter-Array Cable, the offshore portion of the Export Cable, and the HDD portion of the Export Cable.[1] The Inter-Array Cable is modeled for one target burial depth and the Export Cable is modeled for two key sections of the cable route: 1) a submarine section from the generating site to shore and 2) within a HDD submarine-to-shore cable conduit.[2] The modeled cable configuration for each portion of the route is summarized in Table 1.

Table 1. Cable configuration burial depth

Cable Portion	Burial Depth (m)
Inter-Array Cable	1
Export Cable (offshore)	2 0.2
Export Cable Landfall (HDD)	10

The route of the offshore cable from the WTGs to the onshore landfall site, shown in Figure 1, is approximately 45 km with an additional 1 km of inter-array cable between the two WTGs. The cables consist of three bundled 750-kcmil conductors surrounded by layers of insulating material within conductive and non-conductive sheathing. Figure 2 illustrates the typical composition of the cable, including the metallic sheaths that provide protective covering for the electrified portions of the cable and also shield the electric field from the marine environment.

[1] Electric-field levels are not included in this report because the armor surrounding the conductors within the cables will shield the electric fields.

[2] At discrete locations along the cable routes where the minimum target depth of burial cannot be achieved, the cable may be covered with protective materials, such as concrete mattresses, sandbags, rocks, or articulated split pipe protection, at least 0.2 m thick.

Table 2. Cable load (MW) for average- and peak-load cases

Cable Portion	Voltage (kV)	Average load (MW)	Peak load (MW)
Inter-Array Cable	34.5	2.04	6
Export Cable	34.5	4.08	12

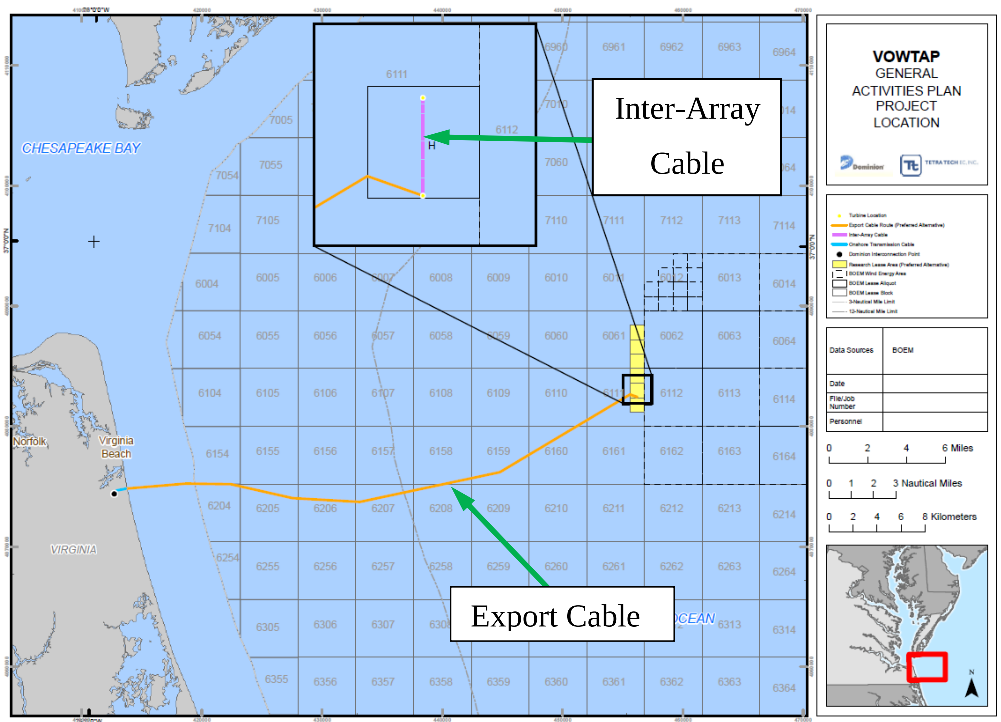

Figure 1. Route of Inter-Array Cable and Export Cable from WTGs to landfall site.

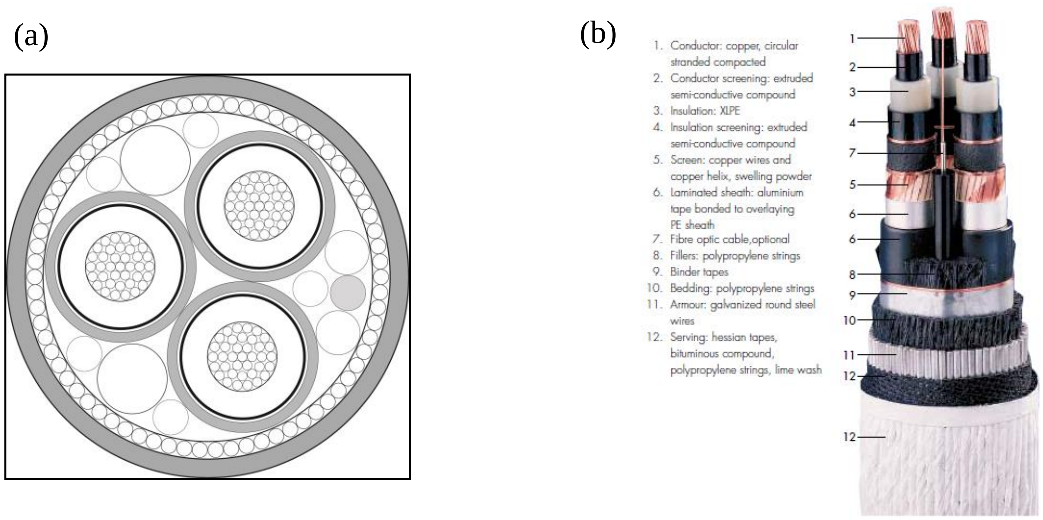

Figure 2. Cross-section of the buried AC cable (a); Configuration of an AC cable, showing 3-phase conductors and surrounding insulation and sheathing (b).

Methods

Magnetic-field levels were calculated using computer algorithms developed by the Bonneville Power Administration (BPA, 1991), which have been shown to accurately predict magnetic-field levels measured near transmission lines. Magnetic-field levels above the buried cables were calculated as the resultant of x, y, and z field vectors and are reported as the root-mean-square (rms) value of the field ellipse along a transect perpendicular to the centerline of the cables at the representative target burial depths.

Dominion provided data regarding load, voltage, phasing of voltage and current, and conductor configurations for each segment. The Export and Inter-Array Cables are specified to operate at 34.5 kV, with the Export Cable at peak power level of 12 MW and the Inter-Array Cable at a peak power level of 6 MW. A more typical load (i.e., average load) is expected to be 4.08 MW for the Export Cable and 2.04 MW for the Inter-Array Cable (34% of peak power). While the shielding effect of cable armoring and sheaths will reduce the magnetic field outside the cables, this effect was not included in the model used to obtain the magnetic-field profiles depicted in Figure 3 through Figure 6 in order to obtain a conservative modeling result.

Results

Calculated magnetic-field profiles along transects perpendicular to the cables are depicted in Figure 3 through Figure 6. The magnetic-field level for the Inter-Array Cable is calculated for a target burial depth of 1 m (with half the projected load of the Export Cable) while the magnetic-field profiles for the Export Cable are calculated at two target burial depths—2 m offshore and 10 m at the Export Cable landfall site.[3] Table 3 summarizes the magnetic field at two levels of current flow (average and peak) at the seabed or ground directly above the different portions of the Inter-Array and Export Cable as well as at horizontal distances of 3 and 10 m on either side of the cable centerlines.

The magnetic-field level at average load for the offshore segment of the Export Cable (2 m target burial depth) is 1.6 mG at the seabed, directly above the cable centerline. At distances of 3 and 10 m from the centerline, the magnetic-field level falls to 0.5 mG and 0.1 mG, respectively. The magnetic-field level at average load calculated above the more shallowly-burried Inter-Array Cable is 3.1 mG. At distances of 3 m and 10 m to either side of the cable the magnetic-field level at the seabed diminishes to 0.3 mG and less than 0.1 mG. At ground level, above the portion of the Export Cable that will be buried via HDD under the beach (buried to a minimum depth of 10 m) the magnetic-field levels calculated at average power load are below 0.1 mG at all transverse locations.[4]

At peak load, which is expected to occur on relatively rare occasions when wind levels are very high and both WTGs are producing electricity at their maximum output capacity, the magnetic-field levels calculated above would be higher, as shown in Table 3.

[3] At discrete locations along the cable routes where the minimum target depth of burial cannot be achieved, the cable may be covered with protective materials, such as concrete mattresses, sandbags, rocks, or articulated split pipe protection, at least 0.2 m thick.

[4] The magnetic-field at the seabed over the cable for short portions of the offshore segment (minimum covering of 0.2 m) is 107 mG at the centerline, but falls rapidly to 0.8 mG at 3 m and 0.1 mG at 10 m.

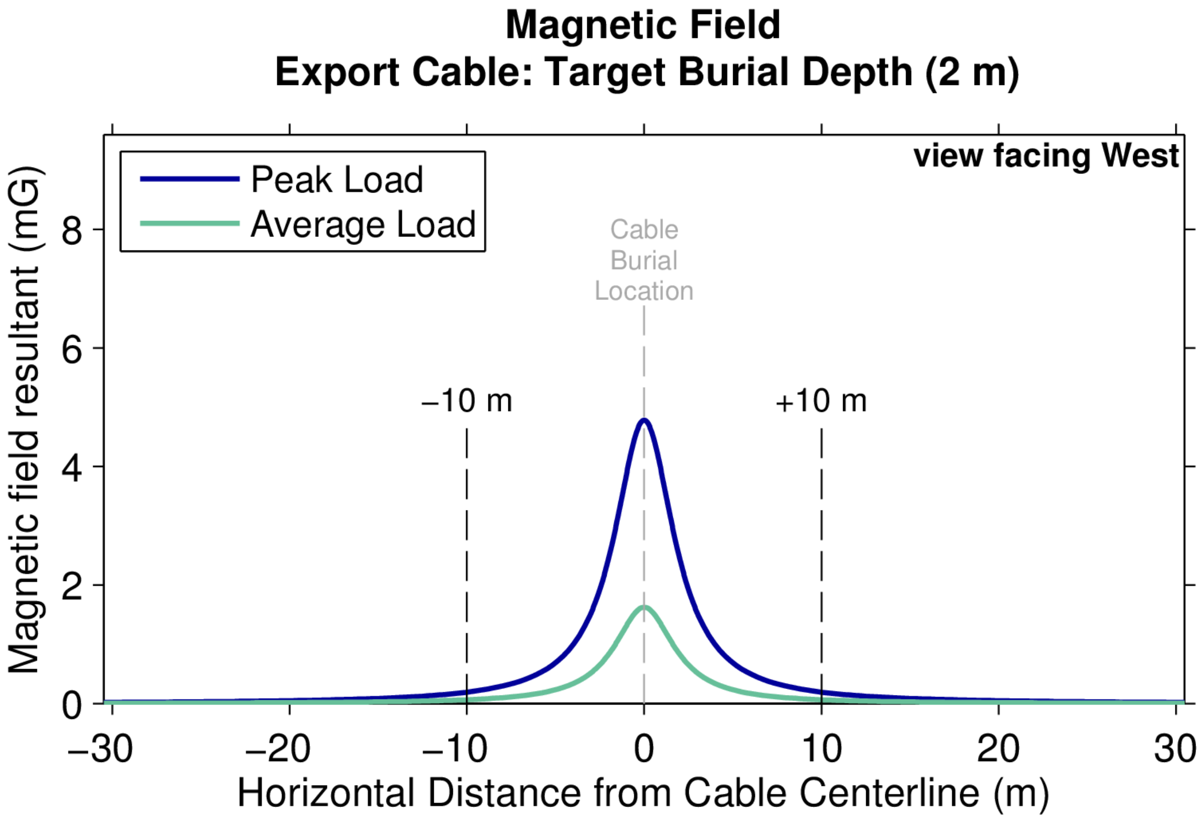

Figure 3. Magnetic field at the seabed at varying distances from the centerline of a cable buried at a target depth of 2 m.

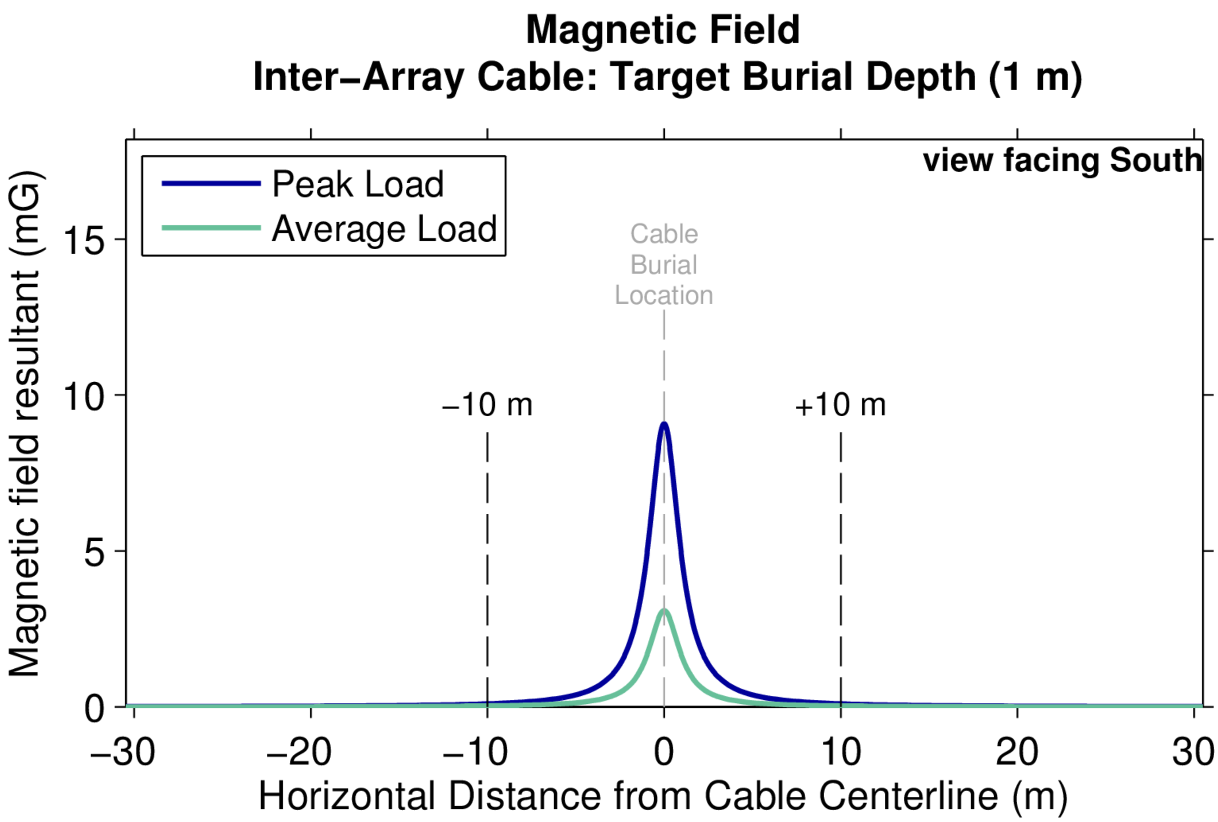

Figure 4. Magnetic field at the seabed at varying distances from the centerline of the Inter-Array Cable buried at a target depth of 1 m.

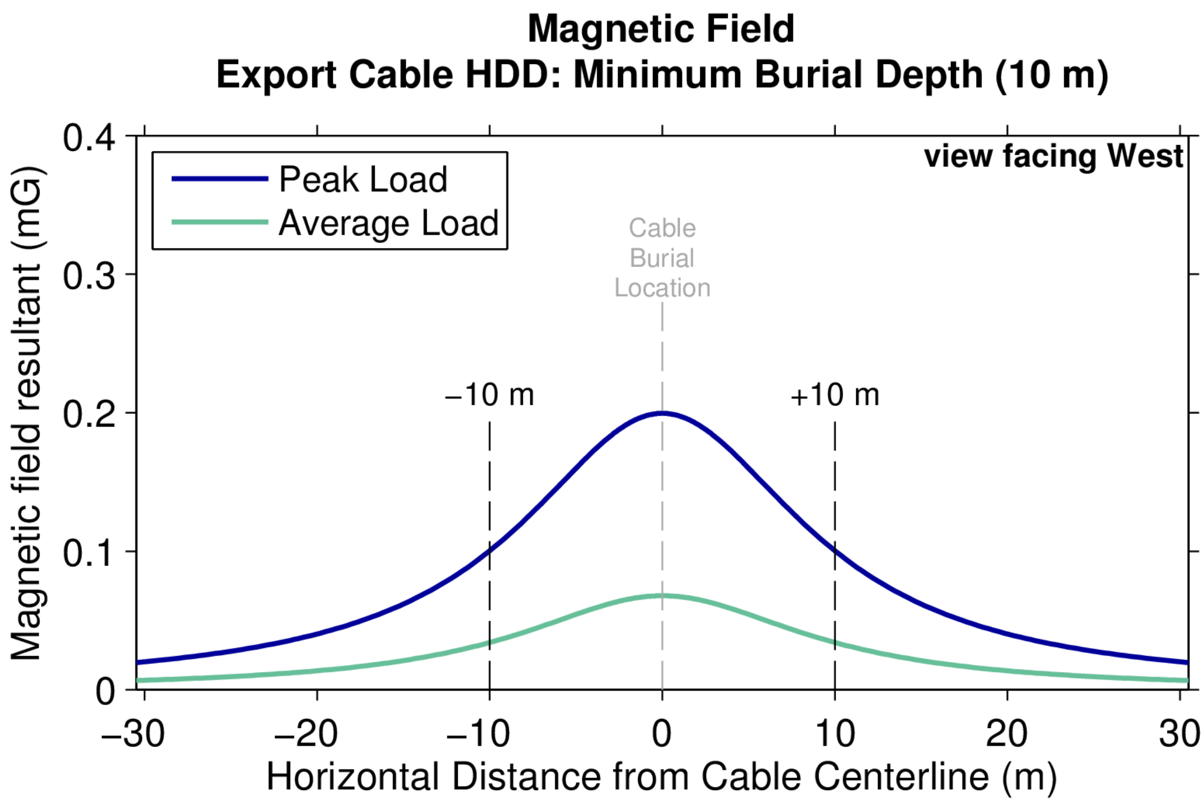

Figure 5. Magnetic field at ground level at varying distances from the centerline of the Export Cable centerline at a minimum burial depth of 10 m under the beach.

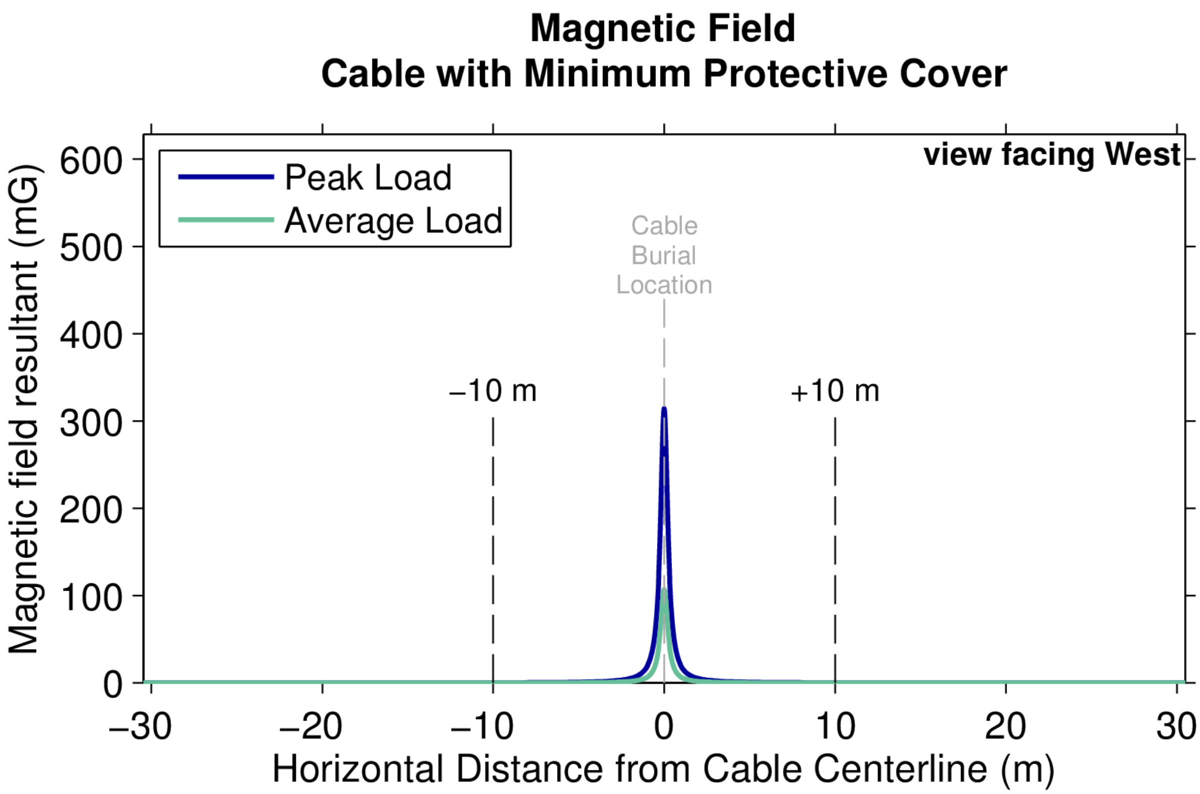

Figure 6. Magnetic field at the seabed at varying distances from the centerline of the cable with a minimum covering of 0.2 m.

Table 3. Calculated magnetic field values (mG) at varying distances from the cable centerline for three burial depths scenarios without armoring or sheathing.

Cable Segment	Depth of covering sediment (m)	Load*	Magnetic Field (mG)				
			-10 m from center	**-3 m from center**	**Max at center**	**+3 m from center**	**+10 m from center**
Offshore Export Cable	0.2	Average	0.1	0.8	106.8	0.8	0.1
		Peak	0.2	2.2	314.2	2.2	0.2
	2.0	Average	0.1	0.5	1.6	0.5	0.1
		Peak	0.2	1.5	4.8	1.5	0.2
Inter-Array Cable	1.0	Average	0.0	0.3	3.1	0.3	0.0
		Peak	0.1	1.0	9.1	1.0	0.1
Export Cable Landfall (HDD)	10	Average	0.0	0.1	0.1	0.1	0.0
		Peak	0.1	0.2	0.2	0.2	0.1

*The Inter-Array cable is modeled with half the load of the other cases.

Discussion

The United States Bureau of Ocean Energy Management, Regulation, and Enforcement (BOEMRE) recently published a comprehensive review and assessment of the potential effects of electric and magnetic fields (EMF) from submarine transmission cables on marine environments, which includes the possible interaction of magnetic fields from submarine cables with various marine species. The report concluded:

> Most marine species may not sense very low intensity electric or magnetic fields at AC power transmission frequencies (i.e., 60 Hz in the US). AC magnetic fields at intensities below 5 µT [50 mG] may not be sensed by magnetite-based systems (e.g., mammals, turtles, fish, invertebrates), although this AC threshold is theoretical and remains to be confirmed experimentally. Low intensity AC electric fields induced by power cables may not be sensed directly at distances of more than a few meters by the low-frequency-sensitive ampullary systems of electrosensitive fishes. If these generalities for AC magnetic and electric fields hold across the many taxa and life stages that have not been investigated, then this limits the area around AC cables in which sensitive species would detect and therefore possibly respond to EMFs. (BOEMRE, 2011, p. 6).

Although certain levels of EMF from buried AC submarine transmission cables have been reported to be detected by some marine species, the area near a submarine transmission cable system where this might be possible is quite limited. This is particularly the case with the low current load (≤ 12 MW) on the offshore Export and and still lower current load on the Inter-Array Cables in this project.

While magnetic-fields are not significantly attenuated by conducting materials such as seawater and earth, magnetic-field levels do diminish quickly with radial distance from the source. The magnetic-field levels as a function of vertical distance above the seabed or ground follow a very similar pattern to that for horizontal attenuation. Modeling of other buried submarine transmission cables shows similar results (Normandeau et al., 2011, Appendix B).

In addition, it is important to consider that since the cable armoring and sheaths were not included in the model, the magnetic field from the VOWTAP cables will be still lower than calculated herein. The level of attenuation caused by the cable armor is a function of its configuration and magnetic permeability (i.e., the higher the permeability the greater the attenuation). In addition, induced eddy currents in conductive sheaths create an opposing magnetic field that partially cancels the magnetic field from the conductors within the cable. In a study by Silva et al. (2006), the investigators presented calculations for a 138-kV AC submarine transmission cable that showed a reduction in the magnetic field from flux shunting by almost a factor of 2 and a further (although much smaller) reduction in the magnetic field attributable to eddy currents.

Conclusions

Magnetic fields were calculated for the proposed offshore and sea-to-shore segments of the VOWTAP Export Cable at an average power load of 4.08 MW and peak power load of 12 MW; average and peak power load for the Inter-Array Cable was 2.04 MW and 6 MW, respectively. The calculated magnetic-field values at grade over the majority of the route including the offshore Export Cable and portion of the Export Cable that will be buried via HDD under the Beach are 1.6 mG or less, at average power loads. Magnetic-field levels above the more shallowly-buried Inter-Array Cable at average power load is 3.1 mG or less. In limited portions of the cable routes where the minimum target burial depth may potentially not be achieved, the magnetic-field levels would be higher. These calculated magnetic-field levels are far below the 2,000 mG reference level recommended for humans by international standards (ICNIRP, 2010) and below the theoretical detection level for magnetite-based magnetic-field detection systems (e.g., mammals, turtles, fish, and invertebrates), except at potential discrete locations along the Inter-Array and/or Export Cable route where protective material of at least 0.2 m may be installed (Normandeau et al., 2011). Though possibly detectable by some marine species, the scientific literature does not indicate that a 60-Hz magnetic-field at these potential locations is likely to represent a barrier to movement or a significant deterrent to marine species in the project area.

References

International Commission on Non-ionizing Radiation Protection (ICNIRP). ICNIRP Statement—Guidelines for limiting exposure to time-varying electric and magnetic fields (1 Hz to 100 KHz). Health Phys 99:819-816, 2010.

Normandeau, Exponent, T. Tricas, and A. Gill. 2011. Effects of EMFs from Undersea Power Cables on Elasmobranchs and Other Marine Species. U.S. Dept. of the Interior, Bureau of Ocean Energy Management, Regulation, and Enforcement, Pacific OCS Region, Camarillo, CA. OCS Study BOEMRE 2011-09.

Silva JM. EMF Study: Long Island Power Authority (LIPA), Offshore Wind Project, 2006.

Limitations

At the request of Dominion and Tetra Tech, Inc., Exponent modeled the magnetic field associated with the VOWTAP power delivery cables.

This report summarizes work performed to date and presents the findings resulting from that work. In the analysis, we have relied on geometry, material data, usage conditions, specifications, regulatory status, and various other types of information provided by the client. We have not verified the correctness of this input data as it was not part of the scope of work and rely on the client for the accuracy of the data. 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.

The findings 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 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.