Appendix M

EMF Analysis

DEEPWATERWIND®

Appendix M-1

Magnetic Fields from Submarine Cables

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Electrical Engineering and Computer Science Practice

Deepwater Wind
Block Island Wind Farm

Magnetic Fields from Submarine Cables

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Deepwater Wind
Block Island Wind Farm

Magnetic Fields from Submarine Cables

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Executive Summary

This report summarizes calculated levels of magnetic fields associated with the submarine cables in the marine segments of the Block Island Wind Farm (BIWF) Project and the Block Island Transmission System (BITS) Project. Electric-field levels are not included in this report because no alternating current (AC) electric fields from the conductors will 'leak' into the surrounding seabed due to the shielding surrounding the current-carrying conductors within the cables. The project consists of three submarine cables, the Inter-Array Cable, the Export Cable, and the BITS (transmission) Cable. Each of these cables will be buried to an assumed depth of 6 feet.

Magnetic fields At anticipated maximum load of 32 MVA, the calculated AC magnetic-field levels from the submarine portion of the BIWF Export Cable, calculated at the seabed directly over the buried cable, are quite low (22.1 milligauss [mG]). At a distance of 10 feet to either side of the cable, the magnetic-field level at the seabed diminishes to 6.0 mG and to 0.5 mG at 40 feet to either side. The magnetic-field levels associated with the BITS Cable are slightly less due to lower assumed current flow on the BITS Cable for an anticipated load of 30 MVA. At the seabed, the highest magnetic field generated by the BITS Cable is 20.7 mG, falling to 5.6 mG and 0.5 mG at distances of 10 feet and 40 feet, respectively. The calculated magnetic fields are about 1/100th of the threshold levels for humans recommended by the International Committee on Electormagnetic Safety and Internation Commission on Non-Ionizing Radiation as international health-based standards and are comparable to the levels found in homes away from appliances. Furthermore, these magnetic-field levels are below a theoretical detection level for magnetite-based systems (e.g., mammals, turtles, fish, and invertebrates).[1]

The five, 6-megawatt (MW) wind turbine generators (WTG) comprising the wind farm are connected to one another in series by the Inter-Array Cable. The magnetic-field level at any point along the Inter-Array Cable, therefore, reflects the current contributed by the WTGs distal to that point and will be highest where the Inter-Array Cable terminates. Assuming a maximum

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[1] 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.

current which matches the Export Cable, the highest magnetic-field levels associated with the Inter-Array Cable will match those of the Export Cable.

Introduction

This report summarizes calculated levels of the alternating current (AC) magnetic field at representative submarine transects of the Block Island Wind Farm (BIWF) project and the Block Island Transmission System (BITS) project.

The BIWF project will consist of five, 6-megawatt (MW) wind turbine generators (WTG), a submarine cable interconnecting the WTGs (Inter-Array Cable), and a 34.5-kilovolt (kV) submarine cable connecting the northernmost WTG to an interconnection point on Block Island (Export Cable). The WTGs will be located on average approximately 3 miles (4.8 kilometers) southeast of Block Island, spaced approximately 0.5 miles (0.8 kilometers) apart in a radial configuration and connected by the Inter-Array Cable.

The WTGs comprising the wind farm are connected in a radial configuration by the Inter-Array Cable through which the power generated by the wind farm will flow. The electrical current carried by the Inter-Array Cable will increase sequentially between each of the respective WTGs as each WTG contributes more power to the system.

At the northeast edge of the WTGs, the Export Cable will carry the current from all the WTGs for approximately 6.2 miles to the Block Island landfall. From this point the Export Cable will be brought ashore and routed along existing public road rights-of-way to BIPCO Property. The Export Cable will terminate at a switchyard (Block Island Switchyard) that is expected to be located on BIPCO Property.

The BITS project is a proposed 34.5-kV alternating current (AC) bi-directional transmission system including a 3-core submarine cable that will run approximately 21.8 miles (35.1 kilometers) from Block Island to an off-shore cofferdam near the Narragansett Town Beach (BITS Alternative 1) or approximately 25.9 miles (41.7 kilometers) to an off-shore cofferdam near the University of Rhode Island (URI) Bay Campus (BITS Alternative 2).

This analysis evaluates the marine portions of the BIWF and BITS project between the off-shore coffer dams off the coast of Block Island and the Rhode Island mainland. The terrestrial portions of the BITS and BIWF Projects on Block Island and on the mainland are detailed in separate reports. These reports will also include the transition portions of the Project from the offshore coffer dams to the respective on-shore landing areas.

The Inter-Array, Export, and BITS Cables will all operate at 34.5 kV and is designed to carry 32 mega-volt-amperes (MVA) of 3-phase AC power. The Inter-Array Cable and the submarine portions of the Export Cable and the BITS Cable will be buried to a target depth of 6 feet (1.8 meters) beneath the seafloor and consist of three bundled 750-kcmil conductors surrounded by layers of insulating material within conductive and non-conductive sheathing. Figure 1 illustrates the typical composition of these AC undersea cables, including the metallic sheaths, which shield the electric field on the conductors from the marine environment.

Magnetic Fields The current flowing in the conductors of a cable generates a magnetic field near the conductors. The strength of project-related magnetic fields in this report is expressed as magnetic flux density in units of milligauss (mG), where 1 Gauss (G) = 1,000 mG. In the case of AC transmission lines, these currents (and thus magnetic fields) vary in direction and magnitude with a 60-Hertz (Hz) cycle. Since load current—expressed in units of amperes (A)—generates magnetic fields around the conductors, measurements or calculations of the magnetic field present a "snapshot" for the load conditions at only one moment in time. On a given day, throughout a week, or over the course of months and years, the magnetic-field level can change depending upon the power generated by the WTGs, which depends on wind speed and operational status.

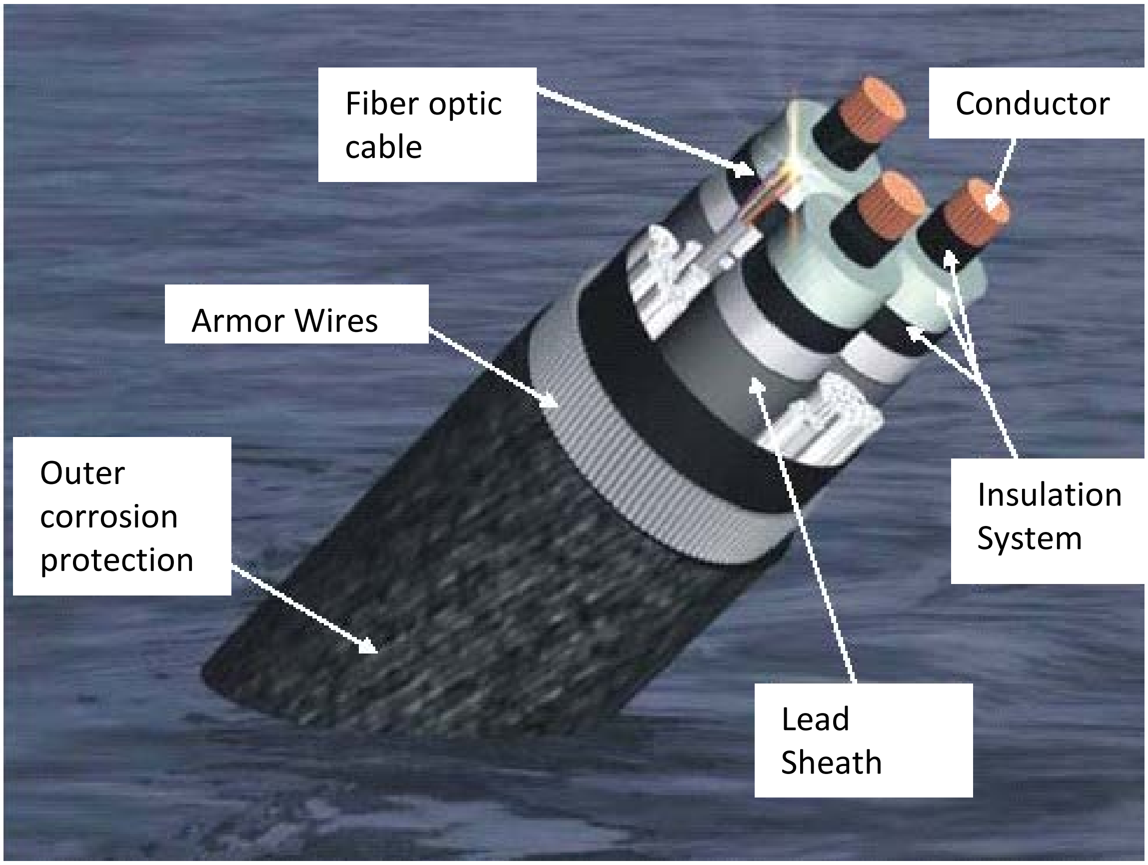

Figure 1. Configuration of an AC Inter-Array, Export, and BITS Cables showing 3-phase conductors and surrounding sheathing.

(Source: Nexans, 2010)

Modeling Cases

The submarine portion of the Inter-Array, Export, and BITS Cables are modeled for three separate cross sections as shown in Figure 2.

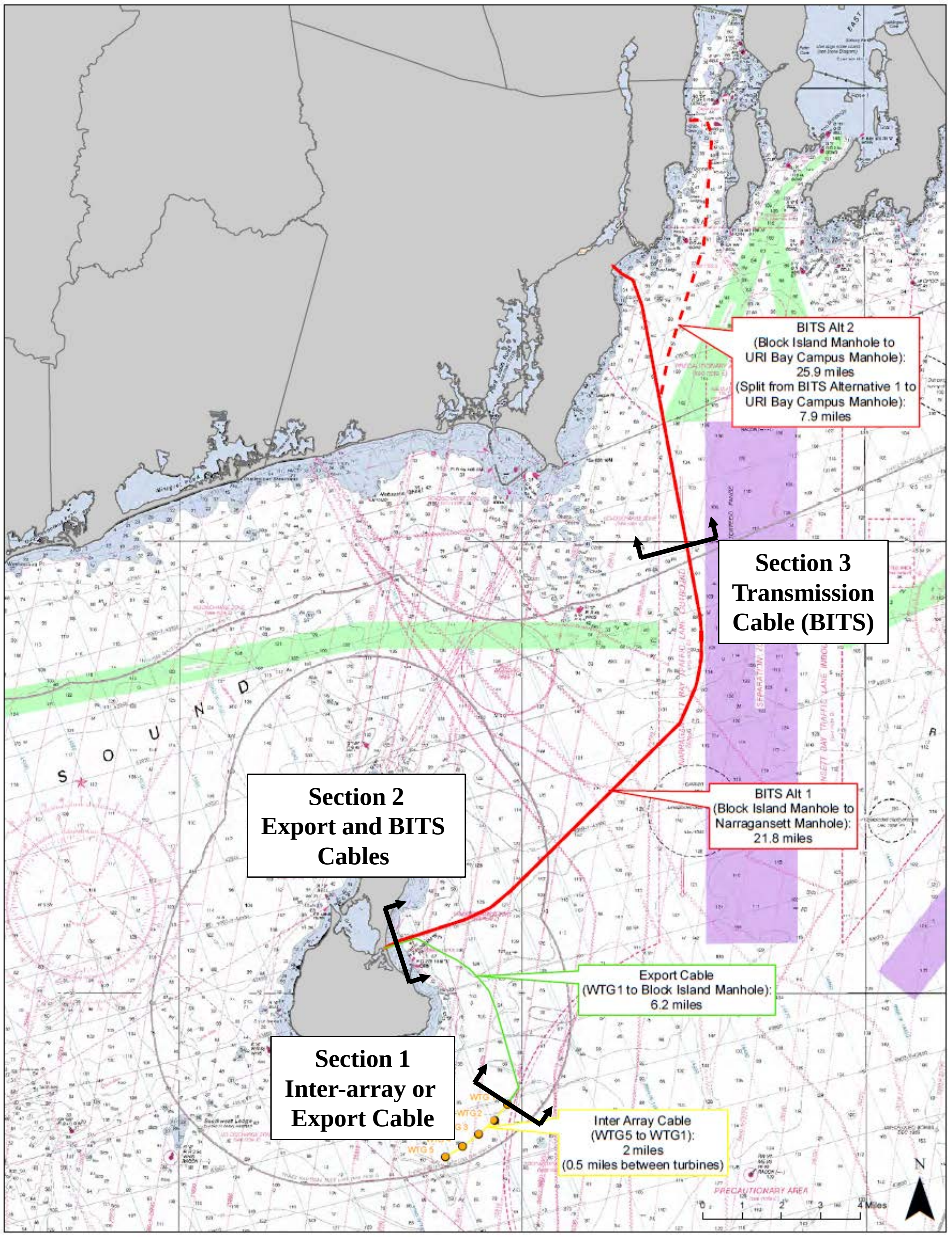

Figure 2. Locations of study for the submarine portions of the route.

Section 1 models the magnetic field along the span of the Inter-Array Cable as well as the approximately 6.2 miles from the northeast edge of the WTGs to a cofferdam off the coast of Block Island. In this section the cables are assumed to carry 32 MVA of power at 34.5 kV. This represents the maximum current flow on the Inter-Array Cable and other portions of the route where the Inter-Array Cable loading is less will produce a correspondingly lower magnetic field.

In ***Section 2***, the BITS (30 MVA) and Export (32 MVA) Cables run in parallel for a short distance off the coast of Block Island, and then diverge. In this section the cables are modeled with a100-foot separation. The mutual summation/cancellation of fields from the two cables, however, is very small because the two cables are so far apart.

Section 3 models the BITS Cable for approximately 21.8 – 25.9 miles (35.1 – 41.7 kilometers) between Block Island and the Rhode Island mainland (to either the Narragansett or URI Bay Campus shore landings).

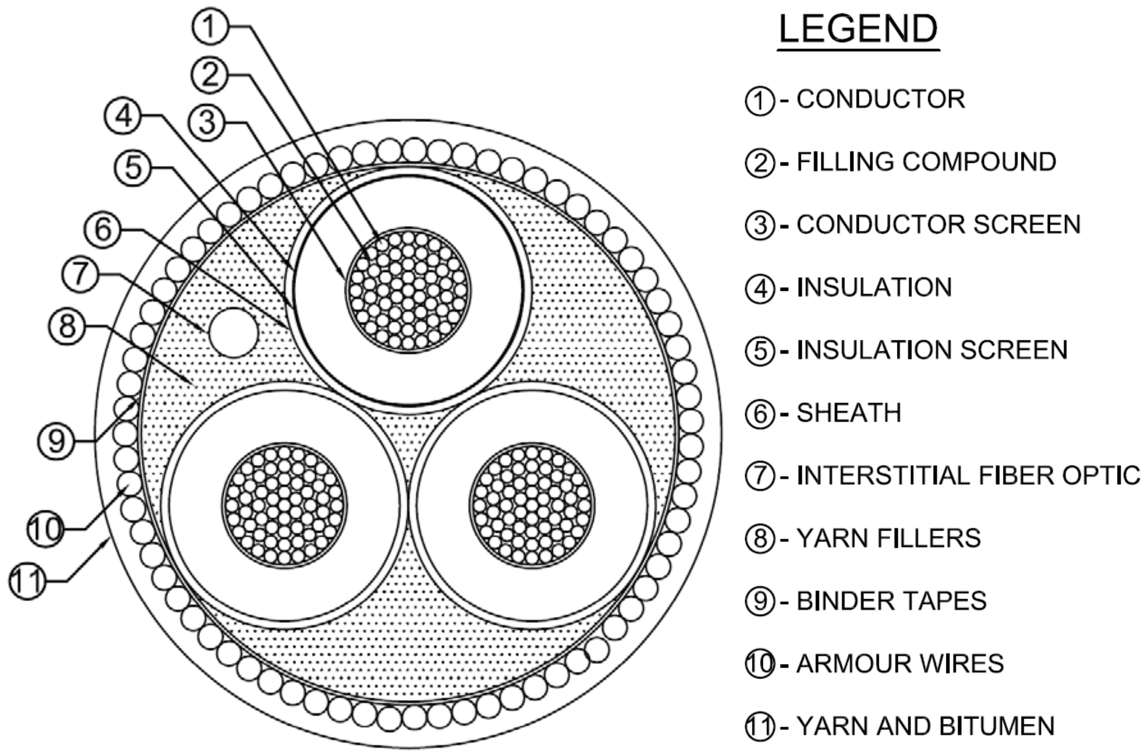

Figure 3. Cross-sectional view of the buried marine Inter-Array, Export, and BITS Cables.

Assessment Criteria

Neither the federal government nor Rhode Island has enacted standards for magnetic fields from power lines or other sources at AC power frequencies. Based on the location of the marine sections of the proposed submarine cable routes, one would not expect for there to be any prolonged or even frequent short-term exposure of humans to the magnetic fields from these cables.

A recent, comprehensive review and assessment of the potential effects of EMF from submarine cables on the marine environments address the interaction of EMF from AC submarine cables and marine life:

> 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 lifestages 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. However, AC electric fields associated with power cables may still evoke responses of individuals and affect populations most closely associated with the benthic habitat, especially in very close proximity to cables. More specific research is required to determine this (Normandeau et al., 2011).

Thus, certain levels of EMF from buried AC submarine cables may be detected by some marine species but the area around the cable system where this might be possible is quite limited, especially in light of the relatively low expected current flows on the submarine cables in this project. Neither this report nor other literature has recommended any environmental assessment criteria for EMF in the marine environment.

Methods

The magnetic-field levels were calculated at 3.28 feet (1 meter) above seabed, similar to the application of IEEE Std. C95.3.1-2010 on land, and are reported as the root-mean-square (rms) value of the field ellipse at each location along a transect perpendicular to the cable centerline. The Inter-Array, Export, and BITS Cables are all assumed to be buried to a target depth of 6 feet (1.8 meters) below the seabed. Magnetic-field levels based upon proposed construction were calculated using computer algorithms developed by the Bonneville Power Administration (BPA), an agency of the U.S. Department of Energy (BPA, 1991). These algorithms have been shown to accurately predict magnetic-field levels measured near power lines. The magnetic fields were calculated as the resultant of x, y, and z field vectors.

The inputs to the program are data regarding voltage, current flow, and phasing of voltages and currents, and conductor configurations as provided by AECOM and Mott MacDonald. These line loadings assume a 2-MVA load on Block Island and are summarized below in Table 1.

Table 1. Cable/circuit data

Cable/Circuit	Voltage (kV)	MVA	Current (A)
Export Cable	34.5	-32	-536
BITS Cable	34.5	30	502
Inter-Array Cable†	34.5	-32	-536

† Maximum current flow on Inter-Array Cable

As a conservative modeling assumption, the shielding effect of cable armoring and sheaths, which will reduce the magnetic-field level outside the cable, were not included in the model used to predict the magnetic-field profiles depicted in Figures 4-6.

Reduction in the magnetic-field level outside the cable is produced by shunting of the magnetic field by the cable armoring. The effectiveness of the armoring in attenuating the magnetic field is a function of its magnetic permeability, i.e., higher permeability will attenuate the magnetic field by shunting. Furthermore, induced eddy currents in conductive sheathing materials will create an opposing magnetic field that partially cancels of the magnetic field from the cores. As shown by calculations for a 138-kV AC undersea cable, flux shunting accounted for an almost

2-fold reduction in the magnetic field, with a much smaller reduction attributable to eddy currents (Silva et al., 2006).

Results and Discussion

Calculated magnetic-field profiles along transects perpendicular to the cables in Sections 1-3 are depicted in Figures 4-6. These magnetic-field profiles are calculated at the seabed, and Table 2 summarizes the maximum calculated magnetic-field level at the seabed above the cables, as well as at horizontal distances of 10 feet and 40 feet on either side of the respective cable.

As can be seen from Figures 4-6 and Table 2, the magnetic field around the buried submarine cables is both symmetric and relatively small in magnitude. In Section 1, the maximum magnetic-field level is 22.1 mG which falls to 6.0 and 0.5 mG at distances of 10 feet and 40 feet, respectively. In Section 2, even though the two cables are run parallel to each other, the potential interaction between the magnetic fields of two cables is minimal due to the large distance (100 feet) between them. The magnetic-field levels in Section 3 are all slightly lower than in Section 1 due to the slightly lower current flow on the BITS Cable compared to the Export Cable. The maximum magnetic-field level in Section 3 is 20.7 mG, which falls to 5.6 and 0.5 mG at distances of 10 feet and 40 feet, respectively.

Table 2. Calculated magnetic field values (mG) at the seabed at varying distances from the cable centerline assuming a burial depth of 6 feet and no armoring or sheathing.

			Location†				
Route	Section	Cable	-40 ft from center	-10 ft from center	Max on ROW	10 ft from center	40 ft from center
Submarine Section	1	Inter-Array Cable	0.5	6.0	22.1	6.0	0.5
	2	Export and BITS Cables	0.5/0.3	6.0/5.6	22.2/20.8	6.0/5.6	0.3/0.4
	3	BITS Cable	0.5	5.6	20.7	5.6	0.5

† Distance from respective cable: Export/BITS Cables

The magnitude magnetic-fields are not significantly attenuated by materials such as seawater and earth; rather the attenuation of the magnetic-field from a buried AC BITS Cable is dominated by the radial distance from the source (cable). The magnetic-field level as a function of vertical distance above the seabed, therefore, follows a very similar pattern to that shown in

Table 2 and Figures 4-6 for horizontal attenuation. Previous work modeling buried sea cables has shown a similar result (Normandeau et al., 2011, Appendix B).

It is also important to note that as a conservative modeling assumption, the shielding effect of cable armoring and sheaths were not included in the model used to predict the magnetic-field levels described above. A reduction in the magnetic-field level outside the cable is produced by shunting of the magnetic field by the cable armoring. The effectiveness of the armoring in attenuating the magnetic field is a function of the magnetic permeability of the armoring, i.e., higher permeability will attenuate the magnetic field by shunting. Furthermore, induced eddy currents in conductive sheathing materials will create an opposing magnetic field that partially cancels of the magnetic field from the cores. As shown by calculations for a 138-kV AC undersea cable, flux shunting accounted for an almost 2-fold reduction in the magnetic field, with a much smaller reduction attributable to eddy currents (Silva et al., 2006). The results discussed here are therefore upper bounds on the magnetic-field levels expected to be produced by the Project.

Conclusions

The magnetic fields in the submarine portion of the route are quite weak even directly over the cables. These field levels are comparable to those from the common low-voltage, low-current distribution cables on land and are below a theoretical detection level for magnetite-based magnetic-field detection systems, e.g., mammals, turtles, fish, and invertebrates (Normandeau et al., 2011). This is primarily due to the containment of all three phases of each circuit within the same submarine cable. This results in significant cancellation of magnetic fields produced by the circuit, unlike the case of overhead power circuits where the phases are widely separated so that the air between serves as insulation. A second factor is that all cables are buried 6 feet under the seabed and thus the magnetic-field level above is reduced because magnetic fields diminish rapidly with distance from the source. The flux shunting and shielding effects of the submarine cables are not modeled here and the presented results, therefore, represent a conservative upper bound on the magnitude of generated magnetic-fields.

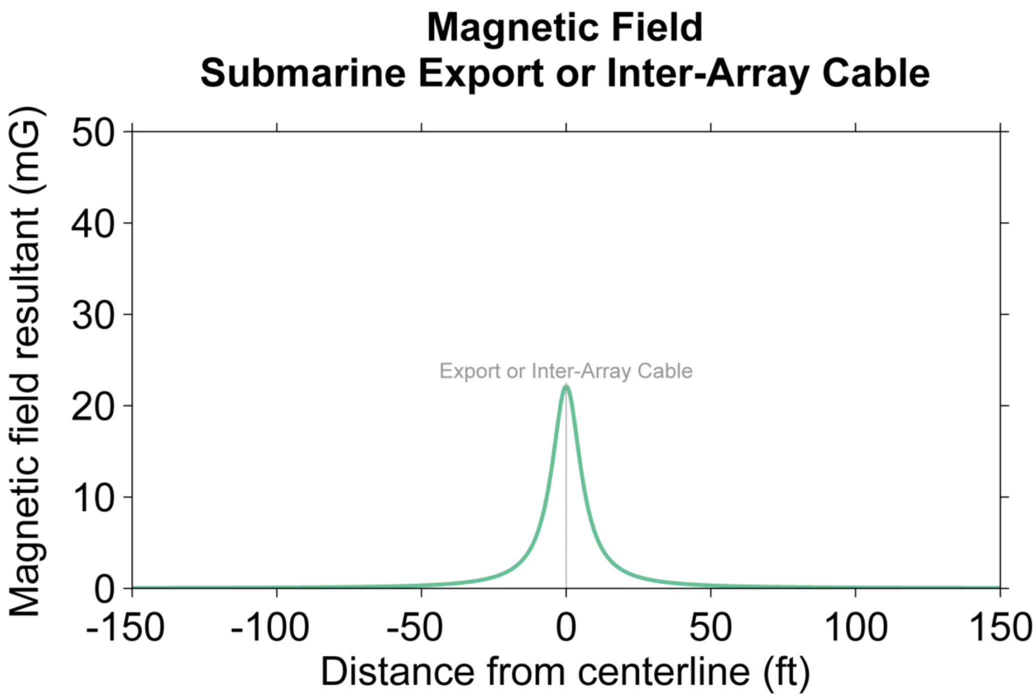

Figure 4. Magnetic field around the Inter-Array or Export Cables at the seabed at varying distances from the cable centerline assuming a burial depth of 6 feet and no armoring or sheathing.

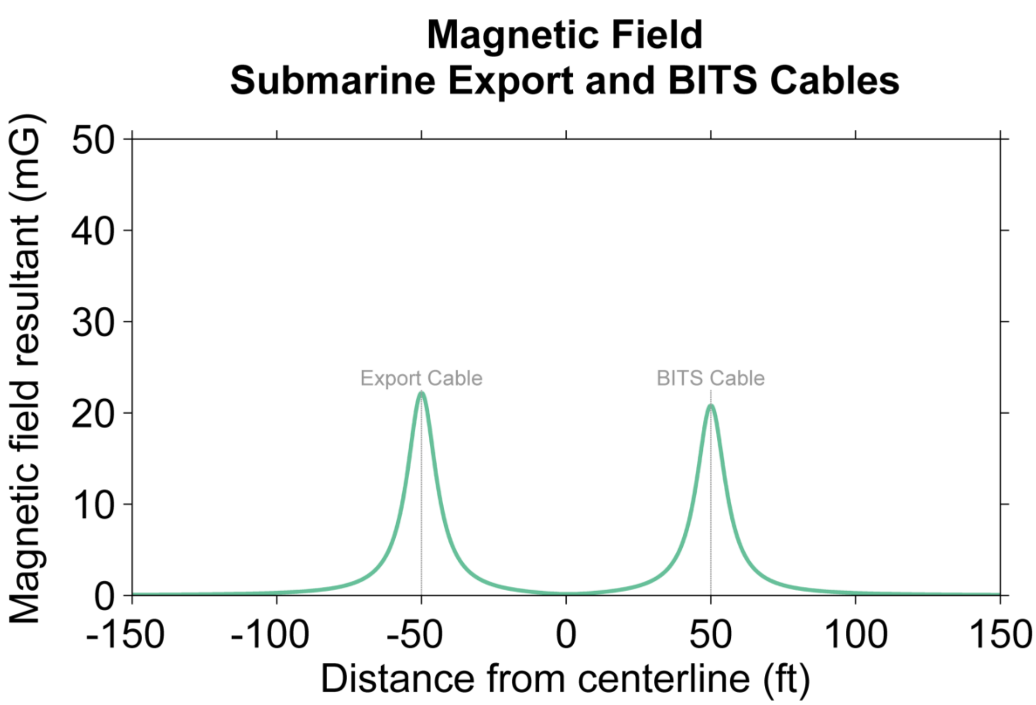

Figure 5. Magnetic field around the parallel Export and BITS Cables at the seabed at varying distances from the cable centerline assuming a burial depth of 6 feet and no armoring or sheathing.

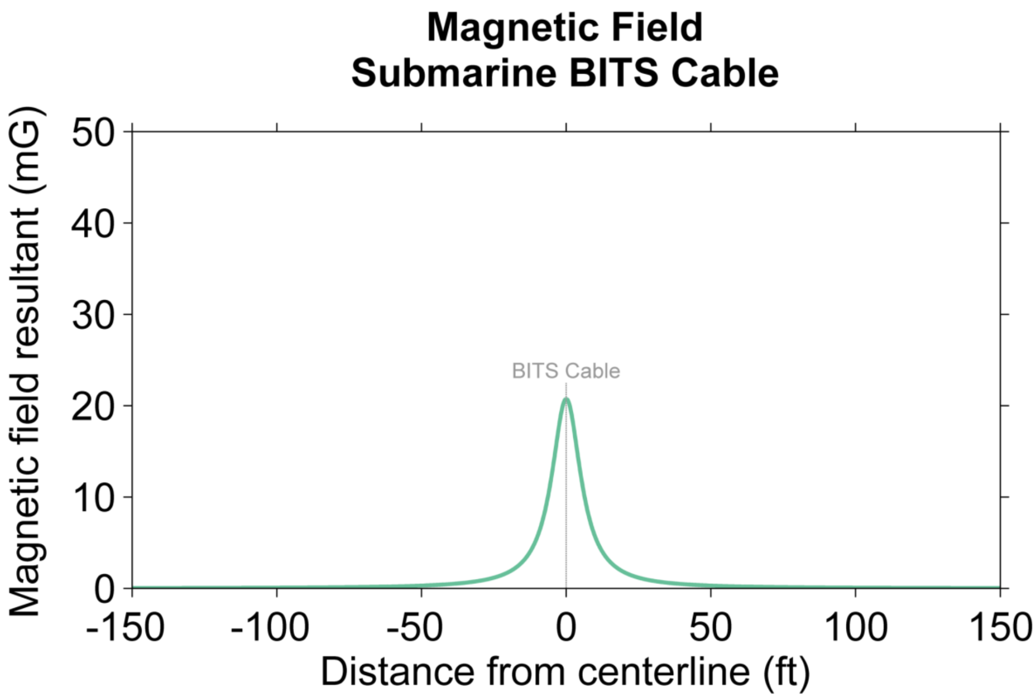

Figure 6. Magnetic field around the BITS Cable at the seabed at varying distances from the cable centerline assuming a burial depth of 6 feet and no armoring or sheathing.

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

Limitations

At the request of Normandeau Associates, Inc. and Tetra Tech, Inc., Exponent conducted specific modeling of components of the electrical environment of the Deepwater Wind Block Island Wind, LLC Block Island Wind Farm (BIWF) and the Deepwater Wind Block Island Transmission, LLC Block Island Transmission System (BITS) projects. Both of the corporate entities associated with the development of the BIWF and BITS projects are wholly owned indirect subsidiaries of Deepwater Wind Holdings, LLC, and for the purposes of this report are collectively referred to as “Deepwater Wind.”

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.