Attachment D

EMF Report

Magnetic Field Modeling Analysis for the New England Wind 2 Connector Project

Prepared for

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Abbreviations

1W×4D	1-Wide-By-4-Deep
12W×1D	12-Wide-By-1-Deep
2W×4D	2-Wide-By-4-Deep
3W×4D	3-Wide-By-4-Deep
A	Ampere
AC	Alternating Current
BOEM	Bureau of Ocean Energy Management
CDEGS	Current Distribution, Electromagnetic Fields, Grounding and Soil Structure Analysis
cm	Centimeter
CPUE	Catch per Unit Effort
CSC	Cross Sound Cable
DC	Direct Current
EMF	Electric and Magnetic Field
ft	Feet
ft bgs	Feet Below Ground Surface
G	Gauss
GCC	Ground Continuity Conductor
HDD	Horizontal Directional Drilling
HVAC	High-Voltage Alternating Current
HVDC	High-Voltage Direct Current
Hz	Hertz
ICNIRP	International Commission on Non-Ionizing Radiation Protection
in	Inch
ISO-NE	ISO New England
kV	Kilovolt
kV/m	Kilovolt per Meter
m	Meter
MF	Magnetic Field
mG	Milligauss
MRI	Magnetic Resonance Imaging
MW	Megawatt
NE	New England
OECC	Offshore Export Cable Corridor
OSW	Offshore Wind Project
RMS	Root Mean Square
ROW	Right-of-Way
SEER	Synthesis of Environmental Effects Research
TJB	Transition Joint Bay
V	Volt
V/m	Volt per Meter
WHO	World Health Organization
XLPE	Cross-Linked Polyethylene

1 Introduction and Summary

Commonwealth Wind, LLC, a wholly owned subsidiary of Avangrid Renewables, LLC (collectively referred to herein as "the Proponent"), proposes to construct, operate, and maintain high-voltage alternating current (HVAC) offshore export cables and onshore underground transmission cables between a proposed offshore Electric Service Platform and a grid interconnection point at the West Barnstable Substation in Barnstable, Massachusetts. The New England Wind 2 Connector Project (NE Wind 2 Connector or "the Project") encompasses the Massachusetts-jurisdictional elements of the Commonwealth Wind Project, which is an offshore wind energy generation facility in federal waters within the southern portion of Bureau of Ocean Energy Management (BOEM) Lease Area OCS-A 0534 (Lease Area) (see Attachment A Project Overview) that will deliver more than 1,200 megawatts (MW) of carbon-free energy to the ISO-New England (ISO-NE) electrical grid.[1] Elements of the Project proposed within state boundaries (*i.e.*, the New England Wind 2 Connector) include portions of the offshore export cables in state waters, all of the onshore export cables, the proposed new onshore substation, the 345-kilovolt (kV) grid interconnection from the new onshore substation to the grid interconnection point at the existing Eversource 345-kV West Barnstable Substation, and some modifications to the 345-kV West Barnstable Substation to accommodate the interconnection from NE Wind 2 Connector.

The offshore export cables – which will consist of three three-core 275-kV submarine cables, each with a capacity of ~400-MW – will be installed within an Offshore Export Cable Corridor (OECC) that travels from the northwestern corner of the Lease Area to the landfall site at Dowses Beach in Barnstable. The OECC is the same one proposed for NE Wind 1 Connector, with two primary differences: (1) the OECC for the NE Wind 2 Connector diverges to the west in Barnstable waters to provide access to the Dowses Beach landfall site; and (2) while the OECC proposed for the NE Wind 1 Connector in the vicinity of Muskeget Channel is the preferred route for the NE Wind 2 Connector, the Proponent has identified a Western Muskeget option that could be used to install one or two of the three offshore export cables associated with NE Wind 2 Connector if warranted by further engineering analysis. The OECC will pass through state waters in the offshore areas of Edgartown, Nantucket, Barnstable, and Mashpee before making landfall in Barnstable. The maximum length of the OECC in state and federal waters is up to 47.2 miles. Of this, the maximum total length of the OECC within Massachusetts state waters is approximately 21.9 miles.

At the Dowses Beach landfall site, the three three-core 275-kV offshore export cables will transition to three sets of single-core 275-kV onshore export cables. The preferred onshore export cable route for the Project is located entirely underground within public roadway layouts or within the existing parking lot area at Dowses Beach and has a total length of approximately 6.7 miles (see the Attachment B map of the onshore Project route). Beginning within the parking lot area at Dowses Beach, the Preferred Route will head west on Dowses Beach Causeway to East Bay Road and will run along existing roadways in Barnstable that include Wianno Avenue, Main Street, Osterville-West Barnstable Road, Old Falmouth Road, Old Stage, Oak Street, and Service Road, until it reaches a staging area for the proposed trenchless crossing of Route 6 into the proposed new substation site. The Project's proposed onshore substation is located on privately owned, undeveloped wooded parcels west of Oak Street near the Oak Street Bridge overpass of Route 6, approximately 0.25 miles west of the interconnection location at the West Barnstable Substation. The new project substation will "step up" the transmission-line voltage from 275 kV to 345

[1] The Park City Wind Project is also located within Lease Area OCS-A 0534, specifically within the north/northeastern portion of the lease area.

kV, and three sets of single-core 345-kV cables will be installed underground to connect the new Project substation to a grid interconnection at the existing West Barnstable Substation interconnection point (*i.e.*, grid interconnection routes).

Epsilon Associates, Inc. (Epsilon) requested that Gradient perform an independent assessment of the electric and magnetic field (EMF) levels associated with the New England Wind 2 Connector Project. This modeling analysis is focused on magnetic fields (MFs) because the electric fields produced by the voltage on the offshore export cables will be contained by the metallic sheathing and/or steel armoring of the cables- *i.e.*, the metallic sheathing and/or steel armoring will completely shield the electric fields arising from the voltage on the cables. Magnetic fields are not completely shielded by either metallic sheathing or steel armoring, although the usage of ferromagnetic steel (*e.g.*, galvanized) steel armoring can serve to partially attenuate the MFs found outside 3-phase 60-hertz (Hz) alternating current (AC) cables (CSA Ocean Sciences Inc. and Exponent, 2019). As discussed in CSA Ocean Sciences Inc. and Exponent (2019), due to their time-varying nature, the MFs associated with 60-Hz AC cables can induce weak electric fields in the immediately surrounding marine environment near cables.[2] These induced electric fields are not modeled by EMF modeling programs such as the FIELDS computer program used in this assessment. However, they are weak in nature and are considered to pose minimal potential risk to marine species relative to the MFs from offshore export cables, especially given that electrosensitive marine species do not appear to have significant problems distinguishing bioelectric fields from the induced electric fields associated with water movement and marine animal movement through the earth's geomagnetic field (Gill and Desender, 2020; CSA Ocean Sciences Inc. and Exponent, 2019). Underground lines produce no aboveground electric fields, so the new onshore export and grid interconnection cables will not produce any aboveground electric fields.

For each of the 275-kV offshore export cables, 275-kV onshore export cables, and 345-kV grid interconnection cables, MF modeling was conservatively performed for representative installation cases assuming maximum wind turbine output (100% capacity). The wind turbine array is expected to operate at an annual-average capacity factor of approximately 50%; thus, much of the time, the actual output and MFs attributable to the Project cables will be correspondingly lower than predicted herein for maximum wind turbine output.

As discussed in more detail in Section 2 of this report, no regulatory thresholds or guidelines for allowable EMF levels in marine environments have been established for HVAC submarine power transmission. The weight of the scientific evidence indicates that 60-Hz AC EMFs are considerably above the typical frequency range of EMFs to which magnetosensitive and electrosensitive marine species are known to detect and respond. In particular, magnetosensitive marine species such as salmon, whales, and sea turtles are specifically tuned to the earth's steady (direct current [DC]) geomagnetic field for navigation/migration purposes, while electrosensitive marine species such as sharks and rays are primarily tuned to electric field frequencies below 10 Hz for helping to locate prey and/or mates (CSA Ocean Sciences Inc. and Exponent, 2019).

With respect to protection of public health, a number of national and world health organizations have developed EMF exposure guidelines or limits designed to be protective against any adverse health effects in humans. The limit values should not be viewed as demarcation lines between "safe" and "dangerous" levels of EMFs, but rather, levels that assure safety with adequate margins to allow for uncertainties in the science. For MF, these health based guidelines range from 1,000 to 10,000 milligauss (mG). For

[2] By Faraday's Law of Induction, a time-varying MF (*i.e.*, changing magnetic flux) will induce a time-varying electric field in a conducting medium, such as seawater. This is the same principle by which coils rotating in a steady MF generate a flow of electricity.

example, the International Commission on Non-Ionizing Radiation Protection (ICNIRP) guideline for allowable public exposure to 60-Hz MF is 2,000 mG.

For the 275-kV offshore export cables, MF levels were modeled at the sea floor for a representative submarine installation cross section that assumed a burial depth of 4.9 feet (ft) (1.5 meters [m]) corresponding to the lower limit of the target burial depth of approximately 5 to 8 ft (1.5 to 2.5 m) for the offshore export cables, and the minimum spacing of 164 ft (50 m) between the cables. As shown in Table 1.1, the modeling showed the highest modeled MF levels at the sea floor were approximately 109 mG directly above the offshore export cables, with rapid reductions in MF levels with lateral distance away from the cable centerlines – *e.g.*, there is a >95% reduction in MF levels at a lateral distance of ±25 ft (±7.6 m) from the cable centerlines. MF levels in the water column will be less than the modeled MF levels at the sea floor, with the rate of decrease in MF levels as a function of height above the cables being similar to the rate of fall-off as a function of distance laterally from the cables. Due to the rapid reductions in MF levels with distance away from the cables, there is minimal interaction of MF from adjacent cables at the modeled minimum separation distance of 164 ft (50 m). Based on the localized nature of the MF impacts of the offshore export cables as well as the weight of the scientific evidence that 60-Hz AC EMFs are above the typical frequency range of EMFs to which magnetosensitive and electrosensitive marine species are known to detect and respond, there is no expectation that the modeled MFs from the HVAC offshore export cables will cause significant population-level harms to marine species in the OECCs.

Table 1.1 Modeled Magnetic Fields at the Sea Floor for Buried Submarine 275-kV Offshore Export Cables[a]

Cross Section	Predicted Resultant Magnetic Field (mG)		
	Maximum Directly Above Cable Centerline(s)	±10 ft (±3 m) from Outer Cables[b]	±25 ft (±7.6 m) from Outer Cables[b]
Buried Submarine Cables	109.4	24.7	5.0

Notes:
ft = Foot; kV = Kilovolt; m = Meter; mG = Milligauss.
(a) The offshore export cable MF modeling assumes straight-laid phase-conductor cable cores rather than helical or "twisted" phase-conductor cores (the expected cable design). As discussed in Section 3.2, field measurements taken for the Block Island "sea2shore" cable show that a helical design achieves a considerable degree of magnetic field cancellation, hence the modeled MF levels are expected to be overestimates of actual MF levels at maximum wind farm output.
(b) The values provided at lateral distances of 10 and 25 ft are for 10 and 25 ft from the outer cables. Only one value is presented for each lateral distance because the predicted results for the left and right of the cables are identical.

Modeling of the offshore export cables was also performed for cross sections representative of two locations at the Dowses Beach landfall site in Barnstable along the horizontal directional drilling (HDD) paths to be constructed for bringing the cables ashore, including: (1) a middle-of-the beach cross section representative of where the cables will pass under the publicly accessible beach with burial depths to the tops of the cables that range from 24.7 ft to 57.4 ft (7.5 m to 17.5 m) for the three HDD paths; and (2) a parking lot cross section representative of the HDDs beneath the paved parking lot at Dowses Beach, where the offshore export cables have moved closer to the ground surface prior to the transition vaults/joint bays and have depths to the tops of the cables of 5.0 to 6.0 ft (1.5 to 1.8 m) for the three HDD paths. As summarized in Table 1.2, maximum modeled MFs of 5.0 and 1.0 mG were obtained at the ground surface directly above the offshore export cables for the two HDD modeling scenarios for the middle-of-the-beach location. For the parking lot location where the HDD paths are closer to the ground surface, maximum modeled MFs were 41.4 and 32.7 mG at 1 m above the ground surface directly above the offshore export cables for the two HDD modeling scenarios. For the parking lot cross section, modeled MFs were found to drop off very rapidly with lateral distance from the cables, with reductions in MF levels of between 85 to 90% for a lateral distance of 25 feet on either side of the cable centerlines.

All modeled MF levels for the landfall site cross sections were below both the ICNIRP health-based guideline of 2,000 mG for allowable public exposure to 60-Hz AC MFs. This is the case despite modeled MF levels for the 275-kV offshore export cables being overestimates of the expected MF levels for actual Project operations due to several conservative assumptions in the modeling analysis, including the lack of accounting for the expected twisting of the conductors within the cables that will contribute to substantially greater self-cancellation of MF than for straight conductors, and the use of cable currents based on maximum wind farm output (100 percent capacity).

Table 1.2 Modeled Magnetic Fields for the 275-kV Offshore Export Cables Along the Horizontal Directional Drilling (HDD) Paths at the Dowses Beach Landfall Site[a]

Cross Section	Predicted Resultant Magnetic Field (mG)		
	Maximum Directly Above Cable Centerline(s)	±10 ft (±3 m) from Reference Point[c]	±25 ft (±7.6 m) from Reference Point[c]
Landfall, Middle of Dowses Beach[b]			
HDD1	5.0	4.3	2.5
HDD2/HDD3	1.0	1.0	0.9
Landfall, Parking Lot Behind Dowses Beach[b]			
HDD1	41.4	17.9	4.5
HDD2/HDD3	32.7	16.1	4.7

Notes:
ft = Foot; m = Meter; mG = Milligauss.
(a) The offshore export cable MF modeling assumes straight-laid phase-conductor cable cores rather than helical or "twisted" phase-conductor cores (the expected cable design). As discussed in Section 3.2, field measurements taken for the Block Island "sea2shore" cable show that a helical design achieves a considerable degree of magnetic field cancellation, hence the modeled MF levels are expected to be overestimates of actual MF levels at maximum wind farm output.
(b) Magnetic fields are modeled at the ground surface for the middle-of-beach cross section, and at 3.28 ft (1 m) above ground surface for the parking lot cross section.
(c) For HDD1, the values provided at lateral distances of 10 and 25 ft are with respect to the centerline of the cable. For HDD2 and HDD3, the values provided at lateral distances of 10 and 25 ft are for 10 and 25 ft from the outer cable. Only one value is presented for each lateral distance because the predicted results for the left and right of the cables are identical.

For the 275-kV onshore export cables, MF levels were calculated 1 meter above the ground surface for several underground circuit cross sections representative of different portions of the Project onshore transmission route, including both the typical and deep installation cases for the underground 3-wide-by-4-deep (3W×4D) duct banks to be used for the majority of the onshore transmission route, the microtunnels to be used for the Route 6 crossing, the transition joint bays to be located beneath the Dowses Beach parking lot, and the splice vaults to be located in groups every 1,500 to 3,000 feet (approximately 460 to 915 meters) or more along the onshore transmission route. In addition, MF levels were calculated 1 meter above the ground surface for both the typical and deep installation cases for the underground 3W×4D duct banks to be used for the 345-kV grid interconnection cables to be installed between the new onshore substation and the grid interconnection point at the existing Eversource 345-kV West Barnstable Substation.

As described in this report and shown in Table 1.3, all modeled MF levels for the 275-kV onshore export cables and the 345-kV grid interconnection cables are below the ICNIRP health-based guideline of 2,000 mG for allowable public exposure to 60-Hz AC MFs. The results in Table 1.3 for modeled MF levels at different distances (±10 ft and ±25 ft) from the centerlines of the underground duct banks, transition joint bays, and splice vaults, and from the outer microtunnel for the Route 6 crossing, illustrate the significant reductions in MF with increasing lateral distance from the cables.

Table 1.3 Modeled Magnetic Fields at 3.28 ft (1 m) Above Ground Surface for Underground Onshore Export and Grid Interconnection Cable Installation Scenarios

Installation Scenario	Predicted Resultant Magnetic Field (mG)		
	Maximum Above Reference Point[a]	±10 ft (±3 m) from Reference Point[a]	±25 ft (±7.6 m) from Reference Point[a]
275-kV Onshore Export Cables			
3W×4D Duct Bank, Typical Installation	77.2	50.1 / 50.1	14.3 / 14.3
3W×4D Duct Bank, Deep Installation	83.4	59.8 / 59.8	21.8 / 21.8
Route 6 Crossing, 6-ft Microtunnel	38.8	30.2 / 18.8	13.9 / 5.2
Transition Joint Bay	96.9	50.2 / 49.1	14.1 / 13.8
Splice Vaults, Cross Section A	232.8	110.8 / 105.5	29.9 / 31.8
Splice Vaults, Cross Section B	121.3	68.7 / 28.2	11.6 / 4.2
Splice Vaults, Cross Section C	253.6	121.9 / 116.1	29.1 / 31.0
345-kV Grid Interconnection Cables			
3W×4D Duct Bank, Typical Installation	58.7	38.1 / 38.1	10.9 / 10.9
3W×4D Duct Bank, Deep Installation	75.7	53.8 / 53.8	19.6 / 19.6

Notes:
3W×4D = 3-Wide-By-4-Deep; ft = Foot; kV = Kilovolt; m = Meter; mG = Milligauss.
(a) The two values presented correspond to the model-predicted fields at the given lateral distances to the left and right of the reference point, respectively, where the reference point for the duct bank, transition joint bay, and splice vault installation scenarios is the duct bank, transition joint bay, or splice vault centerline. For the Route 6 crossing microtunnel installation scenario, the values presented at lateral distances of 10 and 25 ft are for 10 and 25 ft from the outer microtunnel.

MF modeling performed by Stantec for one additional installation case for the 275-kV onshore export cables, namely an underground 12-wide-by-1-deep (12W×1D) duct bank with copper plate shielding proposed for use for the Phinney's Bay culvert crossing on Dowses Beach Causeway in Barnstable, showed that the proposed use of copper plate shielding minimized aboveground MF levels from this shallow duct bank, with a maximum modeled MF level of 63.0 mG directly above the duct bank.

Similar to the MF modeling for the offshore export cables, the MF modeling for both the underground onshore export and grid interconnection cable installation cases is expected to overpredict the magnitude of aboveground MF levels associated with the installed onshore export and grid interconnection cables. This is because minimum expected burial depths were assumed, and the currents used for the cables assume maximum wind turbine output (100 percent capacity). In addition, as discussed earlier, the MF modeling analyses did not account for the phase conductors' main currents inducing currents on ground continuity conductors in the duct banks. Any induced currents on ground conductors would be expected to produce an MF that would tend to oppose (partially cancel) the MF arising from the phase conductor currents.

Section 2 of this report describes the nature of EMFs and provides background on human and marine organism exposures to EMF and published exposure guidelines. Section 3 describes the MF modeling analysis for the offshore export cables, while Section 4 describes the MF modeling analysis for the onshore export and grid interconnection cables. Section 5 summarizes the conclusions, and the Reference list provides the scientific references cited in this report.

2 Nature of Electric and Magnetic Fields

All matter contains electrically charged particles. Most objects are electrically neutral because positive and negative charges are present in equal numbers. When the balance of electric charges is altered, we experience electrical effects. Common examples are the static electricity attraction between a comb and our hair, or a static electricity spark after walking on a synthetic rug in the wintertime. Electrical effects occur both in nature and through our society's use of electric power (generation, transmission, and consumption).

2.1 Units for EMFs Are Kilovolts Per Meter (kV/m) and Milligauss (mG)

The electrical tension on utility power lines is expressed in volts or kilovolts (1 kV = 1,000 V). Voltage is the "pressure" of the electricity and can be envisioned as analogous to the pressure of water in a plumbing system. The existence of a voltage difference between overhead power lines and ground results in an "electric field," usually expressed in units of kV/m. The size of the electric field depends on the line voltage, the separation between lines and the ground surface, and other factors.

Power lines also carry an electric current that creates a "magnetic field." The units for electric current are amperes (A), which a measure of the "flow" of electricity. Electric current is analogous to the flow of water in a plumbing system. The magnetic field produced by an electric current is usually expressed in units of gauss (G) or mG (1 G = 1,000 mG).[3] The size of the magnetic field depends on the electric current in the line conductors, the distance to the current-carrying conductor, and other factors.

2.2 Human Exposure to EMF

2.2.1 There Are Many Natural and Man-Made Sources of EMFs

Everyone experiences a variety of natural and man-made EMFs. EMF levels can be steady or slowly varying (often called "direct current," or "DC fields"); or EMF levels can vary in time (often called "alternating current" or "AC fields"). When the time variation corresponds to that of standard North American power line currents (*i.e.*, 60 cycles per second), the fields are called "60-Hz AC," or power-frequency, EMF.

Man-made magnetic fields are common in everyday life. For example, many childhood toys contain magnets. Such permanent magnets generate strong, steady (DC) magnetic fields. Typical toy magnets (*e.g.*, "refrigerator door" magnets) have fields of 100,000-500,000 mG. On a larger scale, earth's core also creates a steady DC magnetic field that can be easily demonstrated with a compass needle. Along the southern New England coast, the earth's DC geomagnetic field has a magnitude on the order of 500 mG (CSA Ocean Sciences Inc. and Exponent, 2019) (less than 1% of the levels generated by "refrigerator door" magnets).

In North America, electric power transmission lines, distribution lines, and electric wiring in buildings carry AC currents and voltages that change size and direction at a frequency of 60 Hz. These 60-Hz

[3] Another unit for magnetic field levels is the microtesla (μT) (1 μT = 10 mG; and 1 Tesla = 10,000 Gauss).

currents and voltages create 60-Hz AC EMFs nearby. The size of the magnetic field is proportional to the line current, while the size of the electric field is proportional to the line voltage. The EMFs associated with electrical wires and electrical equipment decrease rapidly with increasing distance away from the electrical wires and/or equipment. Specifically, EMFs from three-phased, balanced conductors decrease in proportion to the square of the distance from the conductors (*i.e.*, $1/d^2$) (IEEE, 2014).

When EMF derives from different wires or conductors that are in close proximity, or adjacent to one another, the level of the net EMF produced will be somewhere in the range between the sum of EMF from the individual sources and the difference of the EMF from the individual sources. EMF may partially add, or partially cancel, but generally, because adjacent phase conductors are often carrying current in opposite directions for typical 3-phase lines, the EMF produced tends to cancel.

EMFs in the home arise from electric appliances, indoor wiring, grounding currents on pipes and ground wires, and outdoor distribution or transmission circuits. Inside residences, typical baseline 60-Hz MF (away from appliances) range from 0.5-5.0 mG.

Higher 60-Hz MF levels are found near operating appliances. For example, can openers, mixers, blenders, refrigerators, fluorescent lamps, electric ranges, clothes washers, toasters, portable heaters, vacuum cleaners, electric tools, and many other appliances generate MF levels in the range of 40-300 mG at distances of 1 foot (NIEHS, 2002). MF levels from personal care appliances held within half a foot (*e.g.*, shavers, hair dryers, massagers) can produce average fields of 600-700 mG. At school and in the workplace, lights, motors, copy machines, vending machines, video-display terminals, pencil sharpeners, electric tools, electric heaters, and building wiring are all sources of 60-Hz MF.

Magnetic resonance imaging (MRI) is a diagnostic procedure that puts humans in much larger, but steady, DC MFs (*e.g.*, levels of 20,000,000 mG). The scanning MF superimposed on the large steady DC field (which is the source of the characteristic audio noise of MRI scans) exposes the body to time-varying MF similar to time-varying power-frequency MF.

2.2.2 Health and Safety Guidelines for 60-Hz AC EMFs

Although the US has no federal standards limiting either residential or occupational exposure to 60-Hz AC EMF, Table 2.1 shows exposure guidelines for 60-Hz AC fields from national and world health and safety organizations that are designed to protect workers and the general public against any adverse health effects. The limit values should not be viewed as demarcation lines between safe and dangerous levels of EMFs, but rather, levels that assure safety with an adequate margin to allow for uncertainties in the science. As part of its International EMF Project, the World Health Organization (WHO) has conducted comprehensive reviews of EMF health-effects research and existing standards and guidelines. The WHO website for the International EMF Project (WHO, 2022) notes, "[T]he main conclusion from the WHO reviews is that EMF exposures below the limits recommended in the ICNIRP international guidelines do not appear to have any known consequence on health."

Table 2.1 60-Hz AC EMF Guidelines Established by International Health and Safety Organizations

Organization	Electric Field	Magnetic Field
American Conference of Governmental and Industrial Hygienists (ACGIH) (occupational)	25 kV/m[a]	10,000 mG[a] 1,000 mG [b]
International Commission on Non-Ionizing Radiation Protection (ICNIRP) (general public)	4.2 kV/m[c]	2,000 mG[c]
International Commission on Non-Ionizing Radiation Protection (ICNIRP) (occupational)	8.3 kV/m[c]	10,000 mG[c]
Institute of Electrical and Electronics Engineers (IEEE) Standard C95.1™-2019 (general public)	5.0 kV/m[d]	9,040 mG[d]
Institute of Electrical and Electronics Engineers (IEEE) Standard C95.1™-2019 (occupational)	20.0 kV/m[d]	27,100 mG[d]

Notes:
AC = Alternating Current; EMF = Electric and Magnetic Field; Hz = Hertz; kV/m = Kilovolts Per Meter; mG = Milligauss.
(a) The ACGIH guidelines for whole-body exposure for the general worker (ACGIH, 2022).
(b) The ACGIH guidelines for workers with cardiac pacemakers (ACGIH, 2022).
(c) Source: ICNIRP (2010).
(d) Source: IEEE (2019).

2.3 Marine Organism Exposures to EMF

Naturally occurring EMFs are ubiquitous in coastal environments. Most prominently, the earth's steady geomagnetic field, which is associated with current flows in the earth's liquid core as well as metallic crustal elements, is the largest source of steady MFs for both marine and terrestrial environments (Normandeau Associates, Inc., *et al*., 2011). The intensity of the background geomagnetic field at the earth's surface varies between about 300 mG near the equator to the highest values of ~700 mG near the south and north poles. Along the southern New England coast, the earth's MF has a magnitude on the order of 500 mG (CSA Ocean Sciences Inc. and Exponent, 2019).

Naturally occurring steady (DC) EMFs are also ubiquitous in coastal environments due to other sources besides earth's geomagnetic field. Other natural electric fields are associated with the movement of ocean currents and marine organisms through earth's geomagnetic field and those directly produced by marine organisms. The movement of ocean currents and marine organisms through earth's geomagnetic field produces weak DC EFs (CSA Ocean Sciences Inc. and Exponent, 2019). Marine organisms produce bioelectric fields, such as from heartbeats and gill movement, close to their body surfaces; in addition, electric fish species, such as the electric eel, can generate strong EFs for defense purposes. The bioelectric fields produced by all marine organisms (*e.g.*, from heartbeats, gill movement) can be as high as 0.5 volts per meter (V/m), but typically diminish to negligible levels within 4-8 inches (10-20 centimeters) from the source organism (CSA Ocean Sciences Inc. and Exponent, 2019). While these bioelectric fields can include AC fields that change direction several times per second, they are generally for frequencies of less than 10 Hz (*e.g.*, EFs from a heartbeat of 120 beats per minute would have a frequency of 2 Hz) and thus are considerably below the frequencies of the 60 Hz AC EFs that are characteristic of US power generation and transmission (CSA Ocean Sciences Inc. and Exponent, 2019).

There are already present a variety of submarine transmission cables along the Eastern seaboard. Examples of AC cables include the Nantucket I and II electrical distribution cables and four electrical distribution cables feeding Martha's Vineyard, the 34.5-kV inter-array cables and 34.5-kV offshore export cable that were installed prior to 2016 as part of the Block Island Wind Farm, and the 34.5-kV sea2shore cable connecting Block Island to the mainland. Examples of DC cables include the 330-MW bipolar Cross Sound Cable (CSC) that transects Long Island Sound between New Haven, CT, and Shoreham, NY; and the 660-MW Neptune cable that runs between Sayreville, NJ, and Long Island, NY. It bears mentioning that more than 100 offshore wind farms have been constructed in Europe, with both HVAC and high-voltage direct current (HVDC) offshore export cables (CSA Ocean Sciences Inc. and Exponent, 2019).

Other manmade sources of perturbations to earth's steady DC geomagnetic field in coastal environments include shore-based structures such as docks, jetties, and bridges; sunken ships; pipelines; and ferromagnetic mineral deposits (Normandeau Associates, Inc., *et al*., 2011; CSA Ocean Sciences Inc. and Exponent, 2019). Normandeau Associates, Inc., *et al*.. (2011) reported that MF impacts nearby to these sources can be on the order of tens of mG, while CSA Ocean Sciences Inc. and Exponent (2019) observed that undersea sources of DC MFs including steel ships and bridges can create DC MFs up to 100 times greater than MFs from DC submarine cables.

No regulatory thresholds or guidelines for allowable EMF levels in marine environments have been established for either HVAC or HVDC submarine power transmission.

2.3.1 Marine Organism Sensitivity to 60-Hz AC EMFs

For HVAC transmission, the weight of the scientific evidence indicates that 60-Hz AC EMFs are considerably above the typical frequency range of EMFs to which magnetosensitive and electrosensitive marine species are known to detect and respond. In particular, magnetosensitive marine species such as salmon, whales, and sea turtles are specifically tuned to the earth's steady (DC) geomagnetic field for navigation/migration purposes, while electrosensitive marine species such as sharks and rays primarily respond to electric field frequencies below 10 Hz for helping to locate prey and/or mates (CSA Ocean Sciences Inc. and Exponent, 2019).

Importantly, a seven-year study reported the first findings in the United States of the response of demersal fish (*i.e*., fish living close to the sea floor) and invertebrates to construction and operation of an offshore wind (OSW) project (Wilber *et al*., 2022). Published in March 2022, this study analyzed catch data from monthly demersal trawl surveys conducted by local fisherman and scientists during construction and operation of the Block Island Wind Farm, a pilot-scale 30 MW project that is North America's first offshore wind farm. This study did not identify harmful impacts of EMF from the project's 60-Hz AC submarine export cables or other offshore electrical infrastructure on local demersal fish and invertebrates, and instead reported evidence of increased populations of several fish species near the wind farm during the operation time period relative to the reference areas. Statistically significant interactions in catch per unit effort (CPUE) due to operation of the wind farm were not observed for any of the fish species that were frequently caught in the surveys in the project and reference areas, including black sea bass (*Centropristis striata*), little skate (*Leucoraja erinacea*), summer flounder (*Paralichthys dentatus*), windowpane (*Scophthalmus aquosus*), winter flounder (*Pseudopleuronectes americanus*), winter skate (*Leucoraja ocellata*), and longfin squid (*Loligo pealeii*). These findings are consistent with those for European offshore wind farm projects. In a report to BOEM, CSA Ocean Sciences Inc. and Exponent (2019) provided the following summary of findings from fish surveys conducted in Europe in areas with offshore wind development:

> "Offshore wind energy projects, along with associated undersea power cables, have operated in coastal environments of Europe for more than a decade. During this time, many surveys have been conducted to determine if fish populations have declined following offshore wind energy project installation. The surveys have overwhelmingly shown that offshore wind energy projects and undersea power cables have no effect on fish populations [72,80,81,82]. Fish assessed as part of these surveys include flounder

> and other flatfish, herring, cod, and mackerel. These are similar to species harvested along the U.S. Atlantic coast."

Earlier this year, as part of the U.S. Offshore Wind Synthesis of Environmental Effects Research (SEER) effort, researchers at the U.S. Department of Energy's Wind Energy Technologies Office, National Renewable Energy Laboratory, and Pacific Northwest National Laboratory published a Brief titled "Electromagnetic Field Effects on Marine Life" (SEER, 2022). This Brief was reviewed by external subject matter experts (Dr. Andrew Gill of the Centre for Environment, Fisheries, and Aquaculture Science; and Dr. Zoe Hutchison of the University of St. Andrews) and the SEER Science and Technical Advisory Committee. The Brief included the following summary of the overall state of the knowledge:

> "Overall, there is no conclusive evidence that EMFs from a subsea cable creates any negative environmental effect on individuals or populations. To date, no impacts interpreted as substantially negative have been observed on electrosensitive or magnetosensitive species after exposure to EMFs from a subsea cable. Behavioral responses to subsea cables have been observed in some species, but a reaction to EMFs does not necessarily translate into negative impacts. Continued research and monitoring are required to understand the ecological context within which short-term effects are observed and if species experience long-term or cumulative effects resulting from underwater exposure to EMFs." (SEER, 2022)

The Brief further concluded, "Overall, the effects of EMFs have been considered minor-to-negligible and a less significant issue than other environmental effects at OSW farms" (SEER, 2022). It discussed how such factors as cable burial depth, cable shielding, and the limited range of EMFs result in "a highly localized environmental condition that does not affect the entire habitat range for an animal" (SEER, 2022).

3 MF Modeling for Offshore Export Cables

3.1 Software Program Used for Modeling MF Levels for Offshore Export Cable Installation Cross Sections

The FIELDS computer program, designed by Southern California Edison, was utilized to calculate MF strengths from the proposed offshore export cables. This program operates using Maxwell's equations, which accurately apply the laws of physics as related to electricity and magnetism (EPRI, 1982, 1993). Modeled fields using this program are both precise and accurate for the input data utilized. Results of the model have been checked extensively against each other and against other software (*e.g.*, CORONA, from the Bonneville Power Administration, US Department of Energy) to ensure that the implementation of the laws of physics are consistent. In these validation tests, program results for MF levels were found to be in very good agreement with each other (Mamishev and Russell, 1995).

Modeled 60-Hz AC magnetic field levels from FIELDS are reported as root mean square (RMS) values of the resultant fields, generally referred to as $B_{Resultant}$ or B_{Res}, and sometimes as $B_{Product}$ or B_{Prod}. We have reported B_{Res} values to be consistent with the magnetic field levels that will be reported by instruments relying on three fixed orthogonal coils (*e.g.*, fixed-coil instruments like the EMDEX II), where the electronics calculate the sum of the squares of magnetic fields detected by each orthogonal coil separately. However, it is important to note that B_{Res} will always be larger than the real "maximum" rotating magnetic field (*i.e.*, the RMS value of the semi-major axis magnitude of the field ellipse; known as $B_{Maximum}$ or B_{Max}) when modeling (or measuring) elliptically or circularly polarized fields. In other words, B_{Res} is a conservative overestimate of magnetic field values, in particular for elliptically or circularly polarized magnetic fields typical of phase conductors in a "delta" configuration (IEEE, 2021).

3.2 Offshore Export Cable Specifications

Three three-core 275-kV offshore export cables will be used to deliver power from the Project's offshore wind energy generation facility to the landfall site at Dowses Beach in Barnstable. Each offshore export cable will be a three-core armored submarine cable, and Table 3.1 provides a summary of the cable specifications and currents used in the MF modeling analysis. As illustrated by Figure 3.1, which provides an example schematic of the type of offshore export cable proposed for Project usage, each offshore export cable will consist of three cores for power transmission and one or more fiber optic cables for communication, temperature measurement, and protection of the high-voltage system. Each cable will typically include three copper or aluminum conductors, with each conductor encapsulated by solid cross-linked polyethylene (XLPE) insulation. Water-blocking sheathing will be used to prevent water infiltration. The three insulated conductors will be twisted with a synthetic filler between the conductors, and the twisted or bundled conductors will then be wrapped in stainless steel wire and polyethylene rod armoring and finally encased in a tough outer sheath.

Identical, balanced phase conductor loadings of 1,077 A were assumed for all three offshore export cables. These are maximum loadings for the offshore export cables provided by the Proponent that are conservative values assuming maximum wind turbine output corresponding to 100% capacity. The wind turbine array is expected to operate at an annual-average capacity factor of approximately 50%; thus, for much of the time, the actual power output to the offshore export cables will be correspondingly lower than the maximum output loading levels used in this report. The currents include the charging currents for the Project onshore and offshore export system. See Table 3.1, Note a below for an explanation of charging currents.

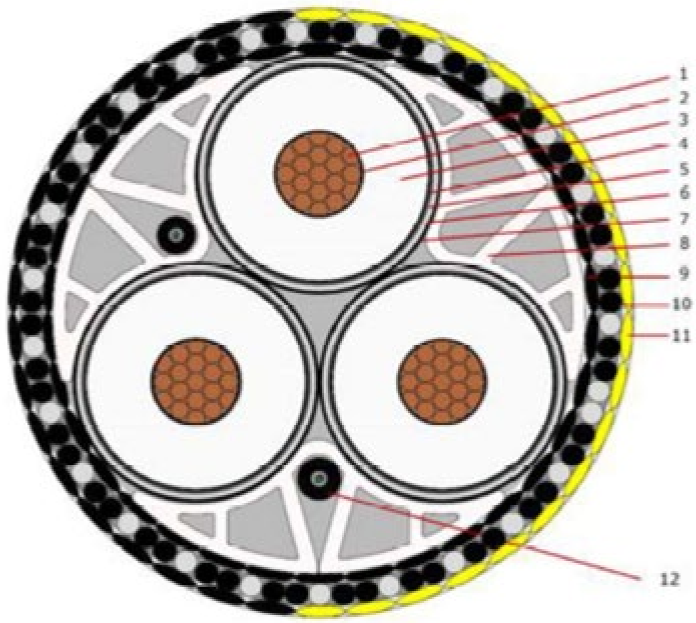
Table 3.1 275-kV Offshore Export Cable Specifications and Currents Used in the MF Modeling Analysis

Parameter	Specification Value
Constructional Data	
Conductor diameter	47.8 mm
Conductor spacing (center to center)	111.4 mm
Outer diameter of single core	110.5 mm
Armor type	Stainless steel wires and PE rod
Armor thickness	7.0 mm
Outer diameter of cable	274.0 mm
Electrical Data	
Current type and frequency	Alternating current 60 Hz
Operating Voltage	275 kV
Per Cable Load[a]	1,077 A

Notes:

A = Ampere; Hz = Hertz; kV = Kilovolt; MF = Magnetic Field; mm = Millimeter; PE = Polyethylene.

(a) Includes the impacts of charging currents – i.e., the additional electric current that occurs as the cables proceed from the offshore substation toward the Project onshore substation, because the cable conductors act to some degree like a capacitor that needs to be charged and discharged in addition to delivering actual electrical power to the onshore substation.



Not to scale – indicative only

No.	Description	Details
1	Conductor	Copper circular stranded, compacted, longitudinally water blocked, Semi conductive Water Swellable Tape on top of conductor
2	Conductor screen	Extruded bonded semi conductive compound
3	Insulation	XLPE (cross linked Polyethylene)
4	Insulation screen	Extruded bonded semi conductive compound
5	Water Blocking	Semi conductive Water Swellable Tape
6	Metal sheath	Lead alloy sheath
7	Inner sheath	Extruded Semi conductive Polyethylene on each phase
8	Fillers	Plastic fillers
9	Armour bedding	Polypropylene Yarns
10	Armouring	One layer mixed: 33% Stainless steel wires and 67% PE rod
11	Serving	Polypropylene Yarns
12	OF cable	2 x Optical Fibres Cable with 48 fibres

Figure 3.1 Example 275-kV Offshore Export Cable Cross Section Illustration. OF = Optical Fibre; PE = Polyethylene. From the cable datasheet provided in Appendix C.

While not shown in Figure 3.1, the three cores within the cables are to be helically wound, where the phase conductors would have a "twisted" design rather than being straight and parallel over long distances. This twisting of the conductors is expected to contribute to substantially greater self-cancellation of MF than predicted from the modeling analysis that assumes continuously straight conductors, although less than the cancellation associated with the triangular geometry of the conductors (CSA Ocean Sciences Inc. and Exponent, 2019). This additional self-cancellation from the twisting of the phase conductors is not typically reflected in MF modeling analyses of submarine cables due to the complexity of modeling it. It has been estimated for the 30-MW 60-Hz AC "sea2shore" cable, which was commissioned in 2016 to connect the Block Island wind energy project with the Rhode Island mainland grid, that the helical twisting of the three-phase cable reduced MF levels by at least 10-fold as compared to an untwisted three-phase cable (CSA Ocean Sciences Inc. and Exponent, 2019; Hutchison *et al.*, 2018).[4]

Although stainless steel armoring is more commonly used, the usage of ferromagnetic metal armoring such as galvanized steel armoring in the cables would also serve to partially attenuate the MFs reaching the sea bed environment as a result of both ferromagnetic shielding and opposing eddy currents that are induced in the armor (CSA Ocean Sciences Inc. and Exponent, 2019). This shielding factor is difficult to calculate due to the discontinuous nature of the wire armoring, although it will provide less shielding than a solid ferromagnetic pipe covering (for which a shielding factor of 10 is generally assumed; EPRI, 1993; EPRI and HVTRC, 1994). Studies provide support for a shielding factor of approximately two from ferromagnetic metal armoring of submarine cables (Lucca, 2013; CSA Ocean Sciences Inc. and Exponent, 2019).

3.3 Modeled Offshore Export Cable Cross Sections

MF modeling was performed for a representative submarine cable cross section consisting of the three three-core 275-kV offshore export cables buried to a depth of 4.9 ft (1.5 m) beneath the seabed and spaced 164 ft (50 m) apart. A burial depth of 4.9 ft (1.5 m) corresponding to the lower limit of the target burial depth of approximately 5 to 8 ft (1.5 to 2.5 m) was used. The offshore export cables within the OECC will typically be separated by approximately 164 to 328 ft (50 to 100 m), and the minimum cable spacing of 164 ft (50 m) was used in the MF modeling to capture any interaction of MF fields from adjacent cables at this minimum separation distance.

Modeling of the offshore export cables was also performed for cross sections representative of two locations along the three HDD paths to be constructed for bringing the cables ashore at the Dowses Beach landfall site in Barnstable, including: (1) a middle-of-the beach cross section representative of where the cables will pass under the publicly accessible beach with burial depths to the tops of the cables that range from 24.7 ft to 57.4 ft (7.5 m to 17.5 m) for the three HDD paths; and (2) a parking lot cross section representative of the cables beneath the paved parking lot at Dowses Beach, where they have moved closer to the ground surface prior to the transition vaults and the depths to the tops of the cables are 5.0 to 6.0 ft (1.5 to 1.8 m) for the three HDD paths. Separate modeling cases were performed for the southernmost HDD path (referred to as HDD1), which will come ashore in the southern portion of Dowses Beach with a minimum separation distance of 328 ft (100 m) from the other HDD paths; and for the other two HDD paths (referred to as HDD2 and HDD3), which will make landfall along the northern portion of Dowses Beach in closer proximity to each other.[5]

Table 3.2 summarizes the modeling parameters provided by the Proponent for each of the offshore export cable cross sections. For the representative buried submarine cable cross section, MFs were predicted at the sea floor surface for profiles perpendicular to the cables, consistent with other submarine cable MF modeling analyses (Normandeau Associates, Inc., *et al*., 2011). As discussed previously, MF levels in the water column above the sea floor will be substantially less than the modeled MF levels at the sea floor surface. The rate of MF level decrease as a function of height above the cable will be the same as the rate of fall-off as a function of distance laterally from the cable, *i.e.*, decreasing proportional to the square of

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[4] As sponsored by the BOEM, the Hutchison *et al.* (2018) research study compared modeled MF levels with field measurements of actual MF levels in the proximity of the 30-MW 60-Hz AC "sea2shore" cable. The authors found measured MF levels to be substantially lower than the modeled values, which did not take into account the three-conductor twisted design: "The magnetic field produced by the AC sea2shore cable (range of 0.05-0.3 µT) was ~10 times lower than modeled values commissioned by the grid operator, indicating that the three-conductor twisted design achieves significant self-cancellation" (Hutchison *et al.*, 2018).

[5] The MF modeling was conducted at the minimum separation distance of 65.6 ft (20 m) for the HDD2 and HDD3 offshore export cables to capture any interaction of MFs between adjacent cables.

the distance from the cable. For the middle-of-the-beach cross section at the Dowses Beach landfall site, MF levels were conservatively modeled at the ground (beach) surface, assuming that a beachgoer could be sitting or lying flat on the sand above an HDD path. Per standard industry practices (IEEE Power Engineering Society, 1995a,b), MFs were predicted at a height of 3.28 ft (1 m) above the ground surface for the parking lot cross section to represent the MF exposure of an upright person.

Table 3.2 Summary of Modeling Parameters for the 275-kV Offshore Export Cable Installation Scenarios

Cross Section	Cable Burial Depth	No. Cables	Cable Separation	Per Cable Load[a]
Buried Submarine	4.9 ft (1.5 m)	3	164 ft (50 m)	1,077 A
Landfall, Middle of Dowses Beach				
HDD1	24.7 ft (7.5 m)	1	NA	1,077 A
HDD2/HDD3	57.4 ft (17.5 m) / 57.2 ft (17.4 m)	2	65.6 ft (20 m)	1,077 A
Landfall, Parking Lot Behind Dowses Beach				
HDD1	5.0 ft (1.5 m)	1	NA	1,077 A
HDD2/HDD3	6.0 ft (1.8 m)	2	65.6 ft (20 m)	1,077 A

Notes:
A = Amperes; ft = Foot; HDD = Horizontal Directional Drilling; kV = Kilovolt; m = Meter; NA = Not Applicable.
(a) Includes the impacts of charging currents – i.e., the additional electric current that occurs as the offshore export cables proceed from the offshore substation toward the proposed onshore substation, because the cable conductors act to some degree like a capacitor that need to be charged and discharged in addition to delivering actual electrical power to the onshore substation.

3.4 MF Modeling Results for Offshore Export Cable Installation Scenarios

3.4.1 Representative Buried Submarine Cable Cross Section

Table 3.3 summarizes the modeled 60-Hz AC MF levels for the representative buried submarine cable cross section for the offshore export cables, and Figure 3.2 shows the AC MF magnitudes as a function of distance from the centerline of the cables. The modeling shows that the highest modeled AC MF levels of approximately 109 mG occur directly on the sea bed above the offshore export cables. Consistent with the compact bundling of the conductors within the three-core offshore export cables, Table 3.3 and Figure 3.2 show that MF levels diminish very rapidly with lateral distance away from the cable centerlines – *e.g.*, there is a >95% reduction in MF levels at a lateral distance of ±25 ft (±7.6 m) from the cable centerlines. MF levels in the water column will be less than the modeled MF levels at the sea floor, with the rate of decrease in MF levels as a function of height above the cables being similar to the rate of fall-off as a function of distance laterally from the cables. Due to the rapid reductions in MF levels with lateral distance away from the cables, there is minimal interaction of MF from adjacent cables at the modeled minimum separation distance of 164 ft (50 m).

As discussed in Section 2.3, no regulatory thresholds or guidelines for allowable EMF levels in marine environments have been established for HVAC submarine power transmission. Based on the localized nature of the MF impacts of the buried submarine cables as well as the weight of the scientific evidence that 60-Hz AC EMFs are above the typical frequency range of EMFs to which magnetosensitive and electrosensitive marine species are known to detect and respond, there is no expectation that the modeled MFs from the HVAC offshore export cables will cause significant population-level harms to marine species in the OECCs.

Table 3.3 Modeled Magnetic Fields at the Sea Floor for Buried Submarine 275-kV Offshore Export Cables[a]

Cross Section	Predicted Resultant Magnetic Field (mG)		
	Maximum Directly Above Cable Centerline(s)	±10 ft (±3 m) from Outer Cables[b]	±25 ft (±7.6 m) from Outer Cables[b]
Buried Submarine Cables	109.4	24.7	5.0

Notes:
ft = Foot; kV = Kilovolt; m = Meter; mG = Milligauss.
(a) The offshore export cable MF modeling assumes straight-laid phase-conductor cable cores rather than helical or "twisted" phase-conductor cores (the expected cable design). As discussed in Section 3.2, field measurements taken for the Block Island "sea2shore" cable show that a helical design achieves a considerable degree of magnetic field cancellation, hence the modeled MF levels are expected to be overestimates of actual MF levels at maximum wind farm output.
(b) The values provided at lateral distances of 10 and 25 ft are for 10 and 25 ft from the outer cables. Only one value is presented for each lateral distance because the predicted results for the left and right of the cables are identical.

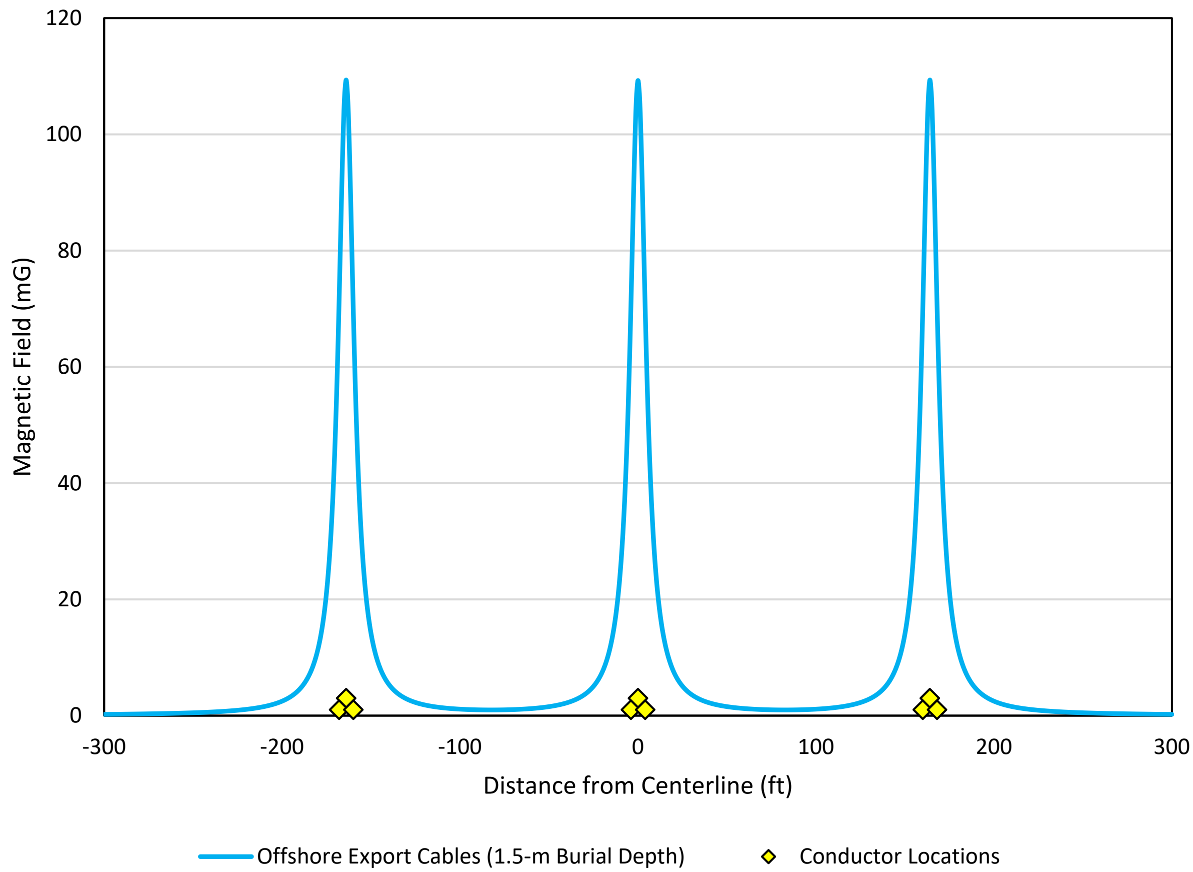


Figure 3.2 Magnetic Field Modeling Results at the Sea Floor for the Representative Buried Submarine Cross Section of the 275-kV Offshore Export Cables. ft = Feet; kV = Kilovolt; m = Meters; mG = Milligauss. Modeling results are based on 164-ft (50-m) cable spacing and a cable burial depth of 4.9 ft (1.5 m). The conductor locations (yellow diamonds) on the graphs are not to scale and are provided only to show relative locations.

3.4.2 Dowses Beach Landfall Site Cross Sections

Results of the MF modeling for the representative middle-of-beach and parking lot cross sections at the Dowses Beach landfall site are summarized in Table 3.4 and Figures 3.3 and 3.4 below. At the middle-of-the-beach location, maximum modeled MFs are 5.0 and 1.0 mG at the ground surface directly above the offshore export cables for the HDD1 and HDD2/HDD3 modeling cases, respectively. At the parking lot location, maximum modeled MFs are 41.4 and 32.7 mG 1 m above the ground surface directly above the offshore export cables for the HDD1 and HDD2/HDD3 modeling cases, respectively. These levels are well below the ICNIRP guideline of 2,000 mG for allowable public exposure to 60-Hz AC MFs (ICNIRP, 2010).

Modeled MF levels for the 275-kV offshore export cables are overestimates of the expected MF levels for actual Project operations due to several conservative assumptions in the modeling analysis, including the lack of accounting for the expected twisting of the conductors within the cables that will contribute to substantially greater self-cancellation of MF than for straight conductors, the use of cable currents based on maximum wind farm output (100 percent capacity), and no allowance for MF shielding by potential use of ferromagnetic armoring wires.

Table 3.4 Modeled Magnetic Fields for the 275-kV Offshore Export Cables Along the Horizontal Directional Drilling Paths at the Dowses Beach Landfall Site[a]

Cross Section	Predicted Resultant Magnetic Field (mG)		
	Maximum Directly Above Cable Centerline(s)	±10 ft (±3 m) from Reference Point[c]	±25 ft (±7.6 m) from Reference Point[c]
Landfall, Middle of Dowses Beach[b]			
HDD1	5.0	4.3	2.5
HDD2/HDD3	1.0	1.0	0.9
Landfall, Parking Lot Behind Dowses Beach[b]			
HDD1	41.4	17.9	4.5
HDD2/HDD3	32.7	16.1	4.7

Notes:

ft = Foot; HDD = Horizontal Directional Drilling; kV = Kilovolt; m = Meter; mG = Milligauss.

(a) The offshore export cable MF modeling assumes straight-laid phase-conductor cable cores rather than helical or "twisted" phase-conductor cores (the expected cable design). As discussed in Section 3.2, field measurements taken for the Block Island "sea2shore" cable show that a helical design achieves a considerable degree of magnetic field cancellation, hence the modeled MF levels are expected to be overestimates of actual MF levels at maximum wind farm output.

(b) Magnetic fields are modeled at the ground surface for the middle-of-beach cross section, and at 3.28 ft (1 m) above ground surface for the parking lot cross section.

(c) For HDD1, the values provided at lateral distances of 10 and 25 ft are with respect to the centerline of the cable. For HDD2 and HDD3, the values provided at lateral distances of 10 and 25 ft are for 10 and 25 ft from the outer cable. Only one value is presented for each lateral distance because the predicted MF results for the left and right of the cables are identical.

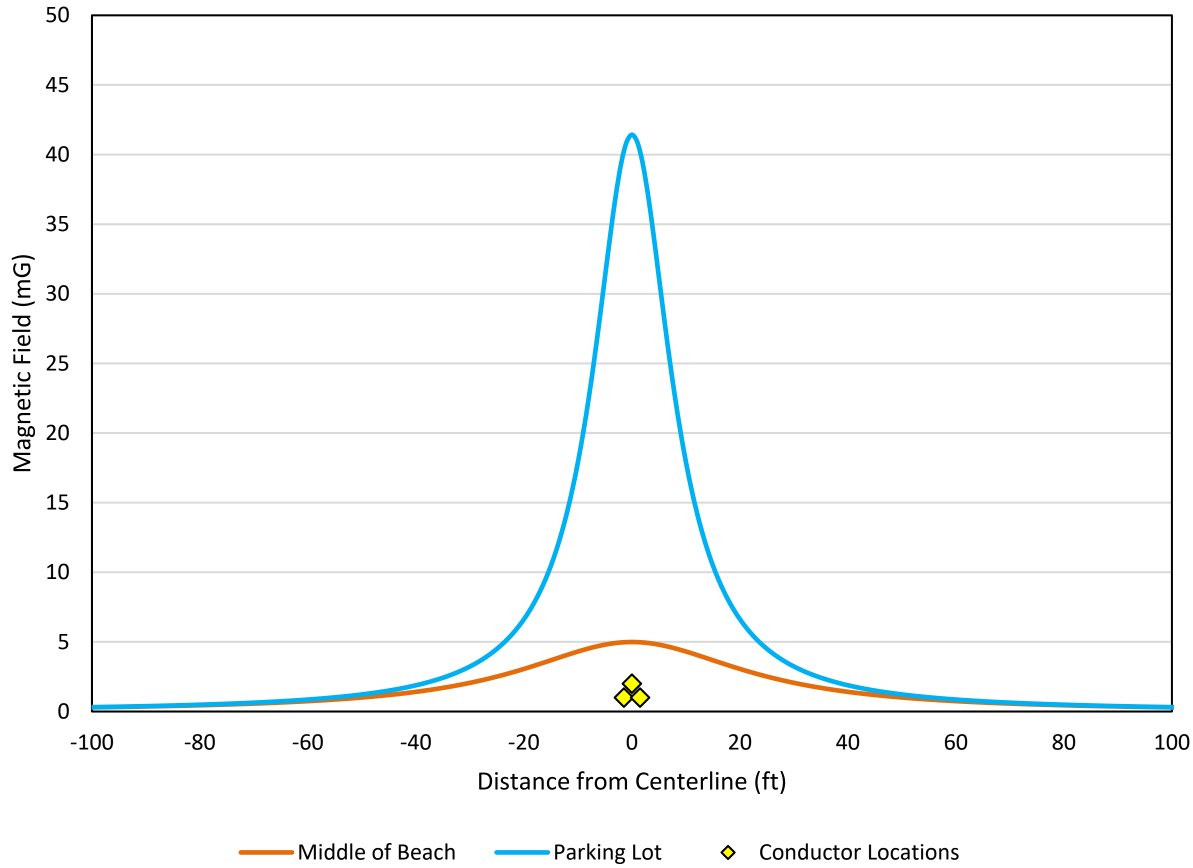


Figure 3.3 Magnetic Field Modeling Results for the 275-kV Offshore Export Cable Within Horizontal Directional Drilling Path 1 (HDD1) at the Dowses Beach Landfall Site. ft = Feet; mG = Milligauss. MF levels are provided for two locations along the HDD1 path (middle of beach – 24.7 ft burial depth, parking lot – 5 ft burial depth). The conductor locations (yellow diamonds) on the graphs are not to scale and are only provided to show relative locations.

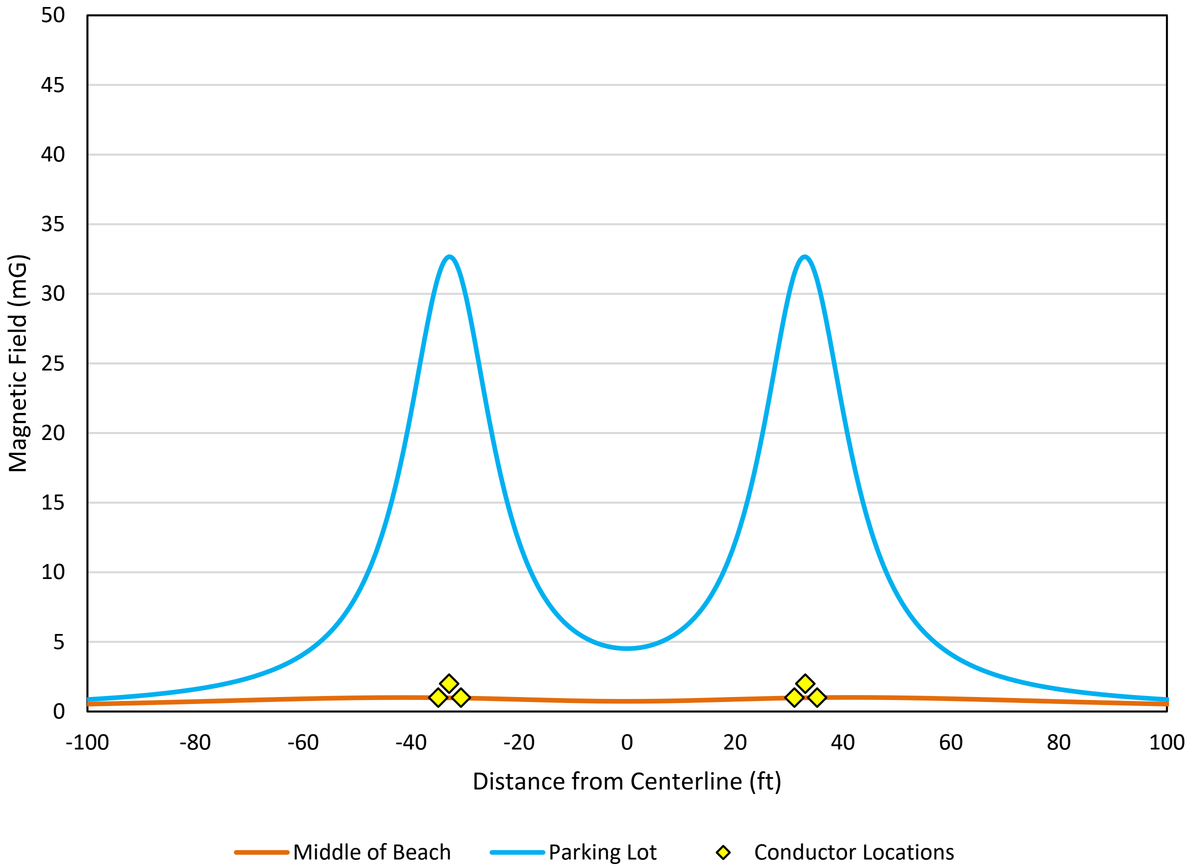


Figure 3.4 Magnetic Field Modeling Results for Two 275-kV Offshore Export Cables Within Horizontal Directional Drilling Paths 2 and 3 (HDD2, HDD3) at the Dowses Beach Landfall Site. ft = Feet; kV = Kilovolt; mG = Milligauss. MF levels are provided for two locations along the HDD2 and HDD3 paths (middle of beach – 57.4 ft (17.5 m) and 57.2 ft (17.4 m) burial depth for HDD2 and HDD3, respectively, and parking lot – 6 ft burial depth for both cables). Cables are assumed to be separated by 65.6 ft (20 m). The conductor locations (yellow diamonds) on the graphs are not to scale and are only provided to show relative locations.

4 MF Modeling for Onshore Export and Grid Interconnection Cables

4.1 Software Program Used for Modeling MF Levels for Onshore Export and Grid Interconnection Cable Installation Scenarios

MF strengths from the proposed onshore export and grid interconnection cables were calculated using the FIELDS computer program, which was previously described in Section 3.1 of this report. Modeled fields using this program are both precise and accurate for the input data utilized. As described previously in Section 3.1, modeled B_{Res} values from FIELDS – which is a conservative metric for modeled magnetic field values, in particular for elliptically or circularly polarized fields– are reported to be consistent with the magnetic field levels that will be reported by instruments relying on three fixed orthogonal coils (*e.g.*, fixed-coil instruments like the EMDEX II).

4.2 Onshore Export and Grid Interconnection Cable Specifications

Table 4.1 provides a summary of key specifications for the 275-kV onshore export cables to be installed in underground duct banks along the Project onshore transmission route between the Dowses Beach landfall site and the onshore substation, and Figure 4.1 provides an example schematic of the cable. The 275-kV single-core onshore export cables will consist of a copper conductor covered by XLPE solid insulation and wrapped in a metallic sheath with non-metallic outer jacket. There will be up to three onshore transmission circuits, with three cables making up a single circuit, for a total of up to nine 275-kV onshore export cables. The circuits are planned to be installed in underground duct banks which will contain 8 inch (20.32 cm) conduits for cables.

Identical, balanced conductor loadings of 1,098 amps were assumed for all onshore export cables. These are maximum loadings for the onshore export cables provided by the Proponent that are conservative values assuming maximum wind turbine output corresponding to 100% capacity. The wind turbine array is expected to operate at an annual-average capacity factor of approximately 50%; thus, for much of the time, the actual power output to the onshore export cables will be correspondingly lower than the maximum output loading levels used in this report. The currents for the onshore export cables include the charging currents for the Project onshore and offshore export system. See Table 4.1 footnote (a) below for an explanation of charging currents.

Table 4.1 275-kV Onshore Export Cable Specifications and Currents Used in the MF Modeling Analysis

Parameter	Specification Value
Constructional Data	
Cable Overall Diameter	138.4 mm
Conductor Diameter	64.5 mm
Conductor Type	Copper
Metal Neutrals and Sheathing	Copper wires and copper or aluminum tape
Electrical Data	
Current type and frequency	Alternating current 60 Hz
Rated voltage	275 kV
Conductor current[a]	1,098 A

Notes:
A = Ampere; Hz = Hertz; kV = Kilovolt; MF = Magnetic Field; mm = Millimeter.
(a) Includes the impacts of charging currents – *i.e.*, the additional electric current that occurs as the export cables proceed from the offshore substation toward the Project onshore substation, because the cable conductors act to some degree like a capacitor that need to be charged and discharged in addition to delivering actual electrical power to the onshore substation.

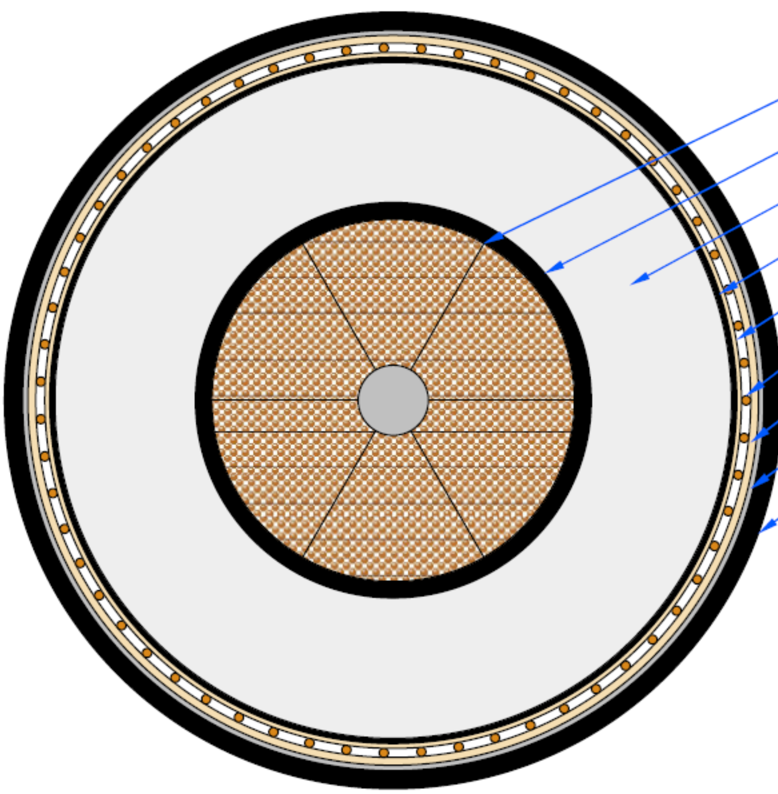


Figure 4.1 Example 275-kV Onshore Export Cable Cross Section Illustration. kg/m = Kilograms per Meter; kV = Kilovolt; lbs/ft = Pounds per Feet; mm = millimeters. From the cable datasheet provided in Appendix D.

Key cable specifications and a sample cable schematic are provided in Table 4.2 and Figure 4.2 for the 345-kV onshore grid interconnection cables to be used for the grid interconnection route between the onshore substation and the grid interconnection point at the existing Eversource 345-kV West Barnstable Substation. The 345-kV single-core grid interconnection cables will consist of a copper or aluminum conductor covered by XLPE solid insulation and wrapped in a metallic sheath with non-metallic outer jacket. There will be up to three grid interconnection circuits, with three cables making up a single circuit, for a total of up to nine 345-kV grid interconnection cables. Similar to the 275-kV onshore export system, the 345-kV grid interconnection circuits are planned to be installed in underground duct banks which will contain 8 in (20.32 cm) conduits for cables.

Identical, balanced conductor loadings of 837 amps were assumed for all 345-kV grid interconnection cables. These are maximum loadings for the grid interconnection cables provided by the Proponent that are conservative values assuming maximum wind turbine output corresponding to 100% capacity. The wind turbine array is expected to operate at an annual-average capacity factor of approximately 50%; thus, for much of the time, the actual power output to the grid interconnection cables will be correspondingly lower than the maximum output loading levels used in this report. Due to the short length of the grid interconnection route (~0.4 to 0.5 miles depending on the route option), charging currents are negligible and not considered for the 345-kV grid interconnection cables.

Table 4.2 345-kV Grid Interconnection Cable Specifications and Currents Used in the MF Modeling Analysis

Cable Specification or Feature	Parameter
Constructional Data	
Cable Overall Diameter	132.4 mm
Conductor Diameter	58.4 mm
Conductor Type	Copper or Aluminum
Metal Neutrals and Sheathing	Copper wires and copper tape
Electrical Data	
Current type and frequency	Alternating current 60 Hz
Rated voltage	345 kV
Conductor current	837 A

Notes:
A = Ampere; Hz = Hertz; kV = Kilovolt; MF = Magnetic Field; mm = Millimeter.

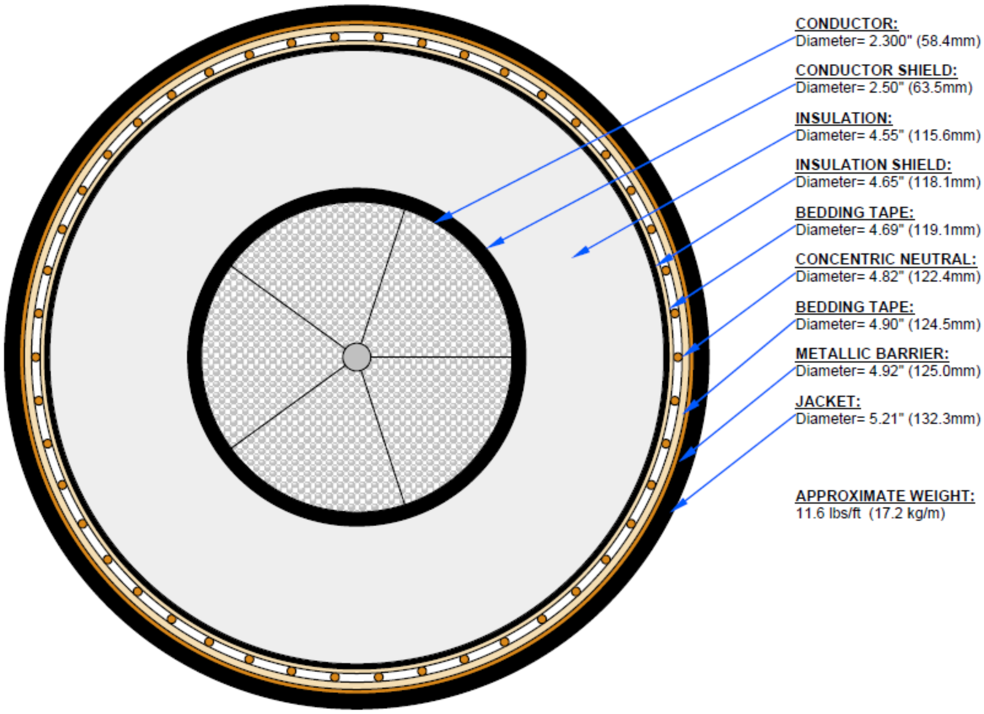


Figure 4.2 Example 345-kV Onshore Grid Interconnection Cable Cross Section Illustration. kg/m = Kilograms per Meter; kV = Kilovolt; lbs/ft = Pounds per Foot; mm = millimeter. From the cable datasheet provided in Appendix E.

4.3 Modeled Underground Onshore Export and Grid Interconnection Cable Installation Scenarios

MF modeling was performed by Gradient for 5 representative onshore export cable installation scenarios and 2 representative grid interconnection cable installation scenarios:

- Three 275-kV onshore export cable circuits arranged in a 3W×4D duct bank, buried 3.5 feet below ground surface (ft bgs) – referred to as the "typical" installation case for the 275-kV onshore export cables;
- Three 275-kV onshore export cable circuits arranged in a 3W×4D duct bank, buried 7.0 ft bgs – referred to as the "deep" installation case for the 275-kV onshore export cables for crossing under utilities and other obstructions;
- Three 275-kV onshore export cable circuits installed in two 72-inch diameter microtunnels (two cables in one microtunnel and one cable in the other), spaced 80 ft apart from each other, for crossing under the Route 6 Highway;
- A single 275-kV onshore export cable circuit installed in a transition joint bay (TJB) to be located beneath the Dowses Beach parking lot;[6]
- A single 275-kV onshore export cable circuit installed in a splice vault and the other two 275-kV onshore export cable circuits installed in either a 2-wide-by-4-deep (2W×4D) bypass duct bank or in individual 1-wide-by-4-deep (1W×4D) bypass duct banks adjacent to the splice vault;

[6] There is a single transition joint bay for each of the three onshore transmission circuits.

- Three 345-kV grid interconnection cable circuits arranged in a 3W×4D duct bank, buried 3.5 ft bgs – referred to as the "typical" installation case for the 345-kV grid interconnection cables;
- Three 345-kV grid interconnection cable circuits arranged in a 3W×4D duct bank, buried 7.0 ft bgs – referred to as the "deep" installation case for the 345-kV grid interconnection cables for crossing under utilities and other obstructions.

Gradient did not perform MF modeling for one additional installation case for the 275-kV onshore export cables, namely an underground 12W×1D duct bank proposed for use within the 24-inches of road surface cover above the Phinney's Bay box culvert on Dowses Beach Causeway. In order to minimize the magnetic fields associated with this shallow duct bank to be installed over the box culvert crossing, Stantec proposed the use of a 40MIL (0.040-inch) copper shield consisting of three conductive copper plates installed over the top and sides of the concrete duct bank. Gradient did not conduct MF modeling for this cross section because the FIELDS program does not have the capability to model the MF mitigation achieved by metallic plating. However, Stantec conducted MF modeling for this installation case using the CDEGS (Current Distribution, Electromagnetic Fields, Grounding and Soil Structure Analysis) software system that can account for the MF mitigation provided by the copper plate shielding proposed for this installation case, and the results for this MF modeling analysis are discussed in Section 4.5.

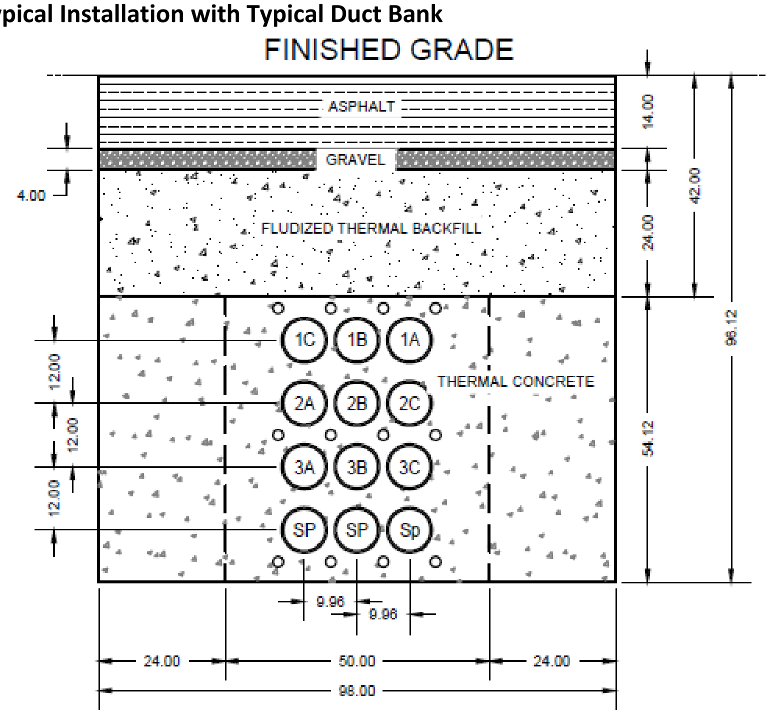
Table 4.3 summarizes the modeling parameters for the underground onshore export and grid interconnection cable installation cases, and Figures 4.3 through 4.7 provide cross section diagrams that show the duct bank configurations and conductor phasing arrangements. Figure 4.3 shows the proposed 3W×4D underground duct banks to be used for both the 275-kV onshore export and the 345-kV grid interconnection cables, with panel (a) showing the duct bank proposed for use for the majority of the Project onshore export and grid interconnection routes where the burial depth is 3.5 ft bgs ("typical installation"), and panel (b) showing the duct bank proposed for use where the Project circuits are to be buried at 7.0 ft bgs to traverse under utilities and other obstructions ("deep installation"). As indicated in these cross section diagrams, the horizontal conduit spacing also differs between the typical and deep installation cases (9.96 inches for the typical installation case *versus* 17.00 inches for the deep installation case). For modeling, each cable was assumed to lie in the bottom of 8-in (20.32-cm) conduits within the underground duct banks.

Table 4.3 Summary of Modeling Parameters for Underground Onshore Export and Grid Interconnection Cable Installation Scenarios

Installation Scenario	Burial Depth[a]	No. of Cable Circuits	Per Cable Load[b]
275-kV Onshore Export Cables			
3W×4D Duct Bank, Typical Installation	3.5 ft (1.1 m)	3	1,098 A
3W×4D Duct Bank, Deep Installation	7.0 ft (2.1 m)	3	1,098 A
Route 6 Crossing, 6-ft Microtunnel	12 ft (3.7 m)[c]	3	1,098 A
Transition Joint Bay	2.5 ft (0.76 m)	1	1,098 A
Splice Vaults	2.5 ft (0.76 m) to inner splice vault wall; 5.5 ft (1.7 m) to top of bypass duct banks	3 (1 in splice vault, and 2 in bypass duct bank[s])	1,098 A
345-kV Grid Interconnection Cables			
3W×4D Duct Bank, Typical Installation	3.5 ft (1.1 m)	3	837 A
3W×4D Duct Bank, Deep Installation	7.0 ft (2.1 m)	3	837 A

Notes:
3W×4D = 3-Wide-By-4-Deep; A = Ampere; ft = Foot; kV = Kilovolt; m = Meter.
(a) Burial depth to top of duct bank, microtunnel, transition joint bay, or splice vault.
(b) For the 275-kV onshore export cables, includes the impacts of charging currents – i.e., the additional electric current that occurs as the export cables proceed from the offshore substation toward the proposed onshore substation, because the cable conductors act to some degree like a capacitor that need to be charged and discharged in addition to delivering actual electrical power to the onshore substation. Charging currents are not considered for the 345-kV grid interconnection cables due to the short length of the grid interconnection route (~0.4 to 0.5 miles depending on the route option).
(c) Corresponds to the estimated burial depth beneath Route 6.

a) Typical Installation with Typical Duct Bank



b) Deep Installation with Typical Duct Bank

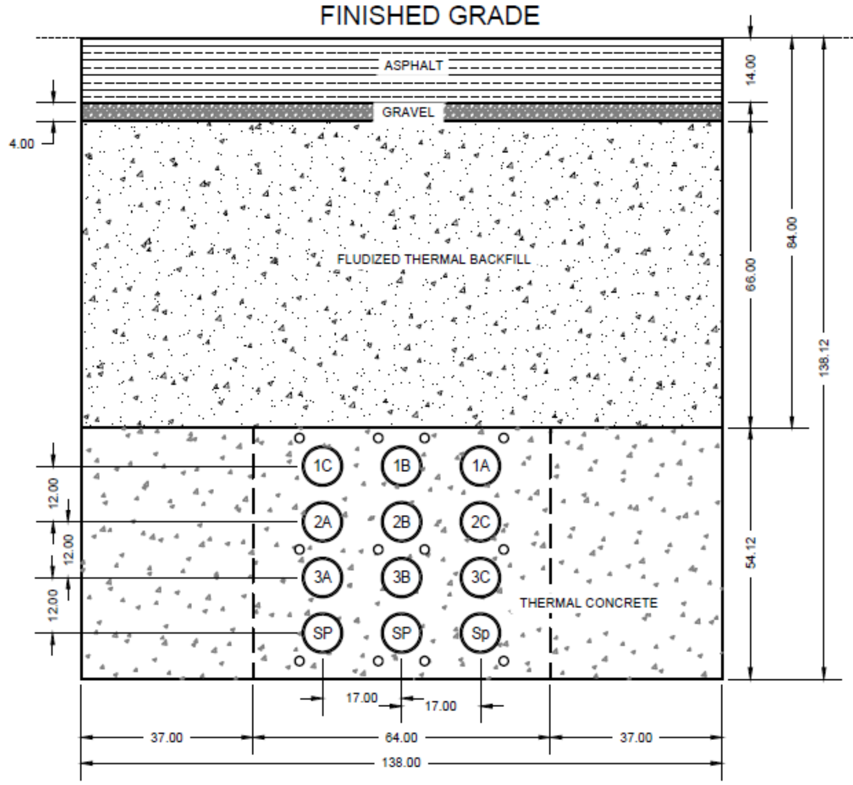


Figure 4.3 Representative Cross Section Drawings for Onshore Export and Grid Interconnection Cable 3W×4D Duct Bank Installation Scenarios. Panel (a) shows the duct bank used for a typical roadway scenario at a burial depth of 3.5 ft bgs, while panel (b) shows the duct bank for a deep installation scenario at a depth of 7.0 ft bgs. SP indicates an empty or spare conduit, while the numbers 1, 2, or 3 indicate the circuit and the letters A, B, or C indicate the conductor phasing.

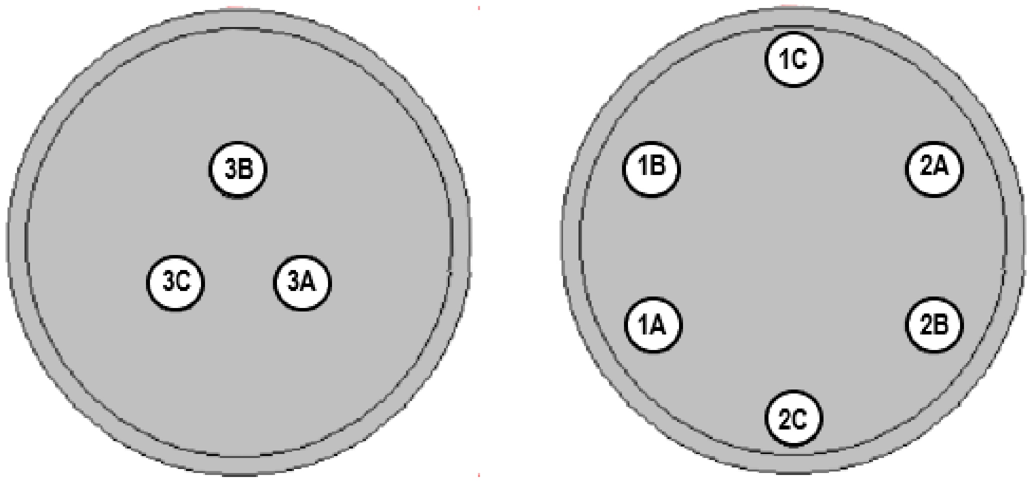


Figure 4.4 Representative Cross Section Drawings of the Microtunnel Conductor Configurations Proposed for the Route 6 Crossing Scenario of the 275-kV Onshore Export Cables. The horizontal separation distance between the two microtunnels is 80 ft (24.4 m). Both microtunnels are assumed to be buried 12 ft (3.7 m) below ground surface corresponding to the estimated burial depth beneath Route 6. The numbers 1, 2, or 3 indicate the circuit and the letters A, B, or C indicate the conductor phasing.

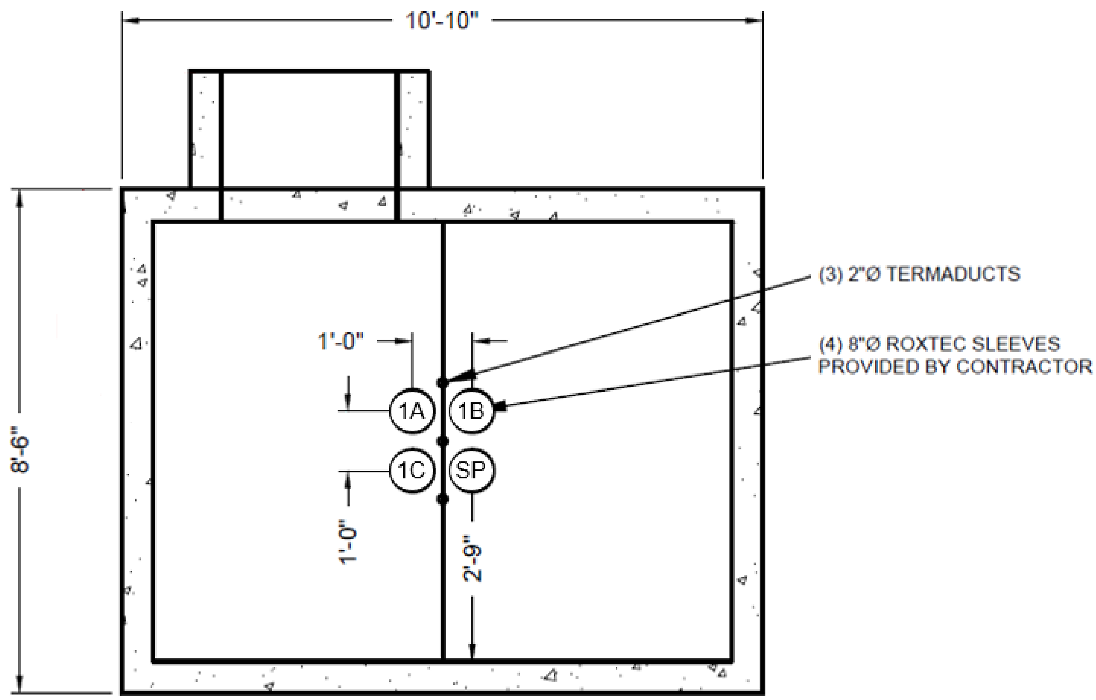
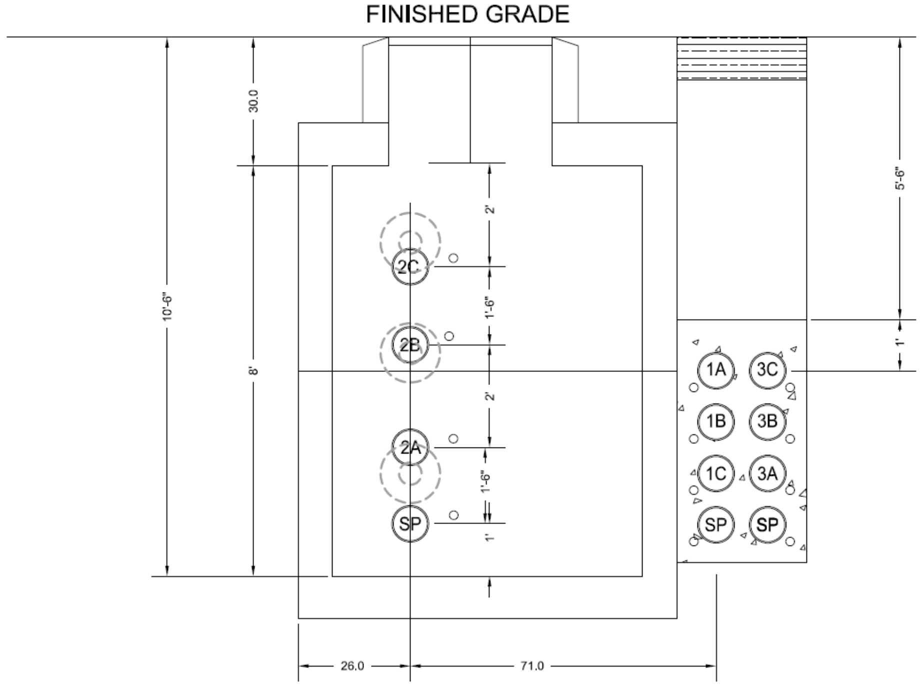
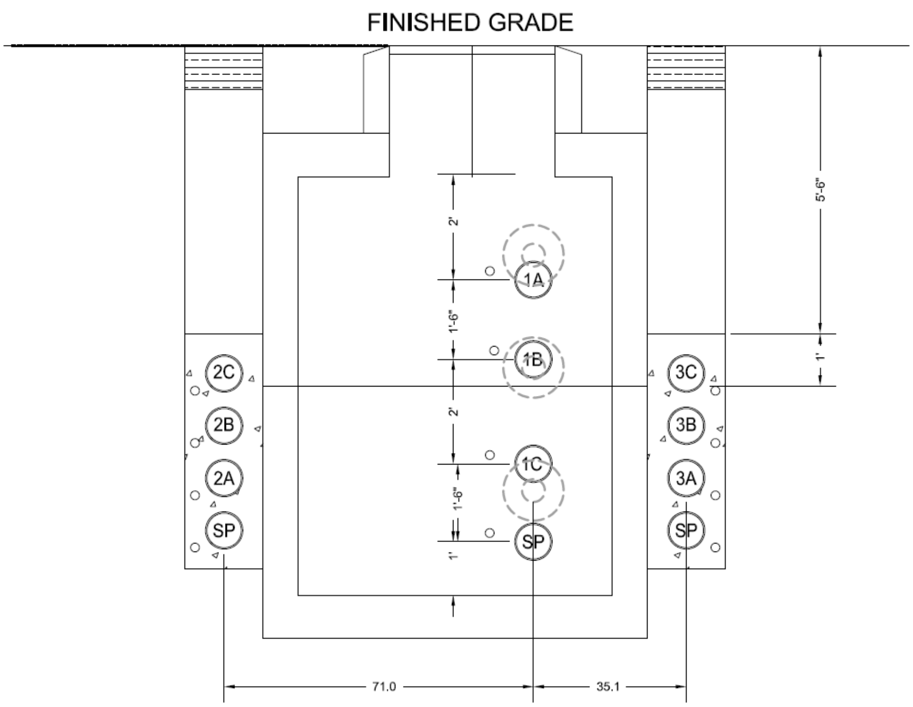


Figure 4.5 Representative Cross Section Drawing of a Single Circuit Transition Joint Bay for the 275-kV Onshore Export Cables in the Dowses Beach Parking Lot. Although the design is for 2.5 to 3.0 ft (0.76 to 0.91 m) of cover on top of the joint bay, modeling assumed the minimum cover of 2.5 ft (0.76 m). The centers of the top conduits are 4 ft (1.2 m) below the top of the joint bay. SP indicates an empty or spare conduit, while the letters A, B, or C indicate the conductor phasing.

a) Splice Vault Cross Section A – Typical Vault Penetrations



b) Splice Vault Cross Section B – Typical Vault Penetrations



c) Splice Vault Cross Section C – Typical Vault Penetrations

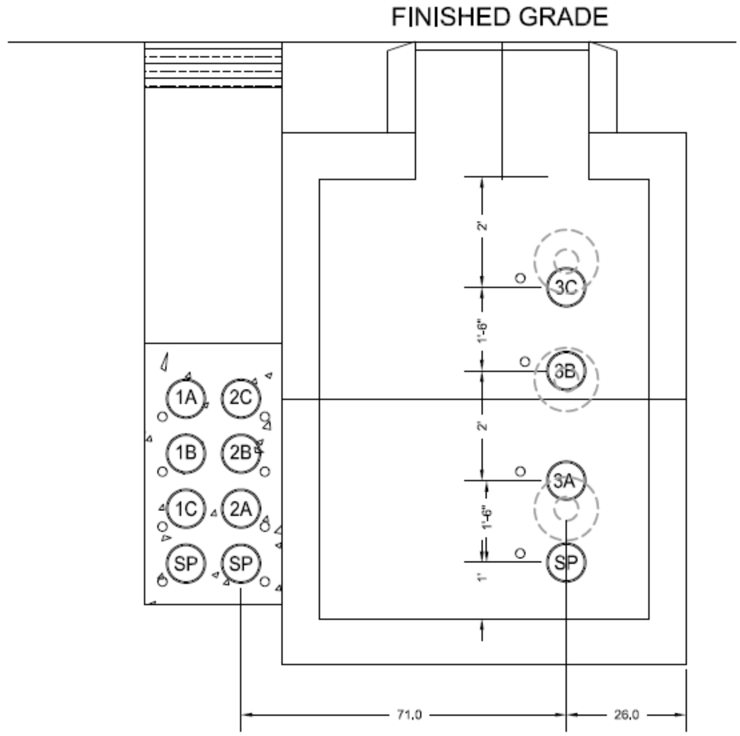


Figure 4.6 Representative Cross Section Drawings of the 275-kV Onshore Export Cable Splice Vaults. There are three cross sections, corresponding to the individual circuit splice vaults for each circuit. The circuits that are not being spliced are contained in either a 2W×4D bypass duct bank on one side of the splice vault (Cross Sections A and C) or individual 1W×4D bypass duct banks on either side of the splice vault (Cross Section B). The numbers 1, 2, or 3 indicate the circuit and the letters A, B, or C indicate the conductor phasing.

Mitigation of magnetic fields has been factored into the design of the underground onshore export and grid interconnection transmission systems. The underground placement of the onshore export and grid interconnection cables is a key design component for mitigating aboveground MF levels because underground phase conductors can be placed relatively close to each other in underground duct banks, contributing to greater self-cancellation of magnetic fields as compared to overhead circuits.[7] MF mitigation has been factored into the identification of minimum burial depths for the underground duct banks. MF mitigation has also been considered in the selection of conductor phasing, in particular the conductor phasing for the typical and deep installation 3W×4D duct bank arrays (*e.g.*, where the Circuit 1 phase conductors in the uppermost conduits are reverse phased with the Circuit 2 phase conductors below them in the middle conduits, and the Circuit 2 phase conductors are in phase with the Circuit 3 phase conductors below them, which results in significantly less aboveground MF levels than other conductor phasing arrangements). MF mitigation informed the design of both the transition joint bays and the splice vaults, including the burial depths, cable configurations, and conductor phasing arrangements. Modeling of the splice vault cross sections was conducted for multiple circuit configurations and phase conductor

[7] The closer spacing also results in more rapid fall-off of the MF levels with distance away from the cable centerlines (*i.e.*, more rapid decay with distance) than is the case with overhead circuits.

arrangements in order to identify constructible circuit configurations and phase conductor arrangements with reduced aboveground MF impacts. Finally, the installation of ground continuity conductors (GCCs) in the underground duct banks, which can carry currents induced by the MFs from the phase conductors and generate MFs that oppose (partially cancel) the phase conductor MFs, is also expected to contribute to some reduction in aboveground MFs.[8]

For each onshore cable installation cross section, aboveground MF strengths were modeled as a function of horizontal distance, perpendicular to the direction of current flow. Per standard industry practices (IEEE Power Engineering Society, 1995a,b), MF levels were modeled at a height of 3.28 ft (1 m) above the ground surface to represent the exposure of an upright person.

4.4 MF Modeling Results for the Underground Onshore Export and Grid Interconnection Cable Installation Scenarios

The results of the MF modeling for the representative underground onshore export and grid interconnection cable installation scenarios are summarized in Table 4.4. Figure 4.7 shows the MF modeling results for the 275-kV onshore export cable underground duct bank arrays, and Figures 4.8, 4.9, and 4.10 show the MF modeling results for the Route 6 crossing microtunnel, transition joint bay, and the splice vault installation scenarios, respectively. Figure 4.11 shows the modeling results for the 345-kV grid interconnection cable underground duct bank arrays. The modeled MFs, including those directly above the underground cables for all installation cases of both the 275-kV onshore export cables and the 345-kV grid interconnection cables, are all well below the ICNIRP health-based guideline of 2,000 mG for allowable public exposure to 60-Hz magnetic fields (ICNIRP, 2010). As shown in the table and each of the figures, the highest modeled MF levels for each of the underground onshore export and grid interconnection cable installation scenarios occur directly above the cables. Despite their greater burial depths, higher MF levels were obtained for the deep installation case than the typical installation case for both the 275-kV onshore export cables and the 345-kV grid interconnection cables due to the increased conductor spacing for the deep installation case that reduces MF self-cancellation and offsets the impact of the deeper burial depth. The plots show significant reductions in MF with increasing lateral distance from the cables including:

- For the 275-kV onshore export cable typical installation underground duct bank array, >80 percent reductions in MF levels at lateral distances of ±25 ft (±7.6 m) from the duct bank centerline;
- For the 275-kV onshore export cable underground transition joint bay cross section, >85 percent reductions in MF levels at lateral distances of ±25 ft (±7.6 m) from the duct bank centerline;
- For the 275-kV onshore export cable underground splice vault cross sections, >86 to >96 percent reductions in MF levels at lateral distances of ±25 ft (±7.6 m) from the duct bank centerline;
- For the 345-kV grid interconnection cable typical installation duct bank array, >80 percent reductions in MF levels at lateral distances of ±25 ft (±7.6 m) from the duct bank centerline.

Lastly, it bears mentioning that the MF modeling for both the underground onshore export and grid interconnection cable installation cases is expected to overpredict the magnitude of aboveground MF

[8] Because the FIELDS model cannot calculate the currents induced on GCCs by the phase conductors' main currents, the GCC induced currents were neglected in the MF modeling analysis. This is thus expected to be a contributing factor to the overestimation of MFs by the MF modeling analysis because any induced currents on ground conductors would be expected to produce an MF that would tend to oppose (partially cancel) the MF arising from the phase conductor currents (Istenic *et al.*, 2001).

levels associated with the installed onshore export and grid interconnection cables. This is because minimum expected burial depths were used, and the currents used for the cables assume maximum wind turbine output (100 percent capacity). In addition, as discussed earlier, the MF modeling analyses did not account for the phase conductors' main currents inducing currents on ground continuity conductors in the duct banks. Any induced currents on ground conductors would be expected to produce an MF that would tend to oppose (partially cancel) the MF arising from the phase conductor currents (Istenic *et al*., 2001).

Table 4.4 Modeled Magnetic Fields at 3.28 ft (1 m) Above Ground Surface for Underground Onshore Export and Grid Interconnection Cable Installation Scenarios

Installation Scenario	Predicted Resultant Magnetic Field (mG)		
	Maximum Above Reference Point[a]	±10 ft (±3 m) from Reference Point[a]	±25 ft (±7.6 m) from Reference Point[a]
275-kV Onshore Export Cables			
3W×4D Duct Bank, Typical Installation	77.2	50.1 / 50.1	14.3 / 14.3
3W×4D Duct Bank, Deep Installation	83.4	59.8 / 59.8	21.8 / 21.8
Route 6 Crossing, 6-ft Microtunnel	38.8	30.2 / 18.8	13.9 / 5.2
Transition Joint Bay	96.9	50.2 / 49.1	14.1 / 13.8
Splice Vaults, Cross Section A	232.8	110.8 / 105.5	29.9 / 31.8
Splice Vaults, Cross Section B	121.3	68.7 / 28.2	11.6 / 4.2
Splice Vaults, Cross Section C	253.6	121.9 / 116.1	29.1 / 31.0
345-kV Grid Interconnection Cables			
3W×4D Duct Bank, Typical Installation	58.7	38.1 / 38.1	10.9 / 10.9
3W×4D Duct Bank, Deep Installation	75.7	53.8 / 53.8	19.6 / 19.6

Notes:

3W×4D = 3-Wide-By-4-Deep; ft = Foot; kV = Kilovolt; m = Meter; mG = Milligauss.

(a) The two values presented correspond to the model-predicted fields at the given lateral distances to the left and right of the reference point, respectively, where the reference point for the duct bank, transition joint bay, and splice vault installation scenarios is the duct bank, transition joint bay, or splice vault centerline. For the Route 6 crossing microtunnel installation scenario, the values presented at lateral distances of 10 and 25 ft are for 10 and 25 ft from the outer microtunnel.

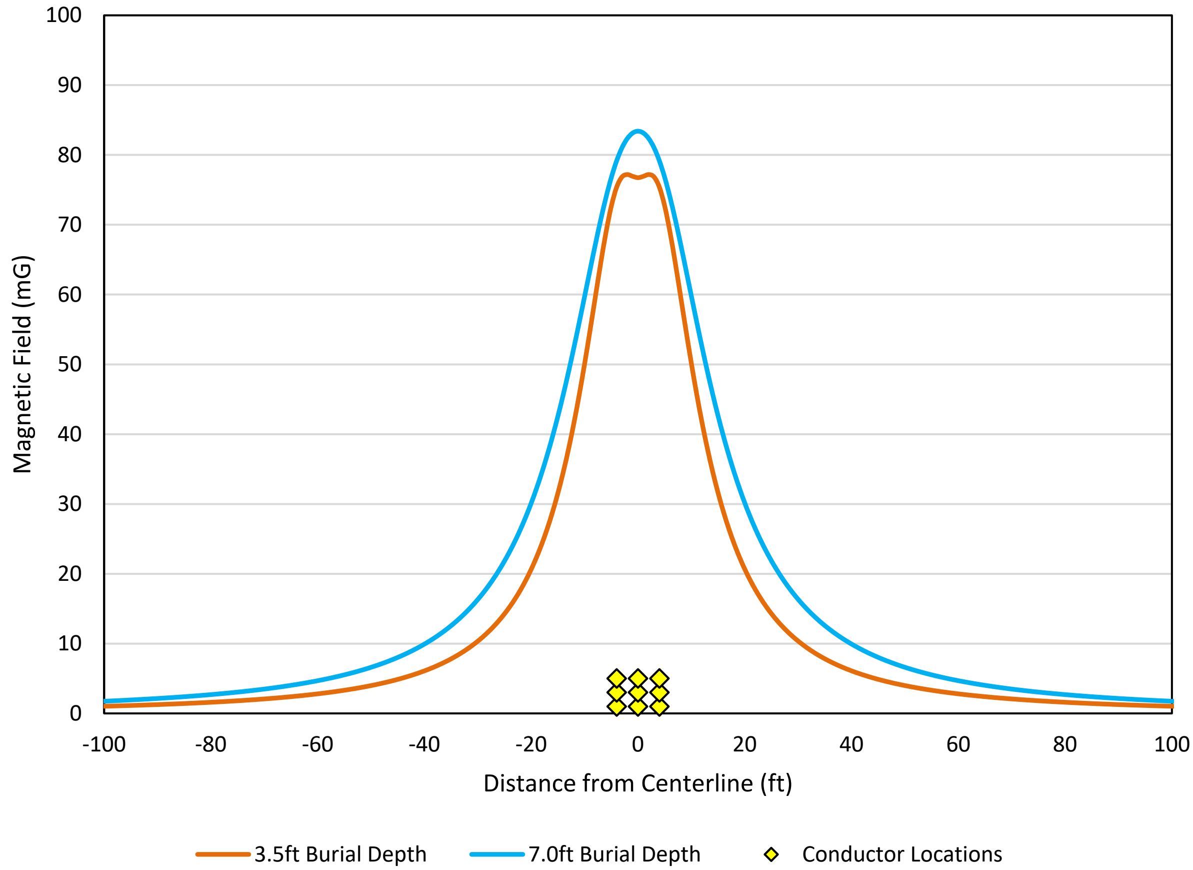


Figure 4.7 Magnetic Field Modeling Results at 1 Meter Aboveground for the 275-kV Onshore Export Cables in the Underground 3W×4D Duct Bank Arrays. ft= Feet; kV = Kilovolt; mG = Milligauss. The conductor locations (yellow diamonds) on the graphs are not to scale and are only provided to show relative locations.

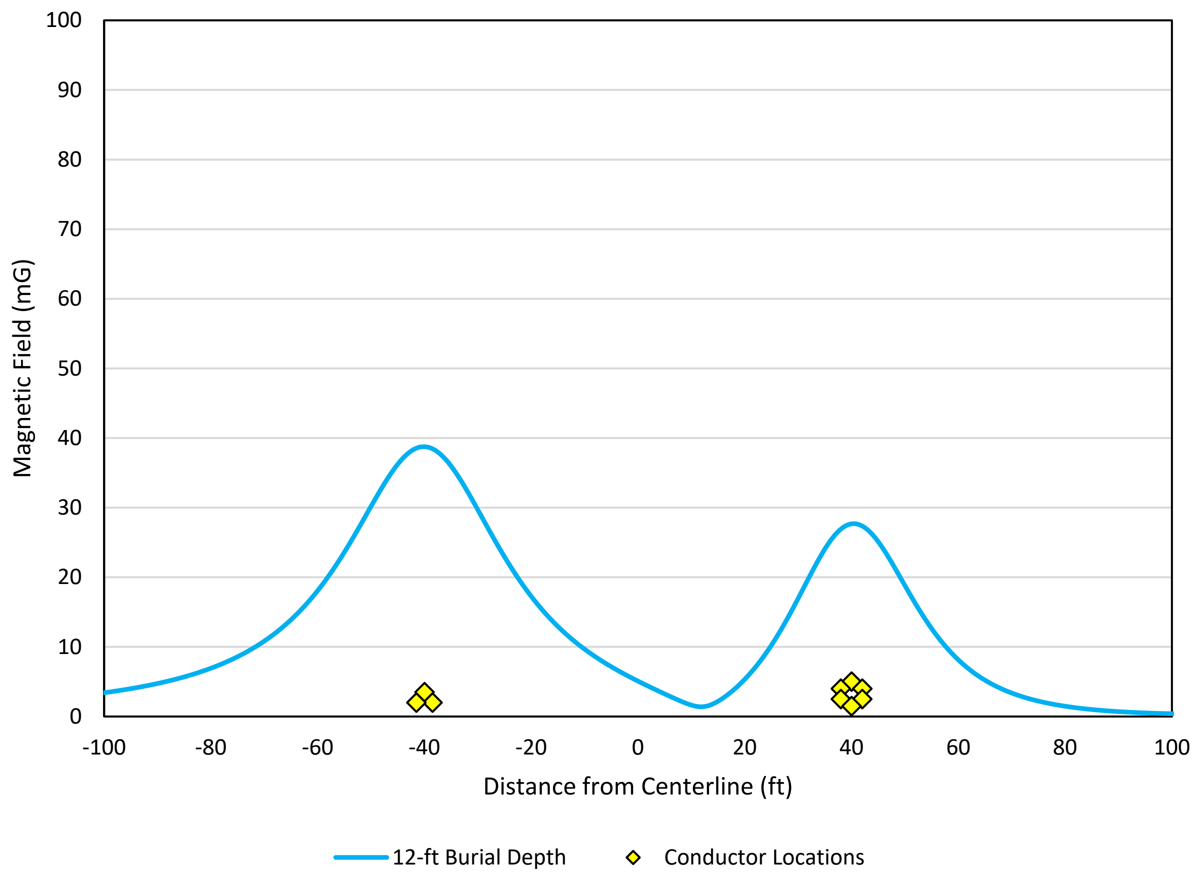


Figure 4.8 Magnetic Field Modeling Results at 1 Meter Aboveground for the Route 6 Crossing of the 275-kV Onshore Export Cables in Underground Microtunnels. ft= Feet; kV = Kilovolt; mG = Milligauss. Modeling was conducted for a burial depth of 12 feet (3.7 m) to the microtunnels, corresponding to the estimated depth where they cross beneath Route 6. The conductor locations (yellow diamonds) on the graphs are not to scale and are only provided to show relative locations.

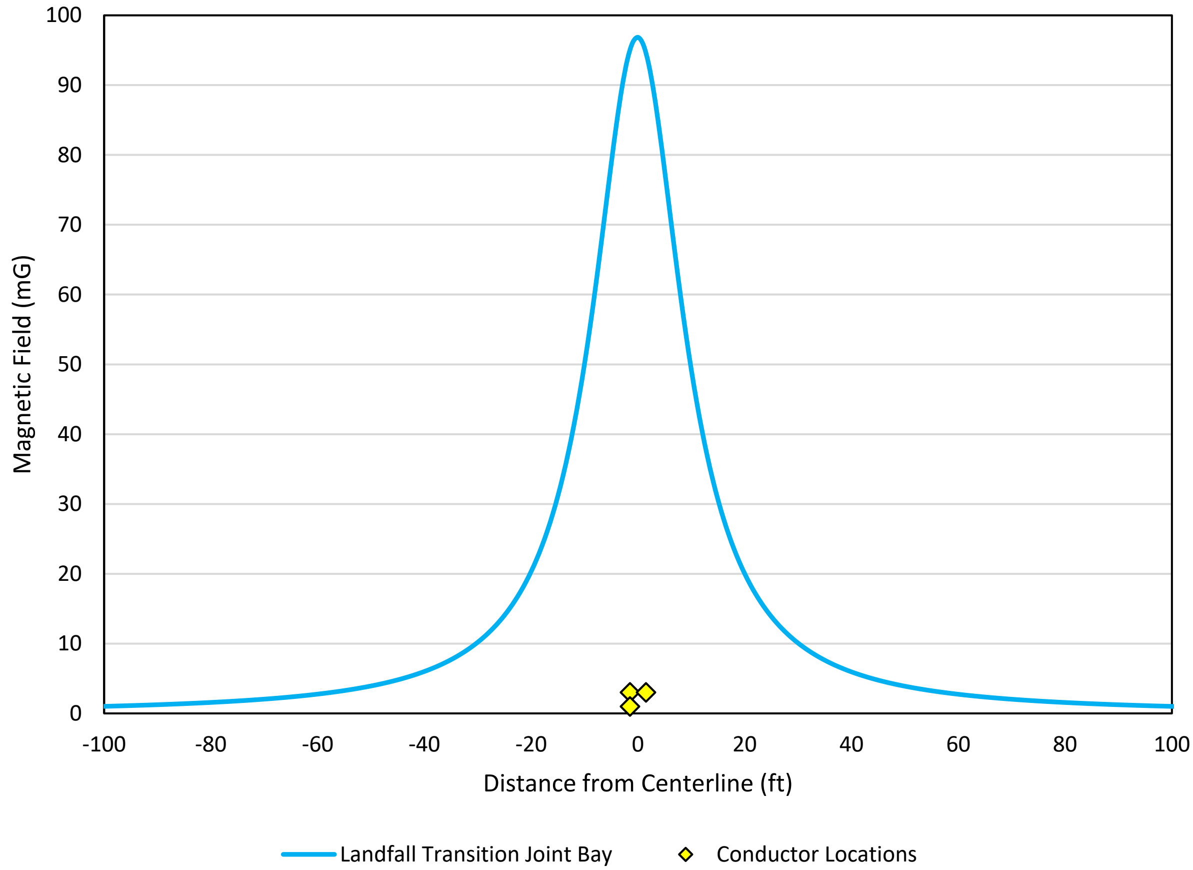
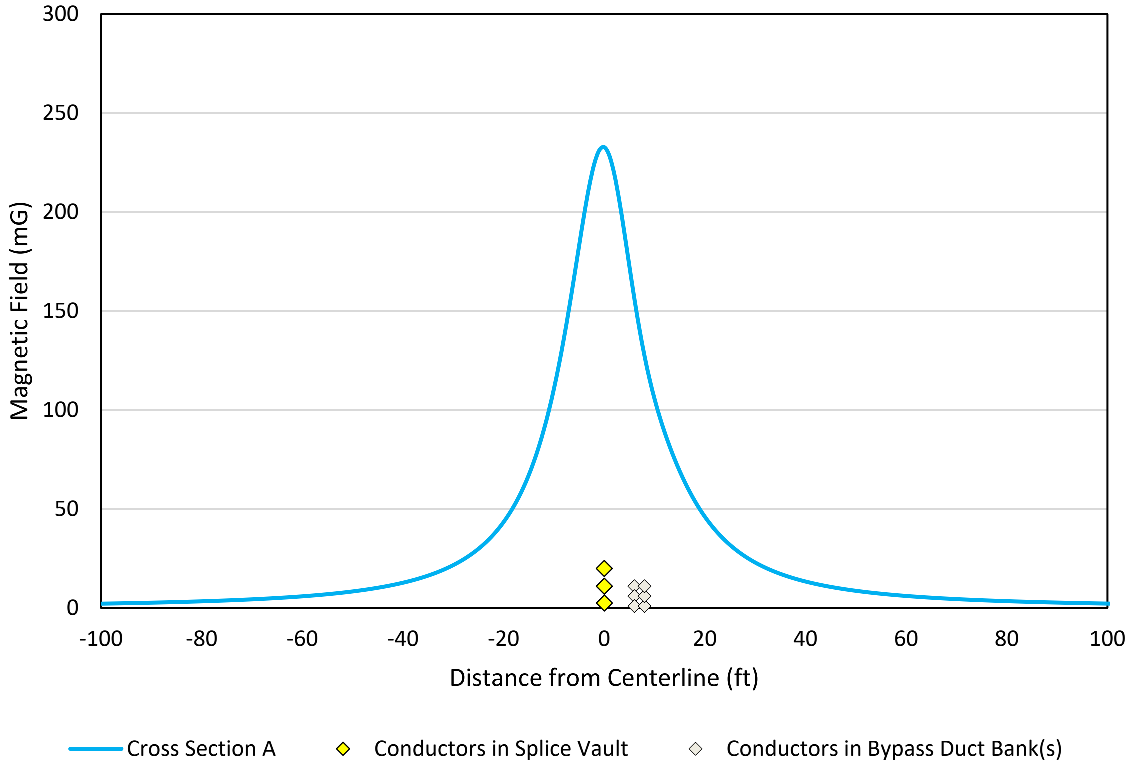
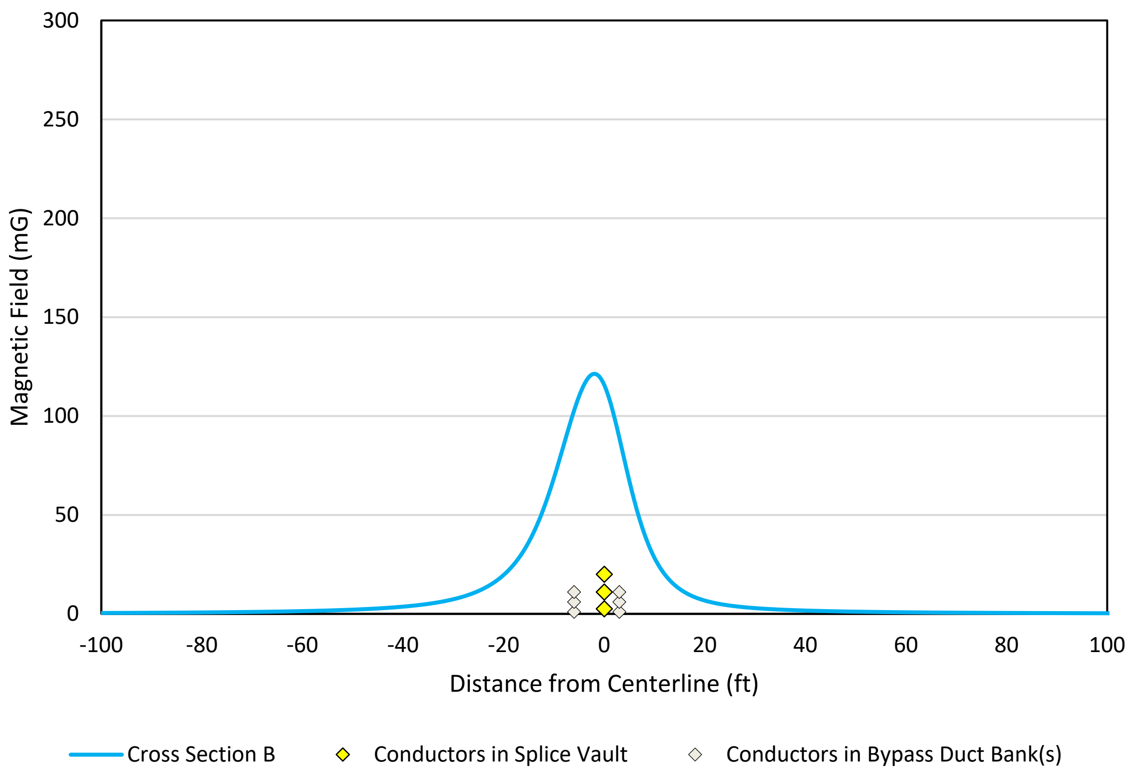


Figure 4.9 Magnetic Field Modeling Results at 1 Meter Aboveground for an Underground Transition Joint Bay at the Dowses Beach Landfall Site Containing an Individual 275-kV Onshore Transmission Circuit. ft= Feet; kV = Kilovolt; mG = Milligauss. The conductor locations (yellow diamonds) on the graphs are not to scale and are only provided to show relative locations.

a) Splice Vault Cross Section A



b) Splice Vault Cross Section B



c) Splice Vault Cross Section C

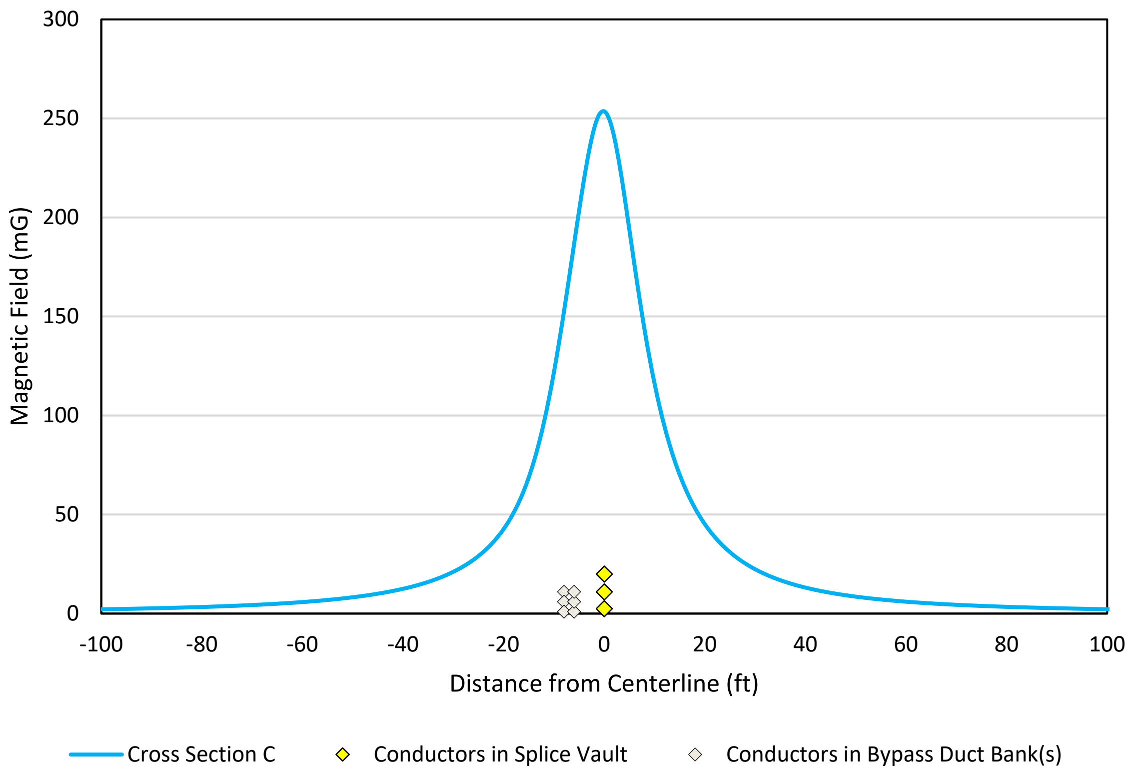


Figure 4.10 Magnetic Field Modeling Results at 1 Meter Aboveground for the 275-kV Onshore Export Cable Splice Vault Cross Sections. ft= Feet; kV = Kilovolt; mG = Milligauss. There are three cross sections corresponding to the individual splicing of the three circuits. The conductor locations (yellow diamonds) on the graphs are not to scale and are only provided to show relative locations.

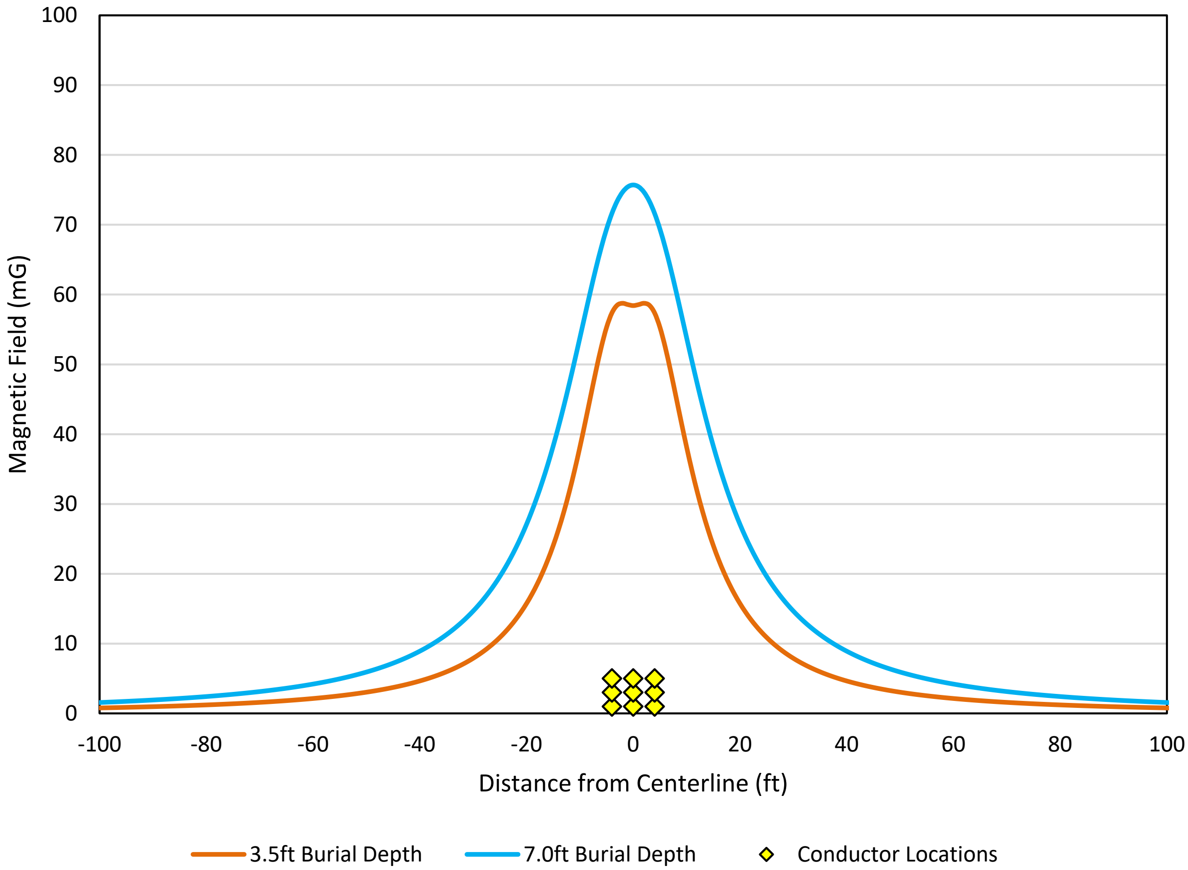


Figure 4.11 Magnetic Field Modeling Results at 1 Meter Aboveground for the 345-kV Grid Interconnection Cables in the Underground 3W×4D Duct Bank Arrays. ft= Feet; kV = Kilovolt; mG = Milligauss. The conductor locations (yellow diamonds) on the graphs are not to scale and are only provided to show relative locations.

4.5 MF Modeling Analysis for the Phinney's Bay Culvert Crossing with the Three 275-kV Onshore Export Cables in an Underground 12W×1D Duct Bank with Copper Plate Shielding

For the crossing of the existing Phinney's Bay box culvert located on Dowses Beach Causeway in Barnstable, it has been determined that it is not feasible to bury the typical underground 3W×4D duct bank to be used for the onshore export cables (Epsilon Associates, Inc., 2022; Stantec Consulting Services, Inc., 2022). Instead, the three 275-kV onshore export circuits will be arranged in a twelve conduit wide by one conduit deep configuration (*i.e.*, in an underground 12W×1D duct bank approximately 9.75 feet wide by 1.2 feet tall; see Figure 4.12) when crossing the box culvert (Epsilon Associates, Inc., 2022; Stantec Consulting Services, Inc., 2022). The three sets of 275-kV single-core onshore export cables will transition from the typical underground 3W×4H duct bank to a 12W×1D duct bank within the 24-inches of road surface cover above the Phinney's Bay box culvert, and will then transition back to the typical underground 3W×4H duct bank after the culvert crossing. As indicated in Figure 4.12, there will be approximately 10 inches of cover above the shallow concrete duct bank.

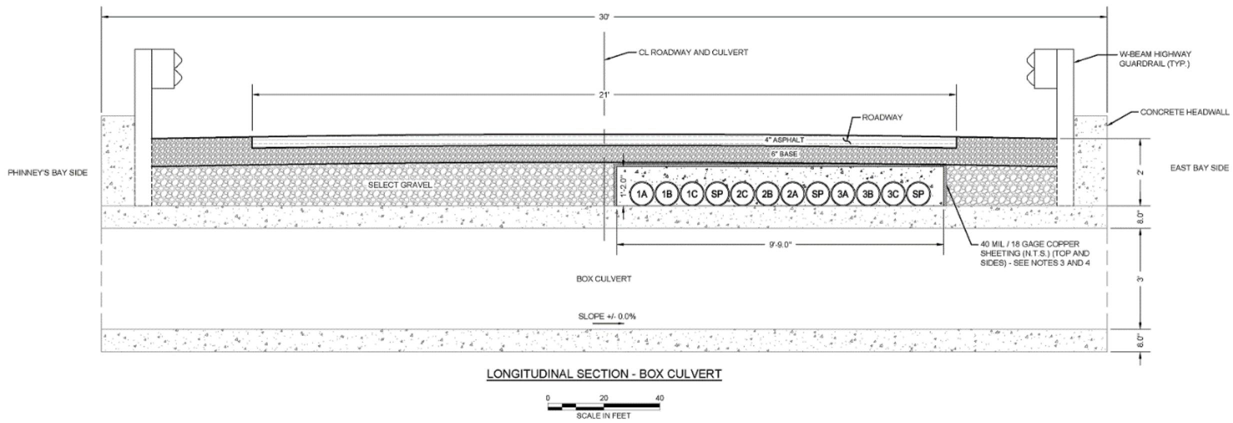


Figure 4.12 Cross Section for the Phinney's Bay Box Culvert Crossing with the Proposed Underground 12W×1D Duct Bank and Conductive Copper Plates. SP= Spare Duct. As indicated in the drawing, a 40MIL (0.040-inch) copper shield consisting of three copper plates installed over the top and sides of the concrete duct bank is proposed for minimizing the magnetic fields associated with this shallow duct bank. The proposed conductor phasing arrangements for the three circuits are also indicated in the drawing.

In order to minimize the magnetic fields associated with this shallow duct bank to be installed over the box culvert crossing, Stantec proposed the use of a 40MIL (0.040-inch) copper shield consisting of three conductive copper plates installed over the top and sides of the concrete duct bank. Stantec proposed that the copper sheeting be fabricated with bends along two edges to ensure continuous contact with the duct bank on three sides. Stantec conducted MF modeling using the CDEGS software system that demonstrated the proposed copper plates to have a shielding factor of approximately 3.6 for peak magnetic field levels above the duct bank. This modeling analysis assumed that the copper plate shielding will be installed along three sides of the duct bank over the entire length of the duct bank.

Figure 4.13 is a figure generated by Stantec from their MF modeling analysis that shows the magnetic fields predicted using CDEGS at a height of 1 meter above the ground surface with the MF mitigation from the copper plating. Gradient did not conduct MF modeling for this cross section because the FIELDS program does not have the capability to model the MF mitigation achieved by metallic plating. The Stantec modeling analysis predicted a maximum MF level of 63.0 mG above the duct bank with the proposed copper plating. Figure 4.13 shows the reduction in MF levels moving laterally along the bridge structure away from the location of the underground duct bank, with a MF level of approximately 32 mG at the bridge edge closest to the duct bank and a MF level of approximately 8 mG at the farther bridge edge, both at a height of 1 meter above the ground surface. These modeling results are consistent with literature reports of the significant shielding effect of conductive copper plates directly above underground cables (CIGRE, 2009, 2014).

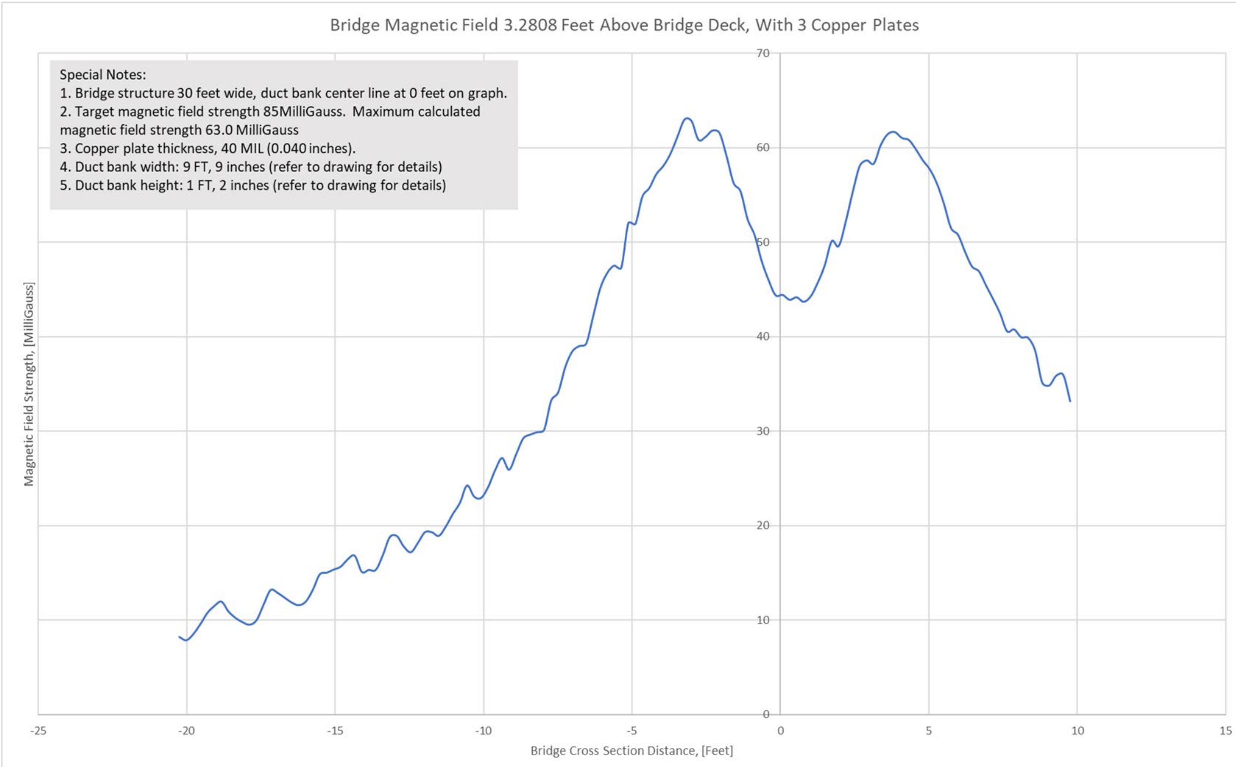


Figure 4.13 Model-predicted Magnetic Fields in Milligauss (mG) at the Phinney's Bay Box Culvert Crossing Located on Dowses Beach Causeway in Barnstable from the Stantec MF Modeling Analysis Using CDEGS. MF levels are shown at a height of 1 meter above the ground surface, and include MF mitigation from the proposed copper plating to be installed on three sides of the proposed underground 12W×1D duct bank with the onshore export cables. The width of the bridge structure is 30 feet, with the centerline of the duct bank assigned as x=0 in the graph.

5 Conclusions

Gradient performed an independent EMF assessment for the New England Wind 2 Connector Project, which will deliver up to 1,200 MW of offshore wind energy generation to the New England energy grid *via* up to three 275-kV three-core offshore export cables, three sets of 275-kV single-core onshore export cables, and three sets of 345-kV single-core grid interconnection cables. This modeling analysis focused on MFs because the electric fields produced by the voltage on the offshore export cables will be contained by the metallic sheathing and/or steel armoring of the cables – *i.e.*, the metallic sheathing and/or steel armoring will completely shield the electric fields arising from the voltage on the cables. In addition, there will be no aboveground electric fields from either the onshore export cables or the grid interconnection cables, since both of these cables will be installed underground and underground lines produce no aboveground electric fields.

For the 275-kV offshore export cables, 275-kV onshore export cables, and 345-kV grid interconnection cables, MF modeling was conservatively performed for representative installation cases assuming maximum wind turbine output (100% capacity). The wind turbine array is expected to operate at an annual-average capacity factor of approximately 50%; thus, much of the time, the actual output and MF attributable to the Project cables will be correspondingly lower than predicted herein for maximum output.

For the 275-kV offshore export cables, MF levels were modeled at the sea floor for a representative submarine installation cross section that assumed a burial depth of 4.9 ft (1.5 m) corresponding to the lower limit of the target burial depth of approximately 5 to 8 ft (1.5 to 2.5 m) for the offshore export cables, and the minimum spacing of 164 ft (50 m) between the cables. The modeling showed the highest modeled MF levels of approximately 109 mG directly above the offshore export cables, with rapid reductions in MF levels with lateral distance away from the cable centerlines – *e.g.*, there is a >95% reduction in MF levels at a lateral distance of ±25 ft (±7.6 m) from the cable centerlines. MF levels in the water column will be less than the modeled MF levels at the sea floor, with the rate of decrease in MF levels as a function of height above the cables being similar to the rate of fall-off as a function of distance laterally from the cables. Due to the rapid reductions in MF levels with lateral distance away from the cables, there is minimal interaction of MF from adjacent cables at the modeled minimum separation distance of 164 ft (50 m). Based on the localized nature of the MF impacts of the offshore export cables as well as the weight of the scientific evidence that 60-Hz AC EMFs are above the typical frequency range of EMFs to which magnetosensitive and electrosensitive marine species are known to detect and respond, there is no expectation that the modeled MFs from the HVAC offshore export cables will cause significant population-level harms to marine species in the OECCs.

Modeling of the offshore export cables was also performed for cross sections representative of two locations at the Dowses Beach landfall site in Barnstable along the HDD paths to be constructed for bringing the cables ashore, including: (1) a middle-of-the beach cross section representative of where the cables will pass under the publicly accessible beach with burial depths to the tops of the cables that range from 24.7 ft to 57.4 ft (7.5 m to 17.5 m) for the three HDD paths; and (2) a parking lot cross section representative of the HDDs beneath the paved parking lot at Dowses Beach, where the offshore export cables have moved closer to the ground surface prior to the transition vaults and have depths to the tops of the cables of 5.0 to 6.0 ft (1.5 to 1.8 m) for the three HDD paths. Maximum modeled MFs of 5.0 and 1.0 mG were obtained at the ground surface directly above the offshore export cables for the two HDD modeling scenarios for the middle-of-the-beach location. For the parking lot location where the HDD paths are closer to the ground surface, maximum modeled MFs were 41.4 and 32.7 mG at 1 m above the ground surface directly above the offshore export cables for the two HDD modeling scenarios. For the parking lot cross section, modeled MFs were found to drop off very rapidly with lateral distance from the cables, with reductions in MF levels of between 85 to 90% for a lateral distance of 25 feet on either side of the cable centerlines. All modeled MF levels for the landfall site cross sections were below both the ICNIRP health-based guideline of 2,000 mG for allowable public exposure to 60-Hz AC MFs. This is the case despite modeled MF levels for the 275-kV offshore export cables being overestimates of the expected MF levels for actual Project operations due to several conservative assumptions in the modeling analysis, including the lack of accounting for the expected twisting of the conductors within the cables that will contribute to substantially greater self-cancellation of MF than for straight conductors, and the use of cable currents based on maximum wind farm output (100 percent capacity).

For the 275-kV onshore export cables, MF levels were calculated 1 meter above the ground surface for several underground circuit cross sections representative of different portions of the Project onshore transmission route, including both the typical and deep installation cases for the underground 3W×4D duct banks to be used for the majority of the onshore transmission route, the microtunnels to be used for the Route 6 crossing, the transition joint bays to be located in the Dowses Beach parking lot, and the splice vaults to be located in groups every 1,500 to 3,000 feet (approximately 460 to 915 meters) or more along the onshore transmission route. In addition, MF levels were calculated 1 meter above the ground surface for both the typical and deep installation cases for the underground 3W×4D duct banks to be used for the 345-kV grid interconnection cables to be installed between the new onshore substation and the grid interconnection point at the existing Eversource 345-kV West Barnstable Substation.

As described in this report, all modeled MF levels for the representative cross sections of the 275-kV onshore export cables and 345-kV grid interconnection cables are below the ICNIRP health-based guideline of 2,000 mG for allowable public exposure to 60-Hz AC MFs. Moreover, the MF modeling results show significant reductions in MF levels with increasing lateral distance from the cables. Similar to the MF modeling for the offshore export cables, the MF modeling for both the underground onshore export and grid interconnection cable installation cases is expected to overpredict the magnitude of aboveground MF levels associated with the installed onshore export and grid interconnection cables. This is because minimum expected burial depths were assumed, and the currents used for the cables assume maximum wind turbine output (100% capacity). In addition, as discussed earlier, the MF modeling analyses did not account for the phase conductors' main currents inducing currents on ground continuity conductors in the duct banks. Any induced currents on ground conductors would be expected to produce an MF that would tend to oppose (partially cancel) the MF arising from the phase conductor currents.

MF modeling performed by Stantec for one additional installation case for the 275-kV onshore export cables, namely an underground 12W×1D duct bank with copper plate shielding proposed for use for the Phinney's Bay culvert crossing on Dowses Beach Causeway in Barnstable, showed that the proposed use of copper plate shielding minimized aboveground MF levels from this shallow duct bank, with a maximum modeled MF level of 63.0 mG directly above the duct bank.

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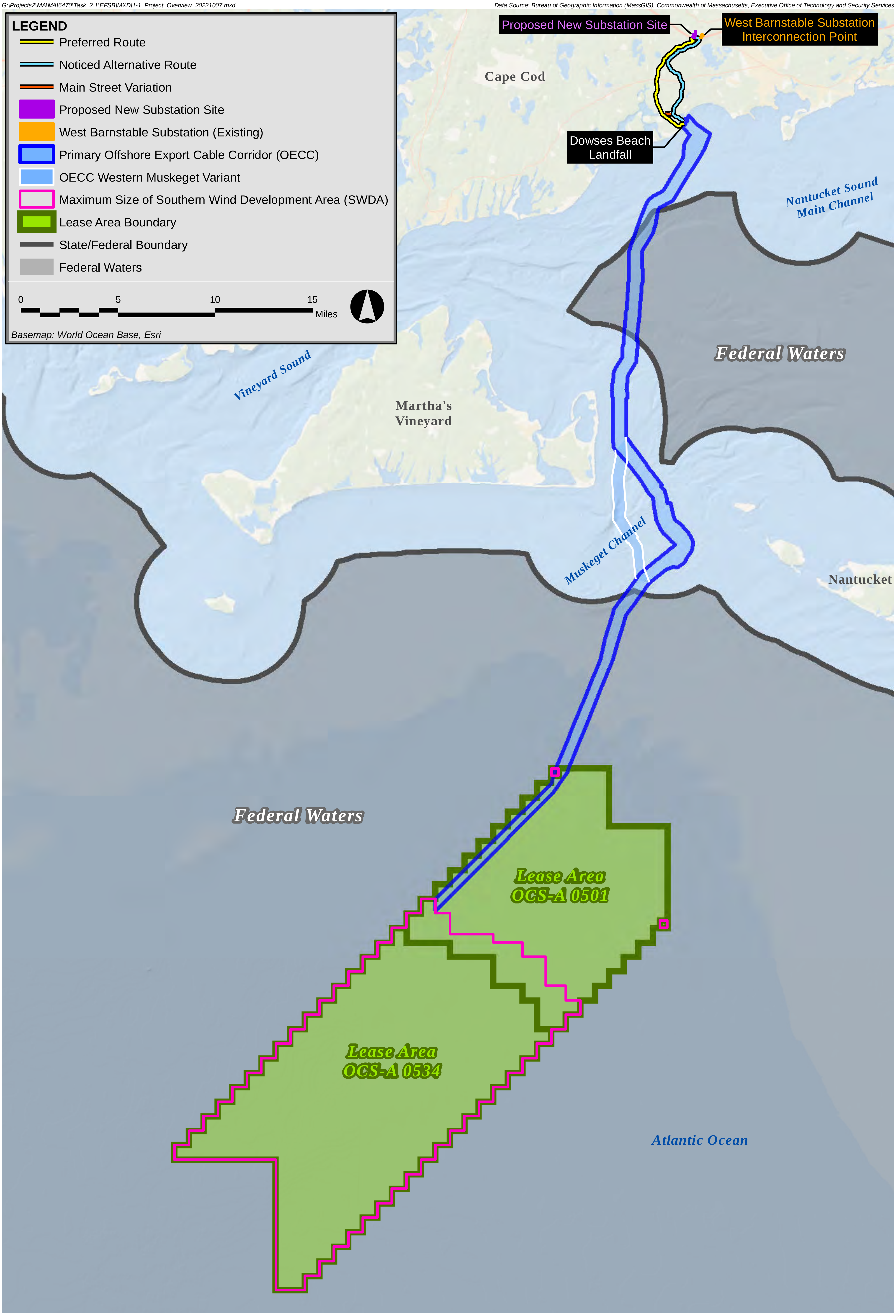
Appendix A

New England Wind 2 Connector Project Overview



New England Wind 2 Connector Project

AVANGRID Offshore Wind

Figure 1-1
Project Overview

Appendix B

New England Wind 2 Connector Project Onshore Transmission and Grid Interconnection Routes

New England Wind 2 Connector Project

AVANGRID Offshore Wind

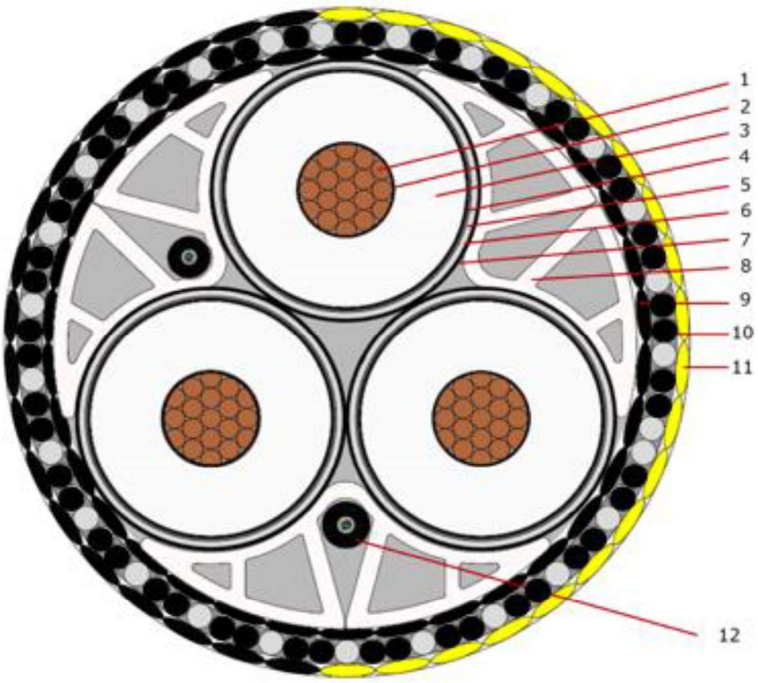
Figure 1-3
Onshore Project Components

Appendix C

Offshore Export Cable Specifications

8 Cable datasheet: 3x1600 mm² Copper with mixed armour (1/3 stainless steel, 2/3 PE) – Option 3

8.1 Cable cross sectional drawing



Not to scale – indicative only

No.	Description	Details
1	Conductor	Copper circular stranded, compacted, longitudinally water blocked, Semi conductive Water Swellable Tape on top of conductor
2	Conductor screen	Extruded bonded semi conductive compound
3	Insulation	XLPE (cross linked Polyethylene)
4	Insulation screen	Extruded bonded semi conductive compound
5	Water Blocking	Semi conductive Water Swellable Tape
6	Metal sheath	Lead alloy sheath
7	Inner sheath	Extruded Semi conductive Polyethylene on each phase
8	Fillers	Plastic fillers
9	Armour bedding	Polypropylene Yarns
10	Armouring	One layer mixed: 33% Stainless steel wires and 67% PE rod
11	Serving	Polypropylene Yarns
12	OF cable	2 x Optical Fibres Cable with 48 fibres

8.1.1 Technical data

Type of cable (Prysmian's designation)		RE4LEOJFJJ
Phase to phase design voltage Uo/U(Um)	kV	159/275(300)
Number of power cores	n°	3
Cross sectional area	mm^2	1600
Construction reference standard (as far as applicable)		IEC 62067; IEC60228

8.2 Constructional data

CONDUCTOR

Type		Longitudinally water blocked compact strand
Material		Copper wires with compound water blocking, Semi-conducting water-swelling tape on top
Diameter	mm	47.8

CONDUCTOR SCREEN

Material		Extruded semi-conducting compound(LE0500)
Indicative thickness	mm	1.25

INSULATION

Material		XLPE compound (LS4201EHV)
Nominal thickness	mm	22

INSULATION SCREEN

Material		Extruded semi-conducting compound
Indicative thickness	mm	1.25

LONGITUDINAL WATER BARRIER

Material		Semi-conducting water-swelling tape(LE0500)

LEAD SHEATH		Lead alloy E
Nominal thickness	mm	2.4

PLASTIC SHEATH

Material		Semi-conducting polyethylene
Nominal thickness	mm	2.9

OUTER DIAMETER

Single core outer diameter (approx.)	mm	110.5

Three cores as above are cabled together with two (2) interstitial fibre optic units placed in the extruded shaped fillers and bound by means of the PP yarn bedding.

BEDDING

Material		Polypropylene strings
Indicative thickness	mm	3.5

ARMOUR

Material		Stainless steel wires (Grade 316 L) and PE rod
Nominal diameter of each bare wire	mm	7
Number of armour wires	Nr.	34 (Stainless steel + 70 PE rods) (±3)

SERVING

Material		double layer Polypropylene strings
Indicative thickness	mm	6.5

OVERALL CABLE DIMENSIONS (approx.):

Diameter	mm	274
Weight in air	kg/m	120
Weight in water	kg/m	75

8.3 Mechanical data

BENDING

Minimum bending radius in static condition (drum)	m	2.7
Minimum bending radius in static condition (installed)	m	3
Minimum bending radius during installation	m	3

MECHANICAL FORCES

Maximum straight pulling tension with Factory Joints	kN	550
Maximum straight pulling tension without Factory Joints	kN	700
Tensile forces expected during installation at sea[16]	kN	75

SIDEWALL PRESSURE

Maximum sidewall pressure (one side)	kN/m	100
Maximum sidewall pressure (two side)	kN/m	70

8.4 Power core thermal data

Maximum continuous conductor temperatures (normal service)	°C	90
Maximum continuous conductor temperatures (short circuit)	°C	250
Conductor short circuit current for 1s (90°C – 250°C)	kA	229
Metallic screen short circuit current for 1s (80°C – 200°C)[17]		
- Each core	kA	20

[16] Calculated according to [9], considered maximum water depth = 45 m.
[17] Calculated according to [10].

8.5 Power core electrical data

Max. conductor D.C. resistance at 20 °C	Ω/km	0.0113
Conductor AC resistance at maximum operating temperature	Ω/km	0.022
Cable capacitance nominal	μF/km	0.219
Inductance	mH/km	0.355
Rated frequency	Hz	60
Thermal Resistance T1	K.m/W	0.42
Thermal Resistance T2	K.m/W	0.06
Thermal Resistance T3	K.m/W	0.05
Positive sequence Resistance R1 (when conductor @ 90ºC)	Ω/km	0.032
Positive sequence Resistance R1 (when conductor @ 20ºC)	Ω/km	0.031
Positive sequence Reactance X1 (when conductor @ 90ºC)	Ω/km	0.134
Positive sequence Reactance X1 (when conductor @ 20ºC)	Ω/km	0.134
Zero sequence Resistance R0 (when conductor @ 90ºC)	Ω/km	0.306
Zero sequence Resistance R0 (when conductor @ 20ºC)	Ω/km	0.257
Zero sequence Reactance X0 (when conductor @ 90ºC)	Ω/km	0.118
Zero sequence Reactance X0 (when conductor @ 20ºC)	Ω/km	0.118

Appendix D

Onshore Export Cable Specifications

XLPE insulated, concentric neutral high voltage power cable with segmental oxidized Copper conductor, metal moisture barrier tape, HDPE jacket

Type Designation: P/N 20380599 5000 kcmil Segmental Oxidized Copper 275kV

Reference Standards		ICEA S-108-720, AEIC CS9		
Temperature Rating		Maximum conductor operating temperature:	90° C	
		Maximum conductor emergency operation temperature:	105° C	
		Maximum permissible conductor temperature at short circuit:	250° C	
Construction:				
Conductor		Class B segmental compacted oxidized Copper conductor water-tight		
		Nominal cross-sectional area	5000 kcmil	2535 mm²
		Number of segments	6	
		Number of strands per segment (1 Aluminum center wire)	85	
		Approximate diameter	2.540 inches	64.5 mm
Conductor Shield	[2]	Water swellable semi-conducting tape applied helical intercalated	50% overlap	
	[2]	Semi-conducting tape applied helical	50% overlap	
	[1]	Extruded semi-conducting thermoset	Super Smooth	
		Minimum point thickness	30 mils	0.76 mm
Insulation		Extruded cross-linked polyethylene compound	Ultra Clean	
		Minimum point thickness	887 mils	22.5 mm
		Nominal thickness	985 mils	25.0 mm
		Maximum eccentricity (Tmax-Tmin)/Tmax	10%	
Insulation Shield	[1]	Extruded semi-conducting thermoset	Super Smooth	
		Minimum point thickness	40 mils	1.02 mm
		Maximum point thickness	100 mils	2.54 mm
Bedding	[2]	Water swellable semi-conducting tape applied helical intercalated	50% overlap	
Concentric Neutral	[59]	Wires, #14 AWG, solid bare soft drawn copper		1.63 mm
Bedding	[1]	Copper tape	gapped	
	[2]	Water swellable semi-conducting tape applied helical	50% overlap	
Metal Moisture Barrier	[1]	Laminated Aluminum tape applied longitudinally folded and bonded to the jacket	8 mils	0.20 mm
Jacket		Extruded black high density polyethylene compound, graphite coated		
		Minimum point thickness	125 mils	3.18 mm
		Maximum point thickness	185 mils	4.70 mm
Complete Cable		Approximate diameter	5.44 inches	138.3 mm
		Approximate weight	23.4 lbs/ft	34.8 kg/m

Marking:

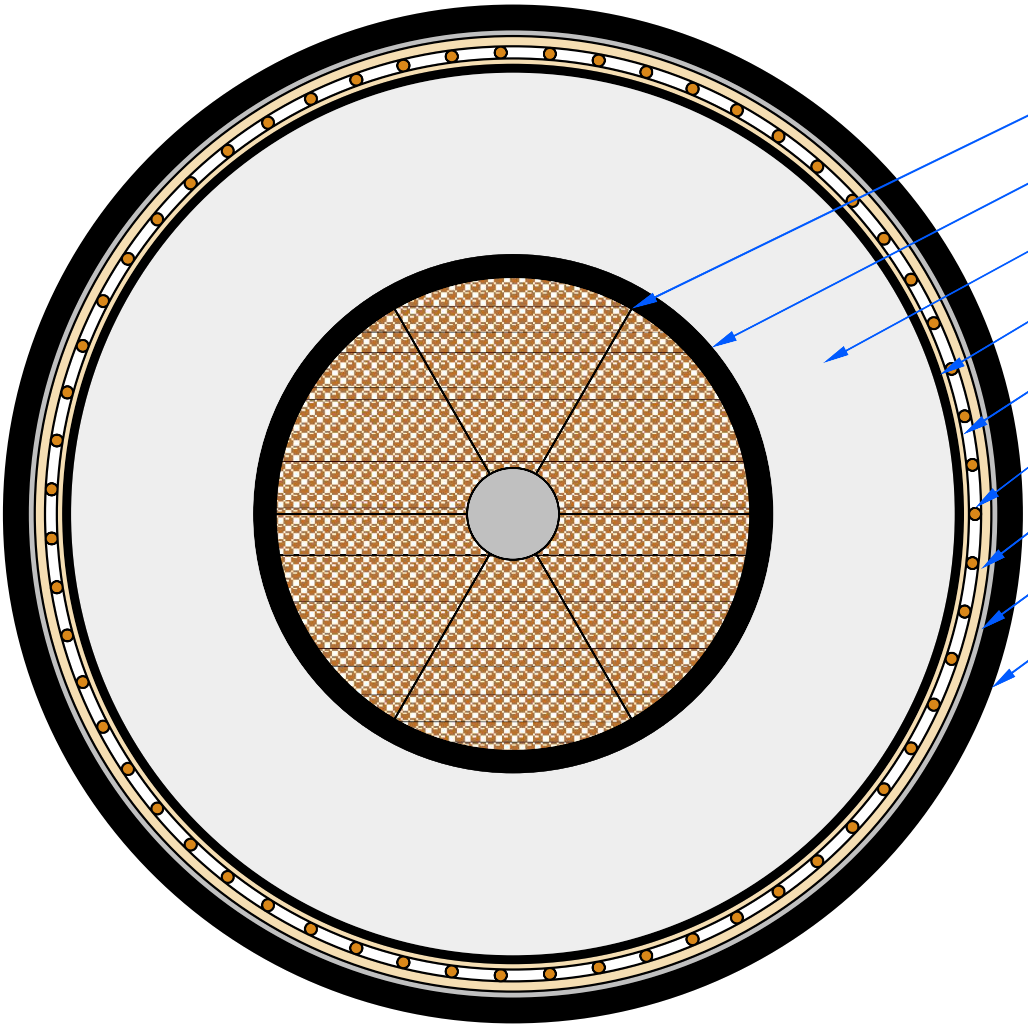
Marks of Origin	Emboss or indent print on the outer sheath: manufacturer, type of insulation, insulation thickness, conductor size and material, rated voltage, year of manufacture at intervals of not more than three feet. Length marking

Electrical Data:

Nominal voltage	275 kV	
Highest system voltage	289 kV	
Basic impulse insulation level (BIL)	1050 kV	
Maximum DC resistance of conductor at 25 °C	0.00224 Ω/kft	
Maximum voltage stress (conductor shield / insulation interface)	219 V/mil	8.6 kV/mm
Minimum voltage stress (insulation / insulation shield interface)	127 V/mil	5.0 kV/mm
Capacitance (nominal)	0.076 µF/kft	0.248 µF/km
Dielectric Constant	2.4	
Maximum permissible short-circuit current (thermal)	1 second	
Concentric neutral - ICEA P-45-482 (T_{init} at 75 °C and T_{final} 200 °C)	16 kA	

Mechanical Data:

Minimum bending radius	109 inches	2.77 m
Maximum pulling tension (with pulling eye)	40,000 lbs	18,143.7 kg
Maximum sidewall-pressure	1,500 lbs/ft	2,232.2 kg/m



CONDUCTOR:
Diameter= 2.540" (64.5mm)

CONDUCTOR SHIELD:
Diameter= 2.77" (70.4mm)

INSULATION:
Diameter= 4.74" (120.4mm)

INSULATION SHIELD:
Diameter= 4.84" (122.9mm)

BEDDING TAPE:
Diameter= 4.88" (124.0mm)

CONCENTRIC NEUTRAL:
Diameter= 5.01" (127.3mm)

BEDDING TAPE:
Diameter= 5.09" (129.3mm)

METALLIC BARRIER:
Diameter= 5.11" (129.8mm)

JACKET:
Diameter= 5.45" (138.4mm)

APPROXIMATE WEIGHT:
23.4 lbs/ft (34.8 kg/m)

Notes:
1. All dimensions are nominal and subject to manufacturing tolerances
2. Drawing is not to scale

Prepared by:	Approved by:
Dale Vinczi	Frank Kuchta

Appendix E

Grid Interconnection Cable Specifications

XLPE insulated, concentric neutral high voltage power cable with segmental Aluminum conductor, metal moisture barrier tape, HDPE jacket

Type Designation: P/N 20230793 4500 kcmil Segmental Aluminum 345kV

Reference Standards		ICEA S-108-720, AEIC CS9		
Temperature Rating		Maximum conductor operating temperature:	90° C	
		Maximum conductor emergency operation temperature:	105° C	
		Maximum permissible conductor temperature at short circuit:	250° C	
Construction:				
Conductor		Class B segmental compacted Aluminum conductor		
		Nominal cross-sectional area	4500 kcmil	2282 mm²
		Number of segments	5	
		Number of strands per segment (1 Aluminum center wire)	60	
		Approximate diameter	2.300 inches	58.4 mm
Conductor Shield	[2]	Semi-conducting tape applied helical intercalated	50% overlap	
	[2]	Semi-conducting tape applied helical intercalated	50% overlap	
	[1]	Extruded semi-conducting thermoset	Super Smooth	
		Minimum point thickness	30 mils	0.76 mm
Insulation		Extruded cross-linked polyethylene compound	Ultra Clean	
		Minimum point thickness	922 mils	23.4 mm
		Nominal thickness	1024 mils	26.0 mm
		Maximum eccentricity (Tmax-Tmin)/Tmax	10%	
Insulation Shield	[1]	Extruded semi-conducting thermoset	Super Smooth	
		Minimum point thickness	40 mils	1.02 mm
		Maximum point thickness	100 mils	2.54 mm
Bedding	[2]	Water swellable semi-conducting tape applied helical intercalated	50% overlap	
Concentric Neutral	[46]	Wires, #14 AWG, solid bare soft drawn copper		1.63 mm
Bedding	[1]	Copper tape	gapped	
	[2]	Water swellable semi-conducting tape applied helical	50% overlap	
Metal Moisture Barrier	[1]	Laminated Copper tape applied longitudinally folded and bonded to the jacket	6 mils	0.15 mm
Jacket		Extruded black high density polyethylene compound, graphite coated		
		Minimum point thickness	125 mils	3.18 mm
		Maximum point thickness	185 mils	4.70 mm
Complete Cable		Approximate diameter	5.21 inches	132.4 mm
		Approximate weight	11.6 lbs/ft	17.2 kg/m

Marking:

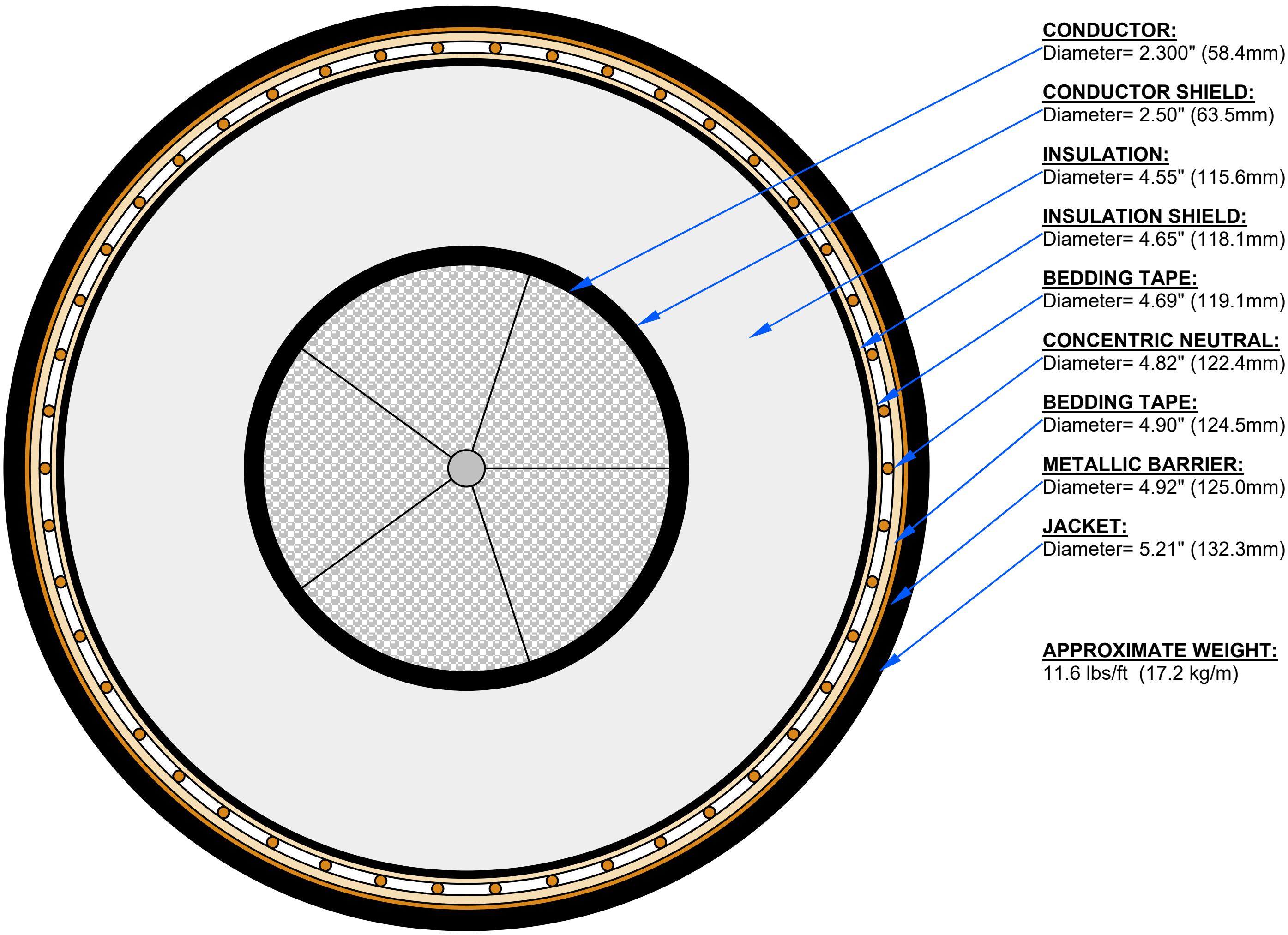
Marks of Origin — Emboss or indent print on the outer sheath: manufacturer, type of insulation, insulation thickness, conductor size and material, rated voltage, year of manufacture at intervals of not more than three feet.
Length marking

Electrical Data:

Nominal voltage	345 kV	
Highest system voltage	362 kV	
Basic impulse insulation level (BIL)	1300 kV	
Maximum DC resistance of conductor at 25 °C	0.00415 Ω/kft	
Maximum voltage stress (conductor shield / insulation interface)	274 V/mil	10.8 kV/mm
Minimum voltage stress (insulation / insulation shield interface)	148 V/mil	5.8 kV/mm
Capacitance (nominal)	0.068 μF/kft	0.222 μF/km
Dielectric Constant	2.4	
Maximum permissible short-circuit current (thermal)	15 Cycles	
Composite Metallic Sheath (concentric neutral and laminated copper sheath) - ICEA P-45-482 (T_{init} at 75 °C and T_{final} 200 °C)	40 kA	

Mechanical Data:

Minimum bending radius	104 inches	2.64 m
Maximum pulling tension (with pulling eye)	27,000 lbs	12,247.0 kg
Maximum sidewall-pressure	1,500 lbs/ft	2,232.2 kg/m



Notes:

1. All dimensions are nominal and subject to manufacturing tolerances
2. Drawing is not to scale

Prepared by:	Approved by:
Dale Vinczi	Frank Kuchta