Empire Offshore Wind: Empire Wind Project (EW 1 and EW 2)
Construction and Operations Plan

APPENDIX FF

Onshore Electric and Magnetic Field Assessment

Prepared for
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Exponent Engineering P.C.

Electrical Engineering and Computer Science Practice

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Empire Offshore Wind: Empire Wind Project (EW 1 and EW 2)

Onshore Magnetic-Field Assessment

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Onshore Magnetic-Field Assessment

Prepared for

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Acronyms and Abbreviations

A	Ampere
AC	Alternating current
COP	Construction and Operations Plan
DC	Direct current
EMF	Electric and magnetic fields
Empire	Empire Offshore Wind LLC
EW 1	Empire Wind 1
EW 2	Empire Wind 2
ft	Feet
Hz	Hertz
ICES	International Committee on Electromagnetic Safety
ICNIRP	International Commission on Non-Ionizing Radiation
IEEE	Institute of Electrical and Electronics Engineers
JTB	Joint Transition Bay
km	Kilometer
kV	Kilovolt
Lease Area	designated Renewable Energy Lease Area OCS-A 0512
m	Meter
mG	Milligauss
mi	Statute mile
mm	Millimeter
MW	Megawatt
nm	Nautical mile
POI	Point of Interconnection
Project	The offshore wind project for OCS A-0512 proposed by Empire Offshore Wind LLC consisting of Empire Wind 1 (EW 1) and Empire Wind 2 (EW 2).
Project Area	The area associated with the build out of the Lease Area, submarine export cables, interarray cables, and all onshore Project facilities.
WHO	World Health Organization
XLPE	Cross-linked polyethylene

Executive Summary

Empire Offshore Wind LLC (Empire) proposes to construct and operate two separate offshore wind facilities in the designated Renewable Energy Lease Area OCS-A 0512 (Lease Area) located approximately 14 statute miles (mi) (12 nautical miles [nm], 22 kilometers [km]) south of Long Island, New York, and 19.5 mi (16.9 nm, 31.4 km) east of Long Branch, New Jersey. Empire proposes to develop the Lease Area with two wind farms, known as Empire Wind 1 (EW 1) and Empire Wind 2 (EW 2) (collectively referred to hereafter as the Project). EW 1 and EW 2 will be electrically isolated and independent from each other. Each wind farm will connect via offshore substations to separate onshore Points of Interconnection at onshore locations by export cables and onshore substations. The Project includes two onshore locations where the renewable electricity generated will be transmitted to the electric grid. In this report, Exponent summarizes calculations of the magnetic fields associated with the operation of the onshore export and interconnection cables planned for installation and operation in Brooklyn, New York, and Long Beach and Hempstead, New York.

Magnetic-field levels for EW 1 were calculated in this report for three representative configurations of the proposed onshore export and interconnection cables constructed in underground duct banks during average and peak electricity generation. For EW 2 magnetic-field levels were calculated for four representative configurations of the proposed onshore export cables and three representative configurations of the proposed interconnection cables all in underground duct banks corresponding to operation at average and peak electricity generation levels. All magnetic field calculations were performed using an optimal phasing of cables to minimize magnetic field levels associated with each underground configuration. The magnetic-field levels associated with the operation of the Project's onshore cables in all of these representative configurations (both for EW 1 and EW 2) at average and peak current flows were calculated to be well below exposure limits published by the International Committee on Electromagnetic Safety and the International Commission on Non-Ionizing Radiation Protection, which were designed to protect the health and safety of the general public.

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

Introduction

Project Description

Empire Offshore Wind LLC (Empire) proposes to construct and operate the Project located in the designated Renewable Energy Lease Area OCS-A 0512 (Lease Area). The Lease Area covers approximately 79,350 acres (32,112 hectares) and is located approximately 14 statute miles (mi) (12 nautical miles [nm], 22 kilometers [km]) south of Long Island, New York, and 19.5 mi (16.9 nm, 31.4 km) east of Long Branch, New Jersey. Empire proposes to develop the Lease Area with two wind farms, known as Empire Wind 1 (EW 1) and Empire Wind 2 (EW 2) (collectively referred to hereafter as the Project). EW 1 and EW 2 will be electrically isolated and independent from each other. Each wind farm will connect via offshore substations to separate Points of Interconnection (POIs) at onshore locations by way of export cable routes and onshore substations. In this respect, the Project includes two separate onshore locations in New York where the renewable electricity generated will be transmitted to the electric grid.

This report summarizes the calculated levels of alternating current (AC) magnetic fields at representative cross-sections of the underground export cables and interconnection cables in the onshore portion of the Project. The assessment of the offshore portion of the Project is provided in a companion report titled *Empire Offshore Wind: Empire Wind Project (EW 1 and EW 2) - Offshore Electric and Magnetic Field Assessment*.

EW 1

EW 1 will connect to an existing substation POI near the Gowanus neighborhood in Brooklyn, New York. An overview of the offshore Project is shown in Figure 1. The routes of the interconnection cables proposed for EW 1 are shown in Figure 2.

Electricity generated in the EW 1 windfarm area will be transmitted to the POI as AC on the following Project components:

1) Two submarine export cables, operating as separate circuits, with a voltage of 230 kilovolts (kV) will exit the offshore substation and traverse independently

approximately 40 nautical miles (46 miles, 74 kilometers) to a landing site in Brooklyn, New York, where the submarine export cable will connect directly to the onshore substation;

2) At the onshore substation, the voltage of the electricity will be stepped up to 345 kV for connection to the electrical grid; and

3) Two 345-kV interconnection cable circuits in a dual-circuit duct bank will connect the onshore substation to the POI.

EW 2

EW 2 will connect to an existing substation at the Oceanside POI in Oceanside, New York via one of two proposed EW 2 Onshore Substations. Figure 3 shows the locations of the two proposed EW 2 Onshore Substations A and C, the four considered landfall locations (EW 2 Landfall A, B, C, and E), and the proposed routes of the onshore export and interconnection cables proposed for EW 2. The colored lines between the EW 2 landfall locations and the onshore substations show the potential 230-kV onshore export cable routes. The colored lines between the onshore substations and the EW 2 POI at Oceanside show the potential 138-kV interconnection cable routes.

Electricity generated in the EW 2 windfarm area will be carried to shore as AC on the following Project components:

1) Three submarine export cables, each operating as a separate circuit, will exit the offshore substations as individual cable circuits at a voltage of 230 kV and traverse the 26 nautical mile (30-mile, 48 kilometer) distance to the cable landfall in Long Beach, New York.

2) At landfall, the submarine export cables will enter the joint transition bays (JTB) where each of the three conductors within the cable will be spliced to corresponding conductors of the onshore export cables. These onshore export cables will continue in a triple-circuit underground duct bank to the proposed onshore substation.

3) At the onshore substation the 230-kV voltage will be stepped down to 138 kV.[1]

[1] Exponent understands that an alternative design is being considered wherein voltage at the onshore substation is stepped up to 345-kV and connects to the POI with 345-kV interconnection cables. As the magnetic fields are

4) Three 138-kV interconnection cable circuits in a triple-circuit underground duct bank will connect the onshore substation to the POI.

generally expected to be lower for 345-kV cables than for 138-kV cables, only 138-kV interconnection cables were modeled here. Additional modeling may be conducted as necessary to document this assumption. The remainder of this report refers to only the 138-kV interconnection cables.

May 10, 2022

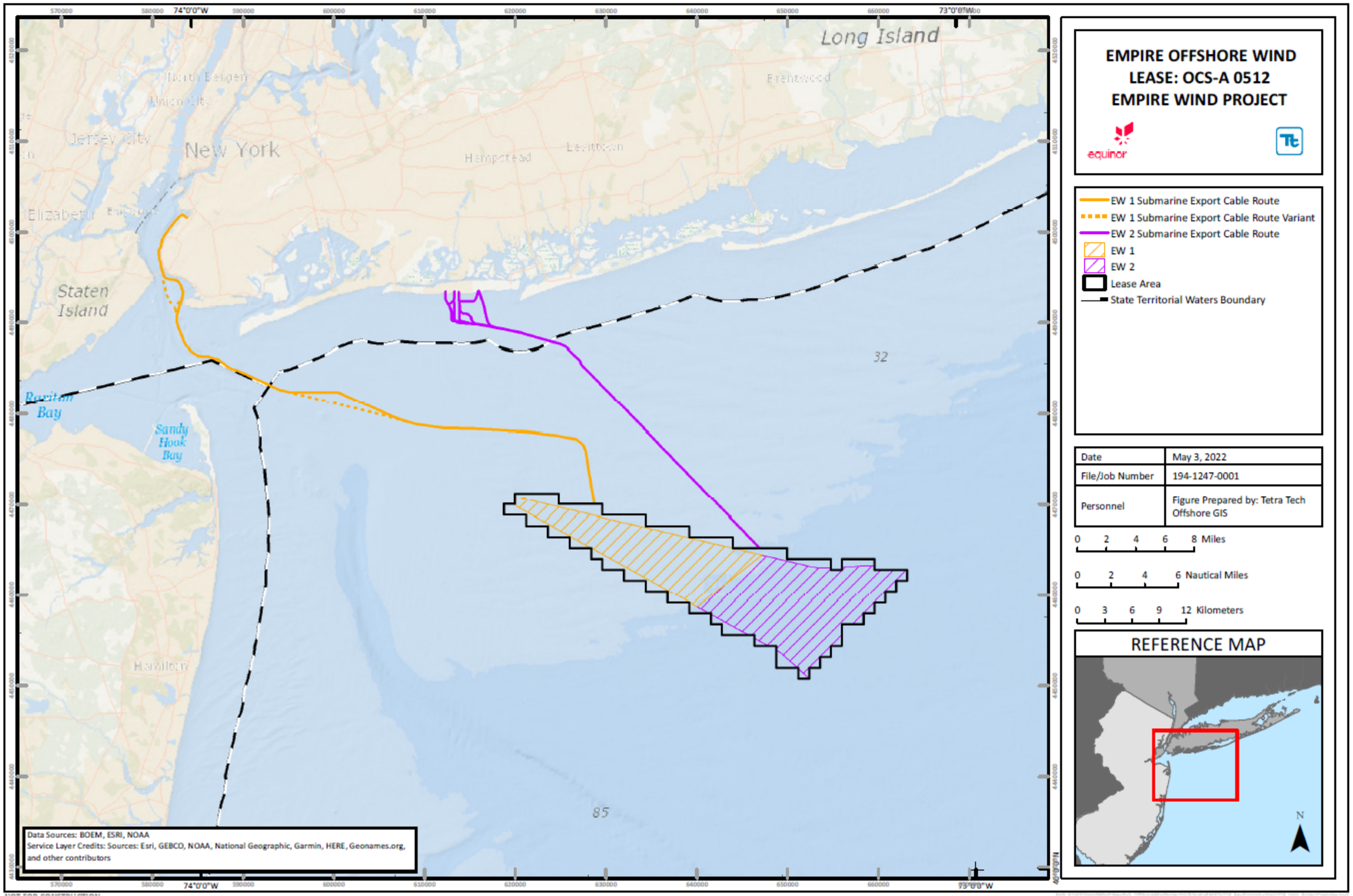

Figure 1. Overview of the Lease Area and submarine export cable routes for EW 1 and EW 2.

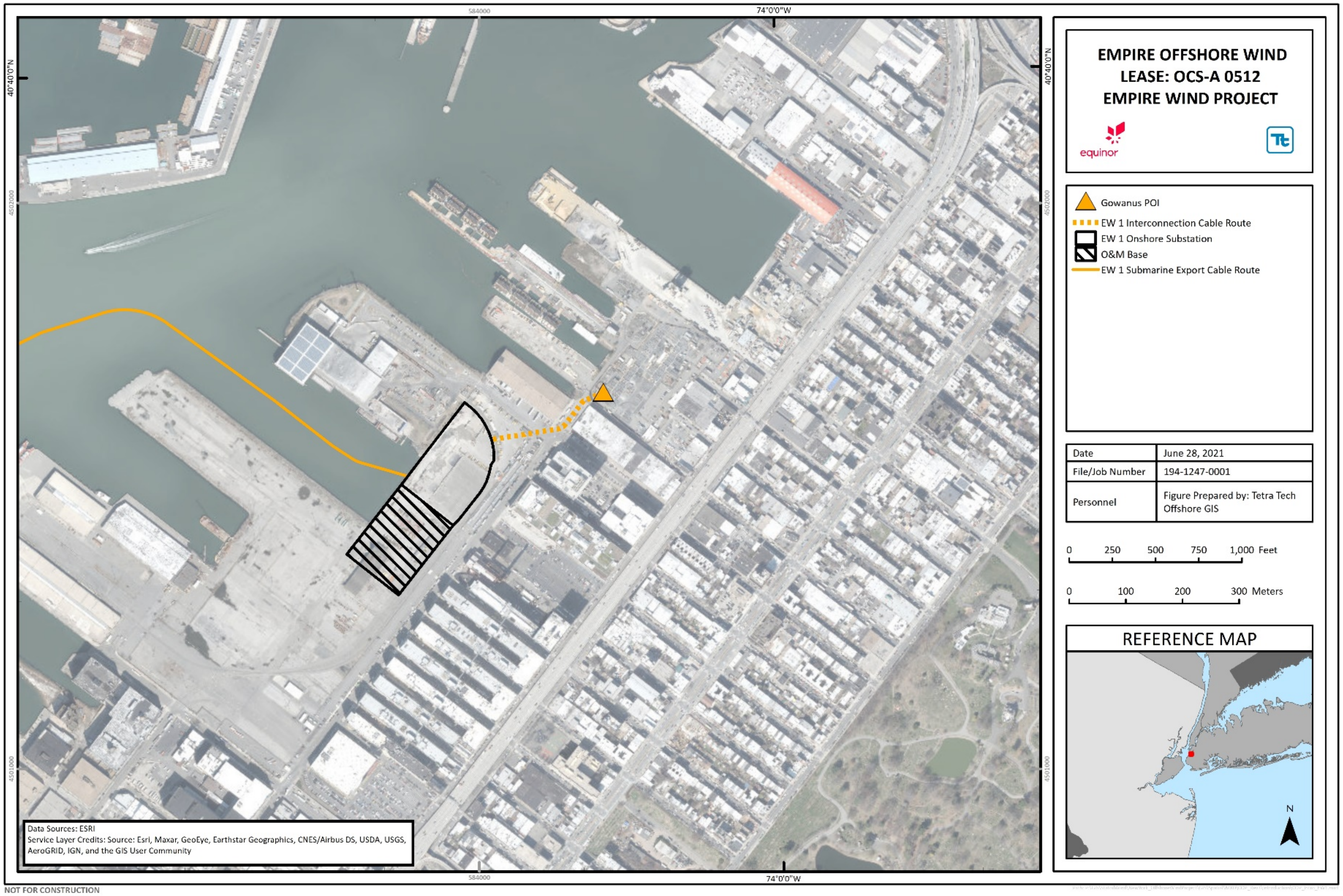

Figure 2. Overview of the proposed EW 1 submarine export cable route at landfall and respective interconnection cable.

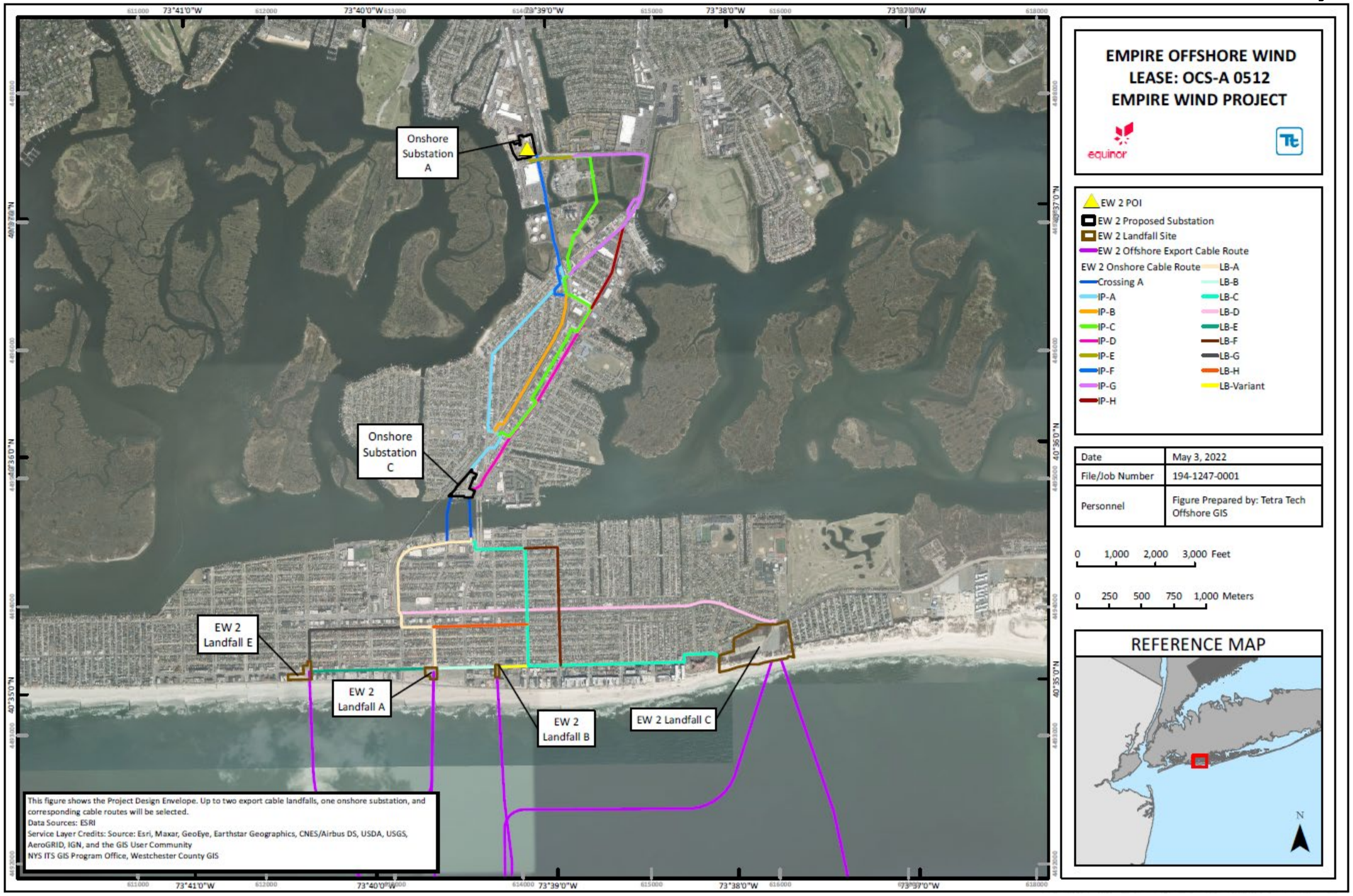

Figure 3. Overview of the proposed EW 2 submarine export cable route options at landfall, the respective onshore export cable route options, and the interconnection cable route options.

Magnetic Fields

The flow of electric currents on the onshore export cables and interconnection cables will create magnetic fields above ground. These magnetic-field levels will be highest near the cables and decrease rapidly with distance, generally in proportion to the square of the distance from the cables. In this report, magnetic fields were reported as root-mean-square magnetic flux density in units of milligauss (mG), where 1 Gauss is equal to 1,000 mG.[2]

The onshore export cables and interconnection cables also will create electric fields underground inside the cable insulation and sheath due to the voltage applied to the conductors located within the cables. However, since the conductors are to be encased within conductive metallic sheathing, these electric fields will not be present above ground because they are entirely blocked by this shielding (CSA Ocean Sciences Inc., and Exponent, 2019).[3]

The levels of magnetic fields will vary depending on the magnitude of electric current—reported in units of Amperes (A)—carried on the cables at any one time. Therefore, calculations of magnetic fields represent only a snapshot at one moment due to the varying power generated by the turbines, which depends both on operational status and wind speed. To account for the variability of current, calculations of magnetic fields were performed for the peak current at which the windfarm can operate, which will indicate the highest magnetic-field levels that can occur, and for the annual average current that represents more typical field levels over time. Additional discussion of the fields associated with offshore windfarm submarine cables in general is provided in a report issued by the Bureau of Ocean Energy Management (CSA Ocean Sciences Inc., and Exponent, 2019).

2 Magnetic fields also are commonly reported in units of microtesla, where 0.1 microtesla is equal to 1 mG.

3 An approximately 300-ft (91-m) segment of the interconnection cable route at the crossing of Barnum's Channel may be located aboveground via a cable bridge. The cable construction will likewise block the electric field outside the cable. The design of the cable bridge segment is not yet sufficiently advanced for modeling and therefore was not included in this assessment.

Assessment Criteria

The State of New York has an interim policy for magnetic-fields at edges of rights-of-way for new AC transmission lines and at winter normal conductor rating, which is the maximum load (and hence maximum magnetic field) that the transmission line can continuously sustain. The Article VII report to be submitted to the New York State Public Service Commission will demonstrate compliance with the magnetic-field standard.

There are no federal standards that limit magnetic fields produced by electric system infrastructure, but two international organizations provide guidance on limiting exposure to magnetic fields, which is based on extensive review and evaluation of relevant research of health and safety issues—the International Committee on Electromagnetic Safety (ICES), which is a committee under the oversight of the Institute of Electrical and Electronics Engineers (IEEE), and the International Commission on Non-Ionizing Radiation (ICNIRP), an independent organization providing scientific advice and guidance on electromagnetic fields. Both organizations have recommended limits designed to protect the health and safety of persons in occupational settings and for the general public. The ICES exposure reference level for the general public to 60-Hertz (Hz) magnetic fields is 9,040 mG, and ICNIRP determined a reference level limit for whole-body exposure to 60-Hz magnetic fields at 2,000 mG (ICES, 2019, ICNIRP, 2010). The World Health Organization (WHO), a scientific organization within the United Nations system with the mandate to provide leadership on global health matters; shape health research agendas; and set norms and standards, views these standards as protective of public health (WHO, 2007). The WHO assessment also states "[g]iven the weakness of the evidence for a link between [long-term] exposure to ELF magnetic fields" and health effects at levels below these standards, "the benefits of exposure reduction on health are unclear and thus the cost of reducing exposure should be very low" (p. 372).

Cable Configurations and Calculation Methods

Exponent calculated the 60-Hz magnetic fields associated with the operation of the onshore export and interconnection cables proposed to be installed as part of the Project. The cables are to be installed predominantly in duct banks onshore and the methods used for calculating the magnetic-field levels above ground are described below.

EW 1: Onshore 345-kV Interconnection Cables

The EW 1 offshore submarine export cables will terminate directly at the onshore substation, so there is no onshore export cable for EW 1. At the onshore substation, the voltage will be stepped up from 230 kV to 345 kV. From the onshore substation, interconnection cables installed in a double-circuit underground duct bank will transmit power to the POI. A cross-sectional drawing of the components of a representative individual single-conductor cross-linked polyethylene (XLPE) cable is shown in Figure A-1 in Attachment A. At 345-kV, each circuit will carry an average current of 618 A and a peak current of 727 A.

The dominant installation configuration for the proposed cables, referred to here as the Typical configuration, has the two circuits in a trefoil arrangement side-by-side at a minimum target burial depth of 3 feet (ft) (0.9 m) to the top of the duct bank,[4] and a minimum separation distance between duct banks of 0.0 ft (0.0 m). The Typical configuration will represent the preferred and most likely installation scenario for the majority of the interconnection cable route between the onshore substation and the POI. A cross-sectional drawing of the Typical configuration is shown in Figure 4.

A circuit spacing greater than the preferred value will only be used for short distances when installation conditions require greater separation such as at JTBs or splice vaults, at locations using horizontal directional drilling, or to accommodate existing utilities. For each of these

[4] For greater burial depth, magnetic-field levels would be lower.

locations it is anticipated that the horizontal separation between the two circuits will be up to 10 ft (3 m).

Other alternative cable installation configurations, such as at road crossings or where deeper burial is not possible, also may be required for limited distances, as discussed in greater detail in Attachment A.

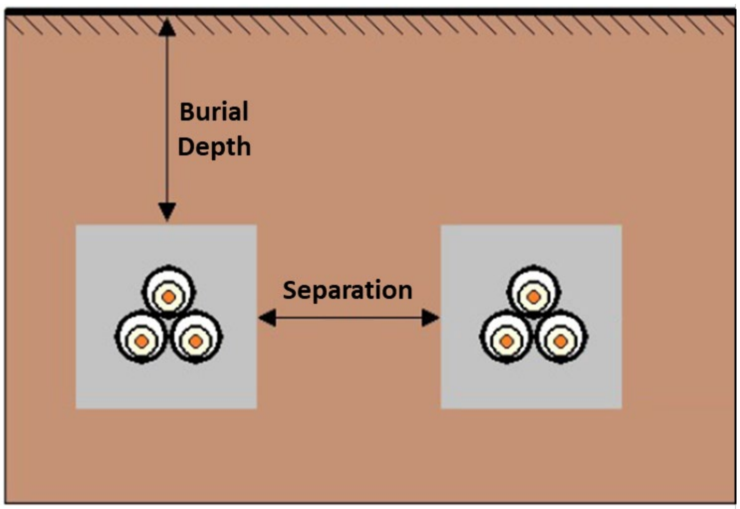

Figure 4. Representative cross-section of the Typical configuration of interconnection cables in 345-kV duct banks for EW 1.

EW 2: Onshore 230-kV Export Cables

At landfall for EW 2, the three submarine export cable circuits will enter JTBs where the submarine cables will be spliced to three individual onshore single-core, cross linked polyethylene (XLPE) export cables (three for each circuit, nine cables total). Between the JTB and the selected EW 2 onshore substation, the onshore export cables will be constructed in one of four triple-circuit underground duct bank configurations, each with a different geometrical configuration—delta (Figure 5a), inverted delta (Figure 5b), horizontal (Figure 5c), and vertical (Figure 5d). All four duct bank configurations will be installed at a minimum target burial depth of 3 feet (ft) (0.9 meters [m]). Each of the three circuits (regardless of duct bank configuration) will operate at 230-kV and will carry an average current of 944 Amperes (A) and a peak current of 1,110 A (i.e., average and peak loading).

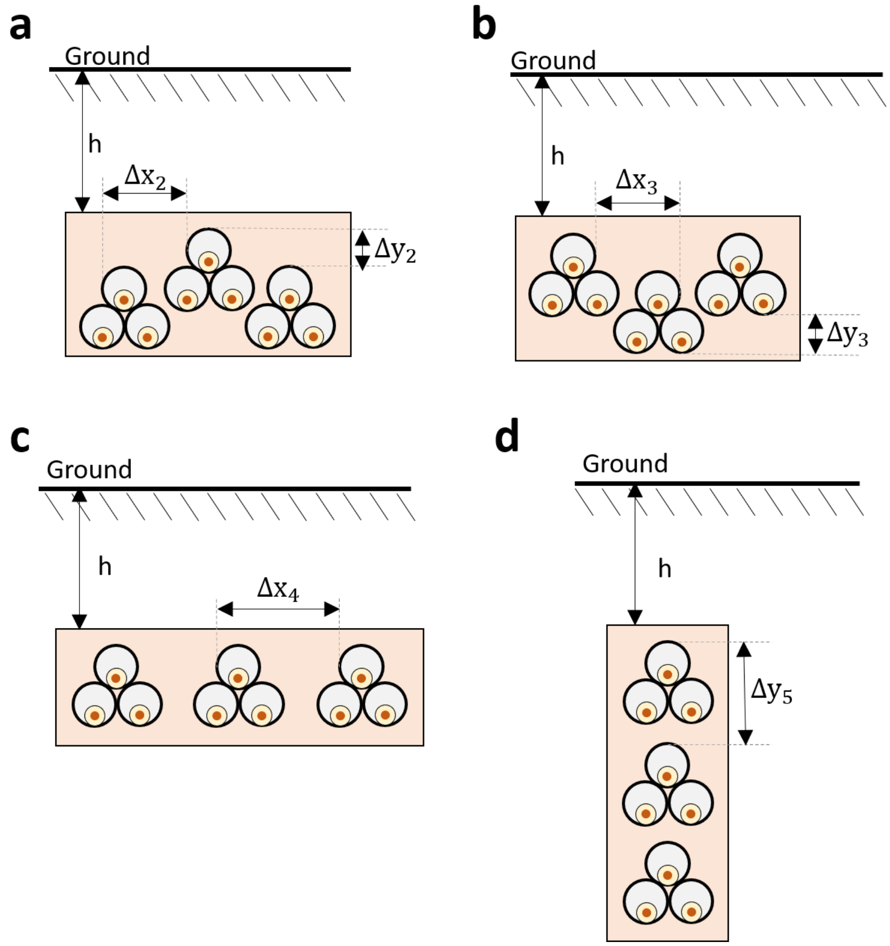

Figure 5. Four duct bank configurations considered for the 230-kV export cable showing three circuits, each in a trefoil configuration: a) delta; b) inverted delta; c) horizontal; and d) vertical.

EW 2: Onshore 138-kV Interconnection Cables

At the selected onshore substation, the 230-kV voltage of the export cables will be stepped down to 138 kV. Each of the possible routes from the three candidate substations circuits, and the POI, will be constructed with 2 conductors per phase due to the lower voltage, resulting in 6 conductors per circuit (i.e., 18 conductors total for the 3 circuits). These 18 conductors will be constructed in underground duct banks with 6 trefoils as shown in Figure 6a. In portions of the route where such a large duct bank cannot be constructed due to space limitations, the six trefoils may be separated into groups of either two or four trefoils, as shown in Figure 6b and Figure 6c, respectively.

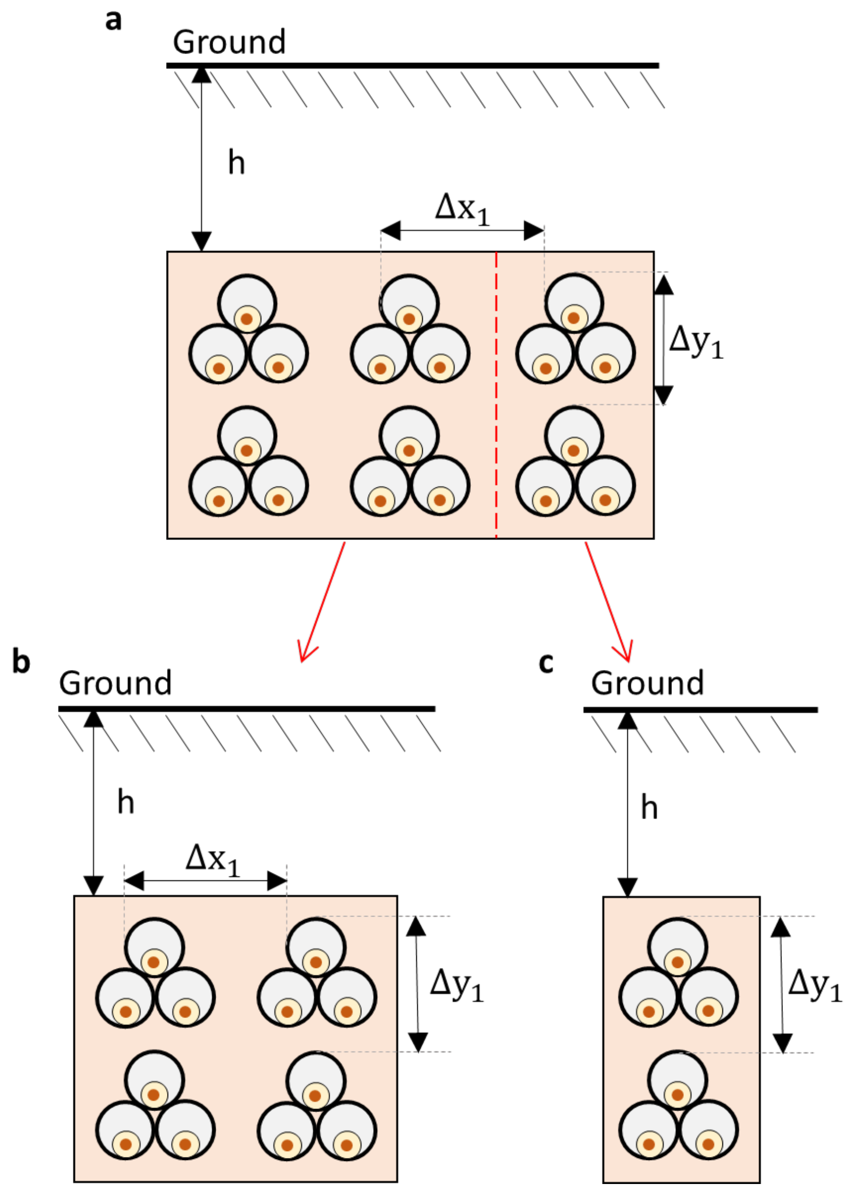

Figure 6. Three duct bank configurations were considered for the 138-kV interconnection cable: a) six trefoils in one duct bank; b) four trefoils in one duct bank; c) two trefoils in one duct bank.

Each of the six trefoils (two per circuit) will operate at 138-kV and will carry current at average loading of 772.5 A (half of the 1,545 A average for each circuit) and current at peak loading of 908.5 A (half of the 1,817 A peak for each circuit).

In EW 2, the onshore export cables will be installed and will operate at 230 kV along the route between the JTBs and the existing onshore substations. The EW 2 138-kV interconnection cable will be installed between the onshore substation and the adjacent POI.

Calculation Methods

Magnetic-field levels were calculated for each cable configuration using conservative assumptions to ensure that the calculated field levels overestimate the field levels measured at any specified current flow. Magnetic-field levels were calculated using computer algorithms developed by the Bonneville Power Administration, an agency of the U.S. Department of Energy (BPA, 1991). All calculations were made assuming that the conductors of the transmission line are parallel to one another and infinite in extent. Although these assumptions simplify the calculations, they do not decrease the accuracy of the model, and the BPA algorithms have been shown to accurately predict magnetic-field levels measured near transmission lines (Chartier and Dickson, 1990; Perrin et al., 1991). Field levels were calculated at a height of 3.3 ft (1 m) above ground and reported as the resultant root mean square field level of the three orthogonal field components in accordance with IEEE Std. C95.3.1-2010 (IEEE, 2010) and IEEE Std. 644-2019 (IEEE, 2019).[6] Although the routes of the onshore export cables and surrounding infrastructure (e.g., existing transmission or distribution lines, substations, etc.) will differ for each landing site, the magnetic-field levels from the proposed duct banks will not vary by location, and the calculations provided are representative of export cable installations along each onshore route.[7]

Phase Optimization

The particular configuration of the phase conductors within each trefoil group, and among trefoil groups, can significantly change the magnetic-field level above the duct bank for each of the EW 1 or EW 2 duct banks. This is due to the mutual cancellation of magnetic fields from adjacent cables and circuits. Phase optimization is one of the low-cost measures to reduce magnetic-field levels, consistent with recommendations of the World Health Organization (WHO, 2007). At the request of Empire Wind, Exponent performed a phase optimization

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6 For an Article VII filing in New York, magnetic-field levels are required to be reported as the maximum of the field ellipse, which is similar to the resultant root mean square field, but may not be exactly the same.

7 The existing electrical power infrastructure adjacent to the proposed route of the onshore export cables is currently unknown and may differ among the routes. Hence, there may be small differences in total magnetic-field level (from both existing and proposed sources) between routes. In that case, magnetic-field levels may be different than calculated here and require additional assessment once existing infrastructure is identified.

analysis for both the EW 1 and EW 2 onshore export cables and the EW 1 and EW 2 interconnection cables in duct banks to determine which of all possible phase permutations of the cables in each duct bank would minimize the calculated magnetic-field levels at a horizontal distance of 25 ft (7.6 m) from the center of the duct banks. The results of this phase optimization for each of the 10 modeled configurations are summarized in Attachment B. Selection of the final phasing design is ongoing and will be based on constructability.

Calculated Magnetic Fields

Magnetic-field levels were calculated for the proposed onshore cables of EW 1 and EW 2 at average and peak current flows, and using the optimal phasing calculated as described above. For EW 1, calculated field levels for the dominant Typical configuration in the preferred arrangement for average current flows are summarized below and represent field levels expected to typically occur along proposed routes. For EW 2, the calculated magnetic-field levels for each of the seven duct bank configurations at average loading are summarized below and represent magnetic-field levels expected to typically occur along proposed routes. Calculated field levels for all configurations and current flows are summarized in Attachment B.

EW 1: Onshore 345-kV Interconnection Cable Duct Banks

Magnetic-field levels for the Typical configuration of the EW 1 interconnection cable between the onshore substation and the POI calculated at 3.3 ft (1 m) above ground, are plotted as a function of horizontal distance from the midpoint between the two duct banks for a representative cross-section of the Typical configuration (Figure 7).

Table 1 summarizes the calculated magnetic-field values for the EW 1 interconnection cable. The highest calculated magnetic-field level at average loading is 37 mG directly over either of the two duct banks, decreasing rapidly to 5 mG or less beyond a horizontal distance of 30 ft (9.1 m) from the center of the two duct banks. All calculated magnetic-field levels for this and short alternative spacings and configurations (including at peak loading) are included in Attachment B. All calculated magnetic-field levels are well below the ICNIRP reference level of 2,000 mG and the ICES exposure reference level of 9,040 mG for exposure of the general public.[8]

[8] The Article VII report to be submitted to the New York State Public Service Commission will demonstrate compliance with the magnetic-field standard

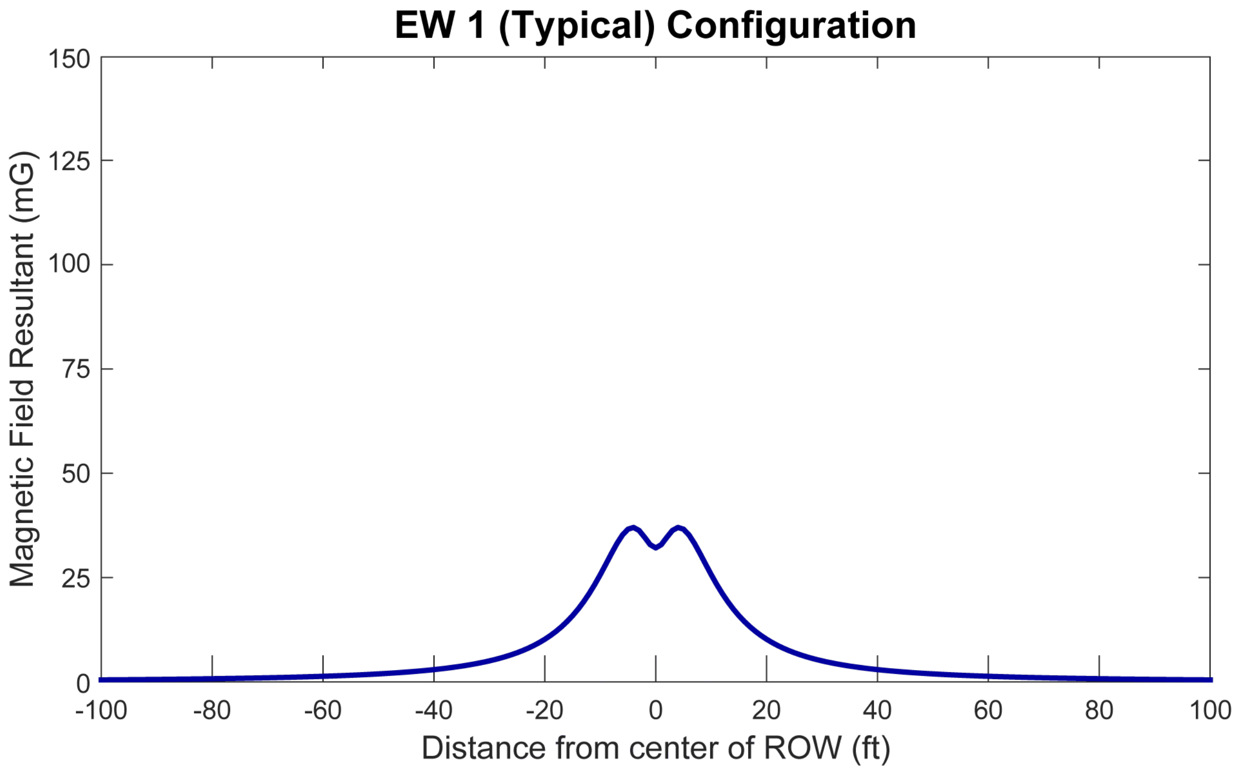

Figure 7. Calculated magnetic-field levels at 3.3 ft (1 m) above ground for the Typical configuration of EW 1 345-kV interconnection cable at average loading.

Table 1. Calculated magnetic-field levels (mG) at 3.3 ft (1 m) above ground for the Typical configuration of the EW 1 345-kV interconnection cable at average loading

	Distance from Center of Configuration						
Cable	**–50ft (–15 m)**	**–25ft (–7.6 m)**	**–10ft (–3 m)**	**Max**	**+10ft (+3 m)**	**+25ft (+7.6 m)**	**+50ft (+15 m)**
EW 1 (Typical) Interconnection	1.9	7.0	26	37	26	7.0	1.9

EW 2: Onshore 230-kV Export Cable Duct Banks

Magnetic-field levels for the EW 2 onshore export cable configurations were calculated for 230-kV voltage and associated current flow. The magnetic-field levels vary among the different configurations, but are generally similar, with the highest calculated magnetic-field level directly above the duct banks and decreasing rapidly with distance. The highest magnetic-field level associated with the 230-kV onshore export cables was calculated to occur over the horizontal duct bank configuration, as shown in Figure 8 (shown at average loading). Directly above the duct bank, the magnetic field was 80 milligauss (mG), decreasing to 3.2 mG at a distance of 25 ft (7.6 m) from the centerline. Tabular summaries of the magnetic fields calculated for the four duct bank configurations of the export cable at average and peak loading are summarized in Attachment B.

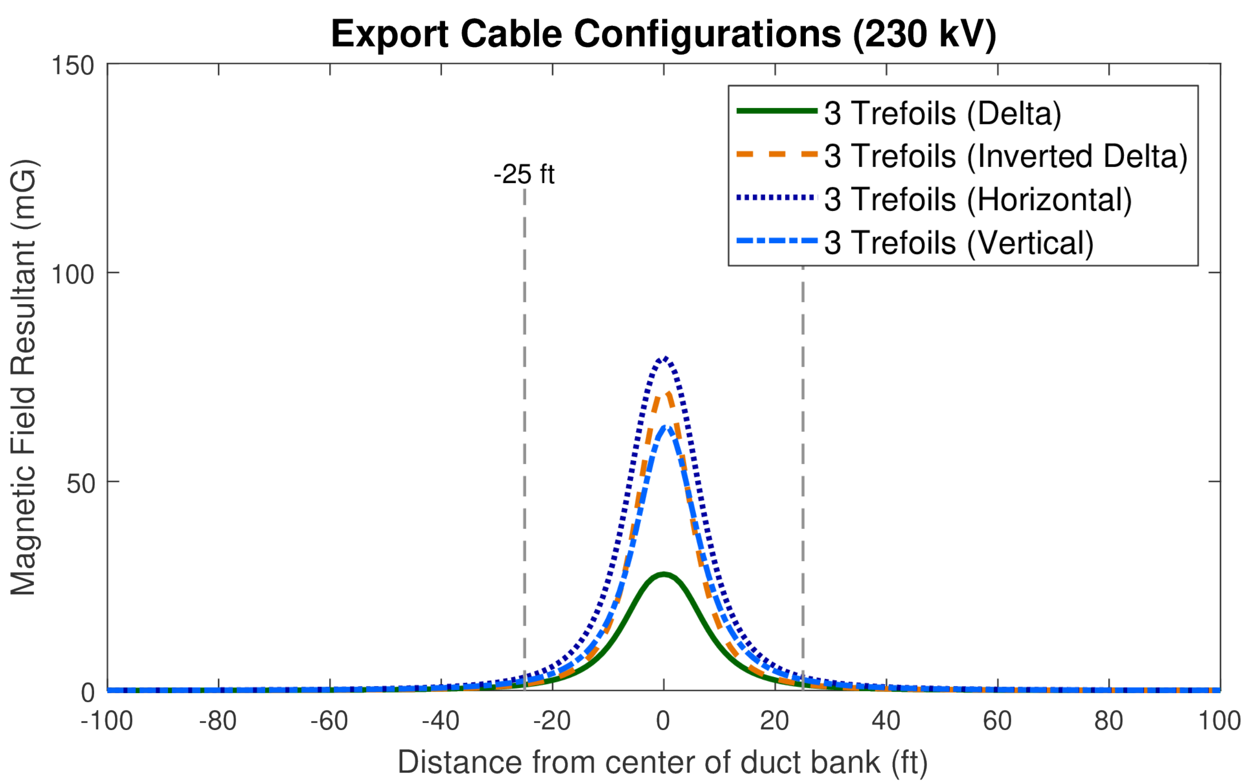

Figure 8. Calculated magnetic-field levels at 3.3 ft (1.0 m) above ground for EW 2, 230-kV onshore export cables configurations at average loading.

Table 2. Calculated magnetic-field levels (mG) at 3.3 ft (1.0 m) above ground for configurations of EW 2 230-kV onshore export cables at average loading

Configuration	Distance from Center of Configuration						
	–50ft (–15 m)	–25ft (–7.6 m)	–10ft (–3 m)	Max	+10ft (+3 m)	+25ft (+7.6 m)	+50ft (+15 m)
Delta	0.2	1.4	11	28	11	1.4	0.2
Inverted Delta	0.2	1.5	15	72	15	1.5	0.2
Horizontal	0.4	3.2	26	80	26	3.2	0.4
Vertical	0.3	2.3	17	63	20	2.6	0.4

All calculated magnetic-field levels for were well below the ICNIRP reference level of 2,000 mG and the ICES exposure reference level of 9,040 mG for exposure of the general public.

EW 2: Onshore 138-kV Interconnection Cable Duct Banks

Magnetic-field levels for the EW 2 interconnection cable duct bank configurations that will connect one of three proposed substations to the existing POI were calculated for 138-kV and average and peak loading. The calculated magnetic-field levels at average loading are shown in Figure 9.

The highest magnetic-field levels were calculated to occur above the duct bank with two trefoil bundles, and the lowest magnetic-field levels were calculated to occur above the configuration with all six trefoil bundles. The configurations with more trefoil bundles have lower magnetic-field levels due to phase optimization and mutual cancellation of fields from adjacent, optimally-phased trefoils. For all three interconnection cable duct bank configurations, however, magnetic-field levels decrease to less than 10 mG within a distance of 25 ft (7.6 m) from the centerline of the duct bank. Tabular results for all interconnection cable duct bank configurations at average and peak loading are summarized in Table 3.

Note that if the option to install these cables for operation at 345-kV is chosen, then the magnetic fields will be lower than shown in Figure 9 and Table 3.

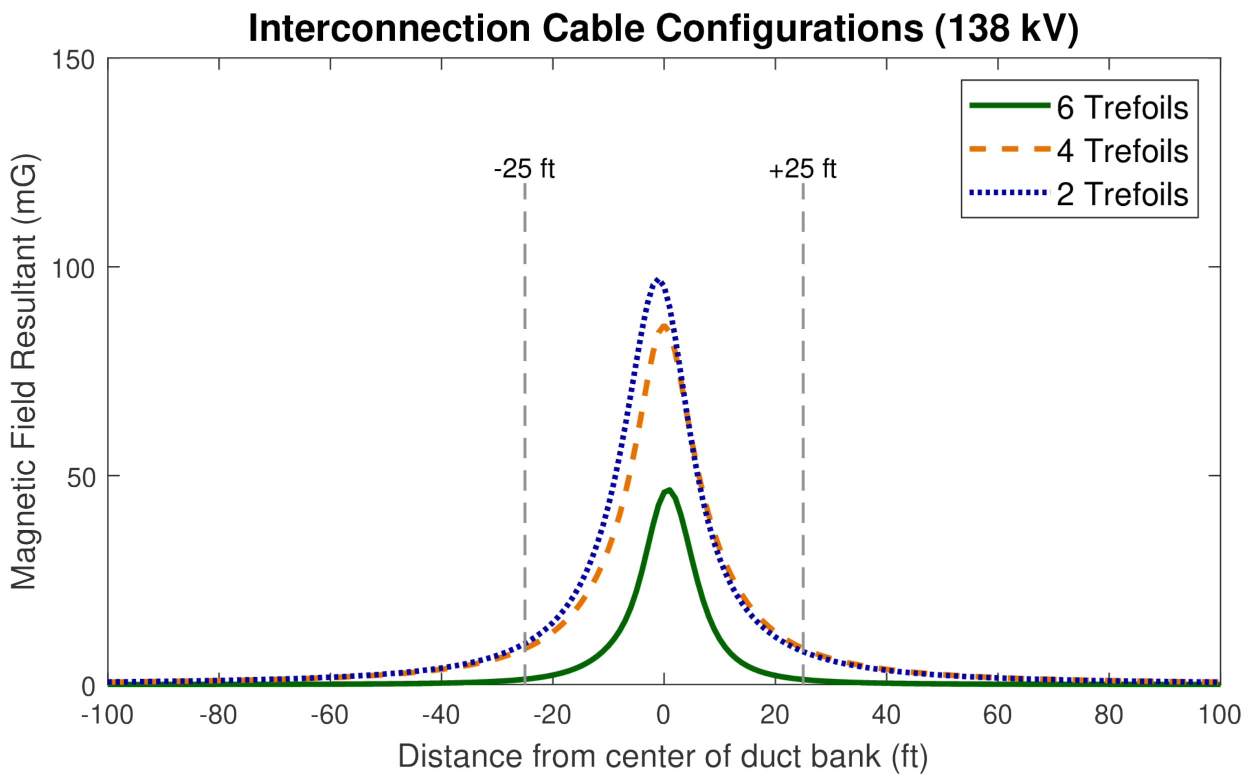

Figure 9. Calculated magnetic-field levels at 3.3 ft (1.0 m) above ground for 138-kV interconnection cable configurations at average loading.

Table 3. Calculated magnetic-field levels (mG) at 3.3 ft (1.0 m) above ground for configurations of EW 2 138-kV interconnection cables at average loading

	Distance from Center of Configuration						
Configuration	**-50 ft**	**-25 ft**	**-10 ft**	**Max**	**10 ft**	**25 ft**	**50 ft**
Six Trefoils	0.2	1.3	9.3	47	11	1.2	0.2
Four Trefoils	2.4	8.6	32	86	32	8.6	2.4
Two Trefoils	2.6	9.9	43	97	30	7.9	2.3

All calculated magnetic-field levels were well below the ICNIRP reference level of 2,000 mG and the ICES exposure reference level of 9,040 mG for exposure of the general public.[9]

[9] The Article VII report to be submitted to the New York State Public Service Commission will demonstrate compliance with the magnetic-field standard

Conclusions

The magnetic-field levels generated by the Project's onshore export and interconnection cables were calculated to be well below limits published by the International Commission of Non-Ionizing Radiation Protection (ICNIRP) (2,000 mG) and International Committee on Electromagnetic Safety (ICES) (9,040 mG) that are designed to protect the health and safety of the general public (ICES, 2019; ICNIRP, 2010).[10] The highest magnetic-field levels were calculated over the duct banks but decrease rapidly with distance.

For EW 1 the calculated magnetic-field level for the Typical interconnection cable configuration (proposed for the majority of the respective onshore cable routes) at 25 ft (7.6 m) at average current flow was 7.0mG, which is more than 280 to 1200 times lower than ICNIRP or ICES reference levels for exposure of the general public. For short distances along the EW 1 route where the cable may be installed in alternate configurations at road crossings or to avoid buried infrastructure, the magnetic fields were slightly higher and lower respectively.

For EW 2, at a distance of 25 ft (7.6 m) from the duct bank centerline, the magnetic-field levels of the onshore export and interconnection cables in any configuration were calculated to be 10 mG or less at average loading, more than 200 to 900 times lower than ICNIRP or ICES reference levels for exposure of the general public.

For all cable configurations, the magnetic field at peak current will be higher than at average current; however, to the extent that the phase-optimized cable arrangements can be used, in accord with the calculations presented herein, the magnetic fields from all configurations and all current levels will remain well below the ICNIRP and ICES limits.

[10] The Article VII report to be submitted to the New York State Public Service Commission will demonstrate compliance with the magnetic-field standard

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Perrin N, Aggarwal RP, Bracken TD, Rankin RF. Survey of Magnetic Fields near BPA 230-kV and 500-kV Transmission Lines. Portland, Oregon: Portland State University, 1991.

World Health Organization (WHO). Extremely Low Frequency Fields. Environmental Health Criteria, Vol. 238. Geneva, World Health Organization, 2007.

Limitations

At the request of Empire Wind, Exponent modeled the magnetic-field levels associated with the operation of the onshore underground cables that will transport electricity generated by the Project from the shore to the proposed points of interconnection.

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

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

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

Benjamin R.T. Cotts, Ph.D., P.E. (Licensed Electrical Engineer, New York, #103209-01), employed by Exponent, performed and reviewed calculations of the magnetic fields associated with the operation of the proposed Project.

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Benjamin Cotts, Ph.D., P.E.

Attachment A

Cable and Duct Bank Details

Table A-1. Summary of onshore cable parameters for EW 1 and EW 2

	EW 1	EW 2	
Description	Interconnection	Export	Interconnection
Source capacity	410 Megawatts	420 Megawatts	410 Megawatts
Voltage	345 kV	230 kV	138 kV
Average Loading per Cable*	618 A	944 A	772.5
Peak Loading per Cable*	727 A	1,110 A	908.5 A
Number of circuits per duct bank	2	3	3, 2, or 1
Number of cables per phase	1	1	2
Typical Separation between Duct Banks (and range)	Typical: 0-10 ft (0-3 m)†	N/A	N/A
Phase Cable Type, Outer Diameter (OD)	Single-core XLPE, 5.2-inch Outer Diameter (133 millimeter)	Single-core XLPE, 3-inch Outer Diameter (150 millimeter [mm])	
Phase Conductor Diameter	2.5-inches (63.4 mm)		
GCC cable type, Outer Diameter	N/A		
Minimum Burial Depth‡	3 ft (0.9m)		
Evaluation Height	At 3.3 ft (1 m) above ground		

* All loading levels are given on a per-cable basis.
† Center-to-center spacing between trefoil bundles.
‡ To the top of the duct bank or conduit.

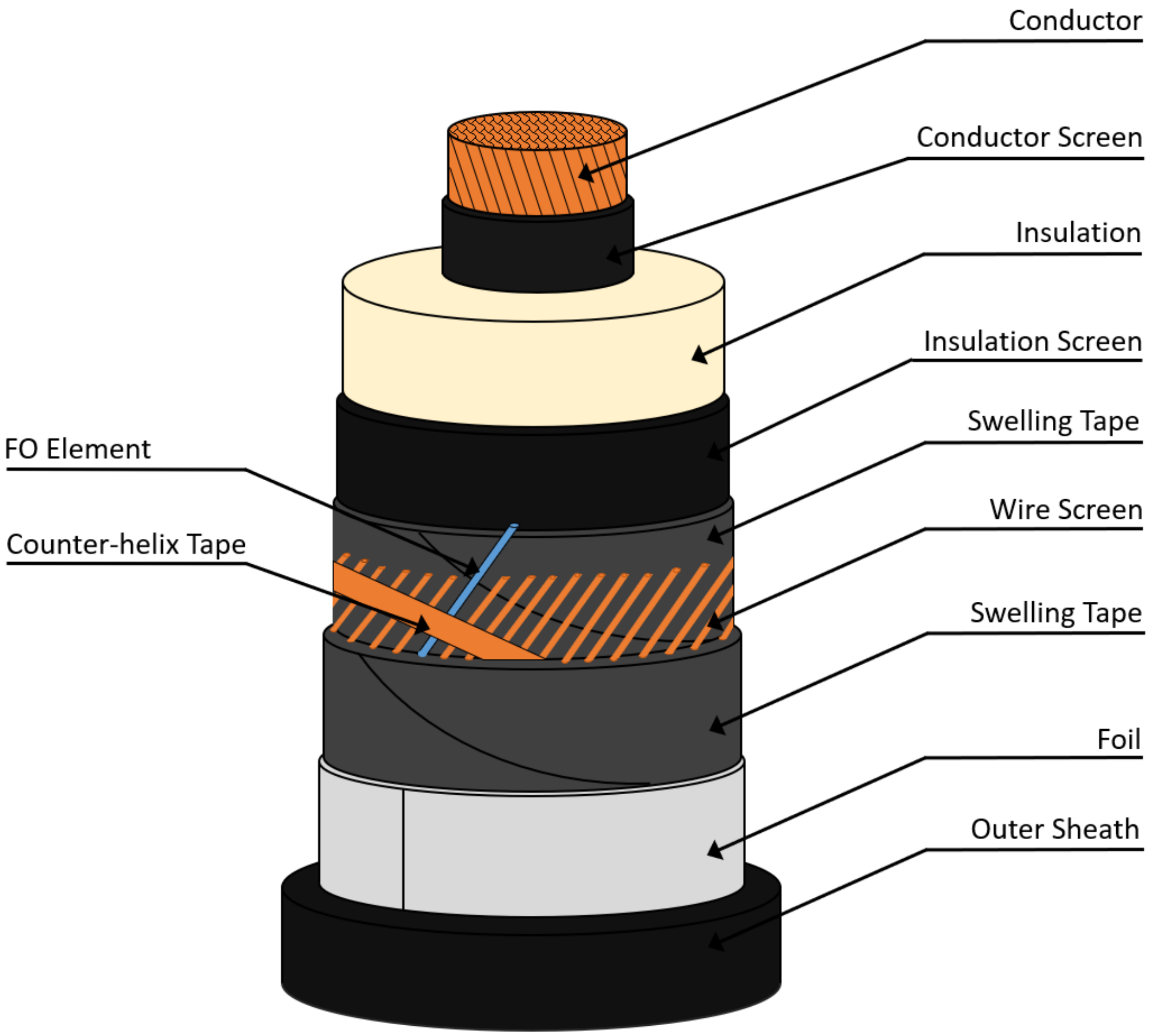

Figure A-1. Representative cross-section of a single conductor of an onshore cable.

EW 1: Duct Bank Configurations

Figure A-2 below shows a cross-section of the underground duct banks with cables in the Typical trefoil configuration. Short cable segments under a road may be in the Road Crossing configuration; in the Road Crossing configuration, the cables will be installed in a trefoil configuration inside of larger direct buried conduits or pipes, rather than in duct banks (Figure A-3). The minimum target burial depth to the top of the trefoil-containing pipes is 3 ft (0.9 m), and the range of possible separation distances between circuit centers at some locations beyond that of the Typical configuration is 10 to 20 ft (3 to 6 m). Alternatively, the cables may be installed in duct banks with a Flat configuration (Figure A-3) for short distances when the Typical configuration is not possible. The minimum separation distance between onshore cable circuits in the Flat configuration is 0 to 10 ft (0 to 3 m).

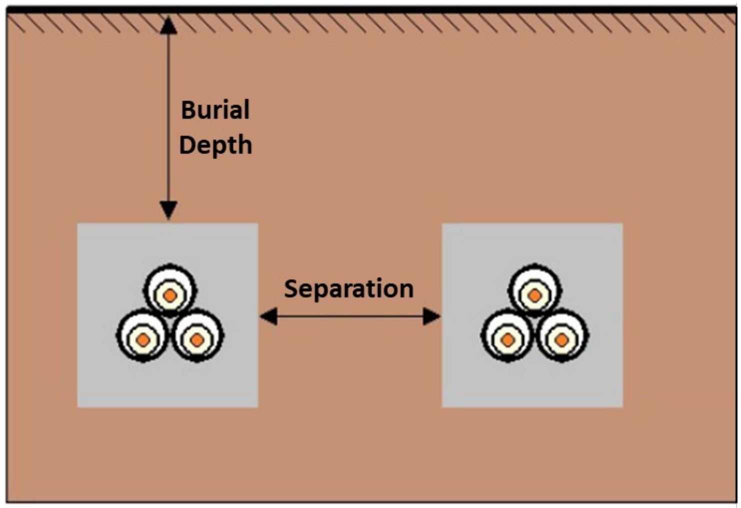

Figure A-2. Representative cross-section of the Typical configuration of onshore cables in duct banks.

The configuration with Separation = 0.0 ft (0.0 m) represents the preferred and most likely configuration for both the onshore export cables and interconnection cables comprising the majority of the route for EW 1.

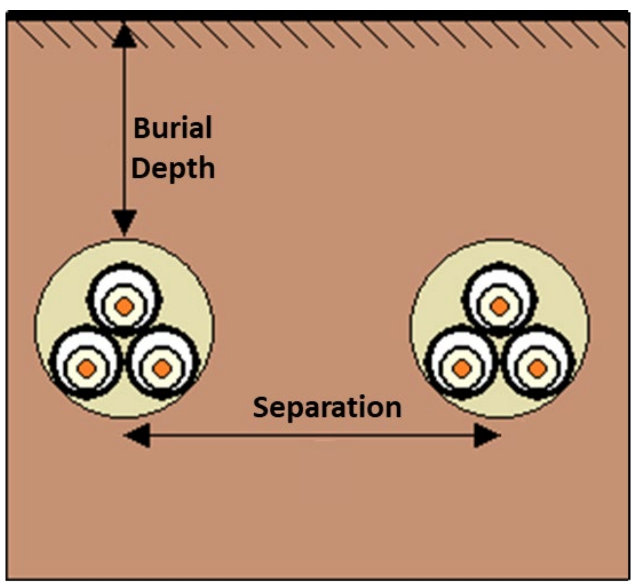

Figure A-3. Representative cross-section of the road crossing configuration of onshore cables.

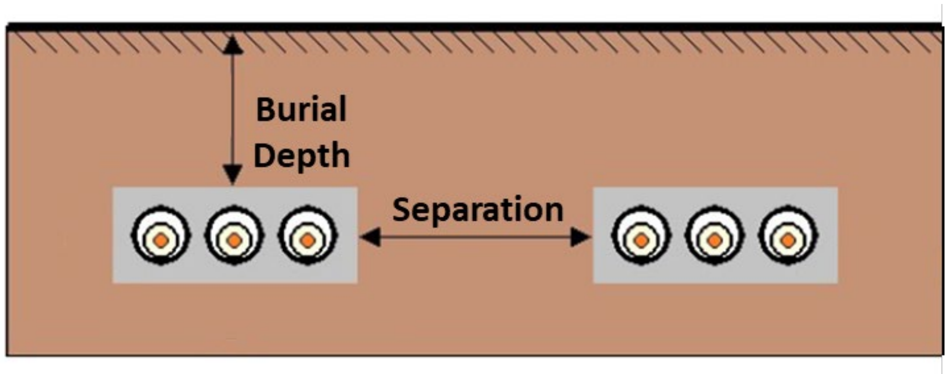

Figure A-4. Representative cross-section of the flat configuration of onshore cables.

EW 2: Duct Bank Configurations

For each of the seven duct bank configurations considered for EW 2 in this report, the particular configuration of the phase conductors within each trefoil group, and among trefoil groups, can significantly change the magnetic-field level above each respective duct bank due to the mutual cancellation of magnetic fields from adjacent cables and circuits. Exponent performed a phase optimization analysis for both the export cable and interconnection cable duct banks to determine which of all possible phase permutations of the cables in each duct bank would minimize the calculated magnetic-field levels at a horizontal distance of 25 ft (7.6 m) from the center of the duct banks. The results of this phase optimization are shown in the figures below.

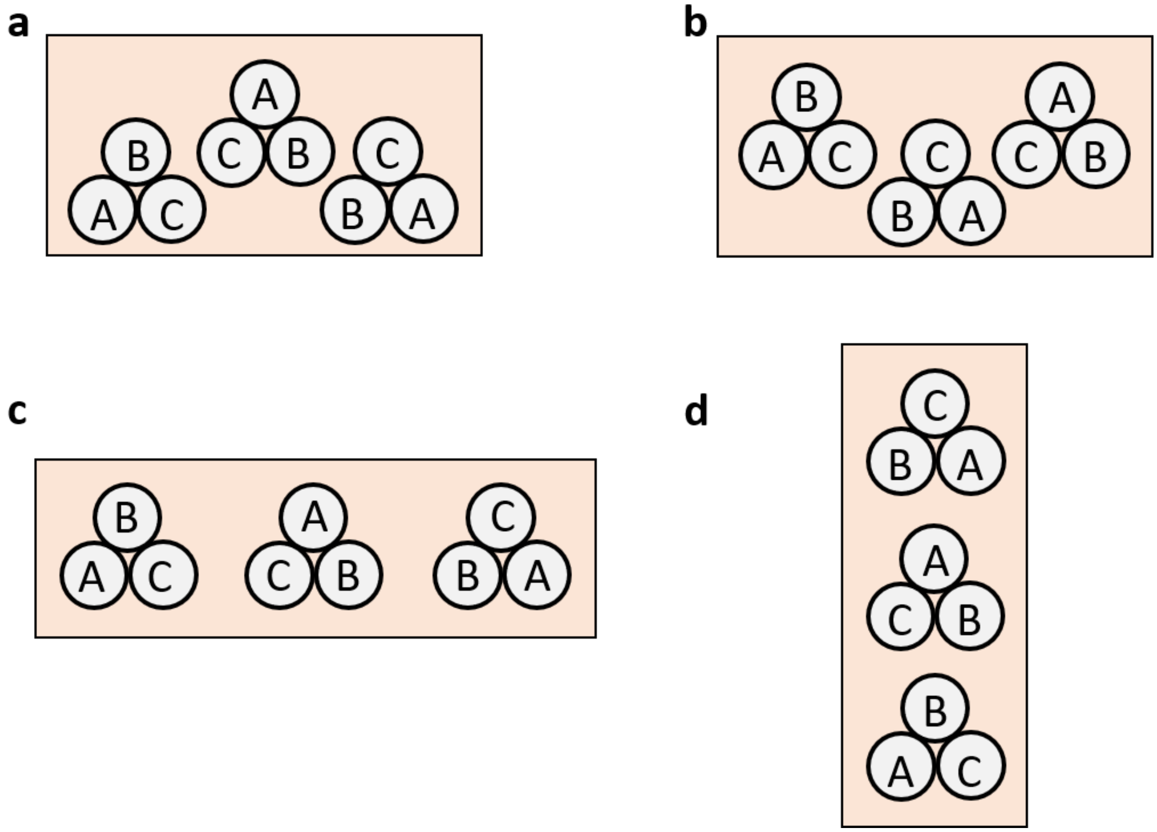

Figure A-5. Optimized arrangement of phase conductors, indicated by letters ABC, for the four respective duct bank configurations considered for the 230-kV export cable: a) delta; b) inverted delta; c) horizontal; and d) vertical.

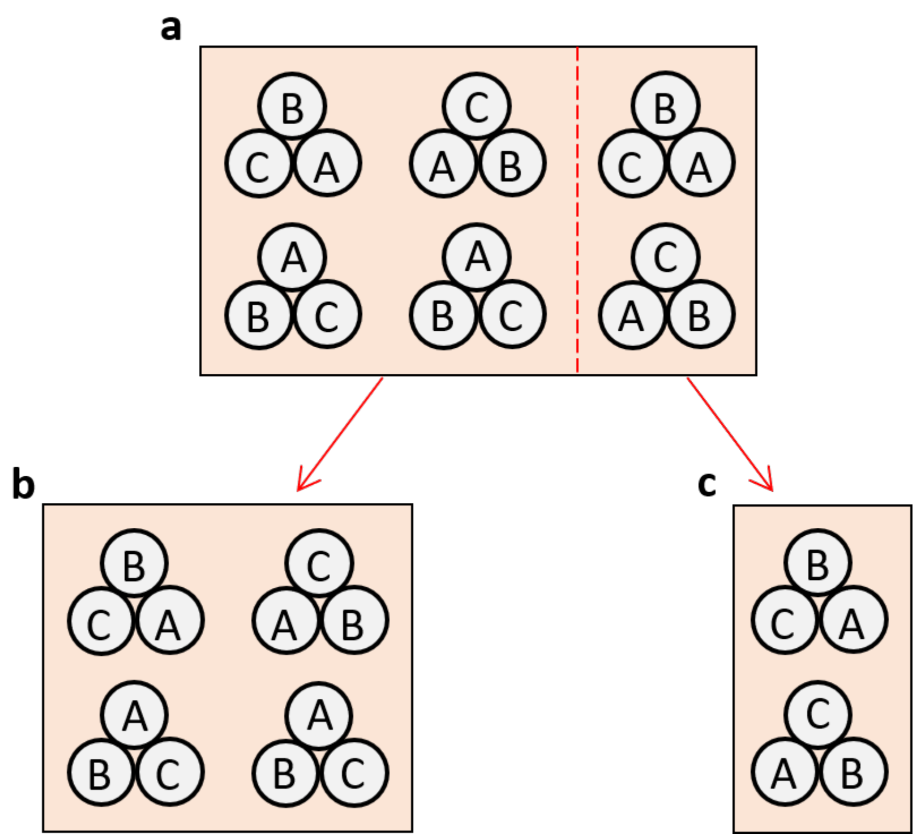

Figure A-6. Optimized arrangement of phase conductors, indicated by letters ABC, for the three respective duct bank configurations considered for the 138-kV interconnection cable: a) six trefoils in one duct bank; b) four trefoils in one duct bank; c) two trefoils in one duct bank.

Attachment B

Calculated Magnetic Field Levels

EW 1 Magnetic Fields

Table B-1. Calculated magnetic-field levels (mG) at 3.3 ft (1.0 m) above ground for the EW 1 345-kV interconnection cables in Typical and alternative configurations at preferred circuit spacing and at **average** loading

Configuration	Spacing	Distance from Center of Configuration								
		-75 ft	-50 ft	-25 ft	-10 ft	Max	10 ft	25 ft	50 ft	75 ft
Typical	**0 ft***	0.9	1.9	7.0	26	37	26	7.0	1.9	0.9
Road Crossing	**10 ft****	0.9	2.0	8.3	44	75	44	8.3	2.0	0.9
Flat	**0 ft***	0.1	0.4	2.9	28	124	28	2.9	0.4	0.1

* Spacing represents the edge-to-edge distance between adjacent duct banks.

** Spacing represents the center-to-center distance between circuits.

Table B-2. Calculated magnetic-field levels (mG) at 3.3 ft (1.0 m) above ground for the EW 1 345-kV interconnection cables in Typical and alternative configurations at preferred circuit spacing and at **peak** loading

Configuration	Spacing	Distance from Center of Configuration								
		-75 ft	-50 ft	-25 ft	-10 ft	Max	10 ft	25 ft	50 ft	75 ft
Typical	**0 ft***	1.0	2.3	8.2	30	44	30	8.2	2.3	1.0
Road Crossing	**10 ft****	1.0	2.4	9.8	52	88	52	9.8	2.4	1.0
Flat	**0 ft***	0.1	0.5	3.4	33	145	33	3.4	0.5	0.1

* Spacing represents the edge-to-edge distance between adjacent duct banks.

** Spacing represents the center-to-center distance between circuits.

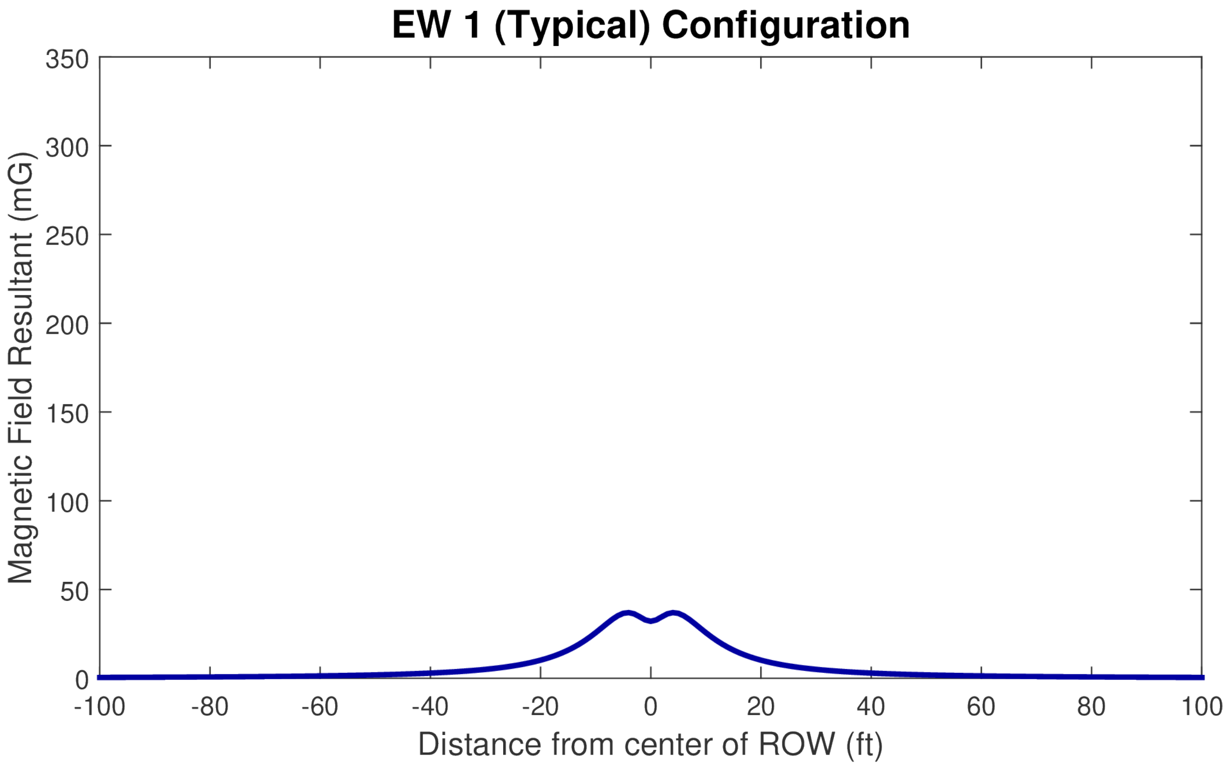

Figure B-1. Calculated magnetic-field levels at 3.3 ft (1.0 m) above ground for the EW 1 345-kV interconnection cable in the Typical configuration at average loading.

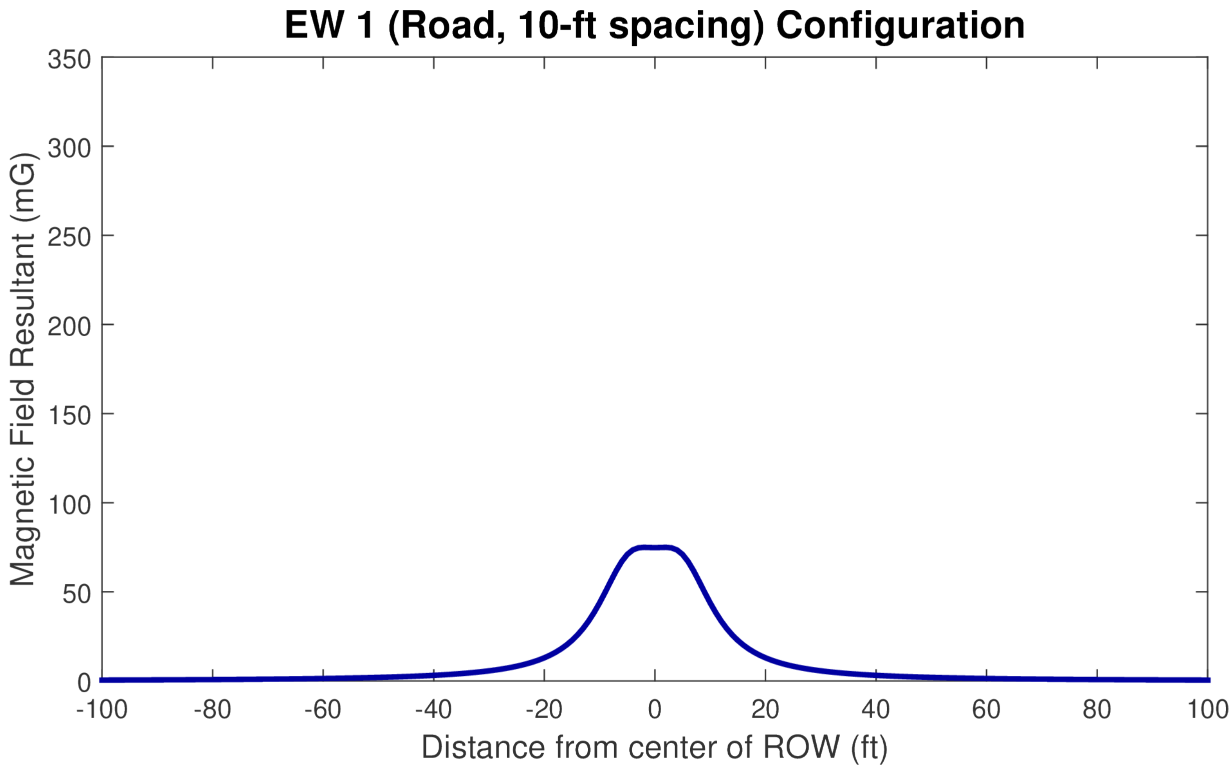

Figure B-2. Calculated magnetic-field levels at 3.3 ft (1 m) above ground for the EW 1 345-kV interconnection cable for the Road Crossing configuration at the preferred circuit spacing (10 ft [3 m]) at average loading.

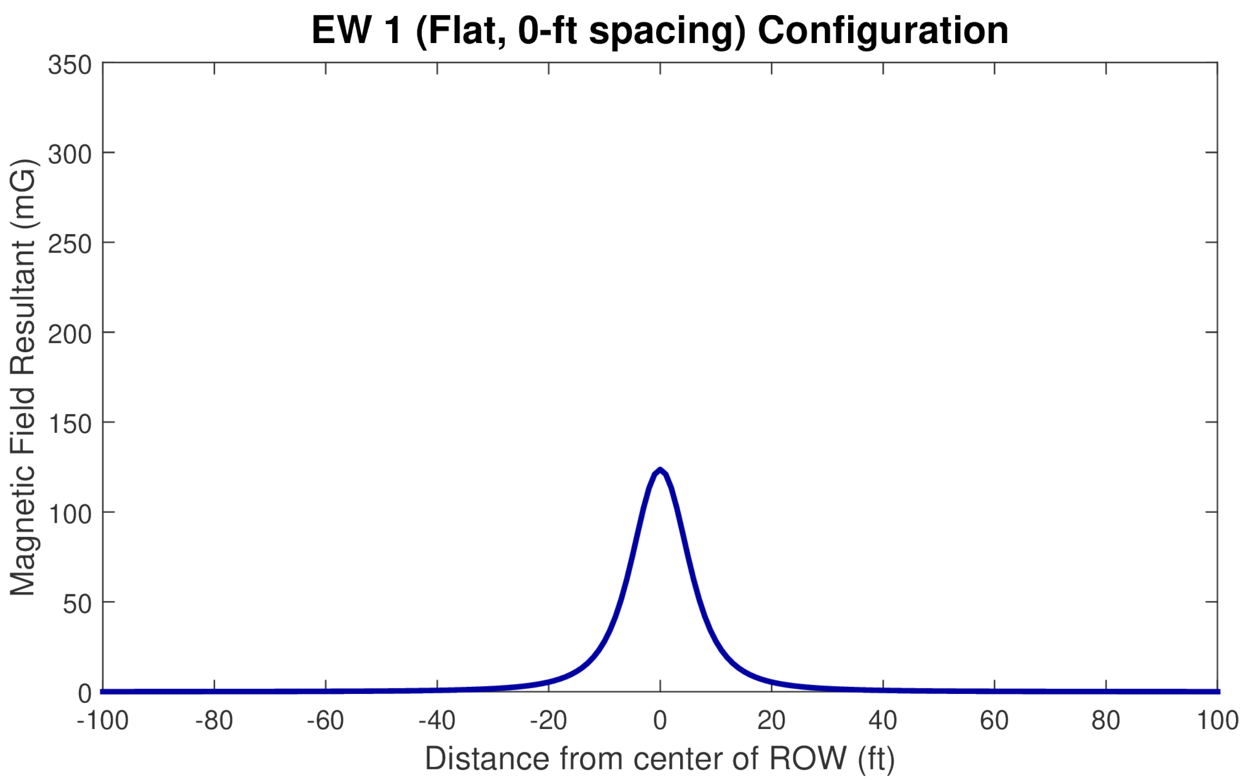

Figure B-3. Calculated magnetic-field levels at 3.3 ft (1.0 m) above ground for the EW 1 345-kV interconnection cable for the Flat configuration at average loading.

EW 2 Magnetic Fields

Table B-3. Calculated magnetic-field levels (mG) at 3.3 ft (1.0 m) above ground for the EW 2 230-kV onshore export cable at average loading in each of the four considered duct bank configurations

	Distance from Center of Configuration								
Configuration	-75 ft	-50 ft	-25 ft	-10 ft	Max	10 ft	25 ft	50 ft	75 ft
Delta	0.1	0.2	1.4	11	28	11	1.4	0.2	0.1
Inverted Delta	0.1	0.2	1.5	15	72	15	1.5	0.2	0.1
Horizontal	0.1	0.4	3.2	26	80	26	3.2	0.4	0.1
Vertical	0.1	0.3	2.3	17	63	20	2.6	0.4	0.1

Table B-4. Calculated magnetic-field levels (mG) at 3.3 ft (1.0 m) above ground for the EW 2 230-kV onshore export cable at peak loading in each of the four considered duct bank configurations

	Distance from Center of Configuration								
Configuration	-75 ft	-50 ft	-25 ft	-10 ft	Max	10 ft	25 ft	50 ft	75 ft
Delta	0.1	0.2	1.7	12	33	12	1.7	0.2	0.1
Inverted Delta	0.1	0.2	1.8	18	85	18	1.8	0.2	0.1
Horizontal	0.2	0.5	3.8	31	94	31	3.8	0.5	0.2
Vertical	0.1	0.4	2.8	20	74	23	3.1	0.4	0.1

Table B-5. Calculated magnetic-field levels (mG) at 3.3 ft (1.0 m) above ground for the EW 2 138-kV interconnection cable at average loading

Configuration	Distance from Center of Configuration								
	-75 ft	-50 ft	-25 ft	-10 ft	Max	10 ft	25 ft	50 ft	75 ft
Six Trefoils	0.1	0.2	1.3	9.3	47	11	1.2	0.2	0.1
Four Trefoils	1.1	2.4	8.6	32	86	32	8.6	2.4	1.1
Two Trefoils	1.1	2.6	9.9	43	97	30	7.9	2.3	1.0

Table B-6. Calculated magnetic-field levels (mG) at 3.3 ft (1.0 m) above ground for the EW 2 138-kV interconnection cable at peak loading

Configuration	Distance from Center of Configuration								
	-75 ft	-50 ft	-25 ft	-10 ft	Max	10 ft	25 ft	50 ft	75 ft
Six Trefoils	0.1	0.2	1.5	11	55	13	1.4	0.2	0.1
Four Trefoils	1.3	2.8	10	38	101	38	10	2.8	1.3
Two Trefoils	1.3	3.0	12	50	114	35	9.3	2.7	1.2