Electrical Engineering and Computer Science Practice

Appendix Q2
Revolution Wind Farm

Onshore Magnetic-Field Assessment

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Exponent®

Appendix N2
Revolution Wind Farm

Onshore Magnetic-Field Assessment

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Acronyms and Abbreviations

A	Amperes
BOEM	Bureau of Ocean Energy Management
BPA	Bonneville Power Administration
EFSB	Energy Facilities Siting Board
DWW Rev I	DWW Rev I, LLC
EMF	Electric and magnetic fields
G	Gauss
HDD	Horizontal directional drilling
Hz	Hertz
ICES	International Committee on Electromagnetic Safety
ICNIRP	International Commission on Non-Ionizing Radiation Protection
IEEE	Institute of Electrical and Electronics Engineers
km	Kilometer
kV	Kilovolt
mG	Milligauss
m	Meter
mm	millimeter
MW	Megawatt
OnSS	Onshore substation
Orsted	Orsted US Wind Power, LLC
Project	Revolution Wind Farm project
ROW	Right of way
RWEC	Revolution Wind Export Cable
RWF	Revolution Wind Farm
TJB	Transition joint bay
VHB	Vanasse Hangen Brustlin, Inc.

Limitations

At the request of Vanasse Hangen Brustlin, Inc. (VHB) and DWW Rev I, LLC (DWW Rev I)[1], Exponent Inc. (Exponent) modeled anticipated magnetic-field levels associated with the operation of the Onshore Transmission Cables proposed as part of the Revolution Wind Farm Project (Project).

This report summarizes the analysis performed to date and presents the findings resulting from that work. In the analysis, we have relied on cable design geometry, usage, specifications, and various other types of information provided by VHB and DWW Rev I. We cannot verify the correctness of this input data and rely on the VHB and DWW Rev I 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. VHB has confirmed to Exponent that the data contained herein are not subject to Critical Energy Infrastructure Information restrictions.

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

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

[1] DWW Rev I is a 50/50 joint venture between Orsted North America Inc. and Eversource Investment LLC.

Executive Summary

At the request of Vanasse Hangen Brustlin, Inc. (VHB) and DWW Rev I, LLC (DWW Rev I)[2], Exponent, Inc. calculated the magnetic fields associated with the operation of the Onshore Transmission Cables that are proposed to convey electricity generated by the Revolution Wind Farm (RWF) to the Onshore Substation (OnSS).

The RWF will have a maximum capacity of 880 megawatts (MW). The Onshore Transmission Cables will be installed in underground duct banks. Modeling results at 880 MW demonstrate that the magnetic field directly over the duct banks is 73 milligauss (mG) or less for the Onshore Transmission Cables at peak loading and decreases rapidly to 11 mG or less a distance of 12.5 feet (3.8 meters) from the duct bank center. These levels are well below the International Commission for Non-Ionizing Radiation Protection's reference level of 2,000 mG and the International Commission for Electromagnetic Safety's maximum permissible exposure limit of 9,040 mG for the general population.

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.

[2] DWW Rev I is a 50/50 joint venture between Orsted North America Inc. and Eversource Investment LLC.

Introduction

DWW Rev I, LLC (DWW Rev I), a 50/50 joint venture between Orsted North America Inc. and Eversource Investment LLC, proposes to construct and operate the Revolution Wind Farm Project (Project). The wind farm portion of the Project will be located in federal waters on the Outer Continental Shelf (OCS) in the designated Bureau of Ocean Energy Management (BOEM) Renewable Energy Lease Area OCS-A 0486 (Lease Area). The Lease Area is approximately 20 statute miles (mi) (17.4 nautical miles, 30 kilometers [km]) south of the coast of Rhode Island. Other components of the Project will be located in state waters of Rhode Island and onshore in North Kingstown, Rhode Island. The Project is proposed to be comprised of up to 100 wind turbine generators (WTG) and will be capable of producing up to 880 megawatts (MW) of electricity.

Up to two offshore substations will receive power generated from individual WTGs via Inter-Array Cables. Up to two submarine export cables (referred to as the Revolution Wind Export Cable [RWEC]) will convey power to shore; the RWEC corridor will be up to 50 mi (80 km) in length. Where the RWEC makes landfall at Quonset Point in North Kingstown, Rhode Island, the cables will be installed via horizontal directional drilling (HDD) or open cut trench to transition joint bays (TJB) located onshore where the cables will be spliced into six distinct Onshore Transmission Cables, which will connect to a new onshore substation (OnSS) located adjacent to the existing Davisville Substation. The Onshore Transmission Cables will be installed within an underground duct bank. Three landfall locations at Quonset Point are being considered: Blue Beach (preferred), White Cap Drive (alternative), and Compass Rose Beach (alternative). Figure 1 shows all three options including the Blue Beach and Whitecap Drive options which will be approximately 1 mi (1.6 km) in length, and the Compass Rose Beach option which will be slightly longer, approximately 1.5 mi (2.4 km).

Electrical components of the Project will be sources of magnetic fields. This report presents magnetic field modeling results for the Onshore Transmission Cables specifically. Results are evaluated with respect to relevant standards. Magnetic fields associated with offshore components of the Project are evaluated in a separate report (Appendix N1) titled *Revolution Wind Farm Offshore Electric- and Magnetic-Field Assessment* (Exponent, 2020).[3]

[3] Exponent, Inc. (Exponent). Revolution Wind Farm Offshore Electric- and Magnetic-Field Assessment. Prepared for DWW Rev I, LLC Bowie, MD: Exponent, 2020.

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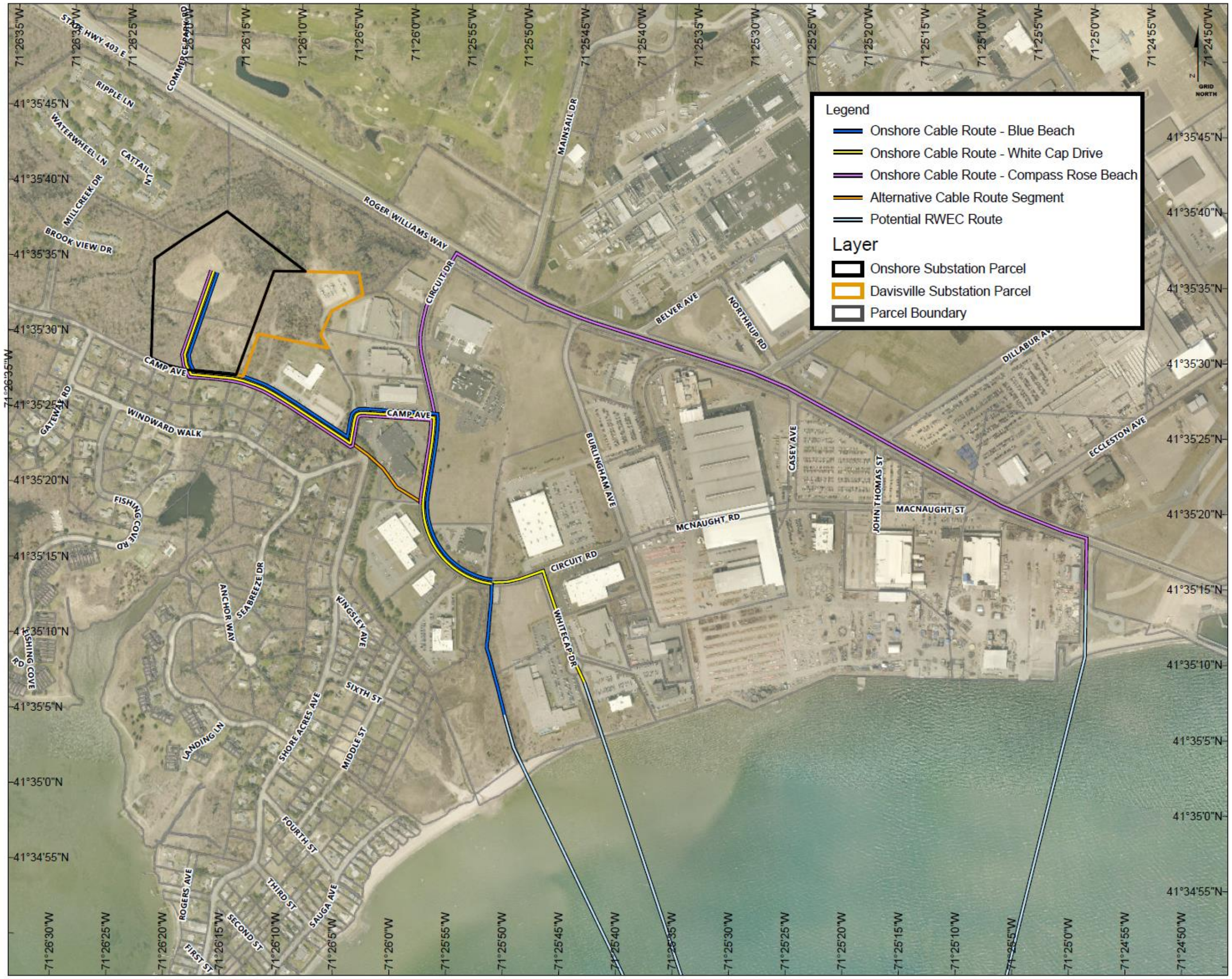

Figure 1. Three potential landing sites at Quonset Point in North Kingstown, Rhode Island.

Technical Background

Magnetic Fields

Magnetic fields surrounding cables associated with the RWF will oscillate with a frequency of 60 Hertz (Hz). The magnetic field results from the flow of electricity along the cable and is reported as the magnetic flux density in units of Gauss (G) or milligauss (mG), where 1 G = 1,000 mG. The magnetic field will be strongest at the surface of the cable and will decrease rapidly with distance from the cables. The voltage applied to the conductors within the cable creates an electric field but will not be a direct source of any electric field above ground due to the cable construction, duct bank, and burial underground, so above ground electric-field levels are not discussed further in this report.

Since load currents—expressed in units of amperes (A)—generate magnetic fields, measurements or calculations present a snapshot for the load conditions at only one moment in time. On a given day, throughout a week, or over the course of months or years, the field levels can change depending upon the power generated by the turbines, which depends on wind speed and operational status. To account for this variability, calculations are performed for annual average load and peak load of the RWF, which will provide the average and maximum field levels expected for the Project.

Relevant Standards

The federal government and Rhode Island have no limits on magnetic-field strength, including magnetic fields from transmission lines.[4] Two international organizations provide guidance on human exposure to magnetic fields. This guidance is the result of extensive review and evaluations of relevant research of health and safety issues, and the limits they propose are designed to protect health and safety of persons in an occupational setting and for the general public. The International Committee on Electromagnetic Safety (ICES), which operates "under

[4] The Rhode Island Energy Facilities Siting Board (EFSB) requires a "…review of the current independent scientific research pertaining to …EMF [electric and magnetic fields]…and…data on the anticipated levels of EMF exposure…" This report will be filed with the EFSB in advance of the state permitting process.

the rules and oversight of the IEEE Standards Association Board,"[5] developed an exposure reference level for magnetic fields of 9,040 mG for the general public. The International Commission on Non-Ionizing Radiation Protection (ICNIRP), an independent organization providing scientific advice and guidance on the health and environmental effects of non-ionizing radiation, determined a reference level limit for whole-body exposure to 60-Hz magnetic fields of 2,000 mG for the general public.[6]

5 http://www.ices-emfsafety.org/

6 International Committee on Electromagnetic Safety (ICES). IEEE Standard for Safety Levels with Respect to Human Exposure to Electromagnetic Fields 0 to 300 GHz. IEEE Std C95.1-2019 (Revision of IEEE Std C95.1-2005/ Incorporates IEEE Std C95.1-2019/Cor 1-2019). New York, NY: IEEE, 2019.
International Commission on Non-ionizing Radiation Protection (ICNIRP). Guidelines for limiting exposure to time-varying electric and magnetic fields (1 Hz to 100 kHz). Health Phys 99: 818-836, 2010.

Modeling Configuration and Methodology

Description of Onshore Transmission Cables

The Onshore Transmission Cables will consist of six 1500 kcmil copper cables, each 4.8 inches (in) (122 millimeters [mm]) in diameter, which will be installed in an underground duct bank as shown in Attachment A, Figure A-1 (a cross section of the single-core cables is shown in Attachment A, Figure A-2). The phasing of the cables within the duct bank has been optimized to minimize magnetic fields. Table 1 summarizes the onshore modeling configuration and loading levels. The maximum proposed capacity of the RWF is 880 MW, so calculations were performed for this loading level. If a lower capacity option is constructed, field levels would be lower.

Table 1. Summary of onshore modeling configurations

RWF Capacity (maximum)	880 MW
Voltage (kV)	275
Average Loading	690 Amperes per conductor
Peak Loading	985 Amperes per conductor
Number of Cables	6 (2 of each phase)
Cable Type	4.8 in (122 mm)
Conductor	1500 kcmil
Installation Type	2x3 duct bank
Burial Depth (to top of duct bank)	3-ft (0.91 m)
Height of evaluation	3.28 ft (1 m)

Modeling Methodology

Magnetic-field levels were calculated using computer algorithms developed by the Bonneville Power Administration (BPA), an agency of the U.S. Department of Energy.[7]

[7] Bonneville Power Administration (BPA). Corona and Field Effects Computer Program. Portland, OR: Bonneville Power Administration, 1991.

All magnetic-field calculations were made assuming that the conductors of the Onshore Transmission Cables 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 have been shown to accurately predict electric- and magnetic-field levels measured near transmission lines.[8] Field levels are calculated at a height of 3.28 feet (1 meter [m]) above ground and are reported as the root mean square value of the field in accordance with IEEE Std. C95.3.1-2010 and IEEE Std. 644-2019.[9]

Additionally, the models assume that the load on the phase conductors is balanced, that there is no attenuation of magnetic fields from any surrounding material, and that there are no ground continuity conductors or unbalanced currents flowing along the outer sheaths of the cables.

[8] Chartier V and Dickson LD. Results of Magnetic Field Measurements Conducted on Ross-Lexington 230-Kv Line. Report No. Ele-90-98. Portland, OR: Bonneville Power Administration (BPA), 1990; Perrin N, Aggarwal RP, Bracken TD, and Rankin RF. Survey of Magnetic Fields near BPA 230-kV and 500-kV Transmission Lines. Portland, OR: Portland State University, 1991.

[9] Institute of Electrical and Electronics Engineers (IEEE). IEEE Recommended Practice for Measurements and Computations of Electric, Magnetic, and Electromagnetic Fields with Respect to Human Exposure to Such Fields, 0 Hz to 100 kHz (IEEE Std. C95.3.1-2010)." New York: IEEE, 2010; Institute of Electrical and Electronics Engineers (IEEE). Approved Draft Standard Procedures for Measurement of Power Frequency Electric and Magnetic Fields from AC Power Lines (ANSI/IEEE Std. 644-2019). New York: IEEE, 2019.

Model Results and Discussion

Exponent calculated the 60-Hz magnetic fields from the proposed Onshore Transmission Cables at the maximum loading of the RWF using the methods described above. Numerical results of these calculations are summarized below for magnetic-field levels above ground.

Results

The results of the magnetic-field modeling at average and peak loading are shown below in Figure 2 and Table 2 summarizes results at average and peak loading for the maximum (880 MW) RWF capacity.

As shown in Table 2, the magnetic-field level from the Onshore Transmission Cables is calculated to decrease very rapidly with distance from the centerline. The calculated magnetic-field level at a height of 3.28 feet (1 m) directly above the duct bank at peak loading is 73 mG, decreasing rapidly to 11 mG at a distance of ±12.5 feet (3.8 m) from the duct bank centerline. At a distance of 25 feet from the duct bank centerline the magnetic-field level is 2.0 mG or less for average or peak loading.

Discussion

Magnetic-field levels are routinely assessed in terms of standards and guidelines developed by scientific and health agencies to protect health and safety and are based on reviews and evaluations of relevant health research. The maximum calculated magnetic-field levels at peak loading and directly above the duct bank are more than 25-times lower than the guidelines of 2,000 mG and 9,040 mG set by ICNIRP and ICES for the general population. In addition, field levels at peak loading decrease rapidly with distance to 2 mG or less within ±25 feet (7.6 m) of the duct bank.

Table 2. Modeled magnetic-field level (mG) calculated at 3.28 feet (1 m) above ground for the average and peak loading for the maximum 880 MW case.

Loading	Voltage (kV)	–25 ft (7.6 m)	–12.5 ft (3.8 m)	Max	+12.5 ft (3.8 m)	+25 ft (7.6 m)
Average	275	1.4	7.7	51	7.7	1.4
Peak	275	2.0	11	73	11	2.0

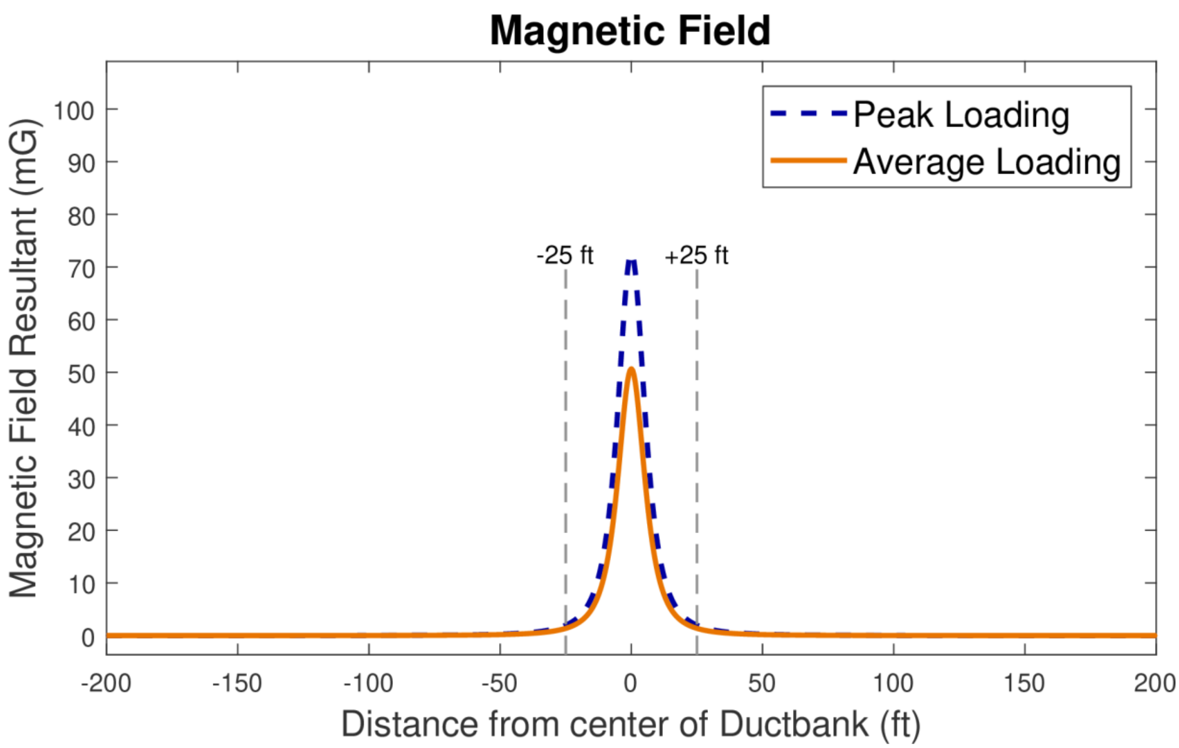

Figure 2. Magnetic-field levels for the Onshore Transmission Cables at 3.28 feet (1m) above ground at average and peak loading for 880 MW RWF Capacity.

Conclusions

Exponent modeled the magnetic-field levels associated with the operation of the Onshore Transmission Cables proposed as part of the Project. The results demonstrate that, for the maximum 880 MW capacity of the RWF, the magnetic field at peak loading directly over the duct banks is 73 mG and is well below the ICNIRP reference level of 2,000 mG and the ICES maximum permissible exposure limit of 9,040 mG for the general population. Lower magnetic-field level would be produced if the power generated by RWF is less than 880 MW.

The Onshore Transmission Cables will not be a direct source of any electric field above ground due to the cable construction, duct bank, and burial underground.

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Attachment A

Duct Bank Cross Section and Cable Configuration

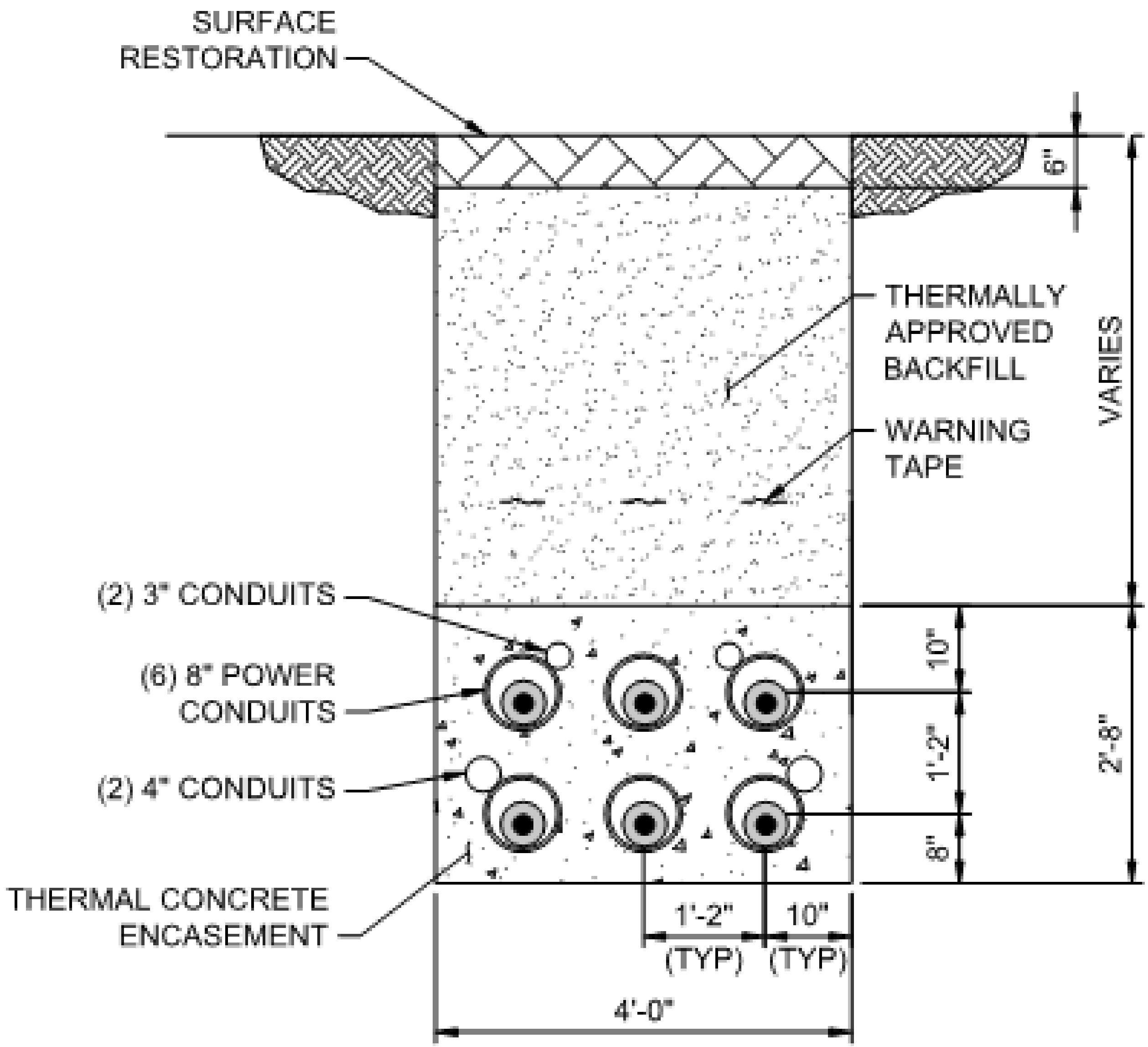

Figure A-1. Onshore duct bank where it is proposed to be constructed between the TJB and OnSS.

The transmission line is proposed to be installed with two conductors per phase, with the phasing arrangement of the conductors selected to minimize magnetic fields above ground.

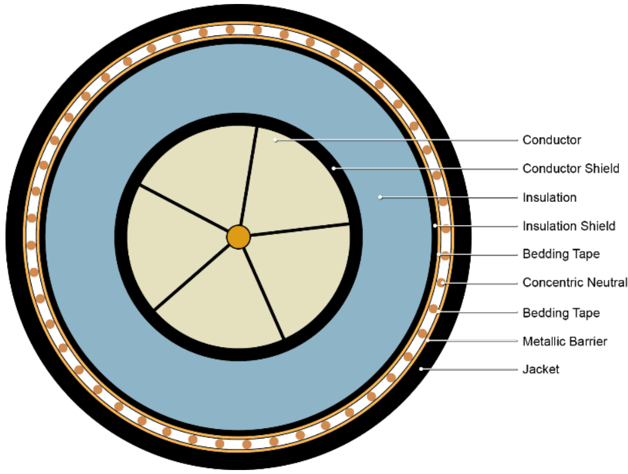

Figure A-2. Illustrative cross section of the onshore single-core cables