Appendix D
Substation and Cable Route Design Report

Substation and Cable Route Design Report

Prepared for LEEDCo by

DNV·GL
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LEEDCo Icebreaker™ Project

DOE EERE
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List of Acronyms

BOS	Balance of System
CDF	Confined Disposal Facility
CPP	Cleveland Public Power
EPR	Ethylene Propylene Rubber
FEED	Front End Engineering Design
SCADA	Supervisory Control and Data Acquisition
HDD	Horizontal Directional Drilling
LEEDCo	Lake Erie Energy Development Corporation, Inc.
WTG	Wind Turbine Generator
XLPE	Cross-Linked Polyethylene

EXECUTIVE SUMMARY

This report summarizes the 50% Front End Engineering Design of key components of the electrical balance of system for Project Icebreaker including the substation, the submarine cable system, and the supervisory control and data acquisition system. This report also describes the cable routing, the cable shore crossing, and cable installation for Icebreaker. The scope of work described herein includes assessment of multiple options for the cable route and shore crossing as well as multiple installation concepts. This report is primarily focused on the mechanical design of the submarine cable and does not include electrical design aspects of the cable (preliminary electrical design is addressed in the Lake Erie Energy Development Corporation, Inc. Grid Interconnect Report [1]). Additionally, the preliminary design presented herein is intended to form the basis for further design activities for Icebreaker and does not represent a comprehensive or complete electrical balance of system design.

During Budget Period 1, Lake Erie Energy Development Corporation, Inc. identified Cleveland Public Power's Lake Road Substation as the point of interconnection. The preliminary design includes a new project substation that will be constructed on Cleveland Public Power property adjacent to the Substation and includes a control building, bus structures, switchgear, and a step-up transformer. The project Substation will be connected to the existing 69 kV system at the Cleveland Public Power Substation via an overhead gen-tie circuit. Detailed engineering design of the substation will be part of the 100% Front End Engineering Design.

As part of the 50% Front End Engineering Design, the preliminary cable layout design was developed based on an assessment of multiple route options driven by the shore crossing route for the export cable. The cable route must cross or go around the breakwater, and then cross the Harbor to connect into the project substation. There is a confined disposal facility, a man-made confinement facility for disposal of dredged materials, inside the Harbor along the direct path to project Substation. As such, there are multiple options for entering and crossing the Harbor.

To compare the different route options, a qualitative comparative analysis was conducted to assess the benefits and risks of each option. This analysis considered multiple criteria including cable length, application of horizontal directional drilling, potential for external damage by third parties, environmental aspects, potential for thermal bottlenecks, permitting considerations, and potential future development plans near the shore crossing. Based on this assessment, the proposed export cable route includes a duct installed with horizontal directional drilling that would route the cable from the project Substation under the Harbor, the confined disposal facility, and the breakwater to a point in the open water of Lake Erie just beyond the breakwater. From that point, the cable route continues on a direct path to the first Wind Turbine Generator (ICE1). The proposed inter-array cable routes are direct paths between the Wind Turbine Generators.

Installation of the cable will be performed with commonly used methods. Horizontal directional drilling with a land-based drilling rig will be used to install a duct under the Harbor, the confined disposal facility, and the breakwater. The export cable will then be pulled through the duct from a cable installation vessel positioned near the entry point for the horizontal directional drilling in the open water of the lake to the exit point at the project Substation using a land-based winch. The portion of the export cable in the open water of the lake and the inter-array cables and will be installed using a jet plow, a device that utilizes high-velocity jets of water to fluidize the lake bottom soil to facilitate simultaneous laying and burial of the cable to a specified depth. The jet plow is towed by a cable installation vessel such as a self-propelled multi-purpose barge that is outfitted for cable installation.

This report includes preliminary specifications for the supply of submarine 34.5 kV cables including the connections and equipment necessary for the installation and operation of the cables. These specifications include operating requirements, general cable construction, attributes and accessories, and requirements for protection, testing, and quality surveillance. The proposed submarine cables are 34.5kV three-core, cross-linked polyethylene or ethylene propylene rubber insulated submarine cables. Due to manufacturing limitations, submarine cables often include factory joints and depending on the capabilities of the manufacturer, field joints may be required. The submarine cables for Icebreaker should be delivered with a minimum number of factory joints. If necessary, field joints shall be installed and tested according to relevant standards to ensure that performance and reliability are not impacted.

The preliminary supervisory control and data acquisition system design reflects the key components for monitoring and controlling Icebreaker.

The preliminary design for the components of the electrical balance of system described in this report represent solutions that will support Icebreaker's objectives, particularly the following:

- Develop an innovative offshore wind system that can be installed in the most rapid and responsible manner possible; minimizes costs, development effort.
- Expedite the development and deployment of innovative offshore wind energy systems with a credible potential for lowering the levelized cost of energy.

This report identifies further studies and design work that will need to be completed to support the final designs of the electrical basis of system. This includes the following:

- Detailed design for the project Substation
- Additional site assessment including geophysical and geotechnical surveying
- Burial assessment for the cable route
- Detailed HDD design
- Vessel planning for cable installation
- Detailed cable design
- Detailed supervisory control and data acquisition system design

Introduction

Lake Erie Energy Development Corporation (LEEDCo) retained DNV GL to develop a preliminary design for the substation and the submarine cable system including the layout of the subsea cable system, the cable shore crossing, and the cable installation for the proposed Project Icebreaker offshore wind project (Project Icebreaker or Icebreaker).

1.1 Scope of Work

This report summarizes the preliminary design of the electrical balance of system (BOS) including the substation, the submarine cable system, and the Supervisory Control and Data Acquisition (SCADA) system; the cable routing; the cable shore crossing; and cable installation for Icebreaker. This scope of work described herein includes assessment of multiple options for the cable route and shore crossing as well as multiple installation concepts. This report was prepared with support from Primo Marine, a global consultancy with extensive experience and expertise with subsea cable design and installation.

The scope of work described in this report is primarily focused on the mechanical design of the submarine cable and does not include electrical design aspects of the cable (preliminary electrical design is addressed in the LEEDCo Grid Interconnect Report. Additionally, the preliminary design presented herein is intended to form the basis for further design activities for Icebreaker and does not represent a comprehensive or complete electrical BOS design.

2 Design Basis

The design basis for the preliminary conceptual design of the electrical BOS is described in Appendix K of the Design Report. The design basis includes the overall project layout, environmental conditions, siting constraints, standards and performance requirements, specifications for the Wind Turbine Generators (WTGs), and existing electrical infrastructure at the point of interconnection.

3 Substation Layout

The project Substation will be situated on the northern edge of the Cleveland Public Power (CPP) property along the shoreline and will be connected to the existing 69 kV bus at the CPP Substation via overhead lines as shown in Figure 3-1. The project Substation will consist of new electrical equipment, including a 34.5 kV to 69 kV step-up transformer, switch gear, bus structures, and a control building, all contained within a fenced area adjacent to the CPP Substation. The conceptual design for the equipment arrangement for Icebreaker Substation is shown in Figure 3-2. The project Substation equipment is described in more detail in the Grid Interconnect Report. The preliminary layout design for the project Substation showing the connection to the CPP Substation is presented in Attachment A.

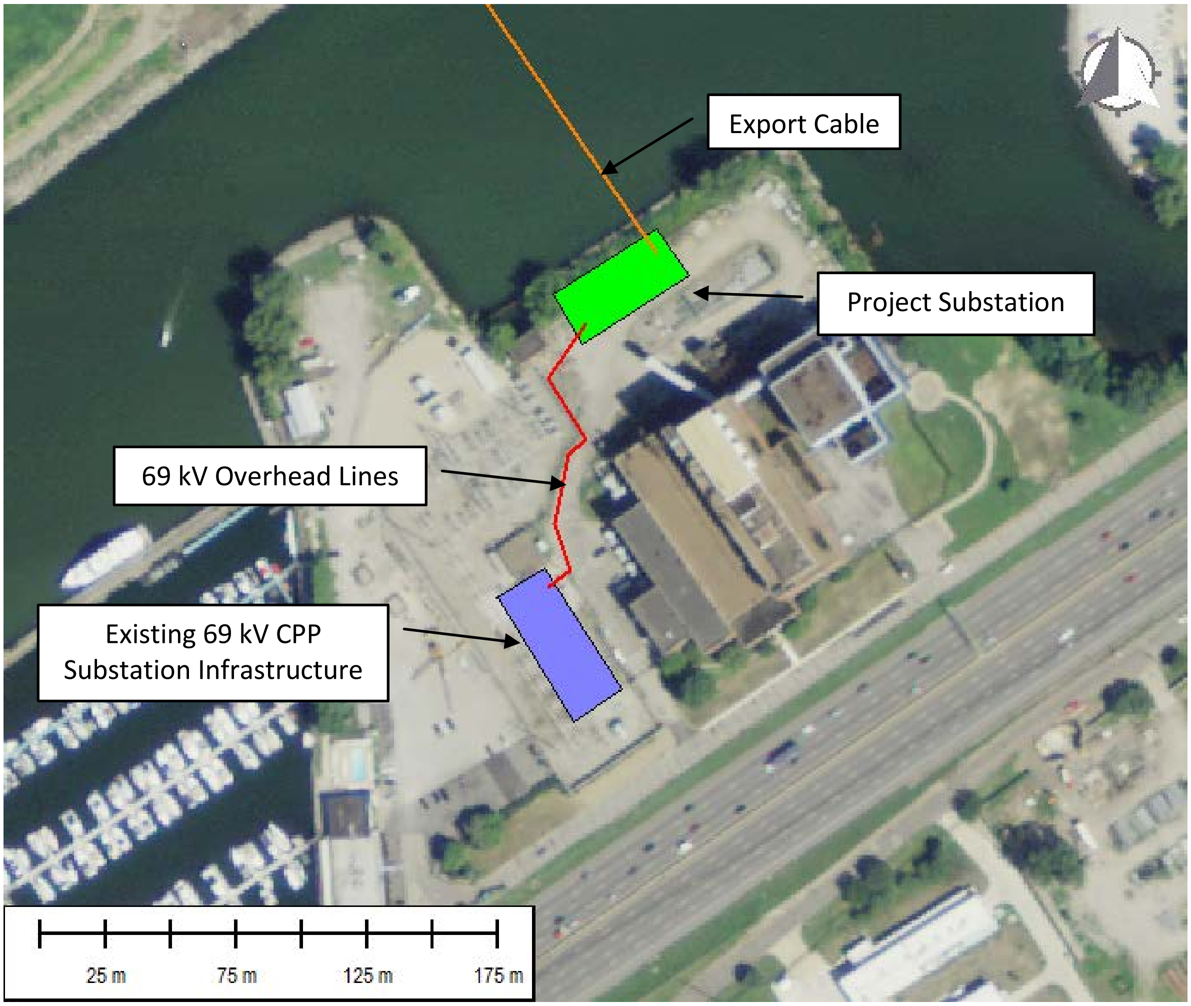

Figure 3-1. Conceptual substation layout

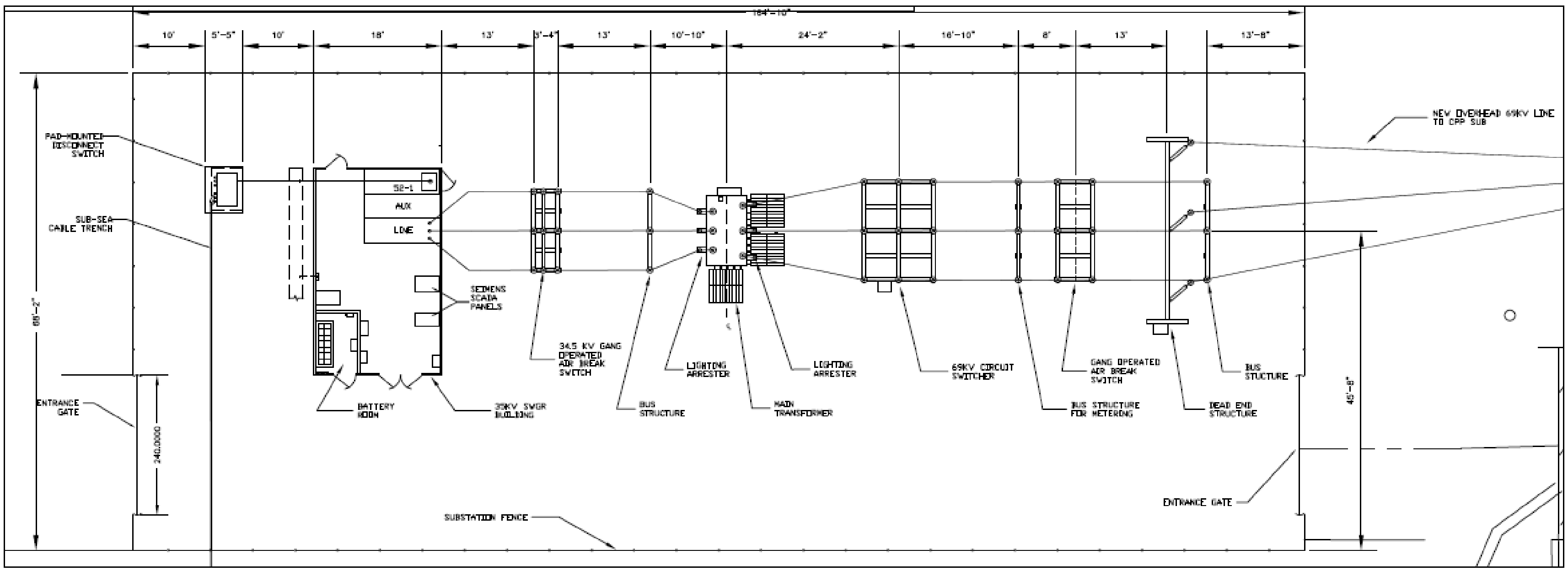

Figure 3-2. Project Substation layout

The layout for the project Substation reflects a compact arrangement that is intended to minimize space requirements. There may be opportunities for further reducing the space requirements for the Project Substation; however, there is a chance that additional space may be required. The ultimate size, arrangement, and location of the project Substation shall be determined as part of detailed design work for the electrical BOS.

4 Cable Layout Design

This section describes the preliminary cable layout design and alternative options.

4.1 General Cable Route

Figure 4-1 shows the export cable route that runs from wind turbine closest to shore (ICE1) to the lakeshore and the inter-array cables between the wind turbines (ICE1 through ICE6). The export cable will be connected to the project Substation.

Due to the relative length of the export cable (approximately 18.3 km (11.4 mi) to 21.1 km (13.1 mi)) compared to the inter-array cables (1 km (0.6 mi)) and the challenges associated with routing of the export cable and the shore crossing, the export cable is the primary focus of this section.

Figure 4-1. Inter-array and export cable route overview

4.2 Cable Route Options

The starting point for the export cable route is the most direct path from the turbines to the project Substation, as this should generally minimize costs of cable and installation costs. As discussed in the Electrical Design Basis Report, the information currently available does not present any constraints preventing a direct path. To connect the export cable to the project Substation, the cable route must cross or go around the breakwater, and then cross the Harbor to the project Substation. A confined disposal facility (CDF), a man-made confinement facility for disposal of dredged materials, is located inside the Harbor along the direct path to project Substation. As such, there are multiple options for entering and crossing the Harbor which is the primary driver for the overall cable route. For this analysis, three different route possibilities have been developed and these are depicted in Figure 4-2. Routes are defined as Option 1, Option 2, and Option 3.

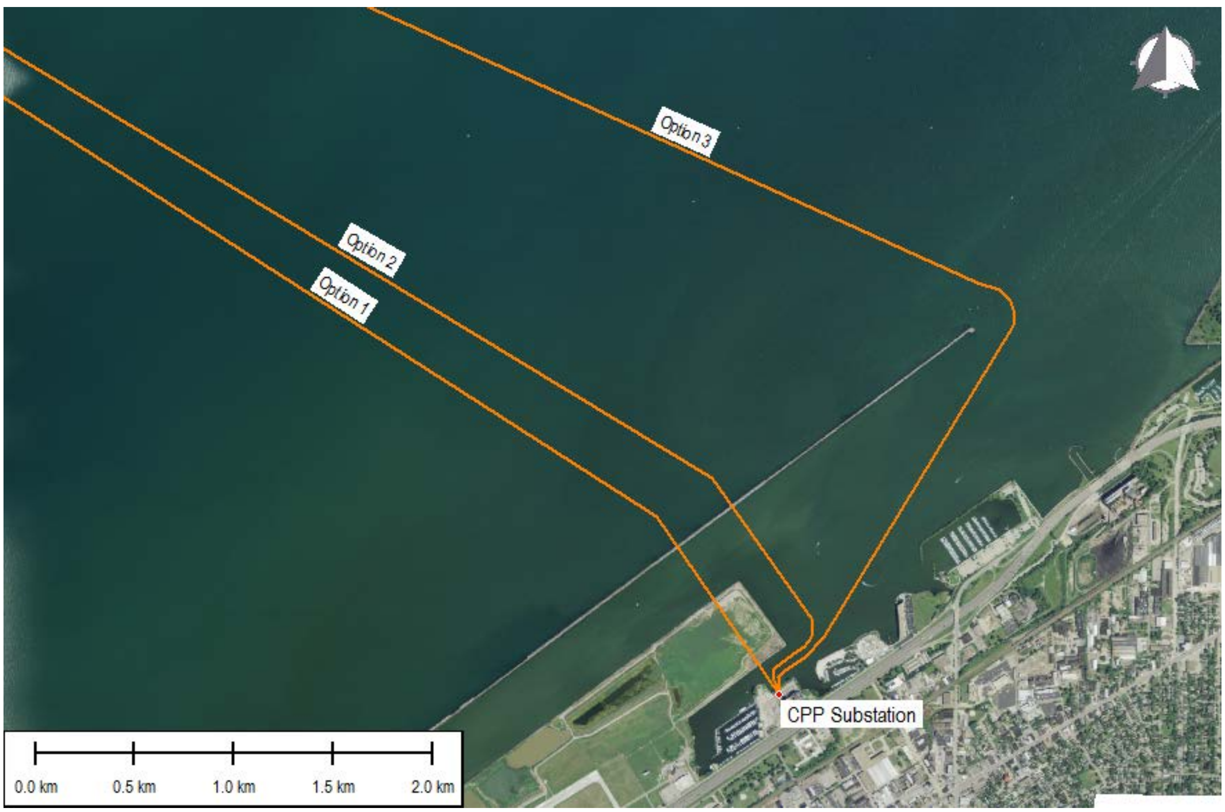

Figure 4-2. Options to route the export cable from the lake to the CPP Substation

These options (including Sub-Options 1a, 1b, and 1c) are described below and are depicted in the conceptual diagram in Figure 4-3.

Option 1

This route is the most direct route and consists of a straight path perpendicular to the general shoreline orientation from the project Substation, crossing the CDF and the breakwater to a point in the open water of Lake Erie beyond the breakwater, then making a bend and continuing in a straight path to ICE1. Option 1 has various implementation or installation options, which are described in brief below:

- **Option 1a:** For this option, the cable is installed completely in a duct which runs from the entry point in the open water of Lake Erie beyond the breakwater to the exit point at the project Substation. The duct, installed with horizontal directional drilling (HDD), would route the cable entirely under the Harbor, the CDF, and the breakwater.
- **Option 1b:** This option consists of an HDD duct from the project Substation under the Harbor to the CDF, a trench across the CDF, and a second HDD duct from the CDF under the Harbor and the Breakwater to an exit point in the open water of Lake Erie beyond the breakwater.
- **Option 1c:** This option consists of a conventional landfall at the project Substation, crossing of the Harbor channel by float-out installation, landfall at the CDF, trenching across the CDF, and an HDD duct from the CDF under the Harbor and the Breakwater to an exit point in the open water of Lake Erie beyond the breakwater.

For each option 1a, 1b, and 1c, from the exit point to the WTGs, the cable is installed using trenching.

Option 2

This route consists of a conventional landfall at the project Substation, crossing of the entrance channel (bypassing the CDF) by float-out installation, and an HDD duct under the breakwater from the Harbor channel to an exit point in the open water of Lake Erie beyond the breakwater. From the exit point towards the WTGs, the cable is installed using trenching.

Option 3

This is a conventional lay operation that comprises a conventional landfall at the project Substation (such as cut and cover), laying the cable in the Harbor bypassing the CDF and the breakwater, then making a bend after the end of the breakwater, then continuing along a straight path towards the WTGs.

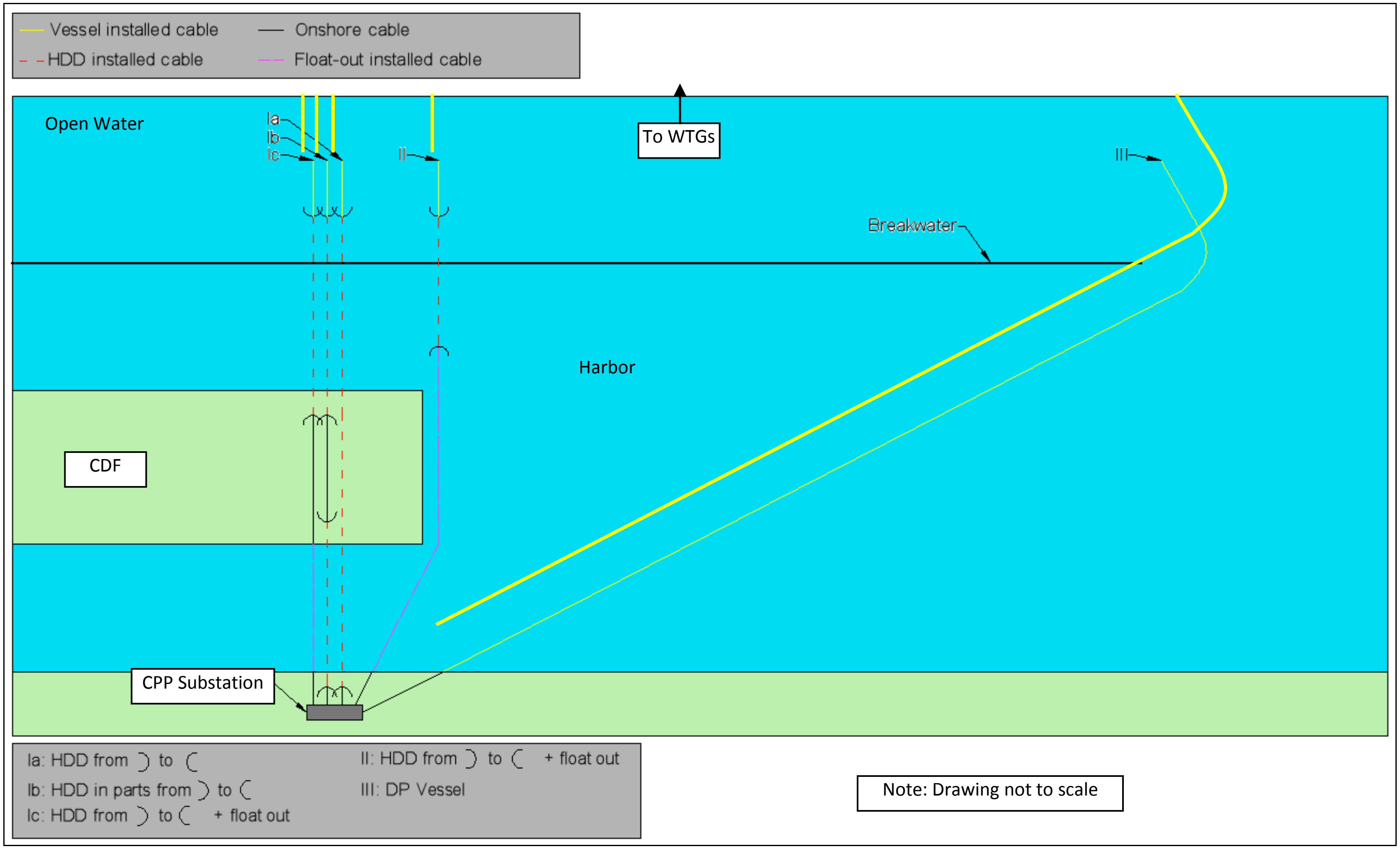

Figure 4-3. Cable route options for shore and harbor crossing

4.3 Comparative Analysis

To compare the different route options, a qualitative comparative analysis was conducted to assess the benefits and risks of each option. The main criteria that have been considered in this analysis for the export cable route include the following:

Cable length

By bypassing the breakwater and the CDF using horizontal directional drilling(s), the total length of the export cable can be reduced by roughly 2.8 km (1.7 mi) compared with going around the breakwater. Reduced cable length will lead to lower capital expenditures.

Application of HDD

HDD can be applied to cross the breakwater, CDF, and Harbor shortening the total cable route and reducing the impact of the cable installation on the activities inside the Harbor. However, HDD will lead to higher installation costs.

External damage by third parties

Anchors in the Harbor, excavation on the CDF, etc., can damage the export cable if it is not well protected by sufficient burial depth and/or cable covers. This can increase the downtime risk for the project, leading to higher operating expenditures during the life time of the cable system and risk of lost revenue.

Environmental aspects

Installation of the cable using trenching, HDD or other methods will impact the environment. Impacts could include disturbance of the lake bed sediments and release of bentonite into the environment (bentonite is used as in drilling fluids to lubricate and cool the drilling tools). During operational life, the heat produced by the export cable might increase the temperature of the seabed, having a possible effect on the environment.

Thermal bottleneck

Different installation methods, burial depths, etc., can impact the thermal bottleneck for the cable system. During operation of the cable system, the cable will heat up and the current rating is determined by the maximum allowed temperature of the cable. The installation method has an impact on the release of heat to the surrounding environment, and the part of the route that has the highest impact is called the thermal bottleneck. This may impact the cable specifications, which in turn may have an impact on capital expenditures.

Permitting

The necessary permits that are required for the export cable installation.

Future regional development plans

Various development plans in and around the Harbor have been proposed. Such developments may present risks to the cable and the presence of a power cable may limit future development plans. These interactions have been considered at a high level.

The key benefits and risks associated with each option are summarized below in Table 4-1.

Table 4-1. Pros and cons of export cable route options

Route option	Pros	Cons
1a	• Shorter cable length • Well protected from external threats (e.g., vessels, anchors, etc.) during its design life	• Drilling (technically challenging) • Long drilling length, feasibility must be checked, feasible up to 3000m • Potential release of bentonite into the environment
1b	• Shorter cable length • Well protected from external threats (e.g.. vessels, anchors, etc.) during its design life except for the buried cable on the CDF • Shorter drilling length	• Two drillings instead of one (technically challenging) • Bentonite might enter environment • Potential thermal bottleneck for the onshore cable on the CDF • More vulnerable for external damage on the CDF • Impact on future development plans
1c	• Shorter cable length • Well protected from external threats (e.g.. vessels, anchors, etc.) during its design life except for the buried cable on the CDF and between the shore and CDF • Shorter drilling length	• Drilling (technically challenging) • Bentonite might enter environment • Potential thermal bottleneck for the onshore cable on the CDF • More vulnerable for external damage on the CDF and between shore and CDF • Impact on future development plans
2	• Shorter cable length • Shorter drilling length	• Drilling from jack-up barge • Bentonite might enter environment • Laying cable close to CDF not feasible • More vulnerable for external damage between shore and HDD • Partly closing of harbor during installation • Impact on future development plans, in particular extension of the CDF
3	• Technically easier • No drilling	• Longer cable length • Lateral movement towards breakwater when bottom tension is too high • More vulnerable for external damage • Potential extra engineering for anchoring pattern, ice • Partly closing of harbor during installation • Impact on future development plans, in particular extension of the CDF

The benefits and risks discussed above in Table 4-1 have been considered in a high level quantitative assessment of the different options whereby each option is assigned a score from 1 to 5 for each criterion (1 indicating high benefit/low risk and 5 indicating low benefit/high risk). Weightings have been assigned to each criterion to reflect the relative importance of each criterion. Total weighted average scores were then calculated to and these scores were used to rank the different options. The scoring and ranking of each option is presented in Table 4-2.

Table 4-2. Quantitative assessment and ranking of the different cable route options

Criteria	Option					Weight	Explanation
	1a	1b	1c	2	3		
Cable length	1	1	1	1	2	20%	The total cable length is approximately 18.3 km (11.4 mi) for Option 1, approximately 18.7 km (11.6 mi) for Option 2 (considered similar to Option 1), and approximately 21.1 km (13.1 mi) for Option 3. Option 3 will result in a moderate increase in the cost for cable relative to Options 1 and 2.
Application of horizontal directional drilling(s)	3	5	3	4	1	20%	For Option 1a and 1c, one HDD is applied for the shore crossing, drilled from either the shore or the peninsula. Option 1b requires two drillings and, thus, is more expensive. Option 2 requires a shorter drilling, but the drilling would be from a vessel which would have higher associated costs and technical challenges relative to drilling from shore, and floating out of the cable along the peninsula which also requires a special vessel. Option 3 does not include any HDD and uses only traditional installation methods with relatively fewer technical challenges and lower costs. Once the shore and breakwater crossing is complete, the remaining cable will be installed using traditional methods that would be consistent for each option.
External damage by third parties	1	2	2	3	4	20%	Typically, the duct for an HDD-installed cable and the greater depth of cover relative to a cable buried via a plow ensures for additional protection of the cable. Therefore, Option 1 has the best score. For Options 1b and 1c, part of the cable is buried on the CDF in a traditional trench, increasing the risk for damage. The path for Option 2 generally avoids the vessel traffic lanes but would have greater exposure to risk of third-party damage relative to Option 1. Option 3 has the highest risk of third-party damage.
Environmental aspects	3	3	3	4	4	10%	During installation of the cable, the environment (lakebed) will be disturbed. Drillings have less impact compared to trenching. Due to the fact that the majority of the export cable will be installed with trenching (outside the breakwater), the relative difference between the options is minor.
Thermal bottleneck	5	4	4	4	2	15%	Typically, a drilling can be a potential thermal bottleneck due to the depth required for the drilling and the limited ability of the cable to radiate heat in the duct because of the lack of circulation of water within the duct and the thermal resistivity of the duct itself. The longer the drilling, the deeper the drilling will be and the higher the thermal resistivity of the surrounding soil. Therefore Option 1a has the worst score and Options 1b, 1c and 2 are scored

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							moderately better. Because Option 3 does not include a drilling, this option is less susceptible to thermal bottleneck issues at the shore crossing. All options will have a thermal bottleneck at some point along the cable. This is often at the point where the cable enters the base of the WTG tower and is exposed to air.
Permitting						0%	Based on the initial correspondence with the relevant authorities it is not expected that there are significant differences in permitting for the different options. Therefore, permitting is not ranked.
Future development plans region	1	5	5	4	3	15%	Various development plans have been proposed for the Harbor area including the CDF. As such, an HDD (Option 1a) around the CDF or deep under the CDF will offer the highest flexibility. A trench on the peninsula (Option 1b and 1c) will potentially present an obstacle for future development, and should be taken into consideration. Having the cable trenched in the seabed inside the Harbor will also limit the expansion of the CDF (Options 2 and 3). However, Option 3 would likely have less impact compared to Option 2.
Weighted Average Score	2.20	3.25	2.85	3.20	2.55		
Ranking	1	5	3	4	2		

The results of this assessment indicate that Option 1a represents the best option. The main reason to opt for Option 1a is the fact that the cable is completely protected during its design life. However, a more detailed cost analysis considering capital expenditures and operating expenditures, as well as risk associated with each, should be conducted at a later stage of the project to confirm this conclusion.

Due to the fact that there is a potential for future development plans on or around the CDF, the HDD should cross the CDF at a position that is chosen based on consideration of such potential future developments, to the extent that such plans are known. If necessary, the HDD can go around the CDF. In this scenario, at the landfall the start angle in the horizontal plane shall be such that the HDD will clear the edge of the CDF. The route has to be chosen such that the total length does not exceed the maximum possible length of an HDD of that diameter. The length, dimensions and material of the duct shall follow from a detailed HDD engineering design.

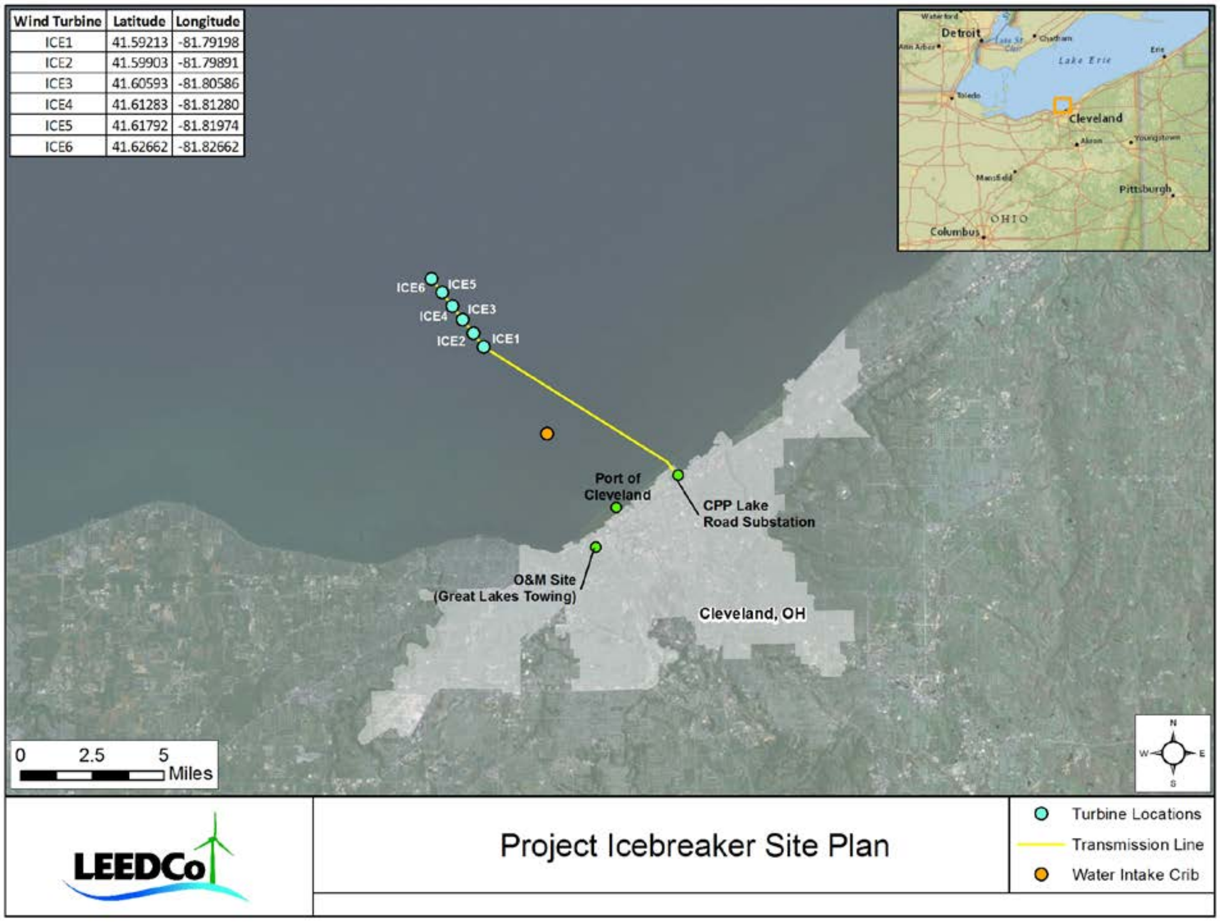
4.4 Inter-Array Cables

The length of the inter-array cables between the WTGs is approximately 1 km (0.6 mi). These cables will follow a straight line between the WTGs and shall be buried. At the base of the of the WTG support structure, the maximum cable bending radius should be respected and limited by an appropriate bending stiffener before being inserted into the pile. To protect the cable against ice ridges, the cable shall be protected by appropriate means, which needs to be investigated in the detailed design stage. Given the predominant wind direction, the optimal side to insert the cable to minimize risk of damage from ice is on the east/north-east side of the support structure. Normally cables are protected by external J-tubes or I-tubes, but due to possible forces of the ice exerted on these tubes, internal tubes are likely a better option.

Protective measures might also be required to protect the cable from solar radiation, but this needs to be investigated in the detailed design stage as well.

4.5 Proposed Cable Route

Based on the analysis discussed above, the proposed cable route for Icebreaker reflects Option 1a as shown in Figure 4-4.



Wind Turbine	Latitude	Longitude
ICE1	41.59213	-81.79198
ICE2	41.59903	-81.79891
ICE3	41.60593	-81.80586
ICE4	41.61283	-81.81280
ICE5	41.61792	-81.81974
ICE6	41.62662	-81.82662

Figure 4-4. Proposed cable route

5 Cable Installation Concept Design

The installation of the cable will consist of a number of components including the inter-array cables, open-water section of the export cable, and the harbor/shore crossing. This section considers each of these components. The installation method for the inter-array cables and the open-water section of the export cable will likely be the same however the sequence of pull-in operations may differ slightly. As indicated in Section 4 the preferred option for the harbor/shore crossing is an HDD under the breakwater and CDF to the project Substation. The installation process for the HDD (Option 1a) is described in this section. Additionally, the installation process for the alternative option of laying the cable in the harbor (Option 3) is described in this section.

5.1 Open-Water Installation

The installation of the export cable in open water will be performed by a cable lay vessel. The direction of the export cable installation will depend on the shore crossing option, and will be from the entry point of the HDD to ICE1 for Option 1a or from ICE1 towards the east entrance of the Harbor for Option 3.

A survey should be carried out to find suitable cable lay vessels or vessels that can be converted in to a cable lay vessel. As an example of a typical vessel that could be used for the cable installation for Icebreaker, Figure 5-1 shows the S/B Victor, a self-propelled, multipurpose barge owned by JD Contractors in Denmark (Drunsic et al. Electrical Basis of Design, 2014). The S/B Victor is shown with a typical cable installation spread similar to what would be required for Icebreaker.

Figure 5-1. Cable installation vessel S/B Victor (courtesy of JD Contractors)

The cable likely will be delivered in two lengths, one for the export cable and one for the inter-array cables. The inter-array cable will be cut at appropriate locations in the field for each individual inter-array cable length. The total length of the cable is approximately 20 km. Jointing in the field is not necessary; although, depending on the cable supplier, field joints may be required (see Section 6 .

The weight of a typical 3-phase 34.5 kV submarine cable is approximately 26.3 kg/m dry weight and 19.6 kg/m in seawater. The total dry weight of the cable is approximately 500 metric tons. The cable can be transported on one cable lay vessel.

Tensile force in the cable will increase during the lay operation from shallow to deeper water. The water depth along the shore is approximately 9 m (30 ft) and increases to 18 m (60 ft) at the WTG. It is assumed that the tensile force will not exceed the specific tensile force of the manufactured cable during the lay operation. This should be evaluated as part of the detailed design work.

The installation process will consist of simultaneous laying and burial of the cable to a sufficient depth to protect the cable against external threats. The minimum burial depth target for Icebreaker is 1.5 m (4.9 ft). In areas with more morphological activity, like the near shore zone where sediment transport is likely greater and the risk of impact from ice ridges is higher, the cable may need to be buried deeper or non-burial protection techniques may be required. Cable protection is discussed further in Section 6.7.

Based on the current understanding of the site conditions along the cable route, a jet plow trenching tool will be used to install the cable. This technology is commonly used to install submarine cables for offshore wind projects and other applications. A jet plow is a specially designed device with an adjustable blade, or plow, which rests on the lake bottom and is either towed by a surface vessel or integrated into a self-propelled remote operated vehicle. The plow creates a narrow trench at the designated depth, while water jets fluidize the sediment within the trench. The cable is fed through the plow and is laid into the trench as it moves forward. The fluidized sediments then settle back down into the trench and bury the cable. In soft soils, the presently available jet plows can bury the cable in a continuous movement up to a depth of 3 meters. For specific areas where cable burial is not possible by a jetting trencher, other techniques, like mass flow excavation may be applicable. Mass flow excavation is a technique which uses a low velocity, high volume column of water to excavate non-cohesive sediments by erosion. In essence, it is the opposite of jetting which uses a high velocity, low volume column of water to cut soils. Jetting is typically applied from a sled-mounted unit which is placed directly on the seabed. Mass flow excavation is typically applied using an excavation unit that hangs above the seabed under a vessel.

As long as the soil in which the cable has to be buried consists of soft soils such as sand, mud, and soft clays, burial with a jet plow is possible. Boulders and cobbles might be present along the export and/or inter-array cable route. When the plow encounters boulders or cobbles, the cable route can be diverted. If possible, boulders and cobbles should be removed before trenching if their locations are known.

Based on the soil conditions along the proposed cable route, use of a self-propelled plow is probably not feasible due to potential problems with traction in the soft soils on the lakebed. The optimal solution likely will be a jet plow with skids that can be towed by the cable lay vessel. An example of a typical jet plow is the Oceanjet 200 Jetting Sled Trencher (Oceanteam Shippin) depicted in Figure 5-2. This jet plow is a remotely operated subsea jetting sled designed specifically for the trenching of submarine cables. The Oceanjet 200 consists of two parallel skids bridged by cross beam support units. The jetting tool is mounted from the central unit, and deployed by means of a hydraulic ram. It is capable of trenching cables down to a depth of approximately 3 m (10 feet) and can be operated in water depths of up to 40 m (130 feet). The requirements for the trenching equipment should be further defined as part of a burial assessment to be completed as part of future design work.

Figure 5-2. Oceanjet 200 Jetting Sled trencher

As stated above, for Option 1a, the cable lay installation starts from the HDD entry point and the cable lay operation terminates near ICE1. At the termination, the cable will be laid down on the lakebed with sufficient cable overlength and marked with a buoy. A pull-in wire is then connected to the cable end and a winch is used to pull the cable into the J-tube or I-tube of the WTG support structure and clamped at the support structure transition piece.

Due to the soft soils, it is possible that cable will bury itself in the lakebed sediments. A survey vessel may be required to determine the location of the cable end to connect the pull-in wire. Use of floatation devices may also be required.

5.2 Shore-Crossing Design / Landfall

From Section 4.3, two options for the shore crossing were identified as the best solutions among the considered alternatives. The preferred alternative (Option 1a) routes the cable under major obstacles utilizing HDD; the second alternative (Option 3) routes the cable around major obstacles utilizing burial methods. Both alternatives are briefly described in this section.

5.2.1 Option 1a: HDD

One of the primary considerations for the HDD option is the amount of available area onshore for setting up the drill rig. **Error! Reference source not found.** shows the relation between the crossing length (length of the HDD) and the required space for drill rig installations. This figure was prepared by Nacap (Nacap, 2014), a global pipeline and HDD contractor, based on input from the North American Society for Trenchless Technologies Horizontal Directional Drilling Good Practices Guidelines, the American Society for Civil Engineers Manual of Practice No. 108 - Pipeline Design for Installation by Horizontal Directional Drilling, and the Drilling Contractors Association Technical Guidelines which all provide guidance on equipment layout and required area.

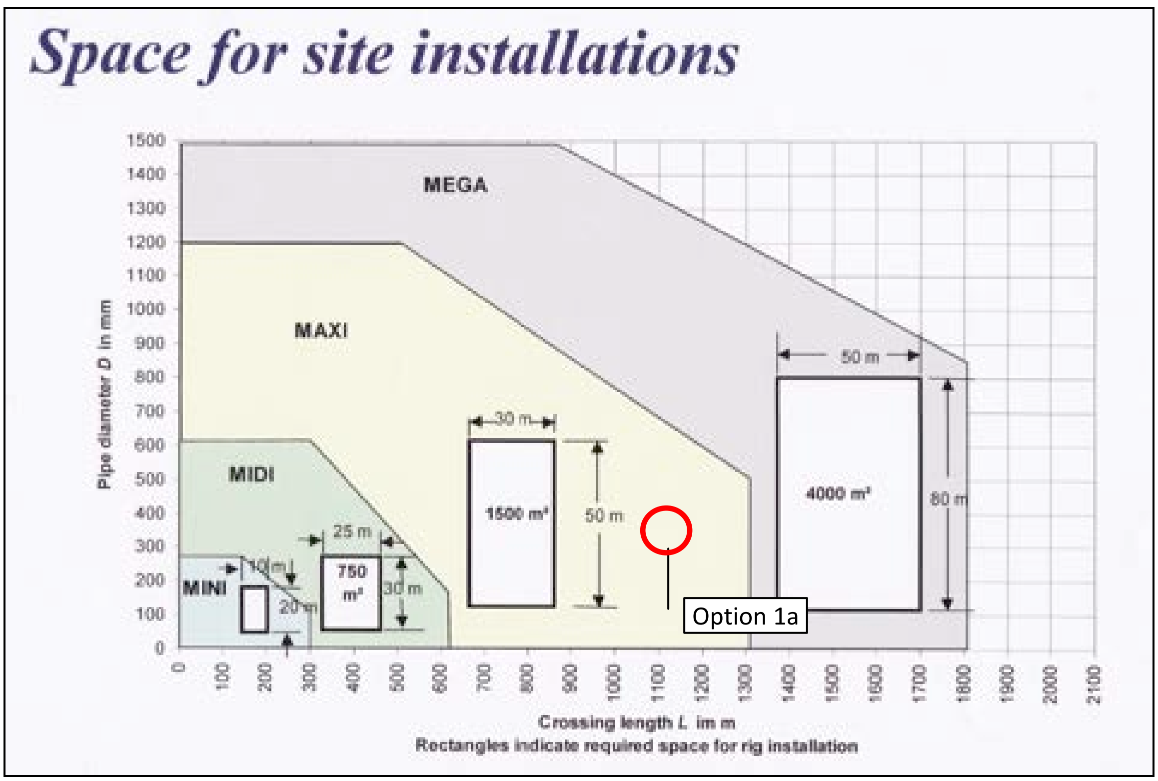


Figure 5-3. Relation between crossing length and space for drill rigs or site installations

Figure 5-3 is useful for determining the required space when either the crossing length L or the pipe diameter D is normative. When the crossing length or pipe diameter increases, the required surface for the site installation also increases. The estimated length of the HDD shore crossing from the project Substation under the breakwater into the lake is approximately 1150 m (0.70 mi). The inner diameter of the duct will depend on the cable size, pulling arrangement, cable weight, pull length, friction coefficient and bends. For long pull lengths, the inner duct diameter may need to be up to 2.5 times the cable outer diameter. For the purposes of this preliminary design, the outer diameter of the cable is assumed to be 120 mm and the inner diameter of the duct is estimated to be approximately 300 mm, but these shall be determined as part of further design work. The required space for the site installation to perform such a drilling is estimated according to **Error! Reference source not found.** to be 1500 m^2 (16145 ft^2). This results in a design basis for the HDD construction as depicted in **Error! Reference source not found.**.

Figure 5-4. Design basis of the HDD near the Substation

The location of the drill hole on land is determined as the 'exit point' of the power cable. The 'entry point' on the lake is where the cable will be pulled in and through to the exit point.

Because of the close proximity of the project Substation and the proposed exit point to the bank at the edge of the Harbor, an entry angle of approximately 12 degrees above horizontal is required to avoid a shallow position of the cable beneath the lake bottom in the Harbor. A minimal cover above the cable crossing the bank at the edge of the Harbor of at least 5 m (16 ft) should be maintained. With this entry angle, the HDD will cross the Harbor at a minimal depth of 7.5 m (24.5 ft) below the lakebed. The transition on the lakebed at the entry point is dredged and provided with a casing. The depth of cover for the portion of the HDD under the CDF is approximately 20 m (65 ft) and assumed to be sufficient, but should be specified as part of further design work.

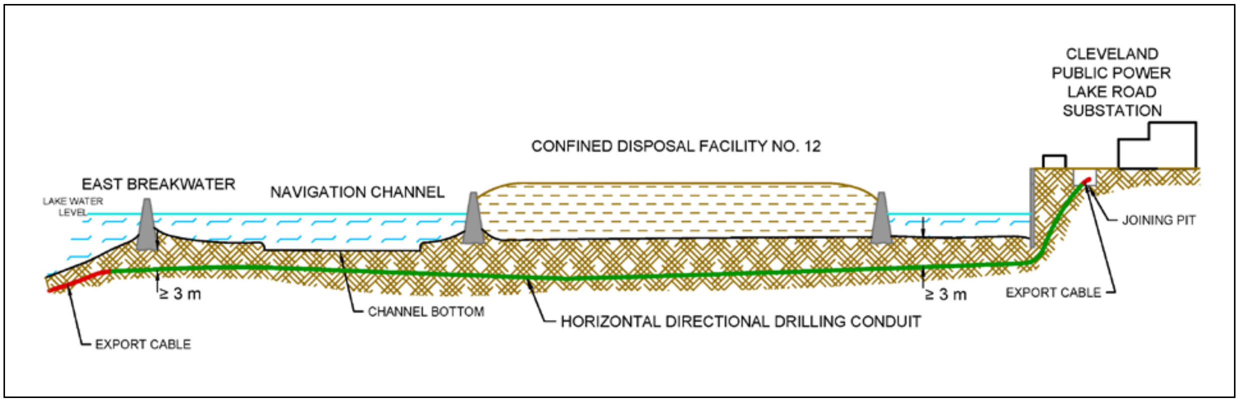


Figure 5-5 HDD cross section from the entry point in the lake to the exit point near the Substation

The equipment required for HDD includes specialized drilling equipment and auxiliary equipment that will need to be arranged on site to support a safe and efficient HDD operation. The size of the site installation (approximately 50 x 30 m or 164 x 98 ft) fits on the parking lot next to the CPP Substation where the exit point of the HDD is indicated in **Error! Reference source not found.**. All onshore drill activities and equipment should be located as close to the exit point as possible including placement of the following equipment:

- Drill rig
- Drill pipes
- Work containers
- Mud pump
- Mud tank
- Generator
- Power unit
- Control cab

An overview of a typical equipment arrangement is depicted in **Error! Reference source not found.**. An arrangement suitable for the requirements of Icebreaker and the site may look different from what is shown in **Error! Reference source not found.** and should be established as part of a detailed HDD engineering design. It should be noted that the 1500 m^2 space for site installations as indicated in **Error! Reference source not found.** is the required space if all equipment is arranged with no working space between the equipment.

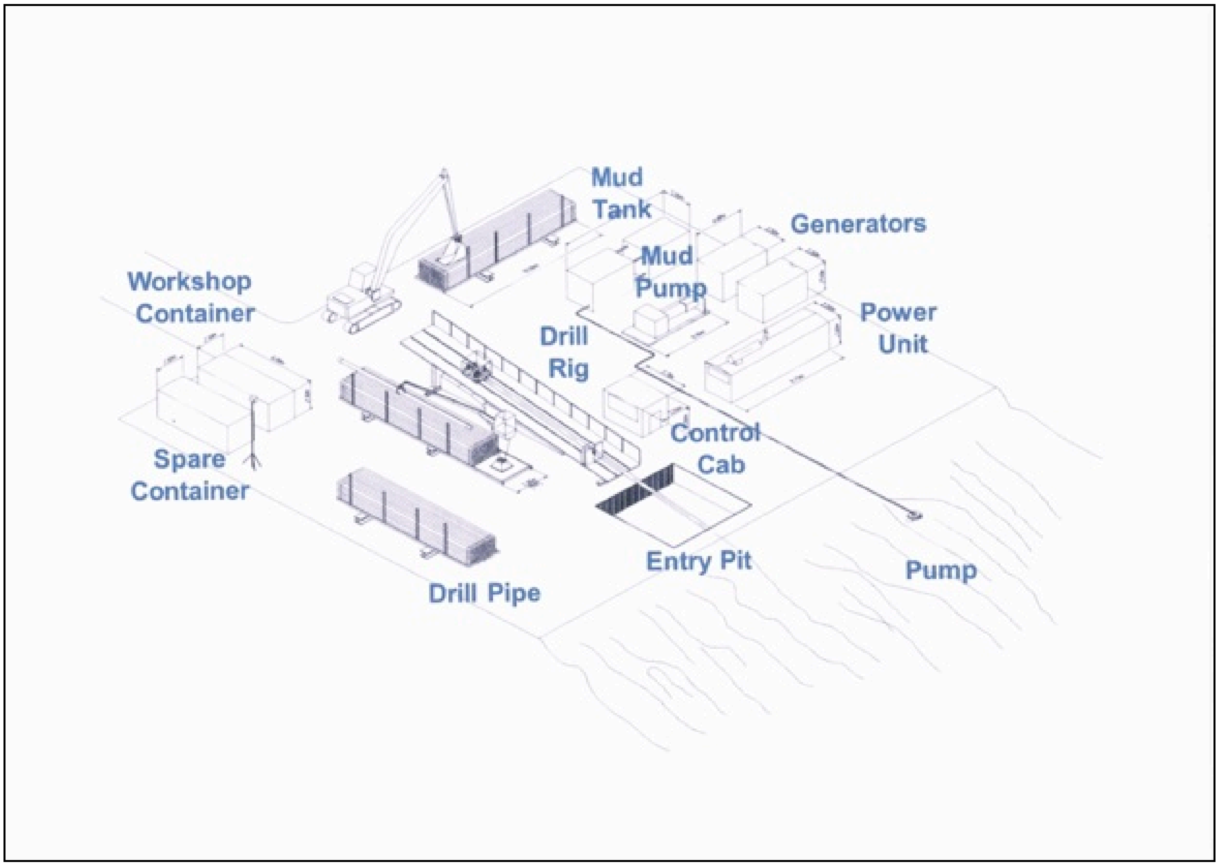


Figure 5-6. Overview of the equipment arrangement for the HDD

The following describes the general process associated with the HDD.

1. Preparation prior to cable initiation:
    a. Drilling of the pilot hole from the exit point to the entry point;
    b. Reaming of the pilot hole from the entry point to the exit point;
    c. Placing the duct the from exit point to the entry point;
    d. Pre-installation of the shore based winch at the HDD exit point; and
    e. Pull wire installation through the HDD duct.
2. Cable initiation:
    a. Positioning of the cable lay vessel at an appropriate location near the entry point of the HDD;
    b. Retrieval of the pull wire from the HDD duct and attachment to the free end of the cable;
    c. Cable pulling from the vessel through the duct by the shore based winch; and
    d. Upon arrival of cable at the landing point (joining pit), securing cable.

After securing of the cable at the landing point, the main lay operation will commence from the HDD entry point to ICE1.

The HDD duct will terminate on land at the pad-mounted disconnect switch at the project Substation where the cable will be terminated. From the landfall point to the project Substation, the HDD duct will provide the necessary protection for the cable.

5.2.2 Option 3: Trenched Installation in Harbor

The working space and the water depth in the harbor are restricted relative to the open lake and this limits the maneuverability of the lay vessel in the harbor for initializing the cable installation on the lakebed. Therefore, the proposed approach for this option includes initialization of the cable lay and burial at ICE1 and proceeding with the installation from ICE1 to the Harbor.

For this alternative, two aspects have been given attention:

1. A cable installation spread that can operate in these restricted areas;
2. A workable cable route and work methodology.

Due to the shallow water depth and the restricted space, a vessel like the self-propelled multipurpose barge S/B Victor depicted in Figure 5-1 should be considered. In order to lay the cable in the Harbor, the barge can be kept in position with harbor tugs and positioning anchors.

The work methodology is depicted in Figure 5-7 and the steps are described below.

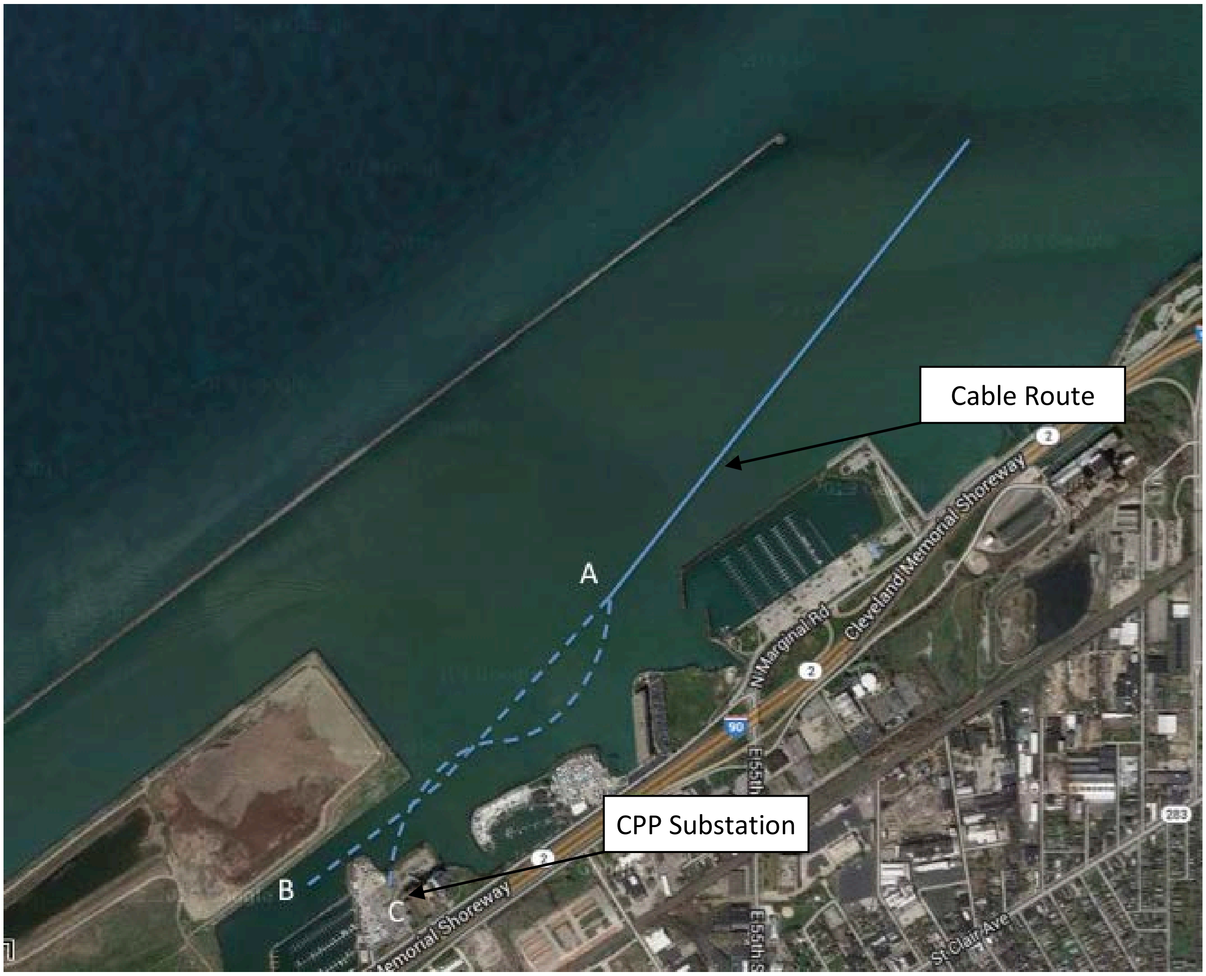


Figure 5-7. Work methodology for Option 3.

1. Installation of the cable with the jet plow will terminate at Point A. Here the trencher has to be recovered in a controlled way on board the lay vessel, maintaining sufficient lay tension on the cable. From this position, the cable will only be laid and not buried further. In the event the cable cannot be released from the trencher, it can be laid through the blade of the trencher. Here attention should be given to the departure of the cable at the sword, such that the overbend radius of the cable is higher than the mininum bending radius.
2. The cable lay vessel will continue to lay towards the lay down point (at B in **Error! Reference source not found.**), where the cable will be cut to its required length. The end of the cable will be capped and prepared for the pull-in operation. For this portion of the lay operation, floatation will be attached to the cable and the cable will be held in position by small workboats as depicted in Figure 5-8.

3. One of the small workboats will apply the required tension to the cable, such that the sag-bend radius of the cable is higher than the mininum bending radius. The other workboats will bring the cable end from Point B to the shore crossing at Point C. The S-curve as shown in **Error! Reference source not found.** is an illustrative example of this maneuver.
4. At this point the pull-in wire from a shore based pull-in winch will be connected to the cable end. The cable will be pulled through a pre-excavated trench at the shore crossing. At a predetermined point, the floatation will be removed to allow the cable to be laid in the trench. Where floatation is no longer present, the cable friction can be reduced by using roller boxes.
5. When the cable has been pulled in completely the remaining floatation can be removed, such that the cable can be lowered into the pre-excavated trench. This pre-excavated trench has been constructed between Point A and Point C, where no trenching with the jet plow can take place.

Figure 5-8. Small workboats keep the cable in position

On land, the cable will be installed in the trench, which will be backfilled and the landfall reinstated to its original shape. From landfall to the pad-mounted disconnect switch at the project Substation, the cable will be installed in a duct according to appropriate standards for the protection of land cables.

6 Cable Specification

The preliminary cable design is described in the Grid Interconnection Report. The detailed cable design shall be the responsibility of the cable supply vendor. This section provides preliminary specifications for the supply of submarine 34.5 kV cables including the connections and equipment necessary for the safe installation and operation of the cables inside the WTGs. The proposed cable route is shown in Figure 4-4 and consists of the following components:

- The export cable, which consists of an HDD of approximately 1.1 km (0.7 mi) from the Substation underneath the CDF and the breakwater into the lake and an approximately 12.0 km (7.5 mi) section laid in the lakebed from the exit point of the HDD to ICE1, for a total export cable length of 13.1 km (8.2 mi).
- The inter-array cable, which consists of five cable lengths of approximately 1.0 km (0.6 mi) between the WTGs.

The exact cable lengths to be supplied shall be determined by the cable manufacturer following additional field surveys and investigations.

6.1 Operating and Service Conditions

Unless otherwise stated, cables shall be designed to ensure satisfactory operations under site and system conditions as defined in the Electrical Design Basis Report. In addition to conditions described in the Electrical Design Basis Report, the following conditions should be specified:

- Maximum outdoor ambient temperature (shade)
- Temperature at the bottom of the lake in the winter
- Temperature at the laying depth in the winter
- Temperature at the bottom of the lake in the summer
- Temperature at the laying depth in the summer
- Thermal resistivity of the soil (Km/W)
- Laying depth of the cables

6.2 Electrical Data for 34.5 kV Grid

The electrical data for the cable are given in Table 6-1.

Table 6-1. Electrical data

System parameter	Value
Nominal system voltage (U)	34.5 kV
Voltage fluctuation	+/- 5%
Highest voltage for equipment	38 kV
Nominal frequency	60 Hz
Short circuit current (1-phase; imp. grounded)	To be determined from the PJM Feasibility Study
Short circuit current (3-phase; max.)	To be determined from the PJM Feasibility Study

The maximum conductor and screen temperatures are given in Table 6-2.

Table 6-2. Maximum temperatures

Operating Condition	Temperature
Conductor normal operating temperature	$90^{o}C$
Max. short circuit temperature on conductor/metallic screen	$250/200^{o}C$

6.3 Site Surveys

The cable manufacturing/installation contractor shall carry out all necessary pre-design site surveys to determine site conditions. Post installation surveys shall be carried out, where necessary, to determine the actual installation of the cables.

The pre-design surveys shall at least include:

- Site surveys to determine thermal bottlenecks based on soil properties along the route as required for the current carrying capacity calculations
- Site surveys to determine the composition of the layers under the CDF and breakwater, required to determine the optimum depth of horizontal directional drilling.

All results of the surveys shall be submitted to LEEDCo or its representative for approval.

6.4 Current Rating

The 34.5 kV cables shall be designed for the required current rating (20MVA=330A). For calculating the current rating according to IEC 60287 (International Electrotechnical Commision, *IEC 60287*), the losses have to be calculated, together with the thermal resistivities for the operating and service conditions as discussed in Section 6.1. The inter-array cables will be for practical reasons equal to the export cable, although the conductor sizes could be different.

6.5 Submarine Cable Design

The proposed submarine cables are 34.5kV three-core, cross-linked polyethylene (XLPE) or ethylene propylene rubber (EPR) insulated submarine cables. These types of cables are commonly used for offshore wind power applications; however, it should be noted that most manufacturers use XLPE insulation and global experience with EPR-insulated cables for offshore wind applications is relatively low. The cable construction typically includes the following parts:

- Stranded copper conductor with longitudinal water barrier, consisting of swelling tape or yarn
- Extruded semiconducting conductor screening
- XLPE or EPR insulation
- Extruded semiconducting insulation screening
- Copper wire screen
- Longitudinal water barrier
- Polyethylene sheath[1]
- Fiber optic cable and fillers of polypropylene strings
- Binder tapes
- Bedding made of polypropylene strings or polyester tape
- Steel armor
- Serving, with bituminous compound and polypropylene strings

XLPE insulated cables are the most commonly used cables for offshore wind projects; almost all offshore wind farm cables (inter-array and export) use XLPE as insulating material. Ethylene propylene rubber (EPR) insulation has higher water resistance and greater flexibility than XLPE, but incurs higher dielectric losses. The insulation material should be considered in the evaluation of bids for cable supply.

[1] The combination of longitudinal water barrier and a polyethylene sheath functions as a radial water barrier.

Figure 6-1 shows a schematic representation of a typical submarine cable construction. Figure 6-2 is a photograph of a typical submarine cable cross section. A detailed cross-sectional drawing of a typical 34.5 kV submarine cable design is included in Attachment B.

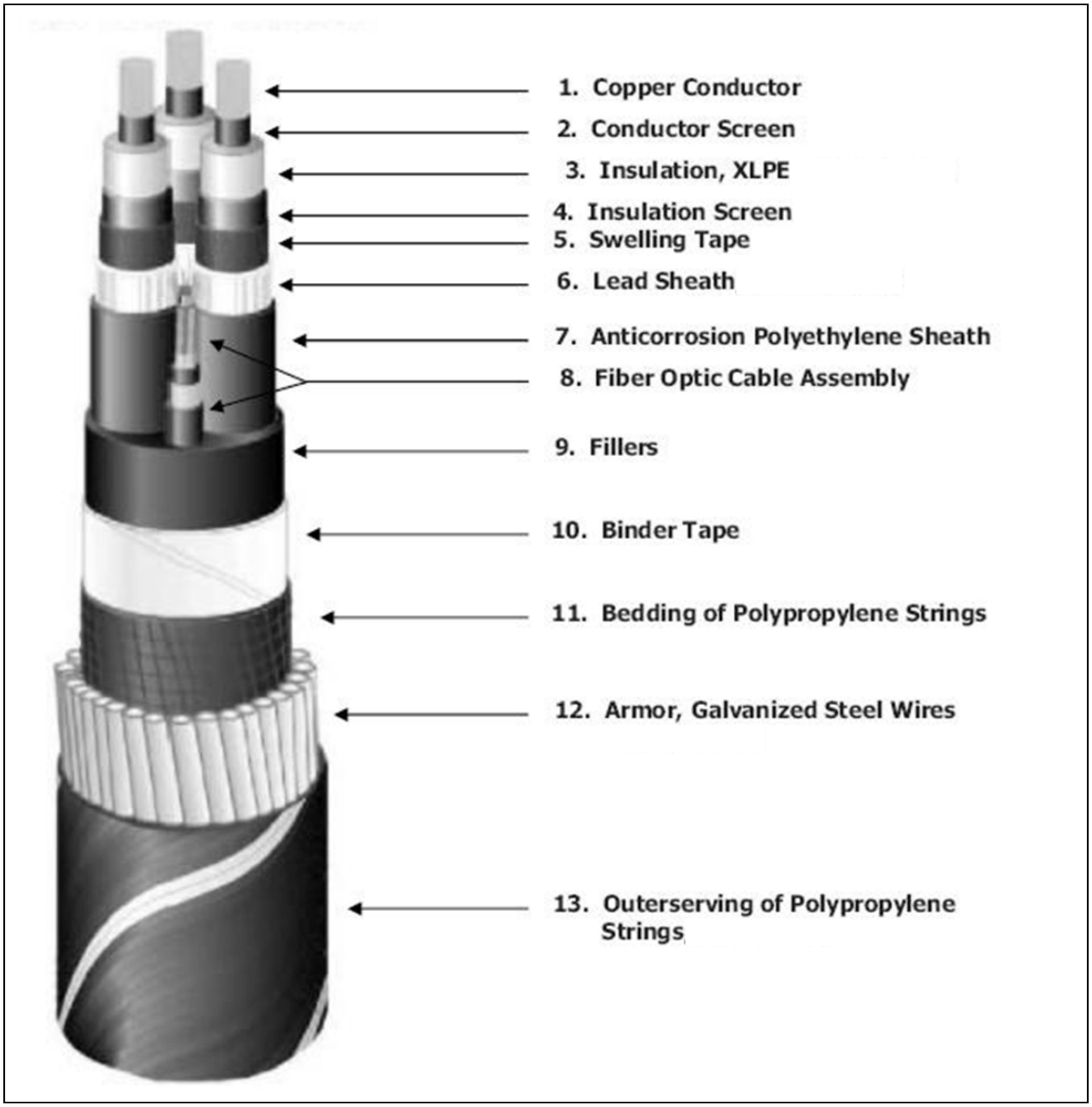


Figure 6-1. Schematic construction for typical 34.5 kV XLPE or EPR submarine cable

Figure 6-2. Typical 34.5 kV Cable Cross Section

The export cable should be delivered as one length with a minimum number of factory joints. Field joints may be acceptable if the supplier is not able to provide the export cable in a single length; however, the cable supplier shall provide evidence that the presence of field joints will not impact the long-term reliability and performance of the cable. The presence of field joints and the number of factory joints should be considered in the evaluation of bids for cable supply.

6.6 Attributes and Accessories

The cable design also includes applicable accessories, including the 34.5 kV terminations. The cable(s) and its accessories shall be compatible on electrical and mechanical aspects and all components shall be proven technologies.

Terminations shall be suitable for and connected to the cable connections of the applicable switchgear. Detailed information about the design of the outgoing bay for the submarine 34.5kV cable is defined in the technical specification for the 34.5kV switchgear (to be determined in the detailed electrical system design).

Terminations shall be suitable to conduct regular measurements such as AC/DC testing and diagnostic testing like 0.1 Hz including partial discharge measurements.

The installation of the cables as well as the connection of the cables to the terminations shall be designed in such a way that neither cables in operation nor cables out of operation will mechanically stress the accessories. The cable length of each individual circuit shall have sufficient length to allow a termination to be repaired twice at the project Substation site.

Factory joints are manufactured prior to the armoring process, so that the section of cable containing the joint is continuously armored without any discontinuity. The main feature of a factory joint is that it shall not impose any restrictions on further cable handling or installation operations. This generally implies that factory joints are fully flexible, with the same bending radius, pulling force limit and coiling performance (if applicable), as specified in CIGRE TB 490.

A repair joint is made on the complete cable and usually onboard on a repair vessel or barge. Repair joints should be available and fully type tested before the start of the installation. Repair joints shall be on stock and appropriate storage conditions should be provided as specified in CIGRE TB 490.

6.7 Cable Protection

Burial should be used as the primary method of protection of a cable to provide adequate and economic mitigation against hazards that may exist along the cable route. Based on the information currently available, sufficient burial will likely be possible to provide adequate protection for the cable. A risk-based burial assessment should be conducted as part of future design work to identify risks along the cable route, determine appropriate burial depth for cable sections, determine the appropriate burial and lay methods, and identify areas where additional protection may be needed. In the event that non-burial protection is required, options include tubular products, concrete mattresses, and/or rock placement.

6.8 Testing

The testing of the cable system, including factory joints, field joints, and repair joints, shall be performed according to CIGRE TB 490. The inter-array cables are connected to the WTG's using terminations, and the export cable is connected to the substation using terminations. The tests on terminations will be according to IEC 60502-4 (International Electrotechnical Commission, IEC 60502-4).

6.9 Quality Surveillance

The submarine cables are considered special equipment which means that manufacturers are required to be certified on their conformity to ISO 9001 (International Organization for Standardization, 2008) by an accredited certification organization.

The cable manufacturer/installer shall prove competence to supply products and services that comply with all requirements mentioned in the applicable specification(s).

The cable manufacturer/installer shall explicitly agree with allowing tests and inspections to be performed at any time by LEEDCo or its representative. It shall be stated that the tenderer shall supply copies of quality documents requested by LEEDCo or its representative.

7 SCADA System Design

The preliminary SCADA system conceptual design is provided in Attachment C and describes the various components to support the control of the Icebreaker WTGs and project Substation components and also includes various communication and network components. The SCADA system design includes the following components:

- Sensors to measure turbine parameters including blade rotational speed and pitch
- Sensors to measure converter parameters such as power, voltage, and current
- Meteorological sensors
- Turbine controllers
- Turbine network switches
- Signal converters

- Fiber optic network
- Fiber optic patch panels
- Ethernet connections
- Servers
- User interfaces
- Project controller
- Network communication and security systems
- Power supply

8 Conclusions and recommendations

This report reflects the preliminary design of the electrical BOS. The preliminary conceptual designs for the project Substation, submarine cable system, and the SCADA system are all subject to change pending further information regarding site conditions and detailed engineering.

Based on the analysis of the available information, the following conclusions about the cable route can be drawn:

1. The cable route is primarily influenced by the selected route for crossing the Harbor and the shore.
2. The preferred alternative for the crossing the Harbor and the shore is by applying an HDD of approximately 1.15 km (0.7 mi) from the CPP substation, underneath the breakwater, into the lake.
3. The cable can be installed using commonly employed installation techniques from the entry point of the HDD up to ICE1 and between WTGs.
4. The exact route for the export cable and the inter-array cables cannot be defined at this point, but based on the information currently available a direct path should be feasible.
5. Environmental conditions including wind, waves, currents and seismic activities are relatively benign and likely will not pose significant challenges for design and installation of the cable system.
6. Cable burial should provide sufficient protection for the cable along the cable route. However, the potential for ice ridges, damage from vessel activity, and near-shore erosion of the lakebed may present a risk of cable damage.

The following investigations are scheduled for BP 2 to assess the detailed cable route, installation, and burial depth:

1. Geophysical investigation of the bathymetry of lakebed using multi-beam echo-sounder or side-scan sonar) along the cable route, geophysical investigation of the sub-bottom geology using sub-bottom profiling, and geotechnical investigations (e.g., soil sampling, thermal conductivity measurements, and/or CPT).

2. Additional investigation regarding ice movements along the export cable route, inter-array cables and within the Harbor should be conducted.
3. Investigation of near shore morphological processes.
4. A burial assessment study to identify risks along the cable route, determine appropriate burial depth for cable sections, determine the appropriate burial and lay methods, and identify areas where additional protection may be needed.
5. A detailed design of the HDD operation, including the length, dimensions, and material of the duct and the required space and layout for site installation equipment.
6. Investigation of the vessel options for the cable installation.

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