Cenos Offshore Windfarm Limited

Cenos EIA

Appendix 14A – Electromagnetic Field Assessment Report Vol. 1

ASSIGNMENT	A100907-S01
DOCUMENT	A-100907-S01-A-ESIA-032
CLIENT	CEN001-FLO-CON-ENV-RPT-0062

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R01	07/10/24	Issued for Review	DC/MS	SJ	LD	Cenos
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CONTENTS

ACRONYMS 4

GLOSSARY 5

APPENDIX 14A ELECTROMAGNETIC FIELD STUDY FOR THE EXPORT/IMPORT CABLE 11

14A.1 Introduction 11

14A.1.1 Project Background 11

14A.1.2 Cable route coordinates 13

14A.1.3 The geomagnetic field 14

14A.1.4 Overview of electromagnetic field theory 16

14A.1.5 Background theory 17

14A.1.6 Required inputs 19

14A.1.7 Calculation assumptions 19

14A.2 Results for the 320 kV Export/Import Cable 20

14A.2.1 Background 20

14A.2.2 Results 21

14A.3 Results for the 525 kV Export/Import Cable 23

14A.3.1 Background 23

14A.3.2 Results 24

14A.4 Discussion 27

14A.5 Conclusion 27

14A.6 References 28

ACRONYMS

ACRONYM	DEFINITION
A	Ampere
B	Magnetic Field
CIGRE	Council Internal for Large Electric Systems
DoL	Depth of Lowering
EIAR	Environmental Impact Assessment Report
EICC	Export/Import Cable Corridor
EMF	Electromagnetic Field
FTU	Floating Turbine Unit(s)
GM	Geomagnetic
GW	Gigawatt
HVDC	High Voltage Direct Current
I	Current
Km	Kilometre
KP	Kilometre Point
kV	Kilo Volt
M	Meter
Mm	Millimetre
mm^2	Millimetres squared
MW	Megawatt
N.D.	No Date
NOAA	National Oceanic and Atmospheric Administration
OD	Outside Diameter
OSCP	Offshore Substation and Convertor Platform
OWF	Offshore Windfarm
PDE	Project Design Envelope
R	Distance to point of interest
UK	United-Kingdom
WTG	Wind Turbine Generator
μ_r	Relative permeability
μT	Micro-Tesla

GLOSSARY

TERM	DEFINITION
2023 Scoping Opinion	Scoping Opinion received in June 2023, superseded by the 2024 Scoping Opinion.
2023 Scoping Report	Environmental Impact Assessment (EIA) Scoping Report submitted in 2023, superseded by the 2024 Scoping Report.
2024 Scoping Opinion	Scoping Opinion received in September 2024, superseding the 2023 Scoping Opinion.
2024 Scoping Report	EIA Scoping Report submitted in April 2024, superseding the 2023 Scoping Report.
Area of Opportunity	The area in which the limits of electricity transmission via High Voltage Alternating Current (HVAC) cables can reach oil and gas assets for decarbonisation. This area is based on assets within a 100 kilometre (km) radius of the Array Area.
Array Area	The area within which the Wind Turbine Generators (WTGs), floating substructures, moorings and anchors, Offshore Substation Converter Platforms (OSCPs) and Inter-Array Cables (IAC) will be present.
Cenos Offshore Windfarm ('the Project')	'The Project' is the term used to describe Cenos Offshore Windfarm. The Project is a floating offshore windfarm located in the North Sea, with a generating capacity of up to 1,350 Megawatts (MW). The Project which defines the Red Line Boundary (RLB) for the Section 36 Consent and Marine Licence Applications (MLA), includes all offshore components seaward of Mean High Water Springs (MHWS) (WTGs, OSCPs, cables, floating substructures moorings and anchors and all other associated infrastructure). The Project is the focus of this Environmental Impact Assessment Report (EIAR).
Cenos Offshore Windfarm Ltd. (The Applicant)	The Applicant for the Section 36 Consent and associated Marine Licences.
Cumulative Assessment	The consideration of potential impacts that could occur cumulatively with other relevant projects, plans, and activities that could result in a cumulative effect on receptors.
Developer	Cenos Offshore Windfarm Ltd., a Joint Venture between Flotation Energy and Vårgrønn As (Vårgrønn).

TERM	DEFINITION
Environmental Impact Assessment (EIA)	The statutory process of evaluating the likely significant environmental effects of a proposed project or development. Assessment of the potential impact of the proposed Project on the physical, biological and human environment during construction, operation and maintenance and decommissioning.
Environmental Impact Assessment Regulations	This term is used to refer to the Environmental Impact Assessment Regulations which are of relevance to the Project. This includes the Electricity Works (Environmental Impact Assessment) (Scotland) Regulations 2017, the Marine Works (Environmental Impact Assessment) (Scotland) Regulations 2017 (as amended); and the Marine Works (Environmental Impact Assessment) Regulations 2007.
Environmental Impact Assessment Report	A report documenting the findings of the EIA for the Project in accordance with relevant EIA Regulations.
Export/Import Cable	High voltage cable used to export/import power between the OSCPs and Landfall.
Export/Import Cable Bundle (EICB)	Comprising two Export/Import Cables and one fibre-optic cable bundled in a single trench.
Export/Import Cable Corridor (EICC)	The area within which the Export/Import Cable Route will be planned and the Export/Import Cable will be laid, from the perimeter of the Array Area to MHWS.
Export/Import Cable Route	The area within the Export/Import Export Corridor (EICC) within which the Export/Import Cable Bundle (EICB) is laid, from the perimeter of the Array Area to MHWS.
Floating Turbine Unit (FTU)	The equipment associated with electricity generation comprising the WTG, the floating substructure which supports the WTG, mooring system and the dynamic section of the IAC.
Flotation Energy	Joint venture partner in Cenos Offshore Windfarm Ltd.
Habitats Regulations	The Habitats Directive (Directive 92/43/ECC) and the Wild Birds Directive (Directive 2009/147/EC) were transposed into Scottish Law by the Conservation (Natural Habitats &c) Regulations 1994 ('Habitats Regulations') (up to 12 NM); by the Conservation of Offshore Marine Habitats and Species Regulations 2017 ('Offshore Marine Regulations') (beyond 12 NM); the Conservation of Habitats and Species Regulations

TERM	DEFINITION
	2017 (of relevance to consents under Section 36 of the Electricity Act 1989); the Offshore Petroleum Activities (Conservation of Habitats) Regulations 2001; and the Wildlife and Countryside Act 1981. The Habitats Regulations set out the stages of the Habitats Regulations Appraisal (HRA) process required to assess the potential impacts of a proposed project on European Sites (Special Areas of Conservation, Special Protection Areas, candidate SACs and SPAs and Ramsar Sites).
Habitats Regulations Appraisal	The assessment of the impacts of implementing a plan or policy on a European Site, the purpose being to consider the impacts of a project against conservation objectives of the site and to ascertain whether it would adversely affect the integrity of the site.
High Voltage Alternating Current (HVAC)	Refers to high voltage electricity in Alternating Current (AC) form which is produced by the WTGs and flows through the IAC system to the OSCPs. HVAC may also be used for onward power transmission from the OSCPs to assets or to shore over shorter distances.
High Voltage Direct Current (HVDC)	Refers to high voltage electricity in Direct Current (DC) form which is converted from HVAC to HVDC at the OSCPs and transmitted to shore over longer distances.
Horizontal Directional Drilling (HDD)	An engineering technique for laying cables that avoids open trenches by drilling between two locations beneath the ground's surface.
Innovation and Targeted Oil & Gas (INTOG)	In November 2022, the Crown Estate Scotland (CES) announced the Innovation and Targeted Oil & Gas (INTOG) Leasing Round, to help enable this sector-wide commitment to decarbonisation. INTOG allowed developers to apply for seabed rights to develop offshore windfarms for the purpose of providing low carbon electricity to power oil and gas installations and help to decarbonise the sector. Cenos is an INTOG project and in November 2023 secured an Exclusivity Agreement as part of the INTOG leasing round.
Inter-Array Cable (IAC)	The cables which connect the WTGs to the OSCPs. WTGs may be connected with IACs into a hub or in series as a 'string' or a 'loop' such that power from the connected WTGs is gathered to the OSCPs via a single cable.
Joint Venture	The commercial partnership between Flotation Energy and Vårgrønn, the shareholders which hold the Exclusivity Agreement with CES to develop the Cenos site as an INTOG project.

TERM	DEFINITION
Landfall	The area where the Export/Import Cable from the Array Area will be brought ashore. The interface between the offshore and onshore environments.
Marine Licence	Licence required for certain activities in the marine environment and granted under the Marine and Coastal Access Act 2009 and/or the Marine (Scotland) Act 2010.
Marine Protected Area (MPA)	Marine sites protected at the national level under the Marine (Scotland) Act 2010 out to 12 NM, and the Marine and Coastal Access Act 2009 between 12-200 NM. In Scotland MPAs are areas of sea and seabed defined so as to protect habitats, wildlife, geology, underseas landforms, historic shipwrecks and to demonstrate sustainable management of the sea.
Marine Protected Area (MPA) Assessment	A three-step process for determining whether there is a significant risk that a proposed development could hinder the achievement of the conservation objectives of an MPA.
Mean High Water Springs (MHWS)	The height of Mean High Water Springs is the average throughout the year, of two successive high waters, during a 24-hour period in each month when the range of the tide is at its greatest.
Mean Low Water Springs (MLWS)	The height of Mean Low Water Springs is the average throughout a year of the heights of two successive low waters during periods of 24 hours (approximately once a fortnight).
Mitigation Measures	Measures considered within the topic-specific chapters in order to avoid impacts or reduce them to acceptable levels. Primary mitigation - measures that are an inherent part of the design of the Project which reduce or avoid the likelihood or magnitude of an adverse environmental effect, including location or design; Secondary mitigation – additional measures implemented to further reduce environmental effects to 'not significant' levels (where appropriate) and do not form part of the fundamental design of the Project; and Tertiary mitigation – measures that are implemented in accordance with industry standard practice or to meet legislative requirements and are independent of the EIA (i.e. they would be implemented regardless of the findings of the EIA). Primary and tertiary mitigation are referred to as embedded mitigation. Secondary mitigation is referred to as additional mitigation.

TERM	DEFINITION
Mooring System	Comprising the mooring lines and anchors, the mooring system connects the floating substructure to the seabed, provides station-keeping capability for the floating substructure and contributes to the stability of the floating substructure and WTG.
Nature Conservation Marine Protected Area (NCMPA)	MPA designated by Scottish Ministers in the interests of nature conservation under the Marine (Scotland) Act 2010.
Offshore Substation Converter Platforms (OSCPs)	An offshore platform on a fixed jacket substructure, containing electrical equipment to aggregate the power from the WTGs and convert power between HVAC and HVDC for export/import via the export/import cable to/from the shore. The OSCPs will also act as power distribution stations for the Oil & Gas platforms.
Onward Development	Transmission projects which are anticipated to be brought forward for development by 3rd party oil and gas operators to enable electrification of assets via electricity generated by the Project. All Onward Development will subject to separate marine licensing and permitting requirements.
Onward Development Area	The area within which oil and gas assets would have the potential to be electrified by the Project.
Onward Development Connections	Oil and gas assets located in the waters surrounding the Array Area will be electrified via transmission infrastructure which will connect to the Project's OSCPs. These transmission cables are referred to as Onward Development Connections.
Project Area	The area that encompasses both the Array Area and EICC.
Project Design Envelope	A description of the range of possible elements that make up the Project design options under consideration and that are assessed as part of the EIA for the Project.
Study Area	Receptor specific area where potential impacts from the Project could occur.
Transboundary Assessment	The consideration of impacts from the Project which have the potential to have a significant effect on another European Economic Area (EEA) state's environment. Where there is a potential for a transboundary effect, as a result of the Project, these are assessed within the relevant EIA chapter.

TERM	DEFINITION
Transmission Infrastructure	The infrastructure responsible for moving electricity from generating stations to substations, load areas, assets and the electrical grid, comprising the OSCPs, and associated substructure, and the Export/Import Cable.
Vårgrønn As (Vårgrønn)	Joint venture partner in Cenos Offshore Windfarm Ltd.
Wind Turbine Generator (WTG)	The equipment associated with electricity generation from available wind resource, comprising the surface components located above the supporting substructure (e.g., tower, nacelle, hub, blades, and any necessary power transformation equipment, generators, and switchgears).
Worst-Case Scenario	The worst-case scenario based on the Project Design Envelope which varies by receptor and/or impact pathway identified.

APPENDIX 14A ELECTROMAGNETIC FIELD STUDY FOR THE EXPORT/IMPORT CABLE

14A.1 Introduction

This Technical Report is an Electromagnetic Field (EMF) study of the Project Export / Import Cable Route along the entire Export/Import Cable Corridor (EICC) from the Array Area to landfall (approximately 230 kilometres (km)). The Project is currently under development and has been informed by preliminary engineering detail provided by the Applicant.

This Technical Report has been authored by:

- [Redacted] EvolvEnergies.

14A.1.1 Project Background

The Applicant, Cenos Offshore Windfarm Ltd., is a Joint Venture between Flotation Energy and Vårgrønn As (Vårgrønn). The Project is a floating offshore windfarm, which is located 200 km offshore, east of Aberdeen, in the Central North Sea (see Figure 1). The Project shall generate renewable electricity to the UK Grid in addition to enabling efficient electrification of offshore Oil and Gas assets within the Onward Development Area. When wind speeds are insufficient to power the Oil and Gas assets directly, additional electricity would be imported from the UK grid through the Export/Import Cable connection which will make landfall at Longhaven. The Project's lifetime is expected to exceed that of the oil and gas assets and, therefore, would continue to produce renewable electricity to the UK Grid after those assets are decommissioned.

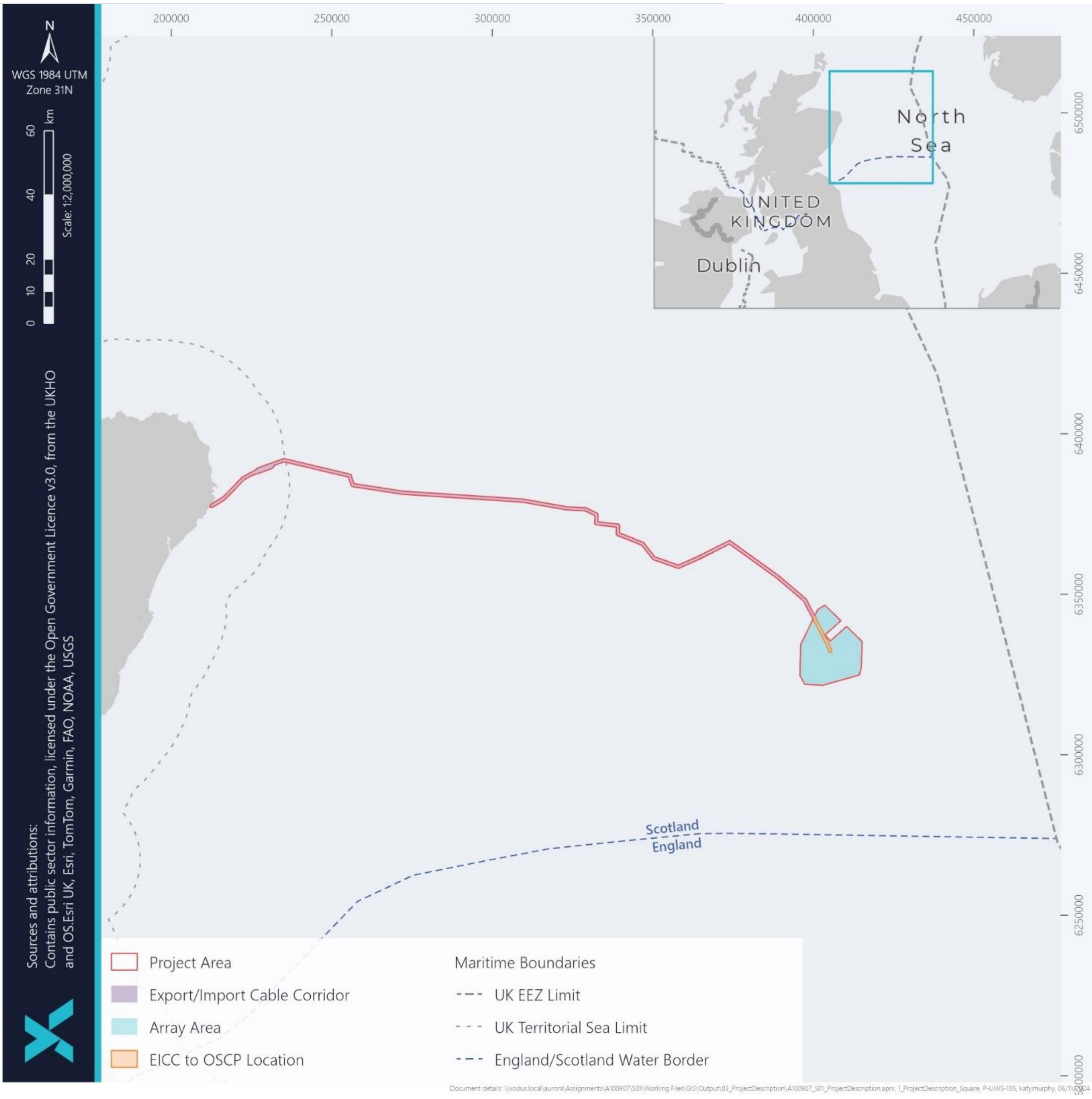

Figure 1. Location of the Project; Array Area and Export/Import Cable Route within the EICC

The Project will consist of up to 95 Floating Turbine Units (FTUs), each with a Wind Turbine Generator (WTG) and floating substructure, which will be anchored to the seabed to ensure station keeping within the Array Area. WTG technology is constantly evolving, and so, a range of WTG options (three options) are being considered within the design envelope assessed in the Environmental Impact Assessment Report (EIAR) to allow for market availability and flexibility in development.

For this EMF study, the cable build dimensions and current flow assumptions were provided by the Applicant, as shown in Table 1. The Export/Import Cable system will operate at either ±320 Kilo Volt (kV) or ±525 kV.

Table 1 HVDC offshore cable dimensions and current flows (turquoise cells are estimated values)

CABLE DESIGN	OUTER DIAMETER (mm)	DIAMETER INCLUDING INNER PE SHEATH (mm)	CORE DIAMETER (mm)	AMPACITY (A)
66 kV HVAC Static	180	80	32	760
66 kV HVAC Dynamic	195	80	32	1120
132 kV HVAC Static	205	80	32	850
132 kV HVAC Dynamic	220	80	32	1255
320 kW HVDC	155	120	60	2325
525 kW HVDC	150	115	45	1310

The High Voltage Direct Current (HVDC) link will allow a generating capacity of up to 1.4 Gigawatts (GW) and will operate as a bundled symmetric monopole system.

The HVDC Export/Import Cable system will require converter stations at each end of the cable; the onshore Converter station and the Offshore Substation and Convertor Platforms (OSCPs) within the Array Area. The Export/Import Cable minimum and maximum Depth of Lowering (DoL) is 0.4 metre (m) and 1.5 m, respectively, along the Export/Import Cable Route. The following Section outlines work carried out to determine the required EMF input parameters from geological and installation data.

14A.1.2 Cable route coordinates

For calculations of EMF intensities for the HVDC cable system, determination of some geographic locations and parameters was required. From survey data provided, it was possible to determine the following:

- Coordinates of longitude and latitude at Kilometre Point (KP) locations along the entire Export/Import Cable Route (230 km). These are derived from Easting and Northing coordinates. Coordinates are used as inputs for geomagnetic field calculations using the online tool (Doogal, No Date (N.D.));
- Circuit angle at KP locations – The HVDC cable route runs approximately east to west. Circuit angles at each KP are then determined.
- Seawater depths at KP locations are calculated with the online tool (EMODnet, N.D.) with inputs of longitude and latitude previously determined; and
- Resultant and component vectors and directions for the geomagnetic field are calculated with the coordinates of longitude and latitude and water depths, with the NOAA online tool (NOAA, N.D.).

Figure 2 shows the Export/Import Cable Route in orange and an example of the KP locations tagged in green.

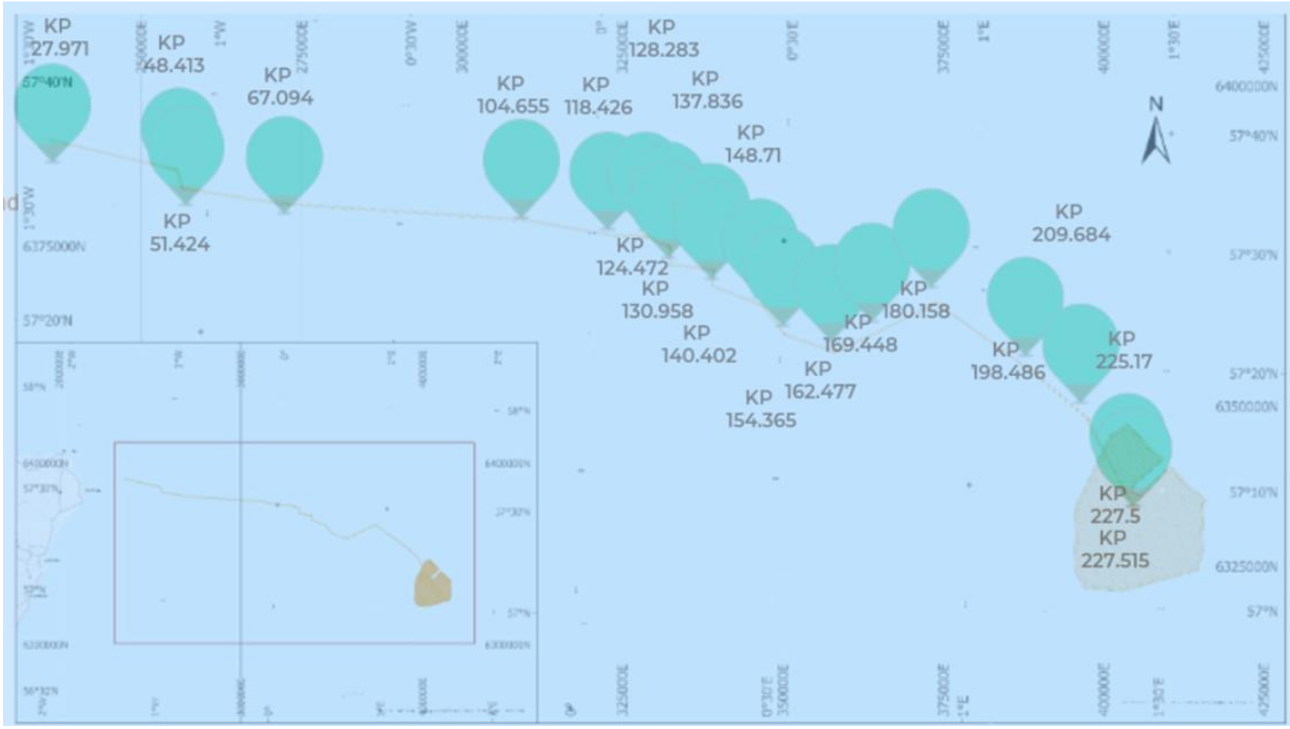

Figure 2. Example locations of KPs for the Export/Import Cable Route

This Technical Report includes calculations for the entire Export/Import Cable Route, from KP1 to KP227 (landfall to the Array Area). The following Section outlines the geomagnetic field and its role in HVDC EMF calculations.

14A.1.3 The geomagnetic field

The Earth has its own magnetic field which varies in intensity according to location on the planet. The geomagnetic field is at maximum intensity at the poles and weakest at the equator. Earth's magnetic field slightly varies in time and is referred to as the geomagnetic field, which is static. Further information regarding the creation of the geomagnetic field is available on the National Centres for Environmental Information website (NOAA, N.D.).

As with any generated magnetic field, the geomagnetic field has a Magnetic North and Magnetic South pole. Figure 3 represents the orthogonal, three-dimensional X-Y-Z coordinate system which is adopted for EMF calculations and modelling. Declination angle D is used to align True North to Magnetic North.

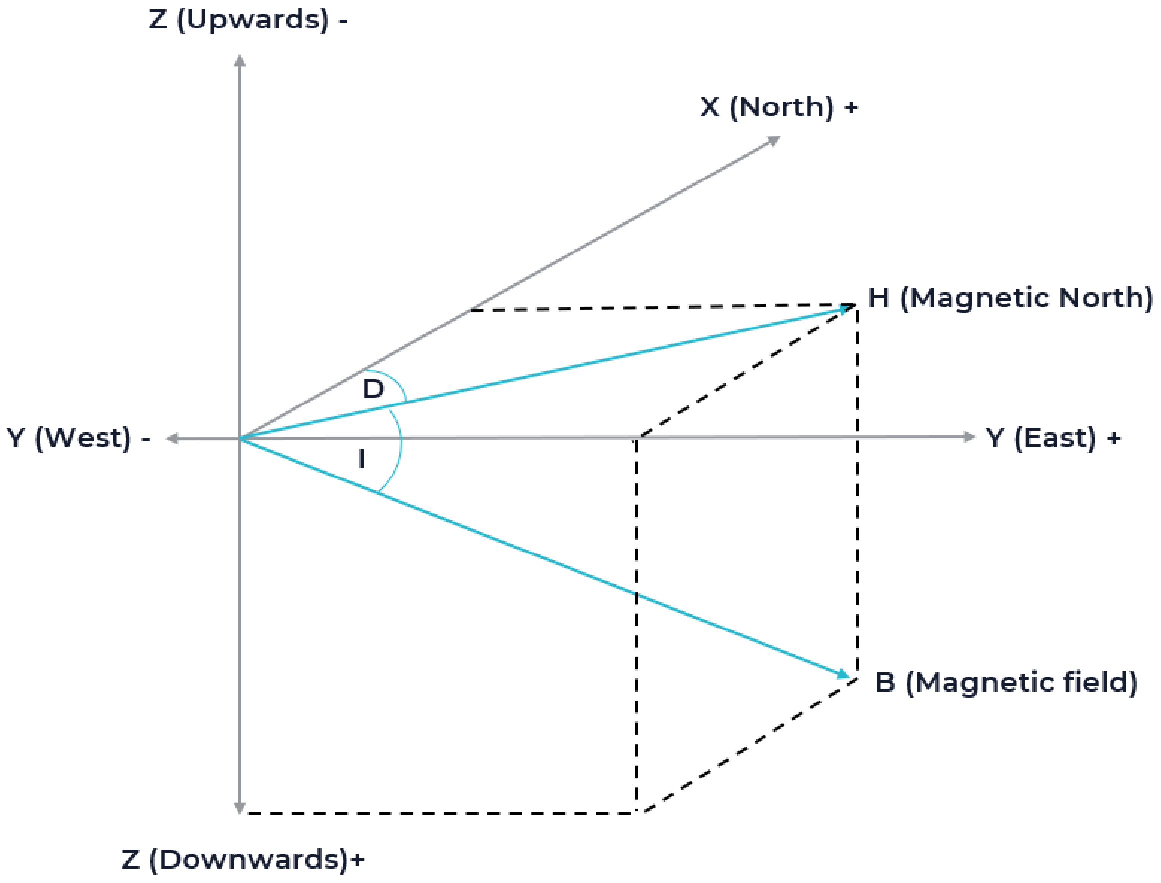

Figure 3. Geomagnetic field components and compass directions

To summarise vectors from Figure 3 the below system of directions and axis is used for Earth's geomagnetic field as illustrated in the coordinate system. Compass direction along each of the X, Y and Z axis is important, as this indicates whether the EMF component vector is positive or negative when added to the cable EMF vector components.

- Declination positive when measured East of North;
- Inclination positive in the Downward direction;
- X-axis positive in the North direction;
- X-axis negative in the South direction;
- Y-axis positive in the East direction;
- Y-axis negative in the West direction;
- Z-axis positive in the Downward direction; and
- Z-axis negative in the Upward direction.

The following Section provides an overview of electromagnetic theory, with relevance to direct current subsea cable systems.

14A.1.4 Overview of electromagnetic field theory

This Section provides a summary of EMF generation from a cable. An EMF is the result of charge carriers (electrical current flow) moving along a conductor and can be described from Maxwell's equations of electromagnetism (EMODnet, N.D.), which explain interactions between magnetism and charge. When electrical current flows through a cable, both an electric field and a magnetic field are produced. The electric field is produced due to the system voltage and a magnetic field is produced due to current flow through the cable. Due to the shielded construction of the cable, the electric field is contained within the insulation system of the cable, between conductor and insulation screens. However, the EMF exists beyond the surface of the cable, into the surrounding seawater.

Intensity of the magnetic field is proportional to the current flowing through the cable and inversely proportional to the distance away from the cable. The magnetic field from a current carrying conductor may be viewed as consisting of concentric, closed loops that reduce in intensity, as distance to the conductor is increased. This is described by Ampere's Law and calculated according to the Biot-Savart Law, given in Equation 1. Calculations in this report have assumed magnetic relative permeability of seawater and seabed are 1.0, i.e. relative permeability (μ_r) = 1.0.

$$B = \frac{\mu_0 \mu_r I}{r} \qquad (1)$$

Where:

B	Magnetic field	(μT)
μ_0	Absolute permeability	$(4\pi \times 10^{-7})$
μ_r	Relative permeability	
I	Current	(A)
r	Distance to point of interest	(m)

The resultant EMF is always perpendicular to current flow direction. Calculations of static EMFs include the circuit angle with respect to Magnetic North, as this determines alignment of the EMF from the cable with the geomagnetic field.

For HVDC systems, EMF calculations require superposition of the geomagnetic field and the combined interactions of both pole cable EMFs (assuming there are two cables). Figure 4 illustrates Ampere's Law for current flow directions, indicated with a dot (·) and a cross (×), and EMF directions shown with blue arrows. The current is assumed to be in the X-axis and to come out of the page from pole 1 (the dot ·) and into the page in pole 2 (the '×'). Pole cables are represented by the orange circles with a black outline.

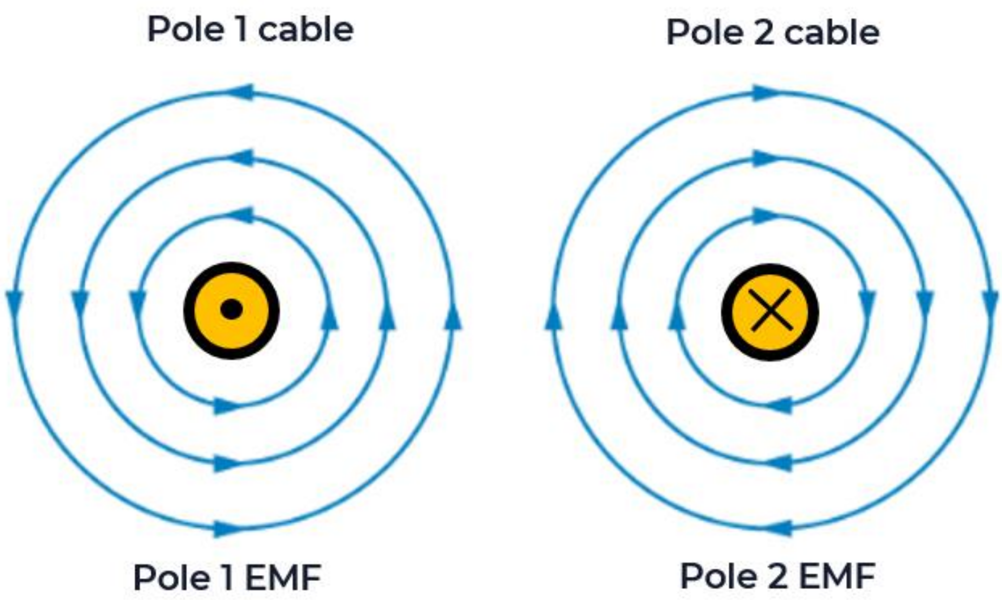

Figure 4. Pole 1 and Pole 2 cables with currents out and into the page

With a bundled configuration, field cancellation will be at a maximum, hence a lower EMF emission will be present.

14A.1.5 Background theory

This Section illustrates direct current flow directions and superposition of magnetic field vector components with Earth's geomagnetic field. The cable is assumed buried within the Y-Z plane, with current flow in the X-axis direction. To allow addition of the cable EMF to geomagnetic field, the coordinate system shown in Figure 3 is applied to all EMF component vectors.

The cable is assumed centred at the origin and interactions between current and the magnetic field being described by Ampere's Law. The Biot-Savart Law provides a method to calculate the EMF generated by the current. These vector relations are according to "Fleming's left hand and right-hand rules" with regards to EMF and current directions.

Figure 5 shows two buried HVDC pole cables[1], separated between centres by distance 'd' in the Y-Z plane with current flowing along the X-axis. Magnetic field vectors are indicated with a 'B' and a relevant subscript for their direction axis. Current flow is taken in the X-axis and assumed to be flowing out of the page for pole 1. The grey circle represents the point of interest where EMF intensities are calculated, assuming compass directions and signs. Dashed lines show pole cable distances to the point of interest and EMF component vectors, calculated with a Pythagorean identity for each pole cable.

[1] *a pole cable refers to the cables and wires that are mounted on utility poles*

The coordinate axis for the Y-Z plane is shown in grey, with direction signs in brackets. The calculation point is referenced to the seabed level and DoL. The DoL is taken as the vertical distance from mean seabed level to top of the cable. The geomagnetic (GM) field at the KP of calculation is indicated in green.

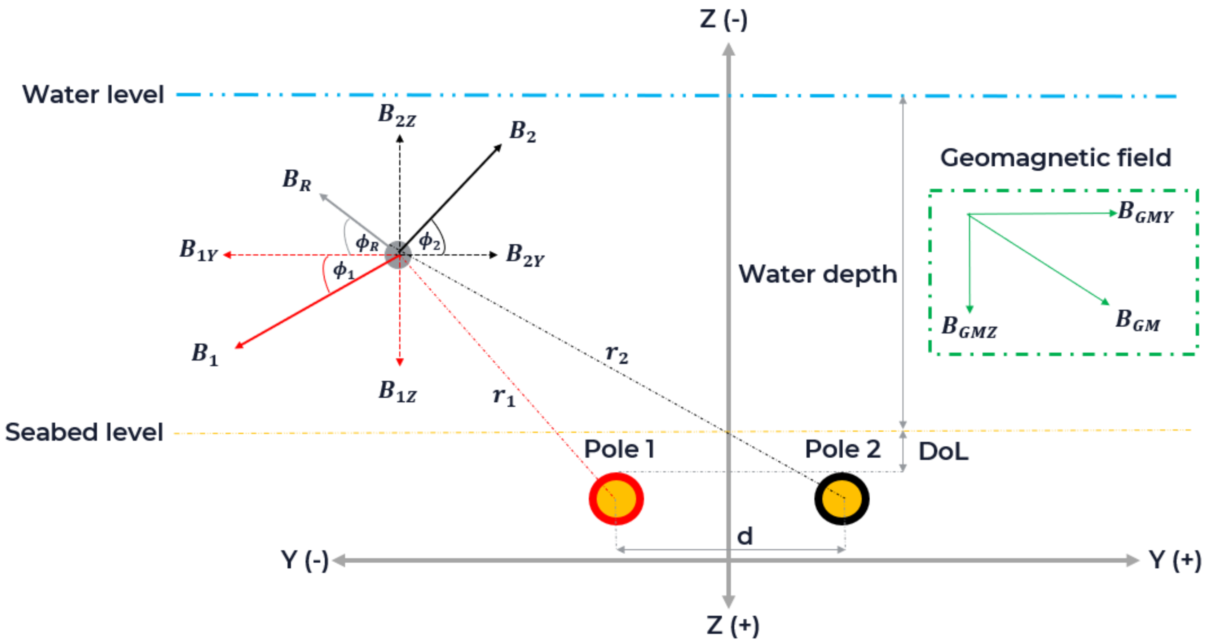

Figure 5. Magnetic field vectors for a pair of HVDC pole cables

In Figure 5 current flow is assumed in the X-axis (out of or into the page) with vectors, distances and relations:

Pole 1	Positive pole cable with current flow out of the page
Pole 2	Negative pole cable with current flow into the page
Y-axis	East-West directions axis
Z-axis	Upwards-Downwards directions axis
d	Separation distance between pole cable centres (shown here as separated, not bundled)
DoL	Depth of Lowering
B_R	Resultant combined EMF vector
B_{1Y}	Pole 1 EMF component vector in the Y-axis
B_{1Z}	Pole 1 EMF component vector in the Z-axis
B_1	Pole 1 resultant EMF vector
B_{2Y}	Pole 2 EMF component vector in the Y-axis
B_{2Z}	Pole 2 EMF component vector in the Z-axis
B_{GMY}	Geomagnetic field component vector in the Y-axis
B_{GMZ}	Geomagnetic field component vector in the Z-axis
B_{GM}	Resultant geomagnetic field
r_1	Resultant distance from pole 1 centre to calculation point
r_2	Resultant distance from pole 2 centre to calculation point
ϕ_1	Angle between pole 1 resultant EMF and horizontal axis
ϕ_2	Angle between pole 2 resultant EMF and horizontal axis
ϕ_R	Angle between resultant EMF and horizontal axis

From Figure 5 the resultant EMF vector from each pole cable is decomposed into its horizontal and vertical components. A bundled pair of cables is considered by setting separation distance 'd' to one cable outside diameter (OD).

14A.1.6 Required inputs

The required inputs for HVDC cable EMF calculations are outlined in this Section. The HVDC cables are assumed buried within the seabed for their subsea route, with DoLs of 0.4 m and 1.5 m being assessed. Parameters of the HVDC system, installation and environment are needed to perform EMF calculations. Required calculation inputs for HVDC EMF calculations are:

- Cable builds – Pole cable ODs (provided by the Applicant);
- Cable DoLs – Depth of lowering to top of cable at each calculation point KP (provided by the Applicant);
- Expected current flow – Continuous maximum current flow during operation (provided by the Applicant);
- KP location coordinates – Coordinates of latitude and longitude at KP locations (determined);
- Geomagnetic field details – Resultant and component vectors for the geomagnetic field at each KP (determined);
- Circuit angle – Angle of the installed cables with respect to Magnetic North, at each KP location (determined);
- Pole cable configurations at each KP – Bundled configuration symmetric monopole (provided by the Applicant); and
- Seawater depths – Seawater depths at each KP, for geomagnetic field calculations (determined).

Inputs into EMF intensity calculations is geomagnetic field component vector magnitudes and directions at seawater depths. From these input parameters, combined EMF intensities are calculated. Assumptions applied in EMF intensity calculations are outlined in the following Section.

14A.1.7 Calculation assumptions

This Section outlines assumptions made for this HVDC cable EMF study. Assumptions below are applicable to HVDC cables. The EMF calculations consider the current flow within the central conductor and is assumed to be constant.

- No harmonic currents, ripple currents or transients are included or their effects modelled;
- Power core positions are assumed constant along the subsea route, in a bundled configuration.
- Any currents induced within the metallic sheath of each power core are not included;
- The cables are assumed to have infinite length, and there is no consideration of external influences such as other cables, crossing locations, nearby metallic structures, magnetic anomalies or pipelines;
- Calculations do not include any EMF attenuation caused by armour wire layers or metallic sheath;
- The DoL is assumed between top of the cable and mean seabed level and is taken as constant. No allowance is made for seabed mobility;
- DoL are assumed to be a minimum of 0.4 m and maximum 1.5 m, both between mean seabed level and top of cable;
- Coordinates of latitude and longitude are applied within the NOAA online calculator (NOAA, N.D.) and used to calculate earth's magnetic field at KP locations;

- The seabed and seawater are assumed homogenous and magnetic permeability of the seabed and seawater is taken as $\mu_r = 1.0$. No allowance has been made for Basalt, Hematite or Magnetite sedimentary compositions, which may slightly increase magnetic permeability;
- Trench back-fill material is assumed to have the same properties of the surrounding seabed; and
- A maximum generating capacity of 1.4 GW has been assumed.

14A.2 Results for the 320 kV Export/Import Cable

14A.2.1 Background

This Section presents EMF calculation results for the 320 kV HVDC cable. A generic design of a 320 kV subsea cable is shown in Figure 6.

Figure 6. Generic 2000 mm^2 320 kV HVDC subsea cable design

Table 2 provides the 320 kV cable dimension and parameters used for the EMF assessment, as provided by the Applicant.

Table 2 Dimensions and current for the 320 kV HVDC cable

PARAMETER	DIMENSION	
Voltage (kV)	320	
Current (A)	2325	
Cable OD (mm)	155	
DoL (m)	Minimum	Maximum
	0.4	1.5

The following Section provides results from EMF calculations for the 320 kV HVDC Export/Import Cable.

14A.2.2 Results

Results from EMF calculations for the 320 kV HVDC cable are presented in this Section. Calculations of EMF intensities were based on DoLs of 0.4 m and 1.5 m to top of cable. Table 3 provides calculated EMF intensities for the subsea route from KP1 to KP227.

Table 3 Maximum EMF intensities for the 320 kV Export/Import Cable for KP1-KP227

KP	Water depth (m)	Circuit angle West (Degrees)	Declination (Degrees)	Maximum EMF intensity along the seabed (μT)	
				DoL 0.4 m	DoL 1.5 m
1	7.75	124.66	-0.20074	482.28	81.47
5	54.41	139.62	-0.18103	482.29	81.48
10	58.90	135.75	-0.16283	482.31	81.49
15	76.42	121.93	-0.14207	482.32	81.50
20	92.62	113.67	-0.1164	482.33	81.51
25	78.09	113.64	-0.08686	482.34	81.52
30	86.58	80.28	-0.05449	482.35	81.52
35	95.04	80.24	-0.01952	482.35	81.52
40	100.96	80.21	0.01539	482.34	81.52
45	102.95	80.17	0.05024	482.34	81.52
50	97.50	20.46	0.07957	482.34	81.51
55	93.26	84.72	0.10884	482.33	81.51
60	85.57	84.69	0.14348	482.33	81.51
65	87.82	84.65	0.17809	482.33	81.51
70	90.15	89.61	0.21251	482.33	81.51
75	93.21	89.57	0.2468	482.33	81.52
80	96.13	89.53	0.28106	482.34	81.52
85	97.89	89.50	0.3153	482.34	81.52
90	102.92	89.47	0.34952	482.34	81.52
95	101.08	89.23	0.3837	482.34	81.52
100	89.47	89.39	0.41784	482.34	81.52
105	89.35	83.18	0.45198	482.34	81.52
110	85.28	83.15	0.48628	482.34	81.52
115	87.11	83.11	0.52055	482.34	81.52
120	88.23	89.68	0.5547	482.34	81.52
125	91.73	67.46	0.58857	482.34	81.52
130	86.93	0.43	0.61194	482.33	81.52
135	80.50	86.34	0.63975	482.33	81.52
140	78.36	38.05	0.66146	482.33	81.51
145	81.00	71.06	0.69184	482.34	81.51
150	80.45	40.73	0.72286	482.32	81.50
155	80.13	73.50	0.74847	482.30	81.49
160	85.30	73.47	0.78162	482.30	81.49
165	87.92	116.82	0.81237	482.31	81.49

KP	Water depth (m)	Circuit angle West (Degrees)	Declination (Degrees)	Maximum EMF intensity along the seabed (μT)	
				DoL 0.4 m	DoL 1.5 m
170	82.02	119.59	0.84064	482.32	81.50
175	90.98	119.56	0.86816	482.33	81.51
180	90.64	70.21	0.89572	482.34	81.52
185	92.94	56.81	0.92542	482.33	81.52
190	94.07	56.78	0.95512	482.32	81.51
195	92.96	56.75	0.98471	482.32	81.50
200	89.06	52.15	1.01381	482.31	81.50
205	86.79	52.13	1.04184	482.30	81.50
210	90.12	29.90	1.06935	482.28	81.49
215	92.67	29.89	1.08832	482.27	81.47
220	95.21	29.87	1.1072	482.26	81.46
225	95.38	24.93	1.12599	482.24	81.45
227	97.83	23.79	1.13236	482.24	81.45

The EMF from the cable remains approximately constant for the entire subsea route at 482 μT along the seabed. This is illustrated with the plot shown in Figure 7.

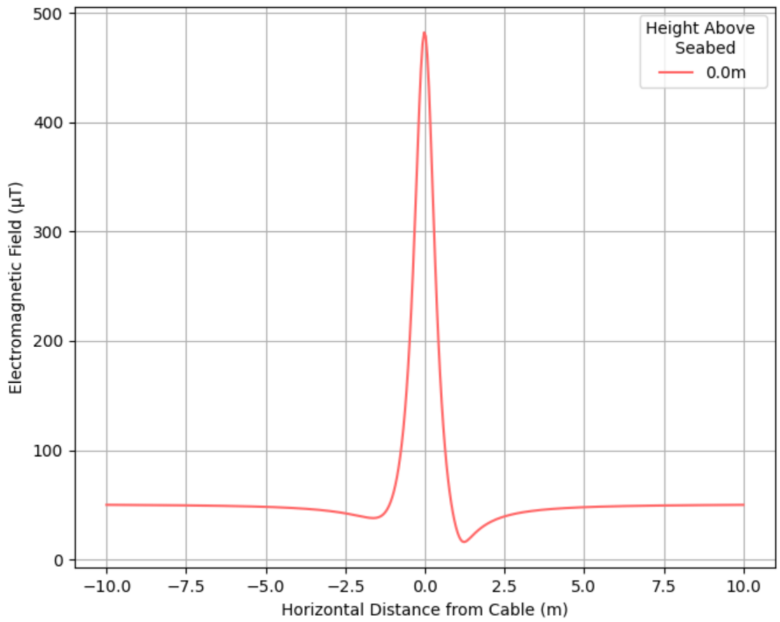

Figure 7. 320 kV cable maximum EMF intensity along the seabed for a DoL of 0.4 m

From Figure 7 it can be seen that the EMF from the cable reduces to the background geomagnetic field level of approximately 50 μT between 5.0 m and 10.0 m either side of the cable. Reduction in the peak EMF can be seen when the cable is buried to 1.5 m, as shown in Figure 8.

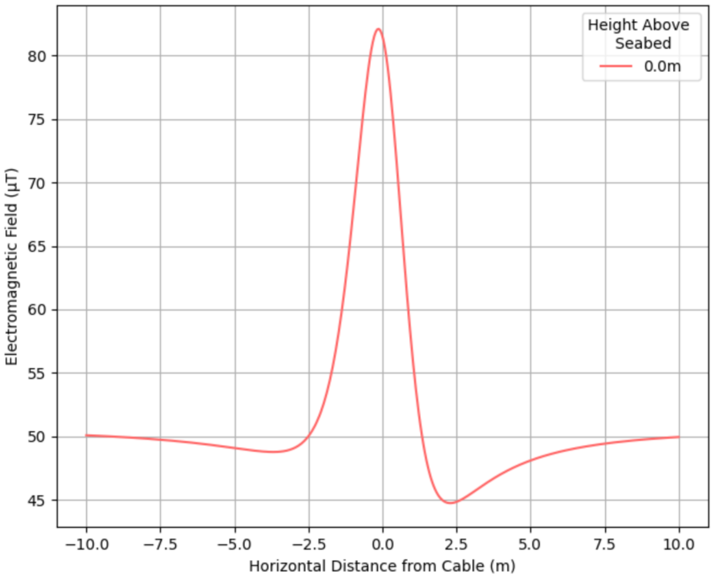

Figure 8. 320 kV cable maximum EMF intensity along the seabed for a DoL of 1.5 m

14A.3 Results for the 525 kV Export/Import Cable

14A.3.1 Background

This Section presents EMF intensity calculation results for the 525 kV HVDC cable. A generic 525 kV cable build is shown in Figure 9.

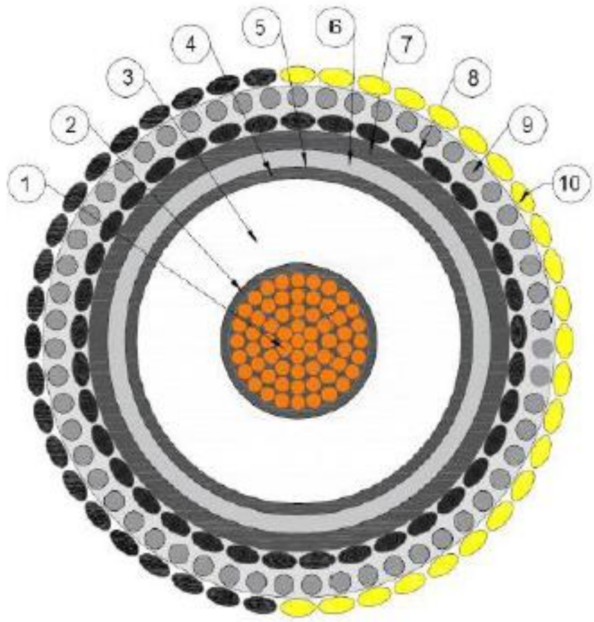

Figure 9. Generic 525 kV 2500 mm² HVDC subsea cable

Table 4 provides details of the 525 kV HVDC cable build, used for EMF calculations along KP locations of the EICC.

Table 4 525 kV HVDC cable dimensions and parameters

PARAMETER	DIMENSION	
Voltage (kV)	525	
Current (A)	1310	
Cable OD (mm)	150	
DoL (m)	Minimum	Maximum
	0.4	1.5

The following Section provides results from EMF calculations for the 525 kV HVDC Export/Import Cable.

14A.3.2 Results

Results from EMF calculations for the 525 kV HVDC cable are presented in this Section. Calculations of EMF intensities were based on a DoL of 0.4 m and 1.5 m to top of cable. Table 5 provides calculated EMF intensities for the subsea route from KP1 to KP227.

Table 5 Maximum EMF intensities for the 525 kV Export/Import Cable at 0.4 m DoL for KP1 to KP227

KP	Water depth (m)	Circuit angle West (Degrees)	Declination (Degrees)	Maximum EMF intensity along the seabed (μT)	
				DoL 0.4 m	DoL 1.5 m
1	7.75	124.66	-0.20074	285.59	67.31
5	54.41	139.62	-0.18103	285.60	67.32
10	58.90	135.75	-0.16283	285.62	67.33
15	76.42	121.93	-0.14207	285.63	67.34
20	92.62	113.67	-0.1164	285.64	67.35
25	78.09	113.64	-0.08686	285.65	67.36
30	86.58	80.28	-0.05449	285.65	67.36
35	95.04	80.24	-0.01952	285.65	67.36
40	100.96	80.21	0.01539	285.65	67.36
45	102.95	80.17	0.05024	285.65	67.36
50	97.50	20.46	0.07957	285.64	67.36
55	93.26	84.72	0.10884	285.65	67.36
60	85.57	84.69	0.14348	285.65	67.36
65	87.82	84.65	0.17809	285.64	67.36
70	90.15	89.61	0.21251	285.64	67.36
75	93.21	89.57	0.2468	285.64	67.36
80	96.13	89.53	0.28106	285.64	67.36
85	97.89	89.50	0.3153	285.64	67.36
90	102.92	89.47	0.34952	285.64	67.36

KP	Water depth (m)	Circuit angle West (Degrees)	Declination (Degrees)	Maximum EMF intensity along the seabed (μT)	
				DoL 0.4 m	DoL 1.5 m
95	101.08	89.23	0.3837	285.64	67.36
100	89.47	89.39	0.41784	285.64	67.36
105	89.35	83.18	0.45198	285.65	67.36
110	85.28	83.15	0.48628	285.65	67.36
115	87.11	83.11	0.52055	285.65	67.36
120	88.23	89.68	0.5547	285.65	67.36
125	91.73	67.46	0.58857	285.65	67.36
130	86.93	0.43	0.61194	285.65	67.36
135	80.50	86.34	0.63975	285.64	67.36
140	78.36	38.05	0.66146	285.64	67.35
145	81.00	71.06	0.69184	286.63	67.35
150	80.45	40.73	0.72286	285.63	67.35
155	80.13	73.50	0.74847	285.64	67.34
160	85.30	73.47	0.78162	285.61	67.34
165	87.92	116.82	0.81237	285.62	67.34
170	82.02	119.59	0.84064	285.63	67.35
175	90.98	119.56	0.86816	285.64	67.35
180	90.64	70.21	0.89572	285.65	67.36
185	92.94	56.81	0.92542	285.64	67.36
190	94.07	56.78	0.95512	285.64	67.36
195	92.96	56.75	0.98471	285.64	67.36
200	89.06	52.15	1.01381	285.64	67.36
205	86.79	52.13	1.04184	285.64	67.36
210	90.12	29.90	1.06935	285.60	67.33
215	92.67	29.89	1.08832	285.58	67.32
220	95.21	29.87	1.1072	285.57	67.31
225	95.38	24.93	1.12599	285.55	67.30
227	97.83	23.79	1.13236	285.55	67.30

In comparison to the 320 kV cable, the EMF emissions are lower for the 525 kV cable, as the current is lower. The maximum EMF along the seabed for a DoL of 0.4 m is shown in Figure 10.

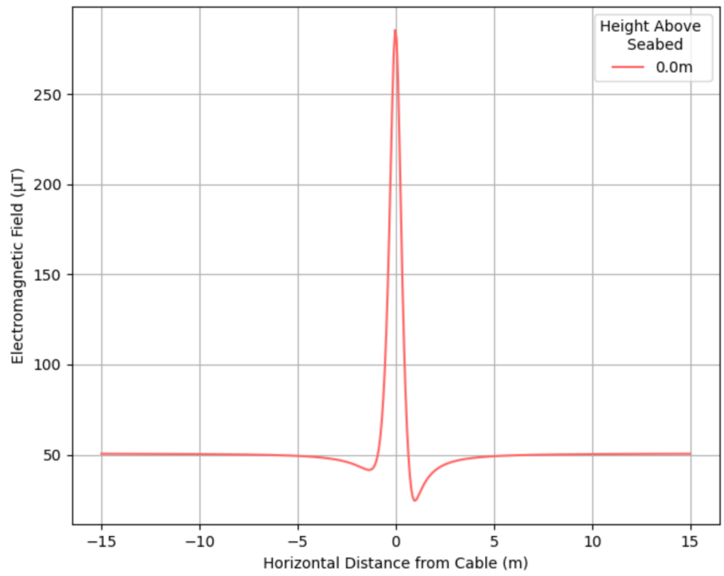

Figure 10. 525 kV cable maximum EMF intensity along the seabed for a DoL of 0.4 m

The EMF is reduced when the DoL is increased to 1.5 m, as shown in Figure 10. The influence of increasing the DoL to 1.5 m for the 525 kV cable is shown in Figure 11.

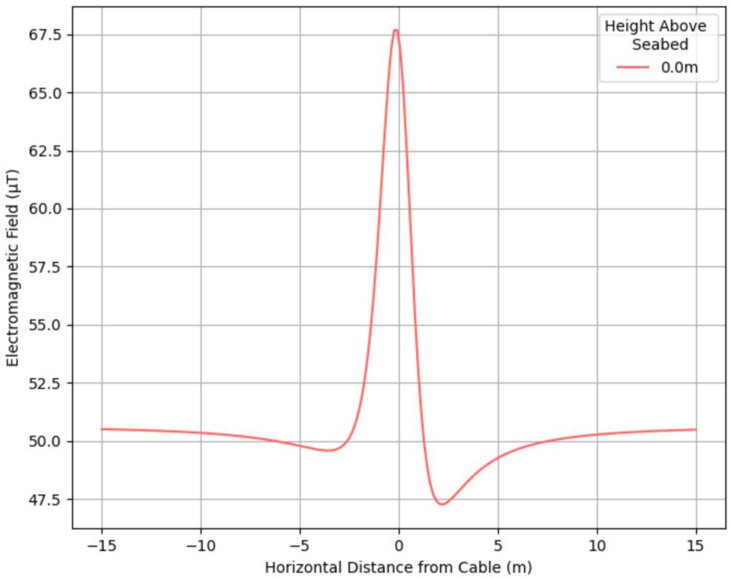

Figure 11. 525 kV cable maximum EMF intensity along the seabed for a DoL of 1.5 m

14A.4 Discussion

This report has provided calculations of EMF intensities for two HVDC subsea cable designs. Seabed magnetic permeability (μ_r) was assumed to be 1.0. Export/Import Cable currents were assumed as 2325 A for the 320 kV cable and 1310 A for the 525 kV cable.

For both 320 kV and 525 kV cable designs, calculations show that lowest EMF intensities on the seabed were calculated for an increased DoL of 1.5 m. The geomagnetic field intensity remains relatively constant along the subsea cable route.

A bundled configuration of pole cables provides lower EMF intensities along the seabed and above the cables due to interactions of the fields. The calculated EMF intensities tend towards Earth's background geomagnetic field levels beyond approximately 5.0 m either side of the cables.

Export/Import Cable current is lower with the 525 kV cable, resulting in reduced EMF intensities along the seabed, in comparison to the 320 kV cable.

14A.5 Conclusion

This report has provided an EMF study for the HVDC Export/Import Cable for the Project. Cable diameters based on 320 kV and 525 kV designs of HVDC cables show that EMF emissions along the seabed are lower for the 525 kV cable, in comparison to the 320 kV cable.

The DoL provides significant attenuation of EMF intensities by placing a greater distance between the EMF source and point of calculation. Beyond approximately 10 m from the cable, all calculated EMF intensities tend towards the background geomagnetic field levels for both the 320 kV and 525 kV cable.

14A.6 References

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