Cenos Offshore Windfarm Limited

cenos

Cenos EIA

Appendix 14C – Electromagnetic Field Assessment Report Vol. 3

ASSIGNMENT	**A100907-S01**
DOCUMENT	**A-100907-S01-A-ESIA-034**
CLIENT	**CEN001-FLO-CON-ENV-RPT-0060**

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REV	DATE	DESCRIPTION	ISSUED	CHECKED	APPROVED	CLIENT
A01	16/12/24	Issued for Use	DC/MS	FdB	LD	Cenos
R02	14/11/24	Issued for review	DC/MS	LD	NB	Cenos
R01	16/10/24	Issued for Review	DC/MS	SJ	LD	Cenos

CONTENTS

ACRONYMS

ACRONYM	DEFINITION
A	Current
CIGRE	Council Internal for Large Electric Systems
D	Declination
DoL	Depth of Lowering
EICC	Export/Import Cable Corridor
EMF	Electromagnetic Field
f	Frequency
FTU	Floating Turbine Unit
GM	Geomagnetic Field
GW	Giga-Watts
HVDC	High Voltage Direct Current
I	Current
km	Kilometre
KP	Kilometre Point
kV	Kilo Volt
m	Metres
mm	Millimetres
MCA	Marine Coastguard Agency
MN	Magnetic North
MW	Megawatt
NOAA	National Oceanic and Atmospheric Administration
OD	Outside Diameter
TB	Technical Brochure
WTG	Wind Turbine Generator
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2023 Scoping Opinion	Scoping Opinion received in June 2023, superseded by the 2024 Scoping Opinion.
2023 Scoping Report	Environmental Impact Assessment (EIA) Scoping Report submitted in 2023, superseded by the 2024 Scoping Report.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''strin'' 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 14C COMPASS DEVIATION STUDY

14C.1 Introduction

This Technical Report is a compass deviation study for the Project High Voltage Direct Current (HVDC) Export/Import Cable Route. It is recommended that the HVDC Electromagnetic Field (EMF) Report (EIAR Vol. 4, Appendix 14A: Electromagnetic Field Study for the Export/Import Cable) is read alongside this report.

The Project is currently under development, and detailed engineering design has not been agreed at the time of drafting this report; therefore, the following report relies on assumptions based on the Project Design Envelope (PDE). A symmetric monopole has been chosen for the assessment, comparing a 320 kV and 525 kV system.

This Technical report has been authored by:

- [Redacted] – Renewable Engineer, EvolvEnergies.

14C.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 located 200 km offshore, east of Aberdeen, in the Central North Sea (see Figure 1). The Project shall principally supply renewable electricity to the United Kingdom (UK) Grid. Construction of the Project shall enable efficient electrification of offshore Oil & Gas installations and a portion of the electricity generated by the Project shall be allocated to these assets. When wind speeds are insufficient to power the Oil & Gas assets directly, additional electricity is to be imported from the UK grid through the connection to shore via an Export/ Import Cable which will make landfall at Longhaven. For this Technical Report, compass deviation is calculated for the full cable route within the Export/Import Cable Corridor (EICC) (230 km) from landfall to the Array Area; KP 1 through to KP227.

The Project will be connected to shore via a HVDC Offshore Export/Import Cable system. Figure 1 shows the proposed location of the Project and EICC between landfall at Longhaven and the Array Area.

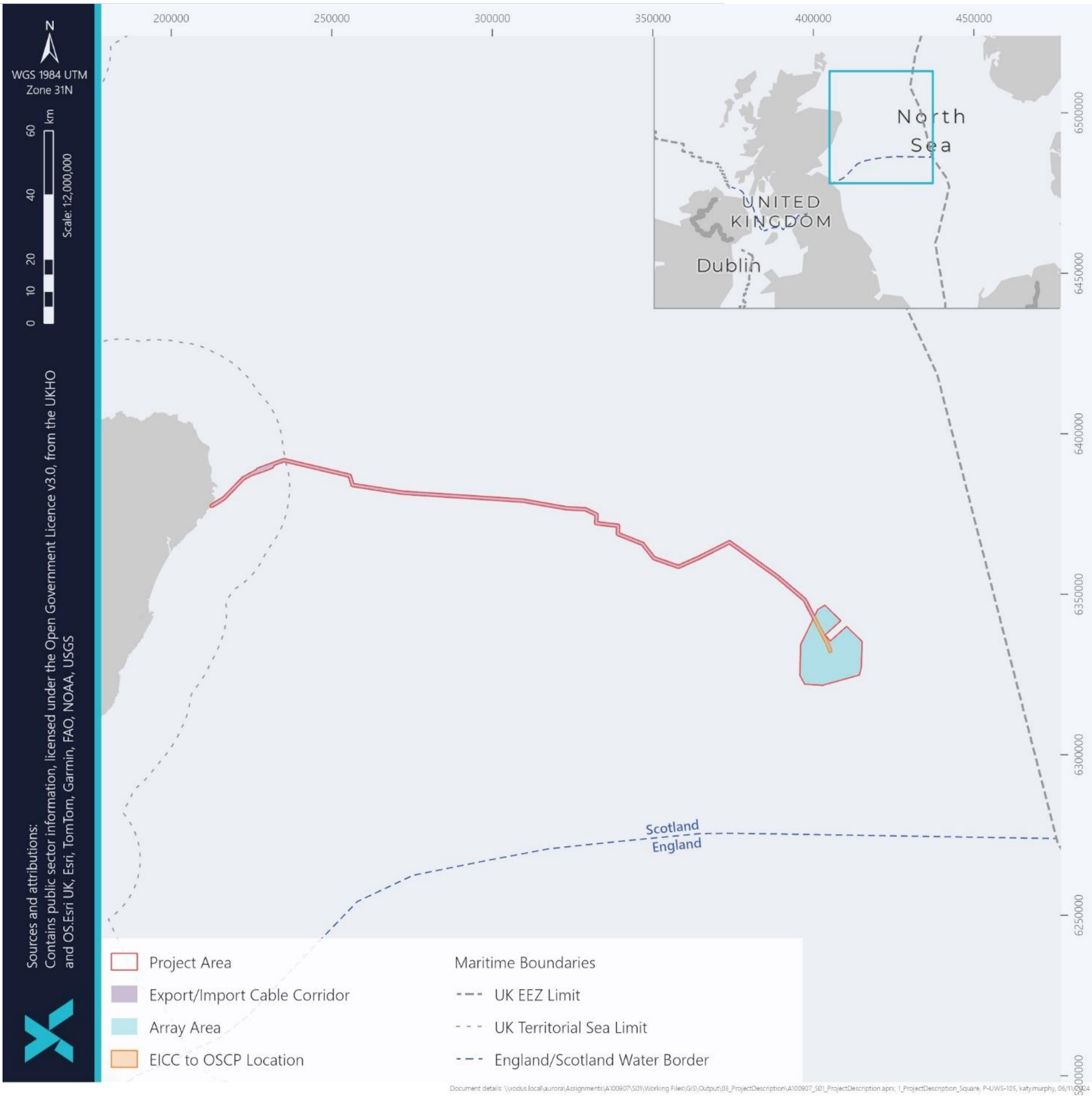


Figure 1. Location of the Project; Array Area, Export/Import Cable Route and EICC

The Project will comprise of up to 95 Floating Turbine Units (FTUs). The Wind Turbine Generators (WTGs) will be installed on floating substructures, anchored to the seabed with mooring lines. It is proposed that the Export/Import Cable system will operate at either ±320 kilovolts (kV) or ±525 kV, as a symmetric monopole system. Construction of the Project is due to commence in 2030.

The Export/Import Cable is assumed to be buried along the EICC at a minimum Depth of Lowering (DoL) of 0.4 m (Mean Seabed Level to the top of the Cable), providing a 'worst-case' scenario. The following Section outlines compass deviation and its relevance to subsea HVDC cable systems.

14C.1.2 Overview of compass deviation

Transmission of electrical power through a cable generates an EMF, an electric field and an induced electric field, which is produced with movement through the magnetic field. The electrical field is produced by the applied system voltage and is contained within the screened insulation system of the cable. Only the generated EMF and induced electric field exist beyond the screened insulation system of the cable. The EMF extends into the seawater and surrounding seabed around the cable, and for a HVDC system, it interacts with earth's geomagnetic field.

Earth's geomagnetic field is static with no frequency (*f*) associated with it. The EMF generated by a HVDC cable is a static field. Interactions of EMF components only occurs with fields generated at the same frequency, meaning that the static field generated by an HVDC cable can interact with Earth's geomagnetic field.

A compass needle always points towards magnetic north (MN), due to earth's geomagnetic field causing alignment. Magnetic North is different from geographic north (sometimes referred to as True North), with the angular difference between these two directions termed as the angle of declination (D). Magnetic declination varies globally and may be negative (to the West) or positive (to the East).

Compass deviation is considered in a plane parallel to the surface of the earth and can be affected by external magnetic influences. Compass deviation is the angular shift experienced by a magnetic compass due to a localised presence of an external magnetic field.

Disturbance of geomagnetic field vectors that are parallel to the surface of the earth (the horizontal EMF component vectors) produces an angular shift between the combined cable EMF, Earth's geomagnetic field and MN.

The next Section outlines the calculation approach applied for compass deviation assessment in this report.

14C.2 Calculation Approach

14C.2.1 Background Theory

The static EMF generated by a subsea HVDC cable modifies direction and intensity of horizontal magnetic field components around the cable. For a compass deviation assessment, only horizontal components of the field are required i.e. components in the X-axis and Y-axis (north-south and east-west directions). The Z-axis EMF component acts in the vertical plane, so does not influence compass deviation, as illustrated in Figure 2.

Compass deviation calculations have been carried out for the sea surface level at each KP location. The EMF component perpendicular to the cable, in the Z-axis direction is not considered, as it will not affect compass orientation (Meijer et al, 2015). At each KP location the mean seawater depth was estimated with coordinate data and use of the online tool (EMODnet, N.D.). The circuit angle was determined from the EICC map shown in Figure 1 and geomagnetic field component directions and intensities were calculated with the NOAA online tool (NOAA, N.D.). Finally, the deviation angle between the horizontal vector components and MN is then considered (Meijer et al, 2015).

Figure 2 shows compass directions and how earth's geomagnetic field and cable EMF north-south (X) and east-west (Y) vectors combine in the horizontal plane (Meijer et al, 2015). Figure 2 illustrates the approximate configuration of the Project Export/Import Cable circuit, as taken installed at an angle approximately west-to-east, with a negative compass deviation angle (to the west) and MN also to the west of True North.

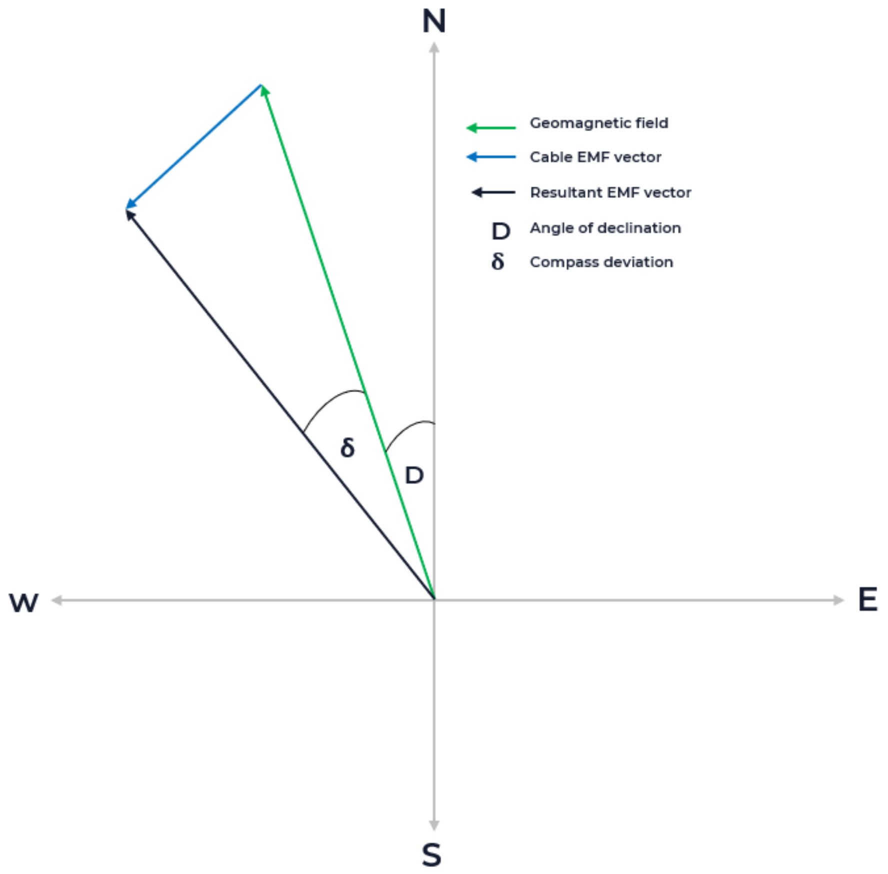


Figure 2. Compass deviation due to interaction with a HVDC cable EMF

Figure 2 illustrates how the compass deviation angle was calculated for the assumed HVDC offshore Export/Import Cable designs. The EMF from the cable is added, vectorially to the geomagnetic field, with geomagnetic field intensities and directions.

In Figure 2 the vectors and angles are illustrated as follows:

- Geomagnetic field – The vector shown in green is the resultant geomagnetic field vector, in the horizontal plane, aligned with MN.
- Cable EMF vector – The vector shown in blue is the resultant vector for the EMF generated by the cable only.
- Resultant EMF vector – The vector shown in black is the combined, resultant geomagnetic field vector and the cable vector.
- Angle of declination – The angle D is the angle between magnetic north and geographic north.
- Compass deviation – Angle δ is the angle between the resultant horizontal geomagnetic field vector and the resultant-combined EMF vector.

Calculation of compass deviation is performed in the horizontal, X-Y plane only and requires using components of EMFs from the cable (Y_{Cable}) and that of the geomagnetic field (Y_{GM}) (Meijer et al, 2015). The trigonometric tangent function is used with the Y-axis components from the cable and geomagnetic filed and the X-axis. The angle of compass deviation is derived from Equation 1.

$$\delta = arctan\left(\frac{Y_{Cable}}{}\right) \qquad (1)$$

Where

δ	Compass deviation	(degrees)
D	Angle of Declination	(degrees)
Y_{Cable}	Y component of the cable EMF	(μT)
Y_{GM}	Y component of the geomagnetic field	(μT)
X_{GM}	X component of the geomagnetic field	(μT)

In Equation 1 the horizontal EMF component from the cable is given by Equation 2.

$$Y_{Cable} = Y_{POLE\ 1} + Y_{POLE\ 2} \qquad (2)$$

The Maritime and Coastguard Agency (MCA) typically specify compass deviation thresholds for submarine cable projects, which developers are expected to adhere to, and where these limits are exceeded, additional mitigation will be required. The MCA thresholds are outlined below, and are used as the basis for this assessment:

- A maximum of 3 degrees compass deviation for 95% of the total route length; and
- A maximum of 5 degrees compass deviation for the remaining 5% of the total route length.

The next Section provides required inputs into the compass deviation calculations.

14C.2.2 Required inputs

The required inputs for compass deviation calculations are outlined in this Section. Parameters of the HVDC system, installation and environment are needed to perform compass deviation calculations.

- EMF intensities – resultant EMF at the sea surface level and EMF vector components;
- KP location coordinates – coordinates of latitude and longitude at KP locations;
- Geomagnetic field details – resultant geomagnetic field at the seawater surface level and vector component directions and intensities;
- Circuit angle – angle of the installed cables with respect to magnetic north, at each KP location;
- Cable build dimensions – cable outside diameter (OD);
- Installation parameters – burial depths at KPs and configuration of the pole cables (bundled); and
- Mean water depths – mean water depths at each KP.

Assumptions applied in the compass deviation calculations are outlined in Section 14C.2.3.

14C.2.3 Calculation assumptions

Below outlines the assumptions and approximations made to produce compass deviation calculations for the HVDC Export/Import Cable for the Project.

- Electromagnetic field calculations are those previously calculated with application of the Biot-Savart Law and installation geometry (EIAR Vol. 4, Appendix 14A: Electromagnetic Field Study for the Export/Import Cable);
- Seawater surface is assumed level and mean water depth known at the KP locations. Previously calculated for the HVDC EMF study (EIAR Vol. 4, Appendix 14A: Electromagnetic Field Study for the Export/Import Cable);
- No allowance is made for magnetic anomalies or disturbances from other pipelines or cables;
- Geomagnetic field intensities and directions are calculated according to the NOAA online tool (NOAA, N.D.);
- Current within pole cables is assumed to be constant and no allowance is made for harmonic content;
- A maximum generating capacity of 1.4 Gigawatts (GW), based on 95 WTGs;
- The DoL is assumed between top of the cable and mean seabed level and is taken as constant at 0.4 m. No allowance is made for sand waves or seabed mobility;
- 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;
- The EMF component in the vertical (Z-axis) does not influence compass deviation and is not included within the calculations; and
- Circuit angles are determined based on the EICC with example locations shown in Figure 3 It should also be noted that each KP location has unique geomagnetic field component intensities and directions.

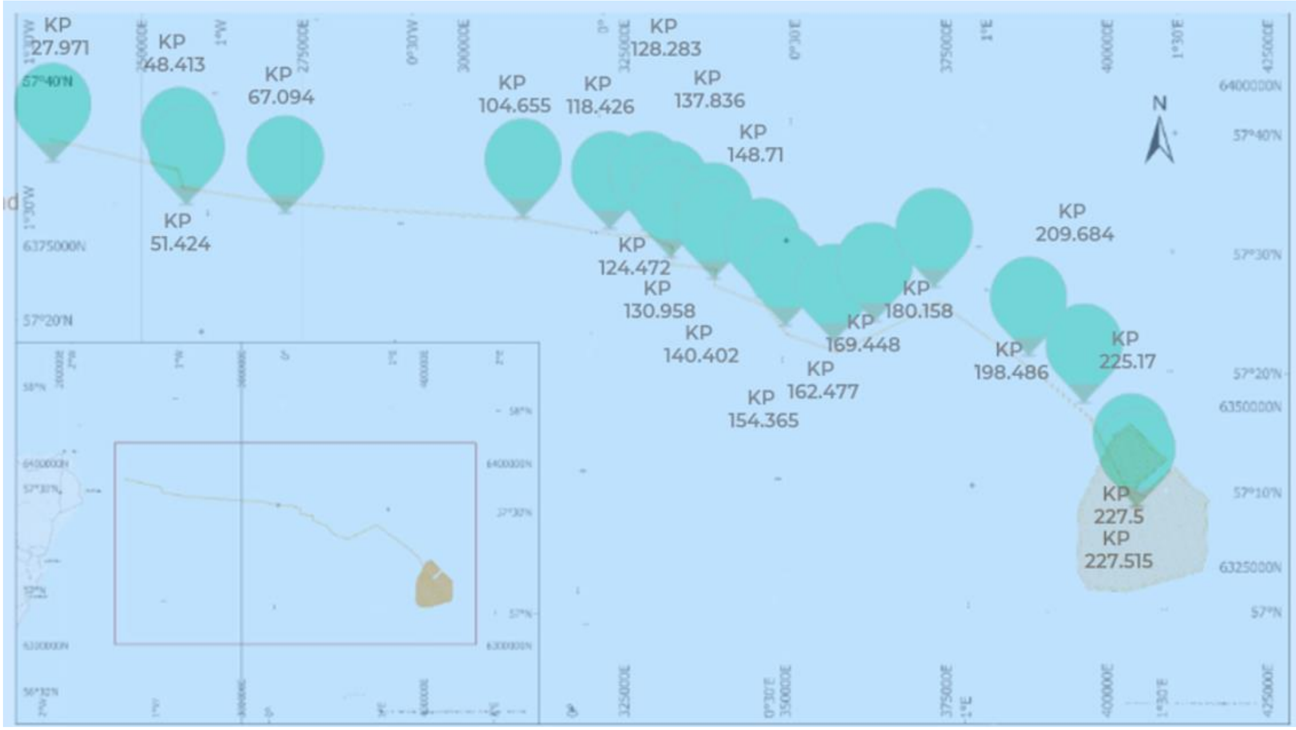


Figure 3. Example location of KPs within the EICC

The following Sections assess compass deviations for the two proposed HVDC cable systems, a 320 kV cable and a 525 kV cable for approximately all of the EICC (KP1 to KP227). Cable diameters and current flows were provided by the Applicant.

14C.3 Results For the 320 kV Export/Import Cable

14C.3.1 Background

This Section presents the compass deviation calculation results for the 320 kV HVDC cable. The outside diameter of the 320 kV HVDC cable is 155 mm. A generic design for a 320 kV HVDC cable, from the Council Internal for Large Electric Systems (CIGRE) Technical Brochure (TB) 880 (CIGRE, 2022) and is shown in Figure 4.

Figure 4. Generic 2000 mm^2 320 kV HVDC subsea cable

Table 1 below provides details of the 320 kV HVDC cable, A single, 'worst-case' DoL of 0.4 m has been applied to compass deviation calculations.

Table 1. Proposed 320 kV HVDC cable dimensions and parameters

PARAMETER	VALUE
Voltage (kV)	320
Current (A)	2325
Cable outside diameter (mm)	155
DoL (m)	0.4

The following Section provides results of the compass deviation calculations for the 320 kV HVDC Export / Import Cable.

14C.3.2 Results

Results from compass deviation calculations for the 320 kV HVDC cable are presented in this Section. Table 2 provides calculated compass deviations from KP1 to KP227 for a DoL of 0.4 m.

Table 2. Compass deviations for the 320 kV HVDC Cable at 0.4 m DoL from KP1 to KP227

KP	Declination (Degrees)	Water depth (m)	Circuit angle West (Degrees)	Compass deviation at sea surface (degrees)
1	-0.20	-7.75	124.66	2.010
5	-0.18	-54.41	139.62	0.040
10	-0.16	-58.90	139.59	0.030
15	-0.14	-76.42	121.93	0.020
20	-0.12	-92.62	113.67	0.020
25	-0.09	-78.09	113.64	0.020
30	-0.05	-86.58	80.28	0.004
35	-0.02	-95.04	80.25	0.003
40	0.02	-102.76	80.21	0.003
45	0.05	-103.93	80.18	0.002
50	0.08	-97.54	20.47	0.020
55	0.11	-93.26	84.72	0.002
60	0.14	-85.57	84.69	0.002
65	0.18	-87.82	84.65	0.002
70	0.21	-90.15	89.61	0.000
75	0.25	-93.21	89.58	0.000
80	0.28	-96.13	89.54	0.000
85	0.32	-97.89	89.50	0.000
90	0.35	-102.92	89.47	0.000
95	0.38	-101.08	89.43	0.000
100	0.42	-89.47	89.39	0.000
105	0.45	-89.35	83.19	0.002
110	0.49	-85.28	83.15	0.003
115	0.52	-87.11	83.11	0.003
120	0.55	-88.23	89.68	0.000
125	0.59	-91.73	67.46	0.007
130	0.61	-86.93	0.43	0.020
135	0.64	-80.50	86.35	0.002
140	0.66	-78.36	38.06	0.020
145	0.69	-81.00	71.06	0.008
150	0.72	-80.45	40.73	0.019

KP	Declination (Degrees)	Water depth (m)	Circuit angle West (Degrees)	Compass deviation at sea surface (degrees)
155	0.75	-80.13	73.50	0.007
160	0.78	-85.30	73.47	0.006
165	0.81	-87.92	116.82	0.019
170	0.84	-82.02	119.60	0.021
175	0.87	-90.98	119.56	0.017
180	0.90	-90.64	70.21	0.007
185	0.93	-92.94	56.81	0.010
190	0.96	-94.07	56.78	0.010
195	0.98	-92.96	56.75	0.010
200	1.01	-89.06	52.16	0.012
205	1.04	-86.79	52.13	0.013
210	1.07	-90.12	29.90	0.017
215	1.09	-92.67	29.89	0.016
220	1.11	-95.21	29.87	0.015
225	1.13	-95.38	24.93	0.016
227	1.13	-97.83	23.79	0.015

All compass deviations along the subsea route between KP1 and KP227 are below 3 degrees. It can be seen that as the water depth increases, the compass deviation is reduced significantly due to the vertical distance (the water depth) between the cable and the sea surface.

Figure 5 shows depth (blue), circuit angle (orange) and compass deviation (grey) along the Export/Import Cable Route for the 320 kV bundled symmetric monopole system. Note that KP locations are joined by dashed lines and are not necessarily representing compass deviations between those KPs.

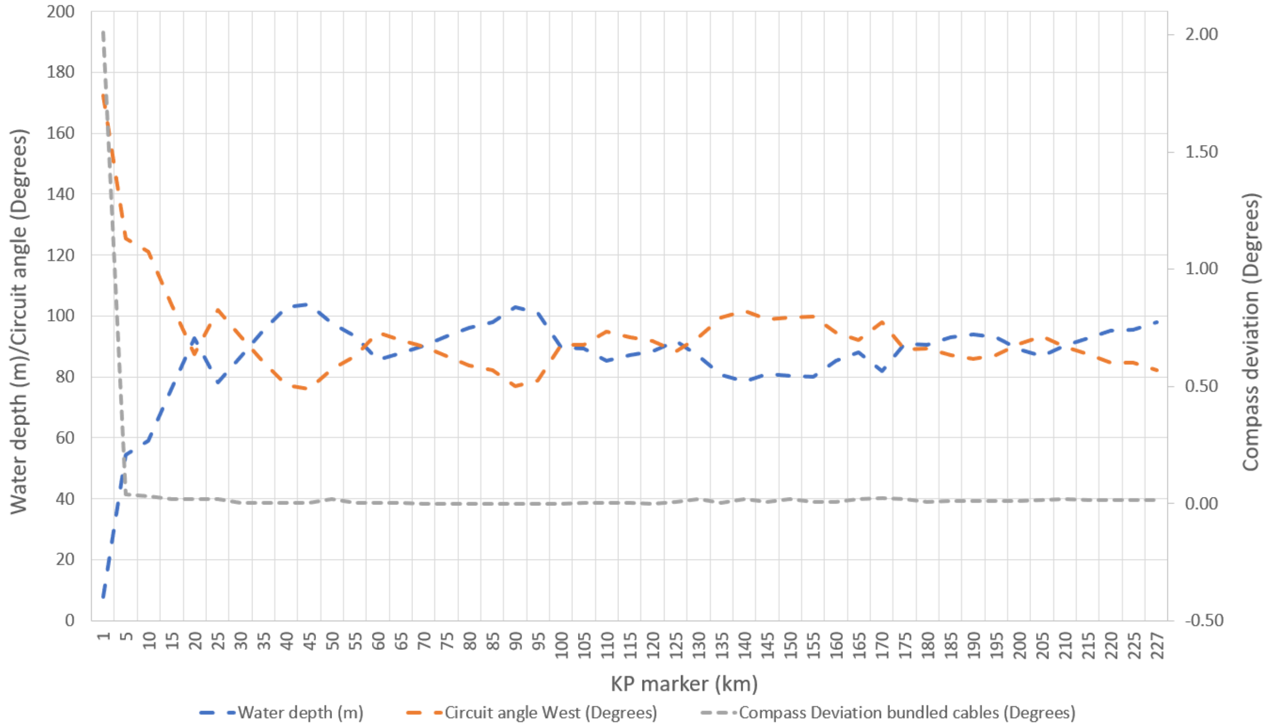


Figure 5. Compass deviation as a function of water depth and circuit angle for the 320 kV cable

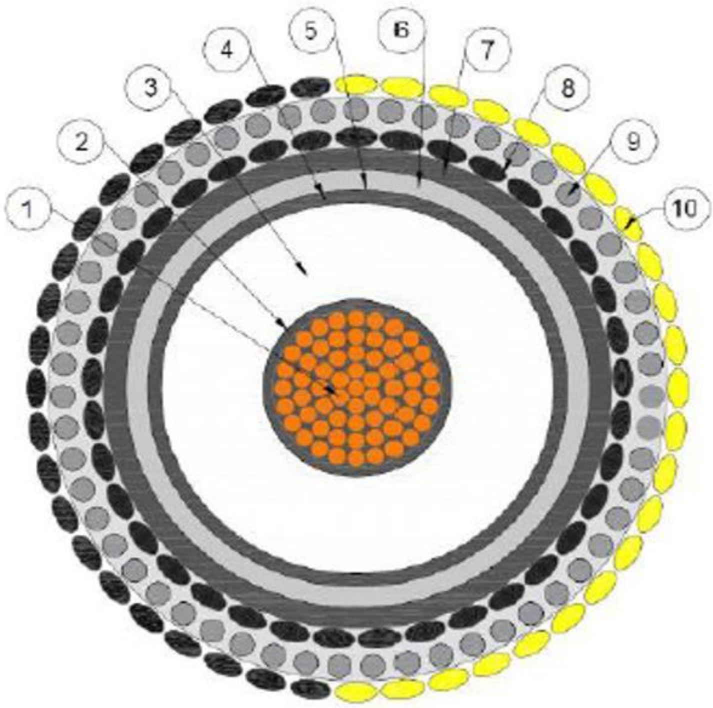
From Figure 5 above it can be seen that the compass deviation is low for all subsea KP locations, mainly due to the water depth.

The following Section provides compass deviation calculations and results for the assumed 525 kV subsea Export/Import Cable.

14C.4 Results for the 525 kV Export/Import Cable

14C.4.1 Background

This Section presents the compass deviation calculation results for the 525 kV HVDC cable system. The 525 kV HVDC cable dimensions are provided by the Applicant. The proposed 525 kV cable has an outside diameter of 150 mm and the current flow will be 1310 A. A generic design of a 525 kV subsea HVDC cable is shown in Figure 6.



#	Component
1	Conductor
2	Conductor Screen
3	Insulation
4	Insulation Screen
5	Water Blocking
6	Lead Alloy Sheath
7	Polyethylene Sheath
8	Armour Bedding
9	Armour
10	Serving

Figure 6. Generic 2500 mm^2 525 kV HVDC subsea cable

Table 3 below provides details of the 525 kV HVDC cable, used to determine compass deviations along the EICC.

Table 3. 525 kV HVDC cable dimensions and parameters

PARAMETER	VALUE
Voltage (kV)	525
Current (A)	1310
Cable outside diameter (mm)	150
DoL (m)	0.4

The following Section provides results from compass deviation calculations for the 525 kV HVDC cable.

14C.4.2 Results

Results from compass deviation calculations for the 525 kV HVDC cable are presented in this Section. Table 4 provides calculated compass deviations from KP1 to KP227 for a DoL of 0.4 m.

Table 4. Compass deviations for the 525 kV EICC for KP1 to KP227

KP	Declination (Degrees)	Water depth (m)	Circuit angle West (Degrees)	Compass deviation at sea surface (degrees)
1	-0.20	-7.75	124.66	1.010
5	-0.18	-54.41	139.62	0.019
10	-0.16	-58.90	139.59	0.016
15	-0.14	-76.42	121.93	0.013
20	-0.12	-92.62	113.67	0.009
25	-0.09	-78.09	113.64	0.013
30	-0.05	-86.58	80.28	0.002
35	-0.02	-95.04	80.25	0.002
40	0.02	-102.76	80.21	0.001
45	0.05	-103.93	80.18	0.001
50	0.08	-97.54	20.47	0.009
55	0.11	-93.26	84.72	0.001
60	0.14	-85.57	84.69	0.001
65	0.18	-87.82	84.65	0.001
70	0.21	-90.15	89.61	0.000
75	0.25	-93.21	89.58	0.000
80	0.28	-96.13	89.54	0.000
85	0.32	-97.89	89.50	0.000
90	0.35	-102.92	89.47	0.000
95	0.38	-101.08	89.43	0.000
100	0.42	-89.47	89.39	0.000
105	0.45	-89.35	83.19	0.001
110	0.49	-85.28	83.15	0.001
115	0.52	-87.11	83.11	0.001
120	0.55	-88.23	89.68	0.000
125	0.59	-91.73	67.46	0.004
130	0.61	-86.93	0.43	0.012
135	0.64	-80.50	86.35	0.001
140	0.66	-78.36	38.06	0.011
145	0.69	-81.00	71.06	0.004
150	0.72	-80.45	40.73	0.010

KP	Declination (Degrees)	Water depth (m)	Circuit angle West (Degrees)	Compass deviation at sea surface (degrees)
155	0.75	-80.13	73.50	0.004
160	0.78	-85.30	73.47	0.003
165	0.81	-87.92	116.82	0.001
170	0.84	-82.02	119.60	0.011
175	0.87	-90.98	119.56	0.009
180	0.90	-90.64	70.21	0.004
185	0.93	-92.94	56.81	0.006
190	0.96	-94.07	56.78	0.005
195	0.98	-92.96	56.75	0.006
200	1.01	-89.06	52.16	0.007
205	1.04	-86.79	52.13	0.007
210	1.07	-90.12	29.90	0.009
215	1.09	-92.67	29.89	0.009
220	1.11	-95.21	29.87	0.008
225	1.13	-95.38	24.93	0.009
227	1.13	-97.83	23.79	0.008

Figure 7 shows depth (blue), circuit angle (orange) and compass deviation (grey) along the subsea EICC, for the 525 kV bundled symmetric monopole system. Note that KP locations are joined by dashed lines and are not necessarily representing compass deviations between those KPs.

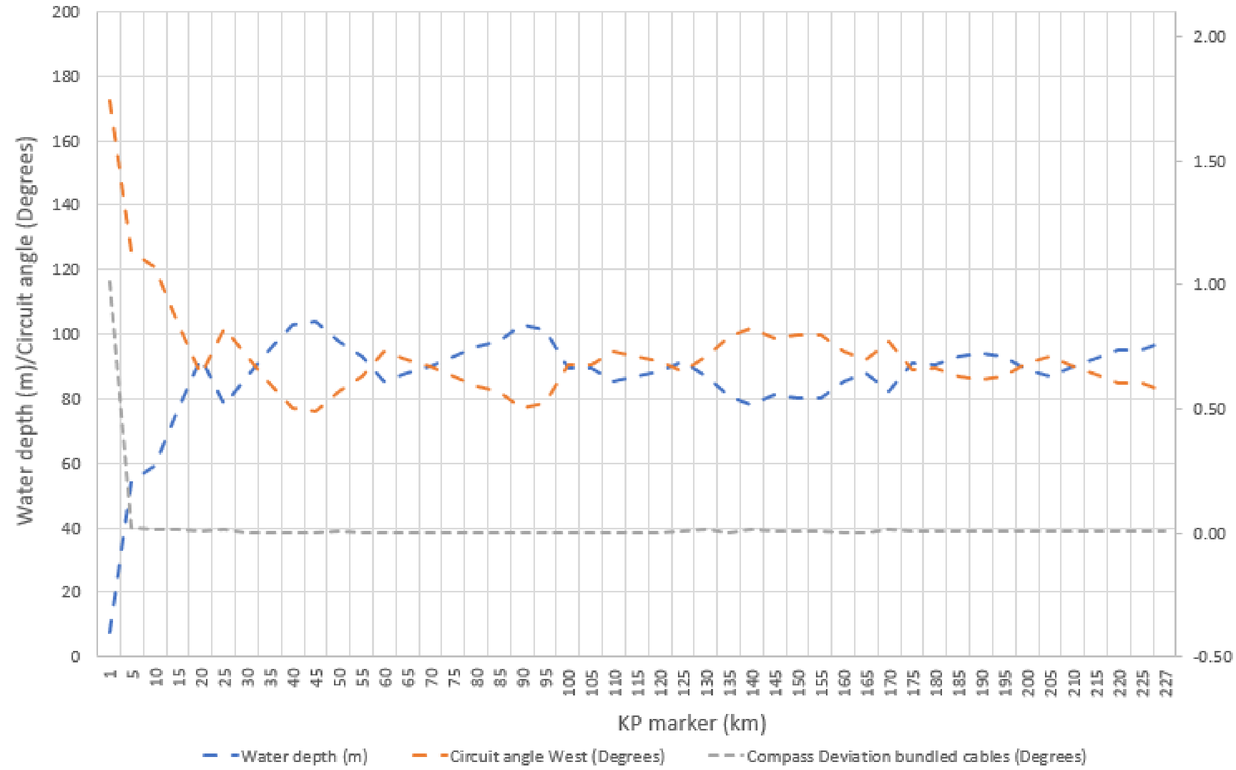


Figure 7. Compass deviation as a function of water depth and circuit angle for the 525 kV cable

14C.5 Discussion

This report has provided theoretical compass deviation results, based on two HVDC subsea cable designs, a 320 kV cable and a 525 kV cable. Indicative cable dimensions were provided by the Applicant.

Compass deviations along the entire Export/Import Cable Route for the 320 kV cable are all below 3 degrees. Compass deviations for the whole cable route of the 525 kV cable are also all below 3 degrees. These results are as expected, due to the water depths involved.

The circuit angle can influence intensities of horizontal EMF components, used for compass deviation calculations, such that when the circuit angle approaches 90 degrees with respect to magnetic north, horizontal EMF components are altered to maintain perpendicular relations between current direction and EMF. This is due to the perpendicular relation between the EMF and current flow direction and Z-axis component not forming part of compass deviation calculations.

14C.6 Conclusion

Compass deviation calculations were performed for two HVDC offshore Export/Import Cable designs. A 320 kV cable and a 525 kV cable with bundled installation was modelled for each design. The compass deviation angle is influenced by disturbance to earth's geomagnetic field horizontal components, which are the EMF components in the Y-axis and X-axis.

The bundled cable configurations result in a reduced compass deviation, as extents of field cancelling are increased with the cables being next to each other. All compass deviations were calculated at below 3 degrees for the entire Export/Import Cable Route.

14C.7 References

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