Cenos Offshore Windfarm Limited

# Cenos EIA

## Appendix 14B – Electromagnetic Field Assessment Report Vol. 2

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|---|---|
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# ACRONYMS

| ACRONYM | DEFINITION |
|---|---|
| A | Ampere |
| AC | Alternating Current |
| B | Electromagnetic Field |
| CIGRE | Council Internal for Large Electric Systems |
| DoL | Depth of Lowering |
| EIAR | Environmental Impact Assessment Report |
| ELF | Extra Low Frequency |
| EMF | Electromagnetic Field |
| FO | Fibre Optic |
| FTU | Floating Turbine Unit |
| Hz | Hertz |
| HVDC | High Voltage Direct Current |
| $I$ | Current |
| IAC | Inter-Array Cables |
| km | Kilometre |
| kV | Kilo Volt |
| m | Meter |
| mm | Millimetres |
| $mm^2$ | Millimetres Squared |
| OCS | Onshore Convertor Station |
| OSCP | Offshore Substation and Convertor Platform |
| TB | Technical Brochure |
| UK | United Kingdom |
| WTG | Wind Turbine Generator |
| $\mu_r$ | Relative permeability |
| $\mu_0$ | Absolute 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| **2023 Scoping Opinion** | Scoping Opinion received in June 2023, superseded by the 2024 Scoping Opinion.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| **2023 Scoping Report** | Environmental Impact Assessment (EIA) Scoping Report submitted in 2023, superseded by the 2024 Scoping Report.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.<br>• 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;<br>• 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<br>• 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).<br>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 14B ELECTROMAGNETIC FIELD STUDY FOR THE INTER-ARRAY CABLES

## 14B.1 Introduction

The following Technical Report is an Electromagnetic Field (EMF) study relevant to static and dynamic Alternating Current (AC) Inter-Array Cables (IACs) within the Array Area. The following Section provides an outline of the Project and an overview of electromagnetic theory, with a focus on AC subsea IACs and the assumptions applied in the study calculations. The Project is currently under development, with preliminary engineering aspects agreed with the Applicant at the time of writing this report.

This Technical Report was authored by:

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### 14B.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 kilometre (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.

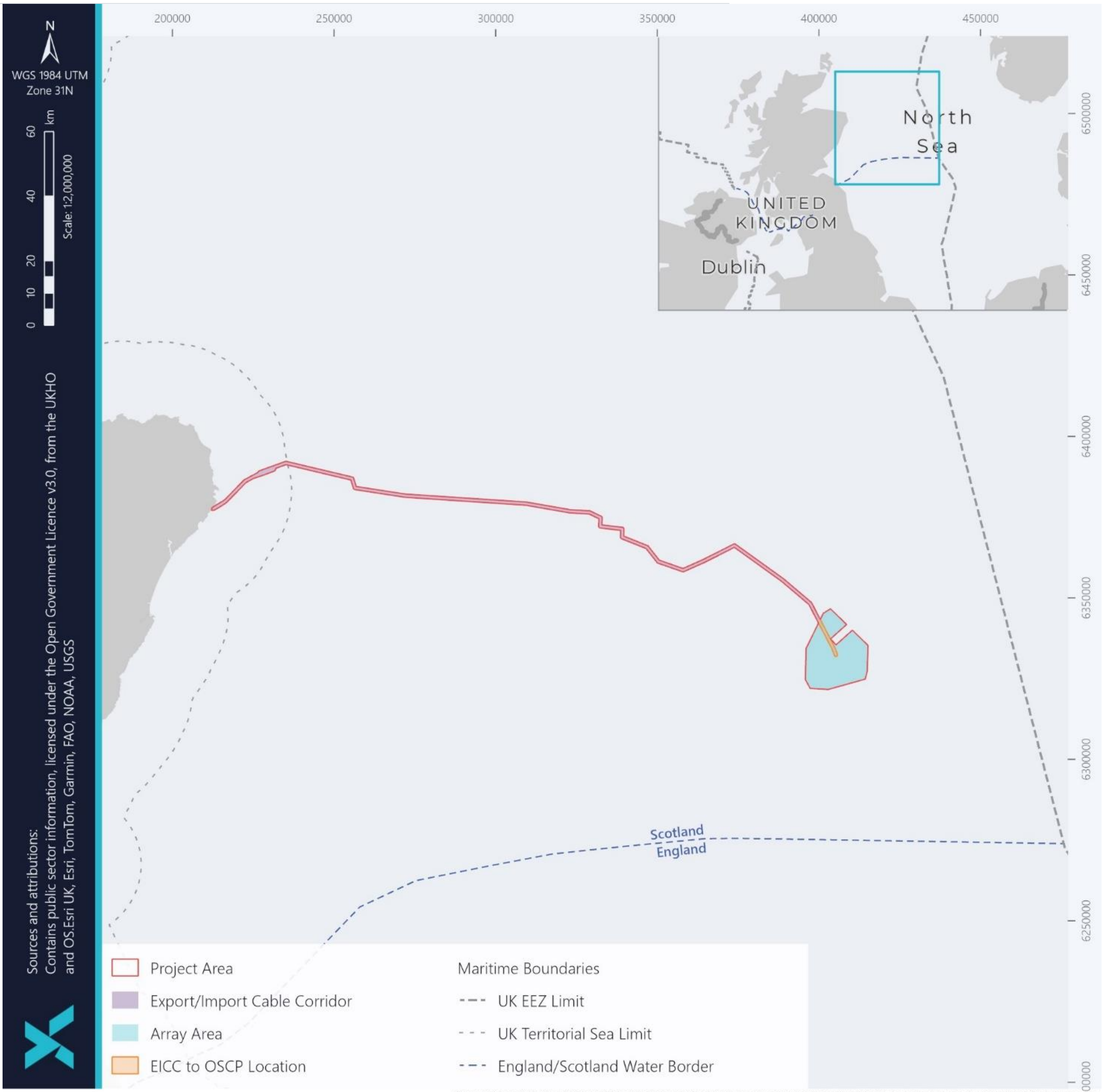

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*Figure 1. Location of the Project; Array Area, Export/Import Cable Route and EICC*

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 maintain 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.

The WTGs will be installed on floating substructures, held in location by a mooring system comprising mooring lines, anchors, connectors, and chains. For floating windfarms, sections of both dynamic and static cabling will be required. Dynamic cabling is required in floating wind developments as cable systems must be able to accommodate the movement of the floating substructure without imparting any direct loads on the cables (i.e., acting as a form of mooring). As such, the cable design often adopts a 'lazy wave', configuration using buoyancy modules attached to a portion / midpoint of the cable. The 'lazy wave' allows the cable configuration to expand and contract in shape, in response to the movements of the floating substructure. From the point where no movement in the cable is expected on the seabed (the static cable) each IAC will be laid on the seabed, either in a trench or buried; where burial to the required depth is not achievable, cable protection measures (e.g. concrete mattresses) will be used and placed over the top of the cable.

For this Technical Report current flow assumptions within IACs are provided by the Applicant. IAC voltages for both static and dynamic cables of 66 kV and 132 kV are considered, operating at a system frequency of 50 Hertz (Hz). Table 1 shows the cable build dimensions for all cables and ampacity.

*Table 1. Cable build dimensions and current flows for all cables (cells in turquoise 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 High Voltage Direct Current (HVDC)** | 155 | 120 | 60 | 2325 |
| **525 kW HVDC** | 150 | 115 | 45 | 1310 |

The proportion of IACs in the water column is 70 km, compared to cable within the seabed (280 km).

Given the distance from landfall to the Array Area (up to 230km), a HVDC Export/Import Cable system has been proposed, which will require converter stations at each end of the cable; the Onshore Converter Station (OCS) and the Offshore Substation and Convertor Platforms (OSCPs) within the Array Area. The EMF HVDC Technical Report can be found on EIAR Vol. 4, Appendix 14A: Electromagnetic Field Study for the Export/Import Cable.

The following Section outlines electromagnetic theory relevant to subsea AC cable systems.

## 14B.1.2 Overview of magnetic field theory

Transmission of electrical power through a cable generates three fields; an electromagnetic field, an induced electric field, and an electric field. The electrical field is produced by the applied system voltage and is contained within the screened insulation system of the cable by conductor and insulation screens. Only an EMF and an induced electric field exists beyond the screened insulation system of the cable. The EMF extends into the space beyond the cable and is the focus of this Technical Report.

At present there is not an agreed, adopted approach for the calculation of EMF emissions from subsea power cables. The approach adopted for calculation of EMF intensities in this report relies on application of the Biot-Savart Law, which is derived from Maxwell's equations for electromagnetism. Geometry of the calculations is set up as presented in the Council Internal for Large Electric Systems (CIGRE) Technical Brochure (TB) 320 Characterisation of Extra Low Frequency (ELF) Magnetic Fields (CIGRE, 2007). The CIGRE TB 320 presents theoretical calculations adopted for EMF modelling within this report (CIGRE, 2007).

The subsea IACs are of a three-core design and will operate as a three-phase electrical system. Each power core of a three-core subsea cable produces its own EMF at a frequency equal to that of the current waveforms, typically 50 Hz or 60 Hz.

A three-core AC submarine cable would contain extruded, circular or shaped fillers, binding tapes, a fibre optic (FO) cable and three power cores. Dependent on the metallic sheath design, power cables can be classified as wet or dry design (CIGRE, 2018). Power cores would be screened, sheathed and helically twisted together. The three power cores are laid up together then armoured, and bitumen-soaked strings applied over the complete lay-up, although cable builds vary according to manufacturer, dynamic or static applications and client requirements.

The EMF emitted from the cable may be visualised as concentric, closed loops originating from the centre of the current carrying conductor, decreasing in intensity as distance from the cable is increased. The relation between the EMF intensity and distance to the cable is such that the EMF is attenuated significantly beyond a few metres from the cable. Armour wire layers and the metallic sheath will provide some reduction of emitted EMF intensity, based on conductivity, material properties, and structure.

The flow of AC through a conductor produces a time-varying EMF, which varies according to the frequency of the system voltage. At an AC frequency of 50 Hz, the EMF emissions are classified within the ELF range. The calculation used to compute magnetic fields for this report are based on the assumption that soil permeability is 1.0 and the Biot-Savart Law, outlined below for the unit of micro-Tesla (µT) and given in Equation 1.

$$B = \mu_0 \mu_r H = \frac{\mu_r \mu_0 I}{2\pi r} = \frac{4\pi \times 10^{-7} I}{2\pi r} \rightarrow B = \frac{0.2I}{r}$$

The Biot-Savart Law (for micro-Tesla units) reduces to that given below in Equation 1, for an infinite cable length and magnetic permeability of $\mu_r$ = 1.0. This is a common simplification and approach applied for subsea cable EMF calculations.

$$B = \frac{0.2I}{r} \qquad (1)$$

Where

| | | |
|---|---|---|
| $B$ | Electromagnetic Field intensity | (µT) |
| $\mu_0$ | Permeability of a vacuum | ($4\pi \times 10^{-7}$ H/m) |

| | | |
|---|---|---|
| $\mu_r$ | Permeability of the material | ($\mu_r$ = 1) |
| $H$ | Magnetic field strength | (A/m) |
| $I$ | Current | (A) |
| $r$ | Distance to the Point of Interest | (m) |

Based on steady state current flow, axial distances between power core centres and resultant distance to the EMF calculation point, calculation of the EMF is performed for each power core and the resultant EMF taken. The calculation approach is explained in the next Section.

## 14B.2 Calculation Approach

At the time of writing this Technical Report, there are no identified, commercially operating floating offshore windfarms, although there are demonstrator projects and projects in the planning stages. This limitation of commercialisation of floating offshore wind limits the number of available EMF reports and no identified and agreed approaches to performing EMF intensity calculations for both fixed and floating offshore wind applications.

The approach taken is that outlined by CIGRE (2007), with the Biot-Savart Law being applied, based on the current and geometry of the installation, and including burial depth, if appropriate. For dynamic cable sections suspended within the water column the EMF intensity is calculated along the cable's outside surface and distances away from it.

This Section provides background to the EMF intensity calculation methodology applied, the required inputs, and a discussion of simplifications made within the modelling. It should be recognised that variations do exist for subsea cable EMF modelling studies; many of these variations are related to the complexity of EMF models and installation and cable build information available.

### 14B.2.1 Introduction

For static, seabed fixed offshore wind farms, IACs are buried between WTGs and the offshore substation a metre or so into the seabed. Burial of subsea cables provide some extent of protection against anchor drops and trawling activities and increases vertical distance to the cable, reducing the EMF intensity along the seabed. The trefoil arrangement of the power cores also provides some extent of field cancelling due to interactions of the three phase EMFs.

For floating offshore wind applications, dynamic cable sections are required to accommodate movement of the FTUs. Movement of the FTUs in the seawater environment means that dynamic IACs do not retain the same shape within the water column. This means that their EMF emissions are shifted within the seawater column according to extents of seawater column movement experienced by the cable. It should be considered that calculations presented assume worst-case. The EMF attenuates rapidly with distance from the cable and the cable build would provide some EMF mitigation through its metallic sheath and armour wire layer.

### 14B.2.2 Required inputs

The required inputs for EMF calculations are outlined in this Section. These inputs are assumed for a floating offshore windfarm, with dynamic cables connecting to static cable sections between FTUs.

Parameters of the OWF and IACs are needed to perform EMF intensity calculations. The required calculation inputs are as follows:

- Current – The current expected to flow under normal, steady state, operational conditions;
- Cable build – Dimensions over the power cores and of the complete cable are required as inputs into the model. Axial distances between power cores alters interactions of EMF emissions from the power cores; and
- Distances – The generated EMF will be highest at the cable surface. However, the EMF will be attenuated as it propagates through the water column. Distances away from the cable, at which the EMF intensity should be calculated are required.

From these input parameters the resultant EMF generated by each power core is calculated at specified distances along the seabed and heights above the cable (or for dynamic cable sections, distances into the seawater column). Each power core EMF is then decomposed into its horizontal and vertical, vector components. Vertical and horizontal vector components can be added. The resultant EMF at each calculation point is computed as the quadrature of the sum of horizontal and vertical components. Assumptions applied in the AC calculations are outlined in the following Section.

### 14B.2.3 Modelling Assumptions

Models for calculating EMF emissions from subsea cable generally differ according to the parameters included. There are more complex finite element models available for EMF modelling, however finite element modelling requires precise cable dimensions, exact material properties, convergent boundary conditions and the finite element mesh for the cable must be studied for interactions with the surrounding environment.

Typically, finite element EMF models are constructed to study EMF interactions between metallic layers of the cable and power cores, not always to approximate EMF intensities into surrounding environments. The parameters below are assumptions and approximations made to produce EMF intensity outputs for the IACs at the Project.

- Metallic sheath currents – For an AC cable, dependent upon earth bonding arrangements of the sheath, an induced current will flow in the metallic sheath, in opposite direction to that of the conductor current. The induced sheath current generates an EMF that counteracts the EMF generated by the conductor. Reduction of the emitted EMF by sheath current inclusion has not been allowed for;
- Armour wire layers – Subsea cables will have one or more armour wire layers. The armour wire layers will reduce EMF emissions by absorbing or reflecting some of the EMF. Armour wires are not in continuous, perfect contact and do not provide a continuous circumferential layer, as the armour is made up of individual wires. Modelling armour wire EMF interactions requires details of material grades, helical period and assumptions of current flows and its structure. It is expected that armour wire layers will, to some extent reduce the overall EMF intensity. Interactions and reduction of EMF emissions caused by armour wire layers have not been considered;
- Helical lay up – Power core strands, power cores and armour wires are all laid up helically, partly to assist handling and installation. The period of the power core twist will also provide some reduction of the EMF intensity, due to field cancellation. No allowance is made for the helical period of the power cores and armour wires;
- Distortions and interactions – No allowance is made for any magnetic anomalies, pipeline crossings and seabed infrastructure which may be nearby upon the seabed. This includes other cables significant extents of metalwork. No inclusion of skin effect or frequency-dependent losses has been included. All relevant materials involved with this EMF study have an assumed magnetic permeability of 1.0, this includes the seawater, air and seabed. It is a

common assumption applied with EMF calculations, to assume that the relative permeability of non-ferromagnetic materials is 1.0; and

- Attenuation – The EMF emission from a cable rapidly reduces with distance away from the cable. Reduction of the EMF emissions is based on the distance from the cable, as described by the Biot-Savart Law. No allowance for harmonic and transient currents has been made. A steady state continuous current is assumed.
- Current flow – The current flow in each cable design was provided by the Applicant (Table 1).

## 14B.3 Results

Calculations of EMF intensity have been performed by assuming a balanced, steady state sinusoidal AC for the 66 kV and 132 kV IACs. This Section is divided into sections for the static, buried IACs and the dynamic IAC sections.

To perform EMF calculations, two 66 kV cable build dimensions and two 132 kV cable build dimensions (as provided by the Applicant) are used. It should be noted that in the geographic area of the Project, the static, geomagnetic field intensity is approximately 50.5 μT. The geomagnetic has some variation, but the geomagnetic field does not combine with the EMF from an AC cable.

### 14B.3.1Static cable EMF emissions

**66 kV static cable**

Dynamic cables within the Array Area will transition to static sections, at touchdown points on the seabed. Results are presented in this Section for the 66 kV static three-core, cable build, carrying 760 A. A typical static array cable build for a 66 kV static array cable is shown in Figure 2.

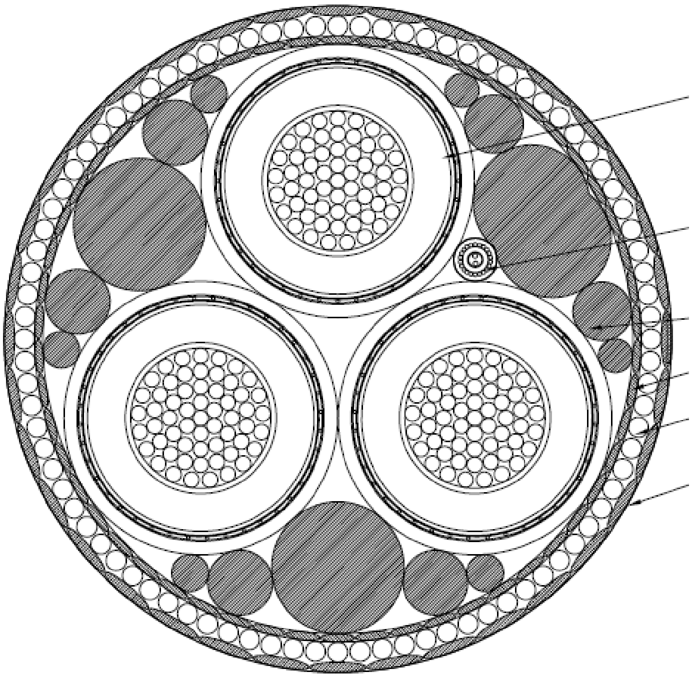

*Figure 2. Generic 66 kV static IAC build*

For the 66 kV, static cable the dimensions and parameters are given in Table 2 below.

*Table 2. 66 kV static IAC parameters and dimensions*

| PARAMETER | DIMENSION | |
|---|---|---|
| **Voltage (kV)** | 66 | |
| **Current (A)** | 760 | |
| **Cable outside diameter (mm)** | 180 | |
| **Power core diameter (mm)** | 80 | |
| **Depth of Lowering (m)** | 0.4 (minimum) | 1.5 (maximum) |

Based on the dimensions of the cable in Table 2, the EMF was calculated for increasing heights above the seabed, based on shallowest and deepest lowering depths of 0.4 m and 1.5 m respectively to the top of the cable. Figure 3 shows the peak EMF intensity, as a function of height above the seabed and horizontal distance along the seabed, for a burial depth of 0.4 m.

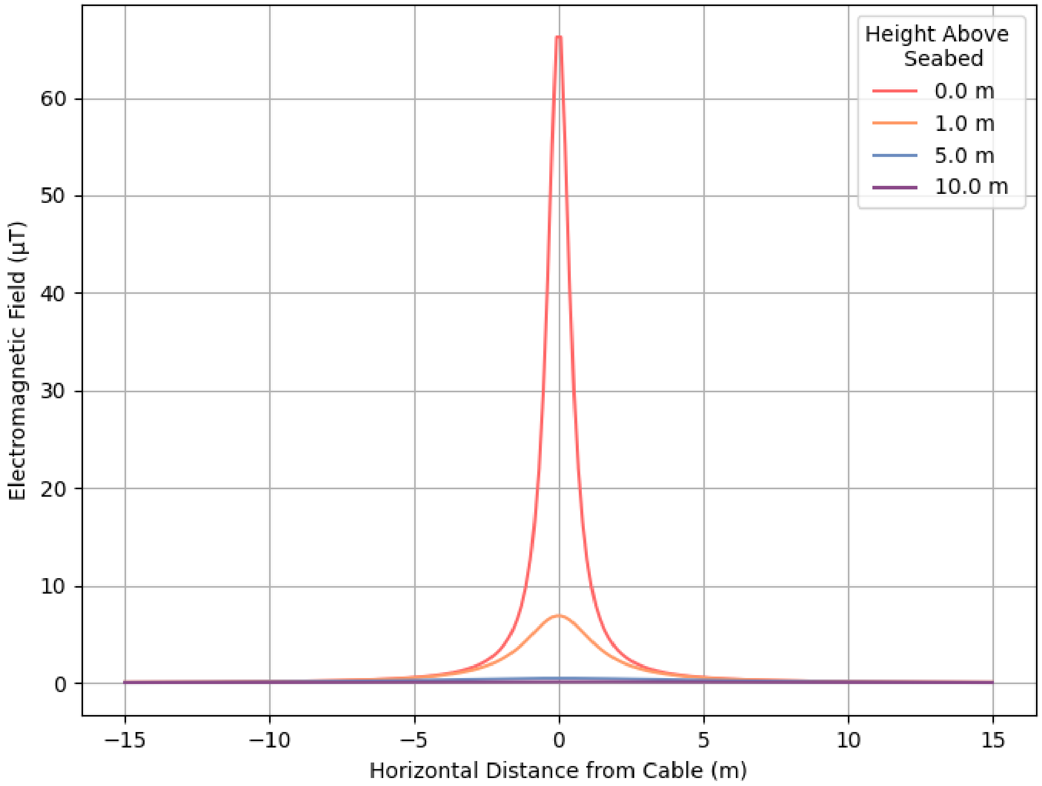

*Figure 3. EMF intensity as a function of height above the seabed and horizontal distance for the 66 kV static IAC at a burial depth of 0.4 m*

As shown in Figure 3 the peak EMF is approximately 15 μT above the background, static geomagnetic field, when calculated directly above the cable on the seabed. The EMF can be seen to attenuate rapidly when moving away from the cable.

Figure 4 shows the EMF intensity from the static cable, when the DoLis increased to 1.5 m to the top of the cable.

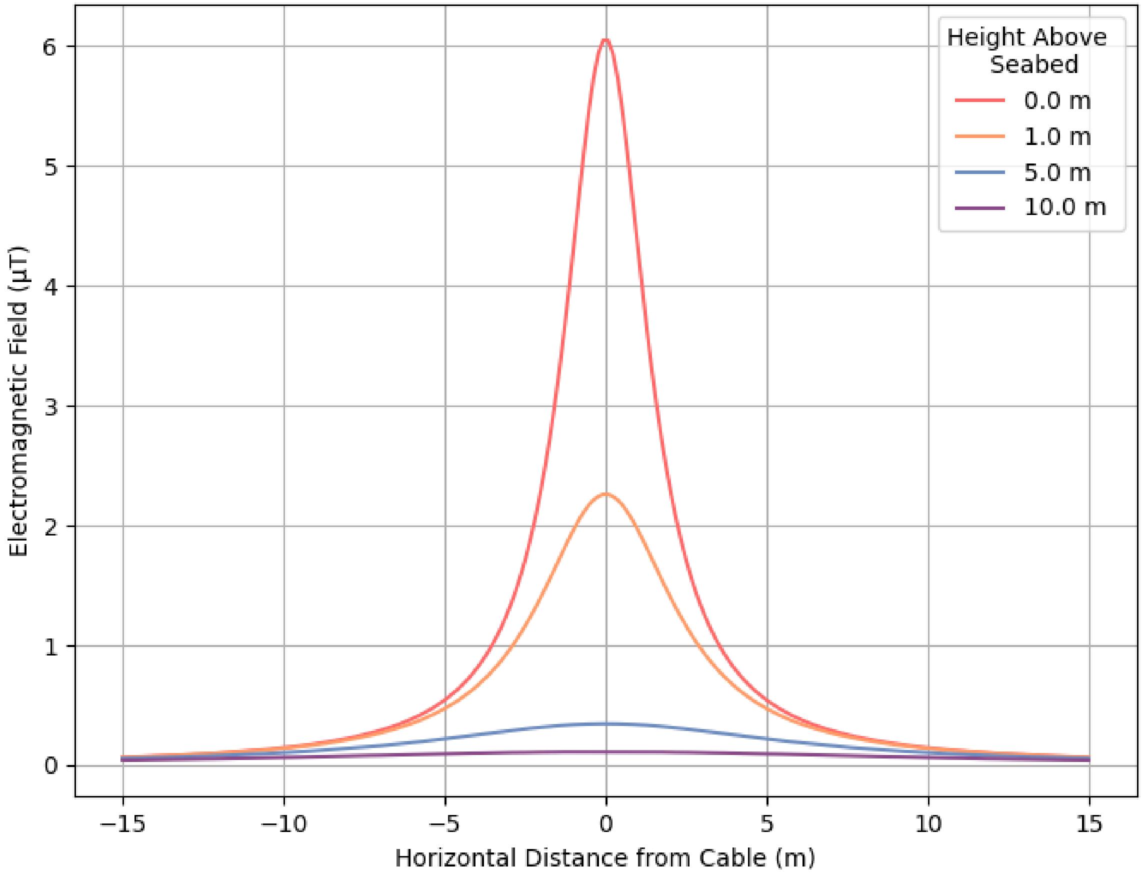

*Figure 4. EMF intensity as a function of height above seabed and distance along seabed for the static IAC at a burial depth of 1.5 m*

Intensities of EMFs from the buried IAC sections at burial depths of 0.4 m and 1.5 m are summarised for in Table 3 for increasing heights above the seabed. All materials of the cable, seabed and seawater are assumed to have a magnetic permeability of 1.0. The seawater is taken to be a homogenous infinite volume. At the system frequency of 50 Hz, conductivity of seawater would not significantly attenuate EMF emissions.

*Table 3. Maximum EMF intensities for the 66 kV static cable build*

| HEIGHT ABOVE SEABED (m) | MAXIMUM EMF (μT) | |
|---|---|---|
| | DoL 0.4 m | DoL 1.5 m |
| **0.0** | 66.23 | 6.05 |
| **1.0** | 6.90 | 2.26 |
| **5.0** | 0.50 | 0.35 |
| **10.0** | 0.14 | 0.11 |

From the EMF intensity plots shown in Figure 3 and Figure 4, it can be seen that the EMF intensity reduces rapidly when the horizontal position is beyond approximately a metre.

### 132 kV static cable

A 2023 report by the Carbon Trust suggested that offshore array voltages should be increased to 132 kV to accommodate larger WTGs and take advantage of cost savings. It is feasible that during the planning and consenting stages of the Project, that 132 kV dynamic static cables may become commercially available. Results are presented in this Section for the 132 kV three-core cable build, carrying 850 A. A 132 kV generic cable build is shown in Figure 5.

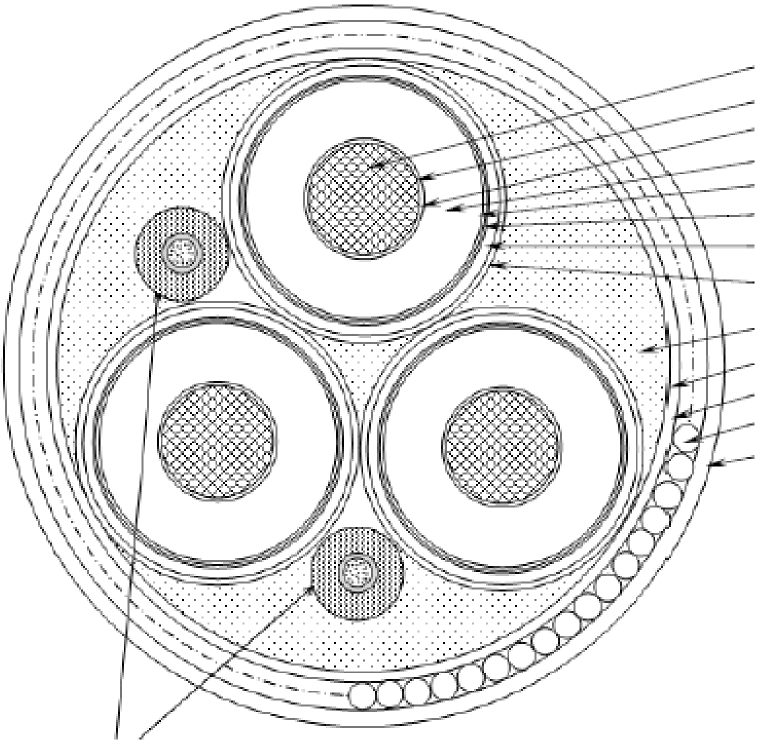

*Figure 5. Generic 132 kV static IAC build*

For the 132 kV, static cable the dimensions and parameters are given in Table 4 below.

*Table 4. 132 kV static IAC parameters and dimensions*

| PARAMETER | DIMENSION | |
|---|---|---|
| **Voltage (kV)** | 132 | |
| **Current (A)** | 850 | |
| **Cable outside diameter (mm)** | 205 | |
| **Power core diameter (mm)** | 80 | |
| **Depth of Lowering (m)** | 0.4 (minimum) | 1.5 (maximum) |

Based on assumed dimensions of the cable build, the EMF was calculated for increasing heights above the seabed, based on shallowest and deepest lowering depths of 0.4 m and 1.5 m, respectively to top of the cable. Figure 6 shows the peak EMF intensity, as a function of height above the seabed and horizontal distance along the seabed, for a burial depth of 0.4 m.

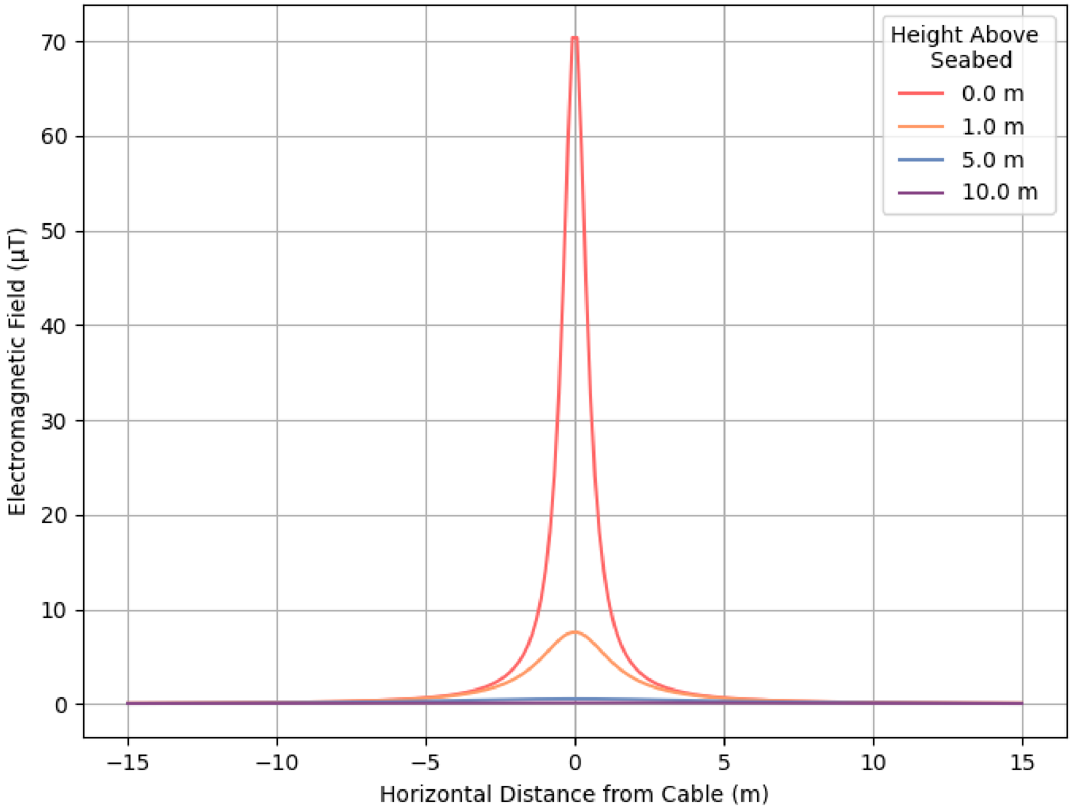

*Figure 6. EMF intensity as a function of height above the seabed and horizontal distance for the 132 kV static IAC at a burial depth of 0.4 m*

As shown in Figure 6 EMF can be seen to attenuate rapidly when moving away from the cable. Figure 7 shows the EMF intensity from the static cable when the burial depth is increased to 1.5 m to top of the cable.

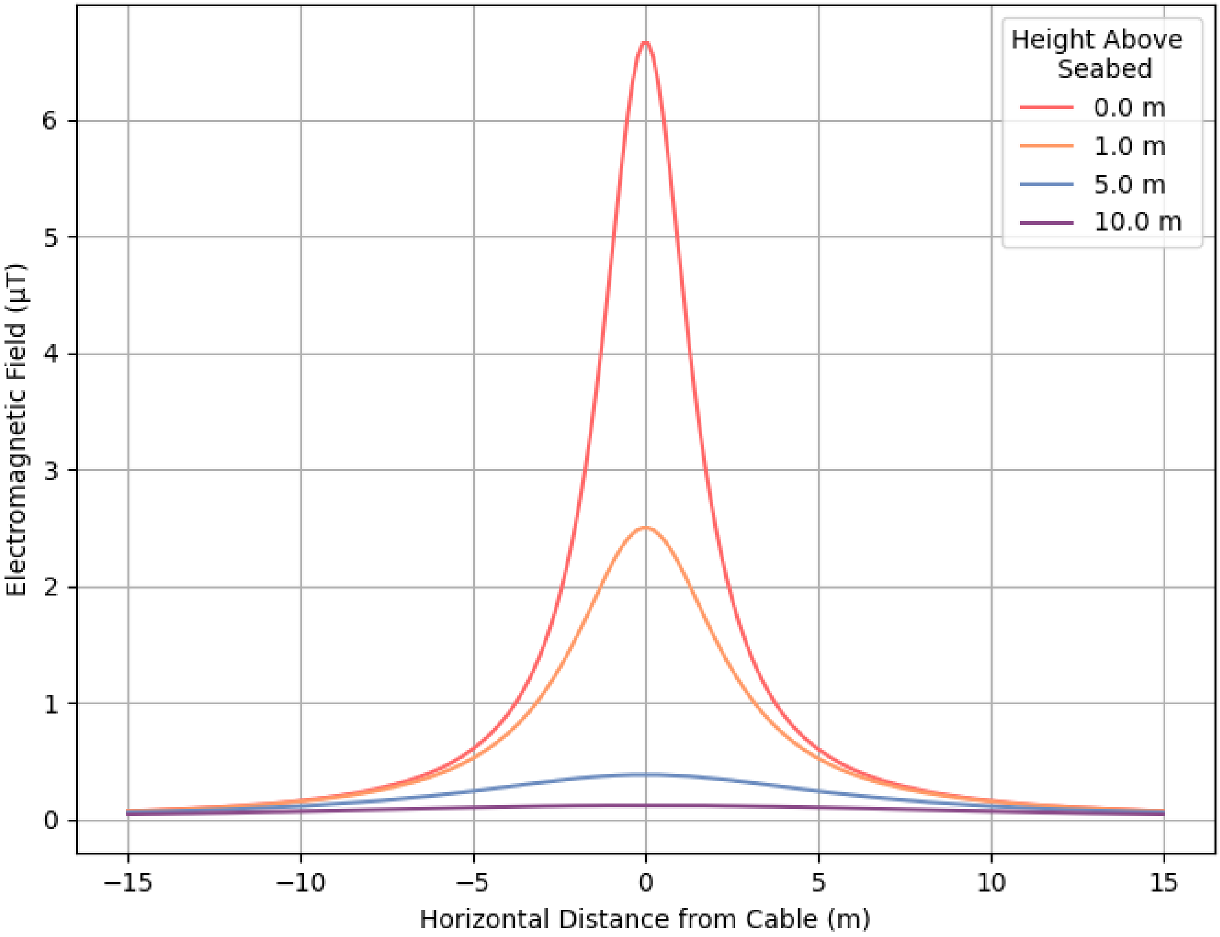

*Figure 7. EMF intensity as a function of height above seabed and distance along seabed for the 132 kV static IAC at a lowering depth of 1.5 m*

As shown in Figure 7 when the lowering depth is increased to 1.5 m, the EMF at the seabed level is decreased significantly, with a peak of approximately 6 µT calculated directly above the cable. Intensities of EMFs from the buried IAC sections at burial depths of 0.4 m and 1.5 m are summarised for in Table 5 for increasing heights above the seabed.

*Table 5. Maximum EMF intensities for 132 kV static cable build*

| HEIGHT ABOVE SEABED (m) | MAXIMUM EMF (µT) | |
|---|---|---|
| | Depth of Lowering 0.4 m | Depth of Lowering 1.5 m |
| **0.0** | 70.37 | 6.66 |
| **1.0** | 7.57 | 2.50 |
| **5.0** | 0.56 | 0.39 |
| **10.0** | 0.15 | 0.12 |

From the EMF intensity plots shown in Figure 6 and Figure 7, it can be seen that the EMF intensity reduces rapidly when the horizontal position is beyond approximately a metre. The following Section presents calculations of EMF intensities for the dynamic cable sections of the IACs.

## 14B.3.2 Dynamic cable EMF emissions

Calculations of EMF intensities for the 66 kV and 132 kV dynamic cable dimensions are presented in this Section. These IAC sections are assumed as being suspended within the seawater column.

**66 kV dynamic cable**

Configurations of the WTGs at the proposed Project is such that dynamic cables will transition to static sections, at touchdown points on the seabed. Results are presented in this Section for the 66 kV dynamic cable build, carrying 1120 A. Dynamic cables typically consist of a double armour wire layer, a corrugated metallic sheath (not lead) and a thick polyethylene over-sheath. Static and dynamic wet and dry designs of IAC are currently under review by CIGRE Working Group B1.92. A generic 66 kV dynamic cable build is shown in Figure 8.

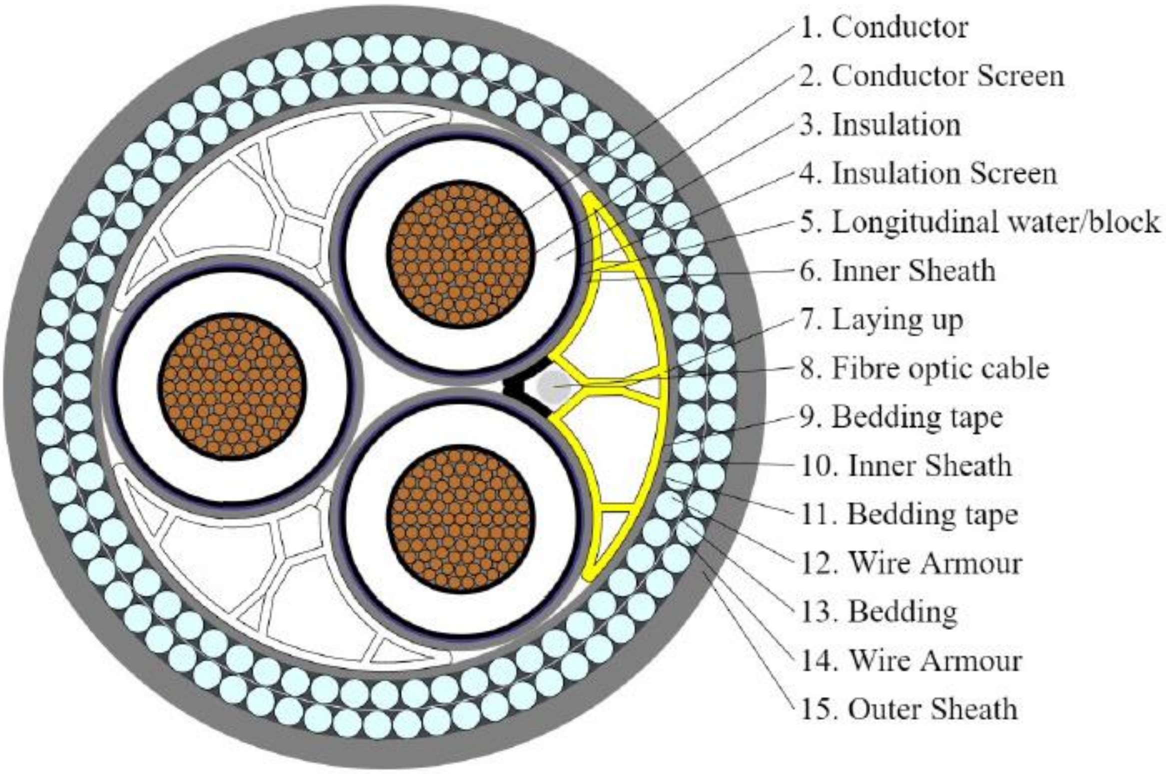

*Figure 8. Generic 66 kV dynamic IAC build*

For the assumed 66 kV dynamic cable, the dimensions and parameters are provided in Table 6.

*Table 6. 66 kV dynamic cable dimensions and parameters*

| PARAMETER | DIMENSION |
|---|---|
| **Voltage (kV)** | 66 |
| **Current (A)** | 1120 |
| **Cable outside diameter (mm)** | 195 |
| **Power core diameter (mm)** | 80 |

This Section provides numerical values of the magnetic field intensity in µT at different measurement radii around the 66 kV dynamic cable. Configurations of dynamic cables connecting between FTUs are understood to be configured as a 'lazy wave' shape, although the shape does not alter the EMF intensity calculation, only the geometry of the calculation position is altered, i.e. the EMF from dynamic cable sections are suspended within the water column.

The EMF intensities from dynamic, water-column located cables would propagate some distance through the seawater and shift according to movements of the cable and floating structure.

Table 7 presents maximum EMF intensities at the dynamic cable surface and extending distances away from the cable into the seawater column.

*Table 7. Maximum EMF intensities for the 66 kV dynamic cable*

| DISTANCE AWAY FROM CABLE SURFACE (m) | MAXIMUM EMF (µT) |
|---|---|
| **Cable surface** | 1861.96 |
| **1.0** | 18.90 |
| **5.0** | 0.85 |
| **10.0** | 0.22 |

At the cable surface the EMF intensity is calculated as 1861.96 µT, however, the intensity rapidly diminishes through the water column and would shift according to extents of movement permitted by sub-structure mooring lines, wind and tidal motions. Typically, the cable would be tethered to the seabed, limiting movement. The tether would likely not influence attenuation of the EMF generated by the current flow.

### 132 kV dynamic cable

Results are presented in this Section for the 132 kV dynamic cable build carrying 1255 A. Dynamic cables typically consist of a double armour wire layer, a corrugated metallic sheath (not lead) and a thick polyethylene over-sheath. A generic 132 kV dynamic cable build is shown in Figure 9.

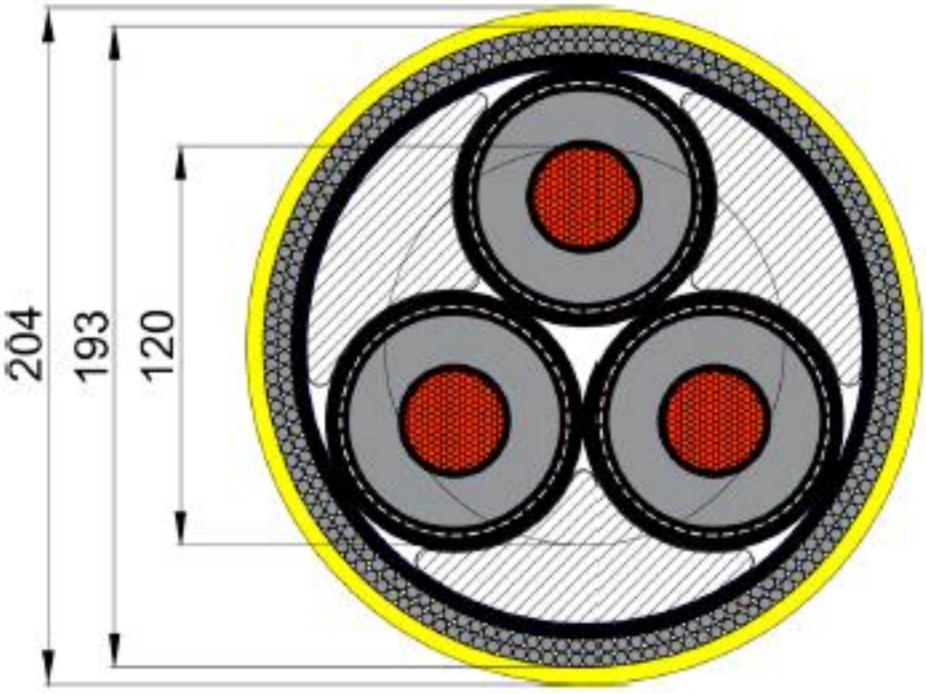

*Figure 9. Generic 132 kV dynamic IAC build*

For the assumed 132 kV dynamic cable, dimensions and parameters are given in Table 8 below.

*Table 8. 132 kV dynamic parameters and dimensions*

| PARAMETER | DIMENSION |
|---|---|
| **Voltage (kV)** | 132 |
| **Current (A)** | 1255 |
| **Cable outside diameter (mm)** | 220 |
| **Power core diameter (mm)** | 80 |

This Section provides numerical values of the magnetic field intensity in µT at different measurement radii around the 132 kV dynamic cable. Table 9 presents maximum EMF intensities at the dynamic cable surface and extending distances away from the cable into the seawater column.

*Table 9. Maximum EMF intensities for the 132 kV dynamic cable*

| DISTANCE AWAY FROM CABLE SURFACE (m) | MAXIMUM EMF (μT) |
|---|---|
| **Cable surface** | 1780.30 |
| **1.0** | 20.69 |
| **5.0** | 0.95 |
| **10.0** | 0.24 |

At the cable surface the EMF intensity is calculated as 1780.3 μT, however, the intensity rapidly diminishes through the water column and would shift according to extents of movement permitted by sub-structure mooring lines, wind and tidal motions. The following Section provides some points for discussion, based on the calculated EMF results.

## 14B.4 Discussion

This report has provided worst-case EMF calculations for both static (buried) and dynamic sections of IAC for the Project. Cable build dimensions and current flows for the 66 kV and 132 kV parameters have been provided by the Applicant.

Static IAC sections will be buried in the seabed to a proposed minimum DoL of 0.4 m, providing some mitigation of EMF intensity through increased burial depth.

Dynamic cable sections will be suspended within the seawater column, down to the seabed where they would transition to a static cable section. Although, it could be the case that the cable is the same design for both buried and dynamic sections. The calculated EMF at the cable surface is exposed throughout the seawater column along the cable surface, with mitigation provided by the extent of EMF attenuation caused by the armour wire layers (typically two for a dynamic cable), metallic sheath and power core helical periods. It should also be considered that dynamic cables move within the water column, effectively shifting the EMF.

Calculated EMF emissions for static and dynamic IACs presented in this report should be taken as worst case. The modelling approach does not include any mitigation provided by induced sheath currents, power core helical periods and armour wire interactions. To combine these parameters and consider their interactions, requires finite element techniques to allow the study of the combination of induced currents and helical periods. In addition, current flow was assumed to be constant from all FTUs.

## 14B.5 Conclusion

Calculation of worst-case EMF intensities have been presented for the 66 kV and 132 kV buried and dynamic IACs for the Project.

Dynamic cable sections will be suspended within the seawater column and move with tidal motion and wind. The calculated EMF intensities for both static and dynamic cables are likely to be higher than those in practice, as the mitigating effects of armour wires, power core helical periods, and induced sheath currents, are not included.

## 14B.6 References

CIGRE (2007). Technical Brochure 320, "*Characteristics of ELF magnetic fields*," Task Force C4.205

CIGRE (2018). Technical Brochure 722, "*Recommendations for additional testing for submarine cables from 6 kV to 60 kV*" Working Group B1.55