



Morven Hawthorn Pit Grid Connection Project

Preliminary Environmental Information Report

Volume 2, Annex 4.2: Morven HVDC EMF Study

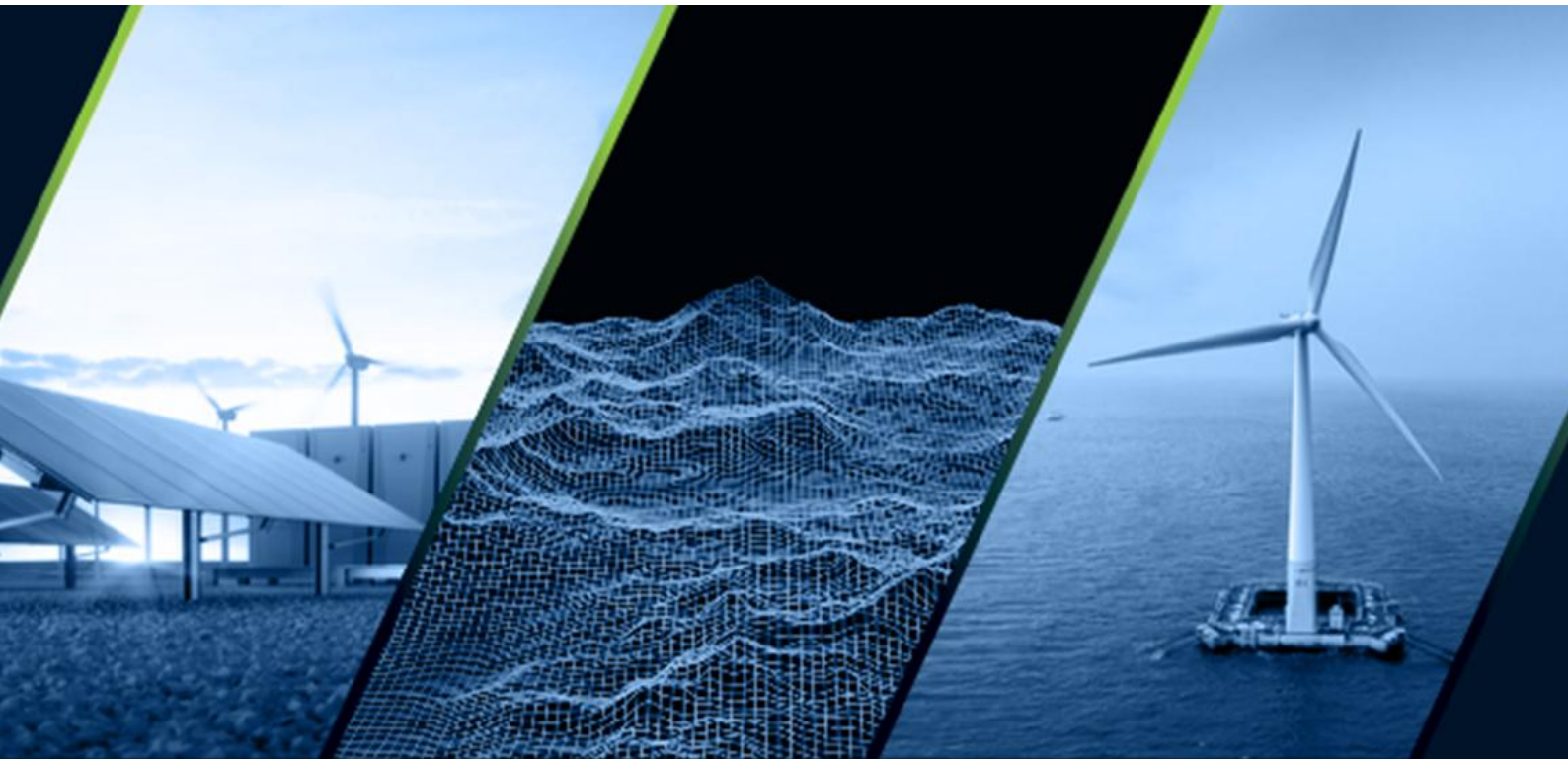
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The **Renewable Energy** Consultants.



Morven Offshore Windfarm HVDC EMF Study

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Acronyms

Acronym	Full Term
B-Field	Magnetic Field
BP	British Petroleum
CIGRE	Conseil International des Grands Réseaux Electriques
ECC	Export Cable Corridor
E-Field	Electric Field
EIA	Environmental Impact Assessment
EMF	Electromagnetic Field
EnBW	Energie Baden-Württemberg AG
FO	Fibre Optic
GW	Gigawatt
HVAC	High Voltage Alternating Current
HVDC	High Voltage Direct Current
IAC	Inter Array Cables
NPS	National Policy Statement
PDE	Project Design Envelope
RMS	Root Mean Square
SE	Southeast
TB	Technical Brochure
WTG(s)	Wind Turbine Generator(s)
XLPE	Cross-Linked Polyethylene

1 Introduction

1.1 General

As part of the development efforts for Morven offshore wind farm, JERA Nex bp (JNbp) and Energie Baden-Württemberg AG (EnBW) (hereafter referred to as “the Client”) are working on the generation of the Environmental Impact Assessment (EIA) and Project Design Envelope (PDE). The Electromagnetic Field (EMF) emitted to the environment by the cables will feed into the PDE and be assessed as part of the EIA. The EMF levels observed in the surrounding environment must be within specific levels dictated by the governing authority to ensure safety to the environment and life.

The requested services involve a detailed assessment of EMF effects associated with the installation and operation of High Voltage Direct Current (HVDC) submarine cables. The objective is to determine optimal cable configurations and separations that minimise navigational impacts and meet regulatory thresholds, thereby supporting safe marine operations and informing post-installation survey requirements.

Multiple scenarios are to be assessed to ensure any project design deviations that may arise further down line are captured by this assessment. The varying parameters include burial depth to top of the cable, cable separation, and cable operational voltage.

When assessing the HVDC transmission cables, results should showcase the EMF when a portion of the HVDC bundled cables are separated for a short portion of the route (for micro-routing purposes or in a repair scenario), as this represents a worse case compared to the scenario of the cable pair bundled together.

This report will focus on the influence of the EMF generated by cables on the surrounding environment, including impacts on fish and shellfish, benthic ecology and marine mammals.

1.2 Scope of Work

OWC has undertaken a comprehensive EMF assessment for subsea HVDC export cable systems. The study involved modelling magnetic flux density (B-field) under a range of operational and installation scenarios, including varying burial depths (1–3 m) and circuit configurations (unbundled for micro-routing).

Magnetic fields have been calculated using established electromagnetic theory, applying Maxwell’s equations and Ampère’s circuital law. The modelling has been performed using validated internal tools benchmarked against industry standards such as CIGRE TB 104.

To ensure conservative outputs, the assessment excluded shielding effects from cable armour and induced sheath/screen circulating currents. Electric fields (E-Field) were not modelled explicitly as they are expected to be contained by the metallic sheaths which are earthed at both ends. Current magnitudes were supplied by the Client.

The results quantify the magnetic field at the seabed level and above, supporting environmental assessments and informing mitigation strategies such as cable spacing and burial depth. The methods were applied to the HVDC transmission cables.

The calculation of localised electric fields from movement of the sea through the magnetic field has been calculated by methods outlined in similar reports by National Grid [1].

The HVDC transmission characteristics have been assessed for 1, 2, and 3 m burial depths and bundled and unbundled cables (significant separation between them).

1.3 Project Background

The Morven Project is a proposed fixed-bottom offshore wind farm located approximately 60 km southeast off the coast of Aberdeen in the North Sea. It is being developed by Morven Offshore Wind Limited, a joint venture between JNbp and EnBW, as part of the ScotWind leasing round. The project is expected to generate 2.9 GW of electricity from turbines installed in water depths of 65–75 metres and has a proposed commercial operation date of 2029.



Figure 1-1 Morven Windfarm Overview [2]

The project will utilise HVDC subsea cables to realise the transfer of power from the wind farm to the onshore grid connection. The Inter Array Cables (IAC) use High Voltage Alternating Current (HVAC) to connect the Wind Turbine Generators (WTG) to the offshore substation and then the offshore converter station. The IAC may be rated at 132 kV or 66 kV and the symmetric-monopole HVDC cables will be rated for ± 320 kV transmission. There will be two fully bundled HVDC cables rated for 1.5 GW of power transfer.

The transmission cable landfall options are in the vicinity of Seaham where the power is then transmitted to the onshore substation, and final grid connection at Hawthorn Pit substation.

2 Method

2.1 General

Electricity has two principal components: an electrical component and a magnetic component. Electric fields are determined by voltage, and the electric field around a transmission line will be essentially constant at any given location. Magnetic fields are determined by current and will change in strength over time in line with the magnitude of the current.

2.2 Magnetic fields

Magnetic fields are one part of electromagnetism. The magnetic field is a time-varying field that occurs in the presence of an electric field. The magnetic field presents a force that results from a moving charge. Electrical current in a cable is a flow of moving charges and thus generates magnetic fields. The magnetic field is proportional to the current; the higher the current, the higher the magnetic field.

The magnetic flux density is a vector field and thus consists of an amplitude component and direction component. The vector field is represented by $\vec{B}$ and is expressed in terms of Teslas (T) or micro-Teslas (μT , 10^{-6} Teslas). OWC has estimated and discussed the magnetic flux density in terms of its amplitude, B . Its relation to the vector field is:

$$B = |\vec{B}|.$$

The magnetic field intensity, $\vec{H}$, is also used to describe magnetic fields. The magnetic field intensity is a vector field that describes the magnetizing force (strength of the magnetic field). It is measured in A/m. The magnetic field intensity is considered a derived quantity of $\vec{B}$ and does not add extra value to this study. For most materials it can be simplified to the following equation (μ is the permeability of the material).

$$\vec{H} = \frac{\vec{B}}{\mu}$$

In this report, the term "magnetic field" is used as the convention for magnetic flux density, the B-field. While technically distinct in electromagnetic theory, in engineering practice, particularly in cable design and short-circuit analysis, the term "magnetic field" is commonly used to refer to the B-field, the vector quantity that represents the density and direction of magnetic flux.

It is important to note that magnetic field strength, denoted as the H-field, is a separate quantity related to the B-field through the material's permeability (i.e., $B = \mu H$). However, unless specifically stated, references to the "magnetic field" in this document pertain to the B-field.

The magnetic field resulting from a three-phase system can be determined using Maxwell's equations, Ampère's circuital law (which relates the magnetic field to the electric current passing through a loop), and the superposition principle. OWC has used this principle to calculate the magnetic field a three-phase system would produce without a conductive or ferromagnetic shield. Magnetic fields can only be shielded by magnetic materials, and pass-through non-magnetic materials.

Estimated magnetic fields were calculated for the cables. Magnetic fields above the buried cables were calculated as the value of the field along a transect perpendicular to the centreline of the cables at the representative target burial depths.

Sheath induced currents are not included as these are not applicable to HVDC cables. The modelling was only conducted with respect to the main conductors. The magnetic fields calculated in this analysis represent the worst case, given that several cable design features that reduce magnetic field levels outside the cables were not included.

However, this analysis excludes the effects of magnetic armour, which reflects the situation of a break in the armour or use of nonmagnetic armour. This is considered a worst-case scenario as the magnetic permeability of cable armouring can attenuate the magnetic field outside of the cables.

The main variable related to magnetic fields is relative permeability (μ_r), a dimensionless gauge of the ability of a material to support a magnetic field compared to the ability of free space. Materials with a high permeability value will act to support a magnetic field. The relative permeability values used for this study are summarised in Table 2-1.

Table 2-1: Magnetic properties of the cable materials and the surrounding medium

Item	Relative Permeability μ_r
Conductor (Copper)	1.0
Conductor (Aluminium)	1.0
Insulator (XLPE)	1.0
Sheath (Lead)	1.0
Armour (Steel Wire) – subsea cable only	100.0 – Excluded, Not Applied
Seawater	1.0
Seabed	1.0
Soil	1.0
Air	1.0

It is important to consider that any magnetic fields generated by the cables will be superimposed on the earth's magnetic field and any other existing magnetic fields. The earth's magnetic field has a flux of about 60 μT at the poles where the field is vertical and 30 μT at the equator where it is horizontal.

Magnetic fields have been calculated using OWC's internal tools. These tools have been validated against test cases presented in Conseil International des Grands Réseaux Electriques (CIGRE) 104 [3].

2.3 Electric fields

EMF assessments typically include modelling analyses of both magnetic and electric fields, but no electric field levels produced by the cables are included in this technical note because there will be only negligible electric fields outside of the Project cables. This is the case because the electric fields of each of the cables are expected to be contained by metallic sheaths which are earthed at both ends. This metallic layer will shield the electric fields produced by the voltage on the phase conductors.

Although electric fields generated by cables are negligible, an electric field may still present in the water due to a different principle. When saltwater passes through an electromagnetic field, an electric field will arise due to Faraday's law of electromagnetic induction and the Lorentz force.

Faraday's Law states that a changing magnetic field within a closed loop induces an EMF in the conductor. In the case of salt water (which is a conductive fluid) if it moves through a magnetic field the motion itself causes a change in magnetic flux experienced by the ions in the fluid, inducing a voltage. In salt water, the ions (Na^+ , Cl^- , etc.) are moving with the fluid. When the fluid flows through a magnetic field, the ions experience a Lorentz force perpendicular to both the flow direction and the magnetic field. This leads to a charge separation, which in turn creates an electric field.

To assess the electric fields induced by currents flowing through a magnetic field, the following equation was applied, the electric field is measured in V/m:

$$\text{Electric Field } (\vec{E}) = \text{Velocity } (v) \times \text{Magnetic Field } (\vec{B})$$

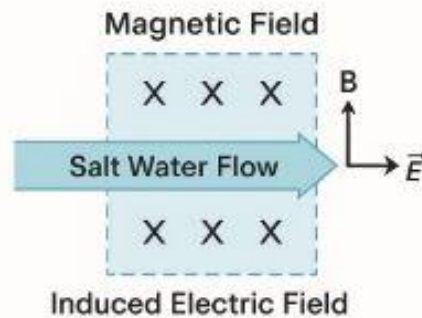


Figure 2-1: Depiction of Electric Field Generation

2.4 Project Data and Input Assumptions

The current magnitude for the project cables was supplied to OWC by the Client, since only one value was provided, OWC assumed that the magnitude is the same for each cable since this value is based on a 1.5 GW capacity with a ± 320 kV operational voltage. The table below gives the necessary physical dimensions of the cables. With this OWC can calculate the spacing between cables when bundled together and the depth to the centre of the cables from the seabed.

Table 2-2: Project HVDC Cable Data

Cable Size	2,000 mm ²	2,500 mm ²	3,000 mm ²
Outer Diameter of Cable (mm)	135	150	165
Bundle Diameter (2 cables) (mm)	270	300	330
Current Magnitude (A)	2,343.75	2,343.75	2,343.75

As seen in Figure 2-2 below the vertical diameter of the bundle is slightly larger than the outer diameter of a single cable. No information is available on the dimensions of the fibre optic (FO) cable hence for modelling purposes it was disregarded which presents a worst case, and the outer diameter of a single cable was used as the vertical diameter of the bundle.

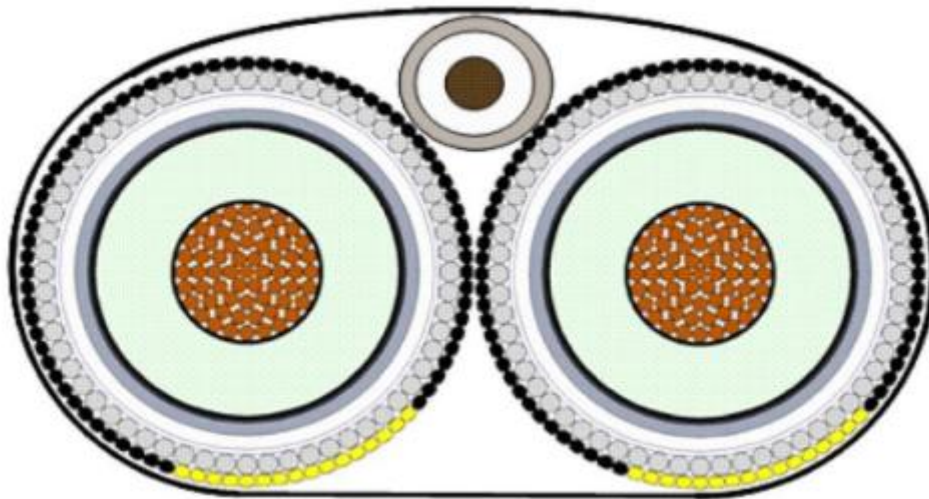


Figure 2-2: Depiction of a Symmetrical Monopole, Bundled Configuration with FO Cable

The impact to the magnetic and electric fields when increasing burial depths from 0.5 to 3 m has been assessed during this study, this refers to the depth of cover to the top of cable. The dimensions of the cables and bundles will then be used to understand the depth to the centre of the cables.

On top of varying burial depths and cable sizes (and thus installation dimensions), three distinct scenarios have been assessed. These are listed below in Table 2-3.

Table 2-3: Definition of Scenarios Assessed

Scenarios	Description
Scenario 1 Fully Bundled	Two cables bundled together with no spacing as depicted in Figure 2-2.
Scenario 2 Separated by 25 m	The two cables are trenched separately, and have a lateral separation of 25 m.
Scenario 3 Fully Separated	The cables are laterally separated enough that the influence of the second cable can be neglected, and hence the results showcase the values associated for a single operational cable.

The cable route is broken down into distinct Export Cable Corridors (ECC) numbered ECC 1 to ECC 6. A diagram illustrating the export cable corridors is shown in Figure 2-3.

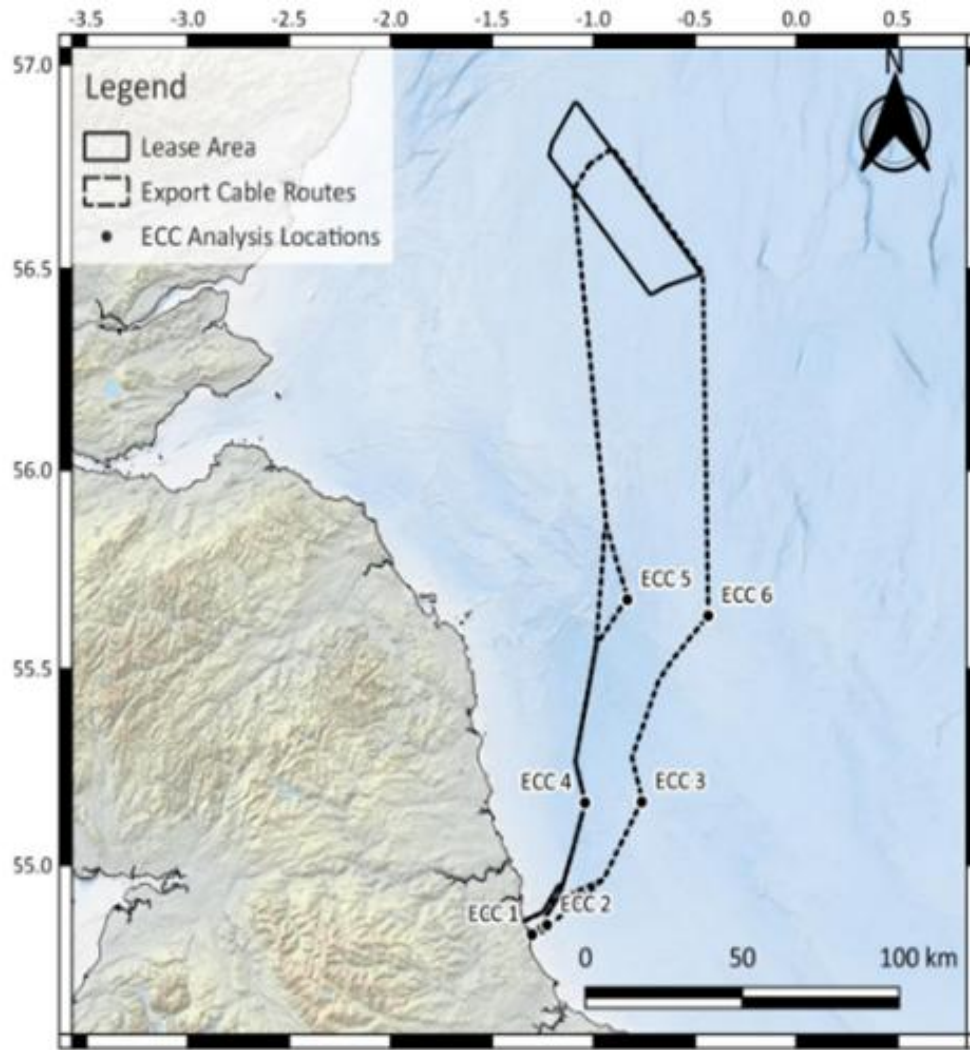


Figure 2-3: Export Cable Corridors [4] [5] [6]

Table 2-4 displays a portion of the current velocities for the given locations, these were provided by the JNbp. The maximum velocities observed at each site were applied so that the worst-case scenarios are accounted for.

Table 2-4: Maximum Current Velocities at Specified Location

Location	Seabed Velocities (m/s)	1 m Above Seabed Velocities (m/s)
ECC 4	0.90	0.47
ECC 5	1.00	0.53
SE	1.17	0.63

3 Results

3.1 Magnetic Flux Density

3.1.1 General

Presented below are the outcomes of the EMF assessment conducted for HVDC submarine cables under varying burial depths and cable configurations. The study evaluated magnetic fields at burial depths ranging from 0.5 to 3 metres, across three distinct scenarios designed to reflect realistic and conservative installation conditions:

- Scenario 1 considered a fully bundled configuration, where two HVDC cables are placed adjacently within the same trench.
- Scenario 2 modelled the two HVDC cables separated by a horizontal distance of 25 metres. This configuration simulates a split trench or spatially separated cable routing.
- Scenario 3 represented a worst-case condition, where only a single HVDC cable was considered. This scenario assumes the absence of any mitigating influence from a second cable and therefore provides the highest expected magnetic flux values.

The results presented herein quantify the magnetic flux density at the seabed surface and at varying depths above the cable, offering insight into the influence of burial depth and cable configuration on EMF exposure levels in the marine environment.

3.1.2 Fully Bundled

Table 3-1, Table 3-2 and Table 3-3 show the magnetic flux density at burial depths of 0.5 to 3 m for different cable sizes.

Table 3-1: Magnetic Flux Density Magnitude for 2,000 mm² cable size

Burial Depth (m)	Magnetic Flux Density at Seabed (μT)	Magnetic Flux Density 1m above Seabed (μT)
0.5	192.42	25.68
1.0	55.20	14.78
2.0	14.78	6.72
3.0	6.72	3.82

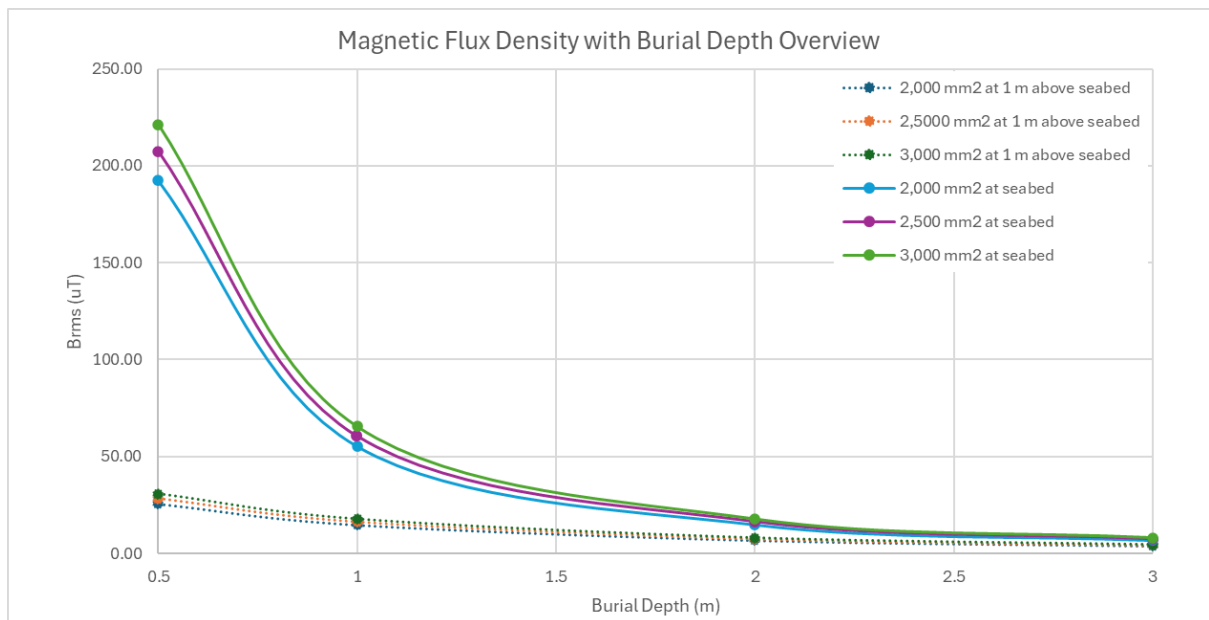
Table 3-2: Magnetic Flux Density Magnitude for 2,500 mm² cable size

Burial Depth (m)	Magnetic Flux Density at Seabed (μT)	Magnetic Flux Density 1m above Seabed (μT)
0.5	207.39	28.25
1.0	60.40	16.30
2.0	16.30	7.43
3.0	7.43	4.23

Table 3-3: Magnetic Flux Density Magnitude for 3,000 mm² cable size

Burial Depth (m)	Magnetic Flux Density at Seabed (μ T)	Magnetic Flux Density 1m above Seabed (μ T)
0.5	221.32	30.76
1.0	65.43	17.79
2.0	17.79	8.13
3.0	8.13	4.64

Figure 3-1 conveys the results for the magnetic flux density observed at the seabed and 1 m above the seabed for each cable size.


Figure 3-1: Overview of Fully Bundled Magnetic Field Results

3.1.3 Separated by 25 m

Table 3-4, Table 3-5 and Table 3-6 below show the magnetic flux density at varying burial depths for different cable sizes with the two cables separated laterally by 25 m.

Table 3-4: Magnetic Flux Density Magnitude for 2,000 mm² cable size 25 m separation

Burial Depth (m)	Magnetic Flux Density at Seabed (μT)	Magnetic Flux Density 1m above Seabed (μT)
0.5	414.06	149.89
1.0	220.12	113.60
2.0	113.60	76.49
3.0	76.49	57.57

Table 3-5: Magnetic Flux Density Magnitude for 2,500 mm² cable size 25 m separation

Burial Depth (m)	Magnetic Flux Density at Seabed (μT)	Magnetic Flux Density 1m above Seabed (μT)
0.5	408.69	149.17
1.0	218.59	113.19
2.0	113.19	76.30
3.0	76.30	57.46

Table 3-6: Magnetic Flux Density Magnitude for 3,000 mm² cable size 25 m separation

Burial Depth (m)	Magnetic Flux Density at Seabed (μT)	Magnetic Flux Density 1m above Seabed (μT)
0.5	403.40	148.46
1.0	217.07	112.79
2.0	112.79	76.11
3.0	76.11	57.35

Figure 3-2 conveys the results for the magnetic flux density observed at the seabed and 1 m above the seabed for each cable size when the two cables are separated by 25 m.

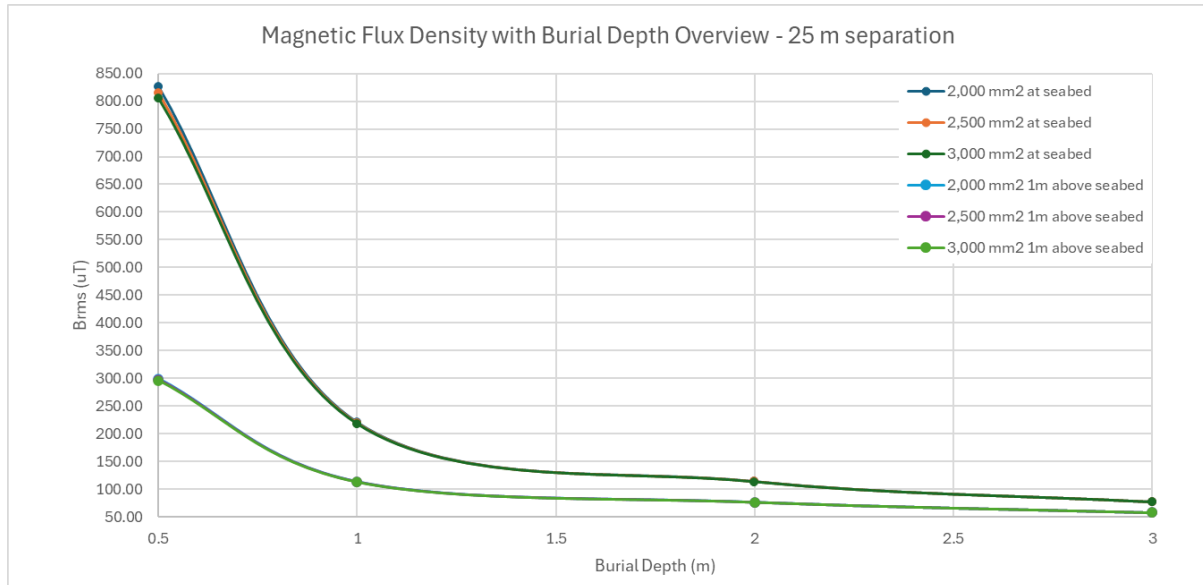


Figure 3-2: Overview of Magnetic Field Results for 25 m Separated Cables

3.1.4 Fully Separated

Table 3-7, Table 3-8 and Table 3-9 below show the magnetic field at varying burial depths for fully separated cables at different cable sizes.

Table 3-7: Magnetic Flux Density Magnitude for 2,000 mm² cable size, single cable

Burial Depth (m)	Magnetic Flux Density at Seabed (μT)	Magnetic Flux Density 1m above Seabed (μT)
0.5	825.99	299.04
1.0	439.10	226.72
2.0	226.72	152.81
3.0	152.81	115.24

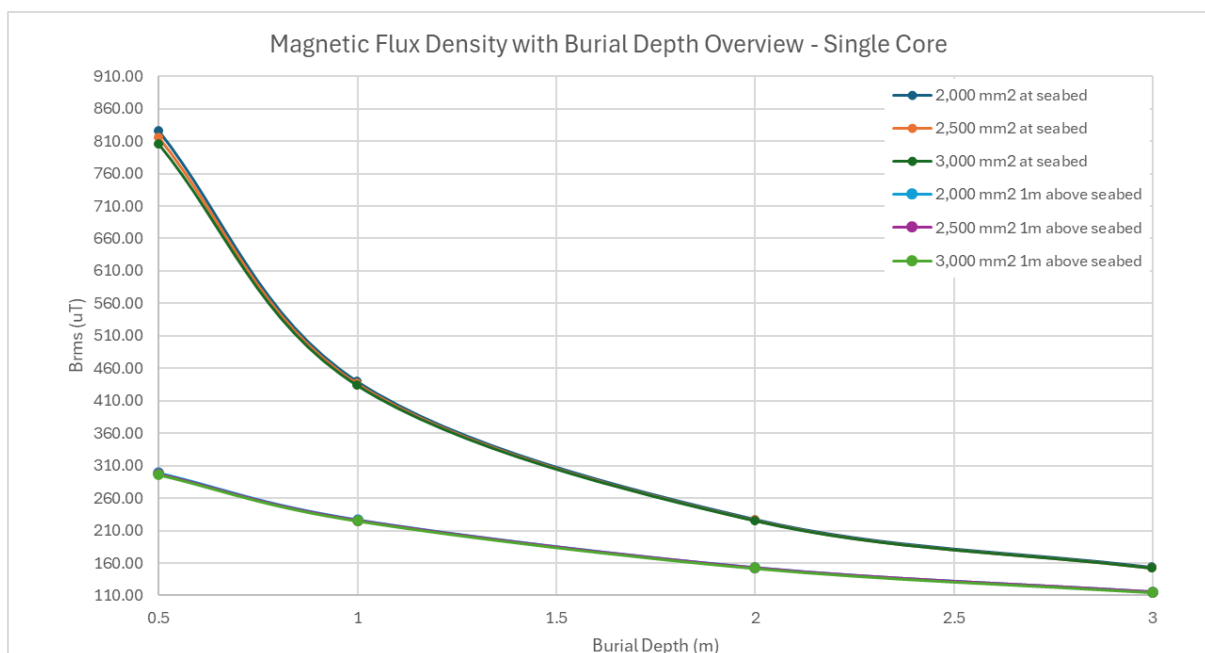
Table 3-8: Magnetic Flux Density Magnitude for 2,500 mm² cable size, single cable

Burial Depth (m)	Magnetic Flux Density at Seabed (μT)	Magnetic Flux Density 1m above Seabed (μT)
0.5	815.22	297.62
1.0	436.05	225.90
2.0	225.90	152.44
3.0	152.44	115.03

Table 3-9: Magnetic Flux Density Magnitude for 3,000 mm² cable size, single cable

Burial Depth (m)	Magnetic Flux Density at Seabed (μ T)	Magnetic Flux Density 1m above Seabed (μ T)
0.5	804.72	296.21
1.0	433.02	225.09
2.0	225.09	152.07
3.0	152.07	114.82

Figure 3-3 conveys the results for the magnetic flux density observed at the seabed and 1 m above the seabed for each cable size for a single cable.

**Figure 3-3: Overview of Magnetic Field Results for a Single Cable**

3.1.5 Minimum Separation Distance

The minimum distance required to ensure that one cable's EMF does not interact with the second cable's EMF has been calculated for each cable size, for a range of burial depths from 0.5 m to 3 m. The values obtained were referenced at the seabed only. The results are given in Table 3-10.

Table 3-10: Minimum Separation Required to Negate EMF Cancellation Effects

Burial Depth (m)	2,000 mm ²	2,500 mm ²	3,000 mm ²
0.5	30 m	40 m	50 m
1.0	35 m	45 m	55 m
2.0	50 m	65 m	90 m
3.0	65 m	70 m	120 m

3.2 Electric Field

3.2.1 General

This section presents the results of the electric field assessment associated with HVDC submarine cable installations under varying burial depths and cable configurations. While HVDC cables themselves do not emit electric fields directly due to their grounded metallic sheaths, electric fields can be induced in the surrounding marine environment when conductive saltwater flows through the magnetic fields generated by the cables. These induced electric fields are governed by the principles of electromagnetic induction and are relevant for assessing potential impacts on electrically sensitive marine species.

The study evaluated induced electric field magnitudes at burial depths ranging from 0.5 to 3 metres across three distinct scenarios:

- Scenario 1 presents two HVDC cables in a fully bundled configuration.
- Scenario 2 presents HVDC cables when separated by 25 metres, simulating a split trench or spatially separated routing.
- Scenario 3 presents a single HVDC cable to represent a worst-case scenario in which the second cable is absent or ineffective.

The results quantify the induced electric field strengths at the seabed surface and at varying elevations above the cable, providing insight into how burial depth and cable configuration influence the spatial extent and intensity of electric field exposure in the marine environment.

A range of current velocities were provided for this assessment, these values were supplied for the route sections Export Cable Corridor (ECC) 4 and 5, and the Southeast (SE) location of the project site. The results provided in the headings below represent the maximum electric field present, for this the maximum current velocity observed for each section of route was applied to the relevant EMF magnitude previously calculated. This way the worst-case scenarios are conveyed.

3.2.2 Fully Bundled

Table 3-11 to Table 3-13 below show the E-Field density for all cable sizes when fully bundled, and for burial depths 0.5 to 3 metres. Results are given when measured at seabed and 1 m above seabed to give a holistic review of the effects on marine ecology and marine life.

Table 3-11: Fully Bundled Maximum Observed E-Field for ECC 4 Route Section

Burial Depth (m)	Max Induced Electric Field at Seabed ($\mu\text{V/m}$)			Max Induced Electric Field 1m above Seabed ($\mu\text{V/m}$)		
	2,000 mm ²	2,500 mm ²	3,000 mm ²	2,000 mm ²	2,500 mm ²	3,000 mm ²
0.5	173.18	186.65	199.19	12.07	13.28	14.46
1.0	49.68	54.36	58.89	6.95	7.66	8.36
2.0	13.30	14.67	16.01	3.16	3.49	3.82
3.0	6.05	6.69	7.32	1.80	1.99	2.18

Table 3-12: Fully Bundled Maximum Observed E-Field for ECC 5 Route Section

Burial Depth (m)	Max Induced Electric Field at Seabed ($\mu\text{V/m}$)			Max Induced Electric Field 1m above Seabed ($\mu\text{V/m}$)		
	2,000 mm ²	2,500 mm ²	3,000 mm ²	2,000 mm ²	2,500 mm ²	3,000 mm ²
0.5	192.42	207.39	221.32	13.61	14.97	16.30
1.0	55.20	60.40	65.43	7.83	8.64	9.43
2.0	14.78	16.30	17.79	3.56	3.94	4.31
3.0	6.72	7.43	8.13	2.03	2.24	2.46

Table 3-13: Fully Bundled Maximum Observed E-Field for SE Site Boundary Location

Burial Depth (m)	Max Induced Electric Field at Seabed ($\mu\text{V/m}$)			Max Induced Electric Field 1m above Seabed ($\mu\text{V/m}$)		
	2,000 mm ²	2,500 mm ²	3,000 mm ²	2,000 mm ²	2,500 mm ²	3,000 mm ²
0.5	225.13	242.65	258.94	16.18	17.80	19.38
1.0	64.58	70.67	76.56	9.31	10.27	11.21
2.0	17.29	19.07	20.82	4.23	4.68	5.12
3.0	7.86	8.69	9.51	2.41	2.67	2.92

3.2.3 Separated By 25 m

Table 3-14 to Table 3-16 below represents the E-Field density for all cable sizes when partially separated cables are installed, and for burial depths 0.5 to 3 metres. Results are given when measured at seabed and 1 m above seabed to give a holistic review of the effects on marine ecology and marine life.

Table 3-14: Separated Cables Maximum Observed E-Field for ECC 4 Route Section

	Max Induced Electric Field at Seabed ($\mu\text{V/m}$)			Max Induced Electric Field 1m above Seabed ($\mu\text{V/m}$)		
Burial Depth (m)	2,000 mm2	2,500 mm2	3,000 mm2	2,000 mm2	2,500 mm2	3,000 mm2
0.5	743.39	733.70	724.25	140.55	139.88	139.22
1.0	198.11	196.73	195.36	53.39	53.20	53.01
2.0	102.24	101.87	101.51	53.39	35.86	35.77
3.0	68.84	68.67	68.50	27.06	27.01	26.96

Table 3-15: Separated Cables Maximum Observed E-Field for ECC 5 Route Section

	Max Induced Electric Field at Seabed ($\mu\text{V/m}$)			Max Induced Electric Field 1m above Seabed ($\mu\text{V/m}$)		
Burial Depth (m)	2,000 mm2	2,500 mm2	3,000 mm2	2,000 mm2	2,500 mm2	3,000 mm2
0.5	825.99	815.22	804.72	158.49	157.74	156.99
1.0	220.12	218.59	217.07	60.21	59.99	59.78
2.0	113.60	113.19	112.79	60.21	40.44	40.34
3.0	76.49	76.30	76.11	30.51	30.45	30.40

Table 3-16: Separated Cables Maximum Observed E-Field for SE Site Boundary Location

	Max Induced Electric Field at Seabed ($\mu\text{V/m}$)			Max Induced Electric Field 1m above Seabed ($\mu\text{V/m}$)		
Burial Depth (m)	2,000 mm2	2,500 mm2	3,000 mm2	2,000 mm2	2,500 mm2	3,000 mm2
0.5	966.41	953.80	941.52	188.40	187.50	186.61
1.0	257.54	255.75	253.97	71.57	71.31	71.05
2.0	132.92	132.44	131.96	71.57	48.07	47.95
3.0	89.49	89.27	89.05	36.27	36.20	36.13

3.2.4 Fully Separated

Table 3-17 to Table 3-19 below represents the E-Field density for all cable sizes when a single cable is present, and for burial depths 0.5 to 3 metres. Results are given when measured at seabed and 1 m above seabed to give a holistic review of the effects on marine ecology and marine life.

Table 3-17: Single cable Maximum Observed E-Field for ECC 4 Route Section

	Max Induced Electric Field at Seabed ($\mu\text{V/m}$)			Max Induced Electric Field 1m above Seabed ($\mu\text{V/m}$)		
Burial Depth (m)	2,000 mm ²	2,500 mm ²	3,000 mm ²	2,000 mm ²	2,500 mm ²	3,000 mm ²
0.5	743.33	733.69	724.18	140.52	139.85	139.18
1.0	395.19	392.44	389.71	106.56	106.17	105.79
2.0	204.05	203.31	202.58	71.82	71.65	71.47
3.0	137.53	137.20	136.86	54.16	54.06	53.97

Table 3-18: Single cable Maximum Observed E-Field for ECC 5 Route Section

	Max Induced Electric Field at Seabed ($\mu\text{V/m}$)			Max Induced Electric Field 1m above Seabed ($\mu\text{V/m}$)		
Burial Depth (m)	2,000 mm ²	2,500 mm ²	3,000 mm ²	2,000 mm ²	2,500 mm ²	3,000 mm ²
0.5	825.92	815.21	804.65	158.46	157.70	156.95
1.0	439.10	436.05	433.02	120.16	119.73	119.30
2.0	226.72	225.90	225.09	80.99	80.79	80.60
3.0	152.81	152.44	152.07	61.08	60.97	60.85

Table 3-19: Single cable Maximum Observed E-Field for SE Site Boundary Location

	Max Induced Electric Field at Seabed ($\mu\text{V/m}$)			Max Induced Electric Field 1m above Seabed ($\mu\text{V/m}$)		
Burial Depth (m)	2,000 mm ²	2,500 mm ²	3,000 mm ²	2,000 mm ²	2,500 mm ²	3,000 mm ²
0.5	966.33	953.79	941.44	188.35	187.46	186.57
1.0	513.75	510.17	506.63	142.83	142.32	141.81
2.0	265.26	264.31	263.35	96.27	96.04	95.80
3.0	178.79	178.35	177.92	72.60	72.47	72.34

4 HVDC Cables in the North Sea

As of 2025, the North Sea hosts several major HVDC interconnector projects that facilitate cross-border electricity exchange and support renewable energy integration. The following are key operational HVDC projects:

- North Sea Link (UK–Norway): 720 km, 1,400 MW capacity
- NordLink (Germany–Norway): 623 km total, including 154 km offshore, 1,400 MW capacity
- Shetland HVDC Link (UK): 260 km subsea cable, 600 MW capacity
- Moyle Interconnector (UK): 4,500 km submarine cable, 540 MW initially, reduced to 250 MW

The cumulative length of operational HVDC cables in the North Sea exceeds 1,500 km. In the future, plans under the European Ten-Year Network Development Plan aim to expand this network to support 23 GW of HVDC interconnection capacity by 2025 [7].

The Moyle Interconnector is a critical subsea electricity link between Northern Ireland and Scotland, operated by Mutual Energy. It plays a vital role in maintaining energy security and enabling access to more affordable electricity for Northern Ireland.

Beginning in 2010, the interconnector experienced significant faults that reduced its operational capacity by half. These issues persisted for several years, limiting the efficiency and reliability of electricity transmission between Northern Ireland and Great Britain. The reduced capacity placed strain on the regional energy system and raised concerns about long-term supply stability.

In response to these challenges, Mutual Energy initiated a major repair programme. By 2015, the company announced that full operational capacity would be restored by 2016, one year ahead of schedule. The resolution involved the installation of two new underwater cables [8].

Installation practices play a critical role in cable reliability. Inadequate burial depth, poor seabed preparation, and insufficient post-installation protection can lead to cable movement, exposure, and failure. Shallow water environments are especially prone to dynamic seabed conditions, which increase the likelihood of cable displacement and abrasion. While fishing activities such as trawling and anchoring remain a risk, especially for exposed cables, most failures in offshore wind farm export cables are attributed to installation and environmental factors rather than third-party interference.

Manufacturing faults also contribute to reliability issues, typically becoming evident during cable energisation. However, transparency around failures and failure causes remains limited, with limited data available publicly [9].

HVDC cables in the North Sea undergo an environmental impact assessment (EIA) as part of the consent process prior to construction. The EIA would assess the potential impacts on receptors that may be affected by EMF on sensitive receptors including benthic ecology, fish and shellfish, and marine mammals. This information is reviewed by regulators and statutory nature conservation bodies (SNCBs) prior to consent being awarded.

5 Conclusion

The earthed metallic shield that is applied over the insulation of HVDC cables ensures that the electric field will be contained entirely within the insulation and grounded sheath, and no external electric field will be emitted from the cable conductor. However, magnetic fields will be seen outside the cables, and this has been assessed for each technology option and installation scenario below, for depths ranging from 1 to 3 m and referenced at the seabed and 1 m above the seabed.

- Fully Bundled - This setup represents the most compact arrangement and presented the lowest external magnetic field due to mutual cancellation effects.
- Separated by 25 m - This configuration simulates a split trench or spatially separated cable routing, resulting in reduced magnetic field interaction and higher net flux magnitudes.
- Fully Separated - This scenario assumes the absence of any mitigating influence from a second cable and therefore provides the highest expected magnetic flux values.

All calculations were performed assuming maximum load and minimum pole separation giving a worst-case scenario. The magnetic fields produced by the bundled cables were highly localised, reducing rapidly from the source due to the two single cables significantly cancelling each other's EMF. The decrease in magnetic fields occurs both in the vertical water column and horizontally along the seabed. The magnetic fields reduced to as low as 6.72 μT at a burial depth of 3 m for a 2,000 mm^2 cable.

The results for both 25 m separated cable and a single cable installation regime show significantly increased magnetic flux density, due to the reduction and negation of cancellation effects. For a cable size of 2,000 mm^2 and for 1 m burial depth, the measured magnetic flux density at the seabed rises from 55.20 μT for fully bundled, to 220.12 μT for separated cables and 439.10 μT for an individual cable with no cancellation. Although these values present the worst-case operational/installation scenarios, it is highly unlikely that these values will be present during operation.

Results showcased in Section 3.1 indicate that when separated, the magnetic field reduces as cable size increase, but the inverse is true when the cables are bundled. This is because the two cables, when bundled, significantly cancel their magnetic fields, hence reducing the overall magnitude. As cable size is increased the separation between the two cables increase, slightly reducing the cancellation effects on one another. However, when the cables are separated and influence of the two cables upon one another is negligible, the increase in cable size slightly increased the depth to the centre of the core, which slightly reduces the observed magnetic field.

Precisely what magnitude of electric field induces an avoidance / repulsion response in Elasmobranchs is uncertain, however current research suggests that the threshold electric field between attraction and avoidance lies somewhere between approximately 400 and 1000 $\mu\text{V}/\text{m}$ [10]. It is not clear from the literature which frequencies these apply to or if there are effects outside this range. The values stated in this report would indicate that issues may arise within route section ECC 5 and the SE location of the project site for a burial depth of 1 m for a scenario where the influence of the second cable is negated, as seen in Table 3-18 and Table 3-19, however this can be easily mitigated by increasing burial depth. It should be noted that this would be a very unusual practice as an increased burial depth provides numerous additional difficulties for installation and would decrease cable carrying capacity.

National Policy Statement EN-3 states mitigation techniques to reduce EMF emitted to the environment. Armoured cables may help to attenuate magnetic fields. If the magnetic field is attenuated this will also reduce the E-field induced in moving salt water. Cables have also been buried to a depth of 3 m, which again reduces the magnetic fields and increased burial depth is a suggested mitigation technique in NPS EN-3. However, bundling the two cables ensures magnetic fields reduce very quickly with distance and ensures that the fields remain highly localised. Bundling HVDC cables is common practice, and this approach is proposed for the Morven HVDC export cable. Any separation will be avoided where possible.

Marine species have specialised physiology to detect EMF and electric fields, but the exact mechanisms of detection are complex, and not fully understood. Under the current understanding there are no known limits at which EMF are known to result in physiological or behavioural changes in marine organisms, and this is likely to differ between receptor groups and species.

6 References

- [1] National Grid, "Preliminary Environmental Information Report, Volume 2, Part 4, Appendix 4.8.B," 2023.
- [2] Morven Offshore Wind Farm, "Morven Offshore Wind Farm," 2025. [Online]. Available: <https://www.morvenoffshorewind.com/MorvenOffshoreWindFarm/>.
- [3] CIGRE, Magnetic Field in HV Cable Systems, TB 104, June 1996.
- [4] MWOL, "Metocean Works (2024) MOWL_C00001_ECC_R02_ECC_4_Operational_Criteria".
- [5] MWOL, "Metocean Works (2024) MOWL_C00001_ECC_R02_ECC_5_Operational_Criteria".
- [6] MWOL, "Metocean Works (2025) MOWL_C00001_R07_Morven_SE_Operational_Criteria (MVGEO-V2003-MOW-00002)".
- [7] NESO, "Electricity Ten Year Statement," 2024.
- [8] BBC News, "Moyle electricity interconnector suffers new fault," 22 February 2017. [Online]. Available: <https://www.bbc.co.uk/news/uk-northern-ireland-39047669>.
- [9] J. Warnock, D. McMillan, J. Pilgram and S. Shenton, "Review of Offshore Cable Reliability Metrics," 2019.
- [10] Centre for Marine and Coastal Studies Ltd. (CMACS), "West Coast HVDC Link environmental appraisal - Assessment of EMF effects on sub tidal marine ecology," 2011.

