Preliminary Environmental Information Report Volume 2

Appendix 2.3 Electromagnetic Field Assessment

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LionLink EMF Assessment

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Contents

Abbreviations

AC	Alternating Current
DC	Direct Current
EIA	Environmental Impact Assessment
ELF	Extremely Low Frequency
EMF	Electric and Magnetic Field
Hz	Hertz
HDD	**Horizontal Directional Drill**
HPA	Health Protection Agency
HVAC	High Voltage Alternating Current
HVDC	High Voltage Direct Current
IARC	International Agency for Research on Cancer
ICNIRP	International Commission on Non-Ionizing Radiation Protection
IPC	Infrastructure Planning Committee
kV/m	KiloVolt per meter
NPS	National Policy Statement
NRPB	National Radiological Protection Board
PHE	Public Health England
WHO	World Health Organisation
μT	Microtesla

1. Introduction

1.1.1. This document provides an assessment of electric and magnetic fields (EMFs) associated with offshore and onshore high voltage direct current (HVDC) assets for the proposed LionLink scheme ("the project").

1.1.2. The Project comprises a new interconnector with a capacity of up to 2 gigawatts (GW) between the National Transmission Systems (NTSs) of Great Britain (GB) and the Netherlands, including a connection into a wind farm located in Dutch waters.

1.1.3. The Project is located partly in the territory of GB and partly in the territory of the Netherlands. This electric and magnetic field (EMF) report covers the assets located within the territory of GB only.

1.1.4. The GB portion of the Project comprises the following key components:

- Proposed Friston substation ;
- Proposed high voltage alternating current (HVAC) Underground Cables between the proposed Converter Station in Suffolk and a Substation in the Leiston area;
- Proposed Converter Station in Suffolk, east of Saxmundham;
- Proposed high voltage direct current (HVDC) Underground Cables between the connection from the existing grid via the proposed Friston substation; and
- Submarine electricity cables from a proposed Landfall Site (at either Southwold or Walberswick) to the edge of the UK Exclusive Economic Zone (EEZ).

1.1.5. This report describes EMFs produced by the operation of the proposed Converter Station and the associated HVAC Underground Cables and HVDC Underground and Submarine Cables connecting the proposed Converter Station to the proposed National Grid 400kV Substation, in the onshore and offshore environments.

1.1.6. All equipment that generates, transmits, distributes or uses electricity produces EMFs. In the UK electricity is normally generated, transmitted, distributed and consumed as Alternating Current (AC). The UK power frequency for AC is 50 Hertz (Hz), which is therefore the principal frequency of the EMFs produced which are also known as Extremely Low Frequency (ELF) EMFs. The LionLink HVDC interconnector uses Direct Current (DC) technology which has a frequency of zero Hertz (0 Hz) and will produce static EMFs. The proposed Converter Station will then convert DC transmission to AC 50 Hz transmission which can be connected to the existing National Transmission System.

1.1.7. All static and alternating fields can have different effects, but in both cases, there are exposure limits set by independent organisations, designed to prevent all established effects of EMFs on people detailed in Section 2.

Electric fields

1.1.8. Electric fields depend on the operating voltage of the equipment producing them and are measured in V/m (volts per metre). The voltage applied to equipment is a relatively constant value. Electric fields are shielded by most common building materials, trees and fences and diminish rapidly with distance from the source.

1.1.9. As a consequence of their design, some types of equipment do not produce an external electric field. This applies to buried cables onshore and offshore (both AC and DC) and gas insulated switchgear (GIS), which are enclosed in a sheath (a protective metal layer within the cable) and have solid metal enclosures respectively. These screen the electric field altogether and as such electric fields are not considered further for these types of equipment.

1.1.10. In the marine environment the movement of the sea through the magnetic field will result in a small localised electric field being produced. The induced electric fields that occur in the sea will be assessed in section 5.4. In the freshwater environment, the low conductivity of the water means that induced electric fields are not a consideration.

Magnetic fields

1.1.11. Magnetic fields depend on the electrical currents flowing, which vary according to the electrical power requirement at any given time and are measured in µT (microtesla). They are not significantly shielded by most common building materials or trees. Magnetic fields diminish rapidly with distance from the source.

1.1.12. Magnetic fields are found in all areas where electricity is in use (e.g. offices and homes), arising from electric cabling and equipment in the area. In UK houses, typical ELF magnetic fields will be in the range of 0.01 – 0.2 µT, with higher values in localised areas close to electrical appliances.

1.1.13. The earth also produces its own DC magnetic field, which in the UK is around 49.9 µT, but this can vary due to geomagnetic material such as ferromagnetic rocks.

1.1.14. The proposed project uses both AC and DC technology, so both static and alternating EMFs will be produced. The underground cables entering the proposed Converter Station via the marine route will use DC, so they will produce static EMFs that always point in the same direction. There will also be AC cables installed between the proposed Converter Station and Proposed Friston substation which will operate at 50 Hz. These change direction at a frequency of 50 times per second, hence 50 Hz.

1.1.15. The proposed Converter Station will contain specialist electrical equipment which will produce both DC and AC fields which are assessed in this report.

2. Legislation and Policy

2.1. Policy and assessment guidelines for the Protection of People

2.1.1. At high enough levels, EMFs can cause biological effects, which depending on the frequency of the fields can impact nerve function or blood flow. Whilst there are no statutory regulations in the UK that limit the exposure of people to power-frequency EMFs, responsibility for implementing appropriate measures for the protection of the public lies with the UK Government, which has a clear policy, restated in January 2024 and incorporated in NPS EN-5[1], on the exposure limits and other policies they expect to see applied. Practical details of how the policy is to be implemented are contained in Codes of Practice[2] agreed between industry and the Government.

2.1.2. UK Government policy on EMF requirements for all electricity infrastructure projects is given in NPS EN-5[1].

2.1.3. The key provision is in section 2.10.9:

> *"…Government has developed with the electricity industry a Code of Practice, "Power Lines: Demonstrating compliance with EMF public exposure guidelines – a voluntary Code of Practice" published in February 2011 that specifies the evidence acceptable to show compliance with ICNIRP (1998) in terms of the EU Recommendation[3]. Before granting consent to an overhead line application, the IPC should satisfy itself that the proposal is in accordance with the guidelines, considering the evidence provided by the applicant and any other relevant evidence."*

2.1.4. The ICNIRP[4] guidelines are based on the avoidance of known adverse effects of exposure to EMF at frequencies up to 300 GHz, which includes the 50 Hz EMF associated with electricity transmission. This equates, at 50 Hz, to public exposure limits of:

- 9.0 kV/m for electric fields; and
- 360 μT for magnetic fields.

2.1.5. The EU recommendation adopts ICNIRP guidelines[5] for static magnetic field exposure. Acute public exposure should not exceed 40,000 μT (40 milli Tesla). However, ICNIRP's 1994 guidance[5], states that there are potential indirect effects, such as potential interactions with implantable medical devices which could occur at levels below the exposure limits.

2.1.6. Therefore, a lower restriction of 500 μT should be considered, but is not mandated, where indirect effects may be an issue. These levels should be considered but are not threshold limits. The assessment would demonstrate a significant impact if non-compliance with the EMF exposure limits was demonstrated using the principles set out in Codes of Practice 'Power Lines: Demonstrating compliance with EMF public exposure guidelines – a voluntary Code of Practice'

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[1] Department of Energy and Climate Change. National Policy Statement for Electricity Network Infrastructure (EN-5). London: The Stationary Office, 2024.
[2] Department of Energy and Climate Change. Power Lines: Demonstrating compliance with EMF public exposure guidelines. A voluntary Code of Practice. London, 2012.
[3] EU Recommendation 199/519/EC
[4] International Commission on Non-Ionising Radiation Protection (1998). Guidelines for Limiting Exposure to Time-Varying Electric, Magnetic and Electromagnetic Fields. Health Physics
[5] International Commission on Non Ionising Radiation Protection (1994) Guidelines on limits of exposure to static magnetic fields, Health Physics

Table 2.1 Recommended Values for Power Frequencies

Public Exposure Levels	Electric fields	Magnetic fields
	AC	
Basic restriction (induced current density in central nervous system)	**2 mA/m²**	
Field corresponding to the basic restriction	**9,000 V/m**	**360 μT**
	DC	
Exposure limit	**No limit***	**40,000 μT**

2.2. Policy Framework for the Protection of marine life

2.2.1. National Policy Statement EN-3[6] for renewable energy infrastructure provides the primary basis for decisions by the Infrastructure Planning Commission (IPC) on applications it receives for nationally significant renewable energy infrastructure. There are no limits or guidelines for EMF exposure in the marine environment, but potential impacts on marine life should be assessed.

2.2.2. The key provision in Paragraph 2.8.310 states:

"*The use of external cable protection has been suggested as a mitigation for EMF (by increasing the distance between fish species and individual cables). However, the Secretary of State should also consider any negative impacts from external cable protection on benthic habitats, and a balance between protection of various receptors must be made, with all mitigation and alternatives reviewed.*"

2.2.3. The mitigation methods suggested in NPS EN-3 include the use of armoured cables for interarray and export cables. Armoured cables are proposed for the LionLink project. Burial depth can reduce the magnetic fields at distance but to a lesser extent than bundling the pole cables. Therefore, mitigation of EMF from offshore cables can also occur by reducing the separation distance of the cables for each pole. The closer the cables, the more cancellation of the field occurs and the lower the fields.

2.2.4. This report will provide the EMF details to inform the marine impact assessment.

2.3. Effects on magnetic compasses

2.3.1. Magnetic compasses, whether traditional magnetic needle designs or alternatives such as fluxgate magnetometers, operate from the Earth's magnetic field, and are susceptible to any perturbation to the Earth's magnetic field by other sources.

2.3.2. The Maritime and Coastguard Agency (MCA) in their response for the LionLink Scoping Opinion stated that *"There must be no more than a 3-degree electromagnetic compass deviation for 95% of the cable route and for the remaining 5% of the cable route there must be no more than a 5 degree electromagnetic compass deviation. If the MCA requirement cannot be met, a post installation actual electromagnetic compass deviation survey should be conducted for the cable in areas where compliance has not been achieved."*

2.3.3. This is a potential issue with DC conductors or cables, which produce a static magnetic field that perturbs the geomagnetic field. These are assessed in section 5.5.

[6] Department of Energy and Climate Change. National Policy Statement for Renewable Energy Structure (EN-3). London: The Stationary Office, 2024

3. Baseline Environment

Onshore

3.1.1. All equipment that generates, distributes or uses electricity produces EMFs. The UK power frequency is 50 Hz, which is the principal frequency of the EMFs produced, although HVDC circuits are also present which will be a source of additional DC fields.

3.1.2. Electric and magnetic fields both occur naturally. The Earth's magnetic field, which is caused mainly by currents circulating in the outer layer of the Earth's core, is approximately 49.9 μT in the UK. This field may be distorted locally by ferrous minerals or by steelwork such as in buildings or bridges.

3.1.3. As detailed earlier in this report, the Earth's natural electric and magnetic fields are static, and the power system produces alternating fields. In homes in the UK that are over 100 m from high-voltage overhead lines or underground cables, the average "background" power-frequency magnetic field (the field existing over the whole volume of the house) ranges typically from 0.01 – 0.2 μT with an average of approximately 0.05 μT, normally arising from currents in the low voltage distribution circuits that supply electricity to homes. The highest magnetic fields to which most people are exposed in the home arise close to domestic appliances that incorporate motors and transformers. For example, close to their surface, fields can be 2000 μT for electric razors and hair dryers, 800 μT for vacuum cleaners, and 50 μT for washing machines. The electric field in most homes is in the range 1 – 20 V/m, rising to a few hundred V/m close to appliances[7].

3.1.4. There is also a natural static electric field everywhere on the surface of the earth with an intensity of about 100 V/m. This varies significantly and are very dependent on atmospheric conditions. When a thunderstorm approaches, the electric field reaches much higher values, of the order of 10 kV/m to 20 kV/m at ground level[8].

Offshore

3.1.5. The current offshore environment, where LionLink cables are proposed, has naturally occurring DC magnetic fields, which again is around 49.9 μT. As well as the earth's geomagnetic field, there are also other cables, shipwrecks and ferromagnetic rocks, which will add to the background DC EMF in the area.

3.1.6. The Earth's magnetic field can induce an electric field in sea water. The movement of the sea through the magnetic field will result in a small localised electric field being produced. It has been stated that the magnitude of the electric field induced will be dependent upon magnetic field strength, sea water chemistry, viscosity and its flow velocity and direction relative to the lines of magnetic flux. The background geomagnetic field in the area is around 49.9 μT. Given this, the background induced electric field could range between 25.0 and 64.9 μV/m in tidal velocities ranging between 0.5 m/s and 1.3 m/s.

[7] J. Swanson & D.C. Renew, Power-frequency fields and people, Engineering Science and Education Journal, 1994, p 71

[8] A. Bennett, "Measurement of Atmospheric Electricity During Different Meteorological Conditions," Doctor of Philosophy, Department of Meteorology, University of Reading, 2007

4. Assessment methodology

4.1.1. In order to demonstrate compliance with the exposure guidelines, Industry and Government have published a Code of Practice, "Power Lines: Demonstrating compliance with EMF public exposure guidelines". As part of the Code of Practice, the Energy Networks Association maintains a list of types of equipment where design is such that it is not capable of exceeding the ICNIRP exposure guidelines. This list includes all substations which do not contain any air-cored reactors. At the perimeter fence, the highest fields are invariably produced by any overhead lines or underground cables at transmission voltages entering the substation; the compliance of these items of equipment is considered on a case-by-case basis.

4.1.2. For the assessment of effects from a DC system, the proposed Converter Station and underground cables are required to provide evidence of compliance. In line with the Code of Practice, this report sets out the technical specifications of the proposed Converter Station to demonstrate how the development complies with EMF exposure guidelines and provides a calculation of the maximum magnetic fields directly over the underground cable route.

4.1.3. These calculations assume that there is no attenuation of magnetic fields from any surrounding material (e.g., seabed, earth, grout mattresses, etc.) and that there are no unbalanced currents flowing along the outer sheaths of the cables.

4.2. Combining fields from different sources

4.2.1. When more than one source of EMFs is present, such as two different cable circuits, the EMFs can interact with one another, adding or subtracting to the total field. However, this is only the case if the frequencies that the cables operate at are the same. Alternating Current (50 Hz) and Direct Current (0 Hz) fields do not interact with one another due to their differing frequencies (Section 1) and should be considered separately.

4.2.2. The Project crosses a number of telecommunications cables, pipelines and two proposed wind farm export cables. The cables would cross over existing infrastructure on a 'bridge' comprised of either aggregate or concrete mattresses or by making use of a separator system put around the cable at installation. This section would subsequently be covered over with a protective layer of either aggregate (rock) or concrete mattresses. Crossings are proposed to be as near to 90 degrees as possible to the third-party asset.

Telecommunications cables

4.2.3. Repeater (powered) telecommunication systems do have a live current, but electrical fields are shielded, and currents are markedly lower than power transmission cables. Given the small diameter of repeater cables, the magnetic fields induced by fibre optic cable powering are in the order of 30 to 38 μT at the cable surface. These values are lower than the background magnetic field produced by the Earth (49.9 μT).

4.2.4. At 1 metre from the cable the magnetic field would be 0.30 to 0.38 μT or 1/100th of what it is at the surface of the cable.

4.2.5. Repeater telecom cable systems produce highly localised magnetic fields if laid on the seabed surface, and if buried the fields would be reduced further. Unrepeatered telecommunications systems do not produce any EMFs.

4.2.6. Given the very low levels of EMF in a repeater telecommunications cable, and no EMF produced by unrepeatered telecommunications cables, the cumulative impacts of EMFs at the minimum separations distance required for protection of the assets would be negligible and is not considered further.

Wind farm export cables

4.2.7. The project will cross two proposed wind farm export cables, each which operate using HVDC technology as described below:

- Norfolk Vanguard- This consists of 2 x HVDC bipole cable connection (four cables in total), ±325 kV, maximum 900 MW across the 2 circuits. Each bundled bipole pair is separated by 120 m.
- Norfolk Boreas - This consists of 2 x HVDC bipole cable connection (four cables in total), ±325 kV, maximum 900 MW across the 2 circuits. Each bundled bipole pair is separated by 120 m.

4.2.8. Both export cables will emit magnetic fields which will interact with the project. The Norfolk Vanguard EIA does not provide details of the levels of EMFs produced except for the note '*The intensity of EMF emitted by subsea cable is very low due to the design and operation of the cable'*. The cumulative impact of both cables is assessed in section 5.3, using the design information and electrical parameters provided in publicly accessible information.

4.2.9. Where third party crossings occur, the LionLink cables will not be buried but installed on the seabed on a separation layer. Following the installation of the cable on the separation layer, external protection in the form of rock berms will be installed over the top. Indicative designs for rock berms show these may provide up to 1.8 m cover above LionLink cables.

4.3. Assessment of Effects

4.3.1. The onshore LionLink project would be assessed as having an adverse effect on human health if non-compliance with the EMF exposure limits was demonstrated, using the principles set out in Codes of Practice[2]. Conversely, as specified in NPS EN-5[1], if the proposed projects comply with the exposure limits, EMF effects are assessed as not significant, and no mitigation is necessary.

4.3.2. For the marine environments, total field values are produced and compared to the requirements of NPS EN-3 and used to assess potential impacts to marine life. Interpretation of the potential impacts on marine life physiology will be addressed outside this document. The impact of EMF on marine life will be covered within the Fish and Shellfish, and Marine Mammal chapters of the Preliminary Environmental Information Report and Environmental Statement. The impact of EMF on the freshwater environment will be covered within the Onshore Ecology and Biodiversity chapter of the PEIR or similar text.

5. Assessment of Offshore EMF

5.1.1. The offshore elements of the project consist of a new primarily offshore HVDC interconnector operating at 0 Hz (DC).

5.1.2. The installation and electrical design of the interconnector will impact the EMFs produced. Where cables transition to land, cables are installed via HDD. There are currently two design options for the offshore cable installation and each of those have a bipole or monopole method of operation, potentially via a dedicated metallic return. These two design options and each operation mode are detailed in Table 5.1, and each has been considered for the EMF assessment.

5.1.3. The magnetic field produced by the cable will depend on the current flowing in the cables, the separation of the cables, and the distance from the cables. A bipole system will result in a cancellation of the magnetic fields when the cables are close together. As the cables move apart, as is the case with the separated designs, they will act more like single cables which is the worst-case condition for magnetic fields.

5.1.4. The electrical parameters for the project are described in Table 5.1. Normal bipole operation will have the rated current flowing in the pole cables with no current flowing in the metallic return. Under fault or maintenance conditions, involving the loss of one of the poles, the other pole cable and the metallic return would carry the rated current. Cable layout options under consideration correspond to either a bundled design or a separated metallic return design. Figure 5.1, illustrates the various design options considered.

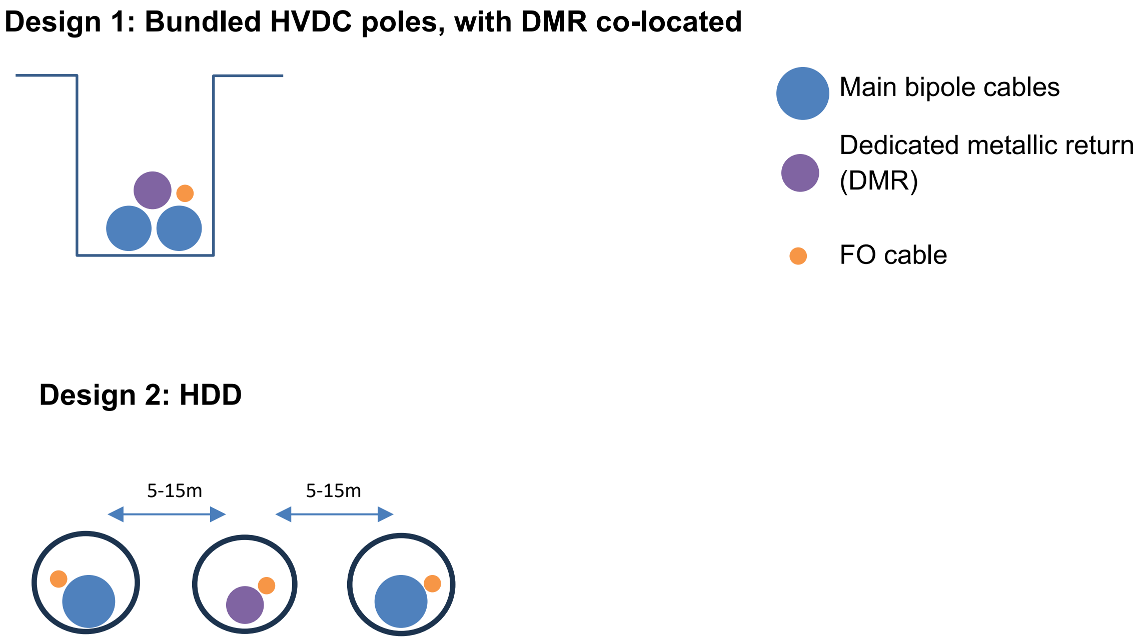


Figure 5.1: LionLink cable design layout options. Option 1 is bundled cable designs, but with the dedicated metallic return collocated with the bipole pair. Design 2 is the Horizontal Directional Drill (HDD) installation technique which will be used to transition cables from offshore to onshore, and under rivers.

5.1.5. Option 1 has a bundled pair of pole cables which are assumed to have a 0.136 m separation, with a bundled DMR. The normal operating conditions would be via the bundled bipole pair design. During a fault or maintenance condition where one pole is out of service, the current will flow in the other pole cable and the metallic return. Where the pole in service is collocated with the metallic return, the magnetic fields will be the same as those of bundled pole cables under normal operation. Both normal and monopole operating conditions will produce the same magnetic fields and are provided in Tables 5.2 and 5.3.

5.1.6. Where cables transition onto land, they will be installed via HDD. The pole cables and metallic return cable will each be in a duct with an expected maximum separation of 15 m and burial depth of 25m or more.

Table 5.1: LionLink cable designs and calculation parameters for all electrical designs

Design option	Cable Configuration	No. of cables	No. of Trenches	Power per cable	Current per cable	Voltage
1	**Bundled cables with metallic return co-located**	2 + metallic return	1	1000 MW	1904A	± 525kV
2	**Three unbundled cables with expected separation of 15m at burial depth of 25m or more (HDD)**	2 + metallic return	One cable per duct	1000 MW	1904A	± 525kV

5.1.7. The magnetic field produced by the cables will in turn induce electric fields in seawater passing through the field, due to the seawater's conductivity. This will be proportional to the magnetic field and the velocity of the water, which is assessed in Section 5.4.

5.2. Magnetic field assessment

5.2.1. All calculations were performed assuming the current maximum circuit separation and minimum burial depth, and 100% load giving a worst-case scenario provided in Table 5.2 for normal operation and Table 5.3 for monopole operation for the cable only, which is non-standard. The magnetic field from the cables will also combine with the earths geomagnetic field and these combined fields are provided in Tables 5.4 and 5.5 for normal and monopole operation respectively. For information calculations were additionally performed for 50 % load, which are presented in Appendix A, Table A1.

5.2.2. The maximum magnetic field for each design option was calculated at vertical distances of 0 to 20 meters from the seabed, and horizontal drop off along the seabed. A worst-case (minimum) burial depth of 1 m was used for all calculations, with the exception of Option 2, the HDD design which will be 25m deep.

5.2.3. Table 5.2 gives the maximum magnetic field at vertical distances from the cables only when operating normally. Table 5.2 also gives the distance from the cables that the magnetic field produced by the cables reduces to below 49.9 μT, the earths geomagnetic field in the area.

5.2.4. Figures 5.2 and 5.3 shows the maximum magnetic field from the cable only and the total magnetic field when combined with the geomagnetic field for the bundled cable operation, HDD operations and monopole operation for each design.

Table 5.2: Calculated maximum cable magnetic fields at vertical distances from the seabed for the offshore LionLink cable circuit options during normal operation. Cables are buried 1 m below the seabed except option 2, which has a burial depth of 25m. Distance for the magnetic field to fall below the background geomagnetic field is included for each option. Distance for the magnetic field to fall below the background geomagnetic field is included for each option.

	Magnetic field (µT)							
	Distance above seabed (m)							Distance for magnetic field to reach background geomagnetic field (m)
	Seabed	0.5 m	1 m	2 m	5 m	10 m	20 m	
Option 1 – bundled cables, normal operation	51.9	23.1	13.0	5.8	1.45	0.43	0.12	0.03 m
Option 2 – HDD transition to onshore	13.4	13.1	12.8	12.0	10.2	7.9	5.1	None above

Table 5.3: Calculated maximum cable magnetic fields at vertical distances from the seabed for the offshore LionLink cable circuit options during monopole operation. Cables are buried 1 m below the seabed except option 2, which has a burial depth of 25m. Distance for the magnetic field to fall below the background geomagnetic field is included for each option.

	Magnetic field (µT)							
	Distance above seabed (m)							Distance for magnetic field to reach background geomagnetic field (m)
	Seabed	0.5 m	1 m	2 m	5 m	10 m	20 m	
Option 1- cables with metallic return collocated: Monopole operation	51.9	23.1	13.0	5.8	1.45	0.43	0.12	0.03 m
Option 2- HDD transition to onshore: Monopole operation	8.4	8.1	7.8	7.3	6.0	4.5	2.7	None above

Table 5.4: Calculated maximum cable magnetic fields at vertical distances from the seabed for the offshore LionLink cable circuit options during normal operation combined with the earths geomagnetic field. Cables are buried 1 m below the seabed except option 3, which has a burial depth of 25m.

	Magnetic field (µT)						
	Distance above seabed (m)						
	Seabed	**0.5 m**	**1 m**	**2 m**	**5 m**	**10 m**	**20 m**
Option 1 – bundled cables, normal operation	99.3	71.3	61.6	54.7	50.7	49.8	49.5
Option 2 – HDD transition to onshore	62.0	61.6	61.2	60.6	58.9	56.7	54.1

Table 5.5: Calculated maximum cable magnetic fields at vertical distances from the seabed for the offshore LionLink cable circuit options during monopole operation combined with the earths geomagnetic field. Cables are buried 1 m below the seabed except option 3, which has a burial depth of 25m.

	Magnetic field (µT)						
	Distance above seabed (m)						
	Seabed	**0.5 m**	**1 m**	**2 m**	**5 m**	**10 m**	**20 m**
Option 1- cables with metallic return collocated: Monopole operation	99.3	71.3	61.6	54.7	50.7	49.8	49.5
Option 2- HDD transition to onshore: Monopole operation	57.2	56.9	56.6	56.1	54.9	53.5	51.9

Figure 5.2: Calculated maximum magnetic fields horizontally along the seabed for option 1 during normal operation: bundled cables. The dark blue line shows the maximum magnetic field from the cables only. The light blue line shows the total magnetic field when combined with the earths geomagnetic field.

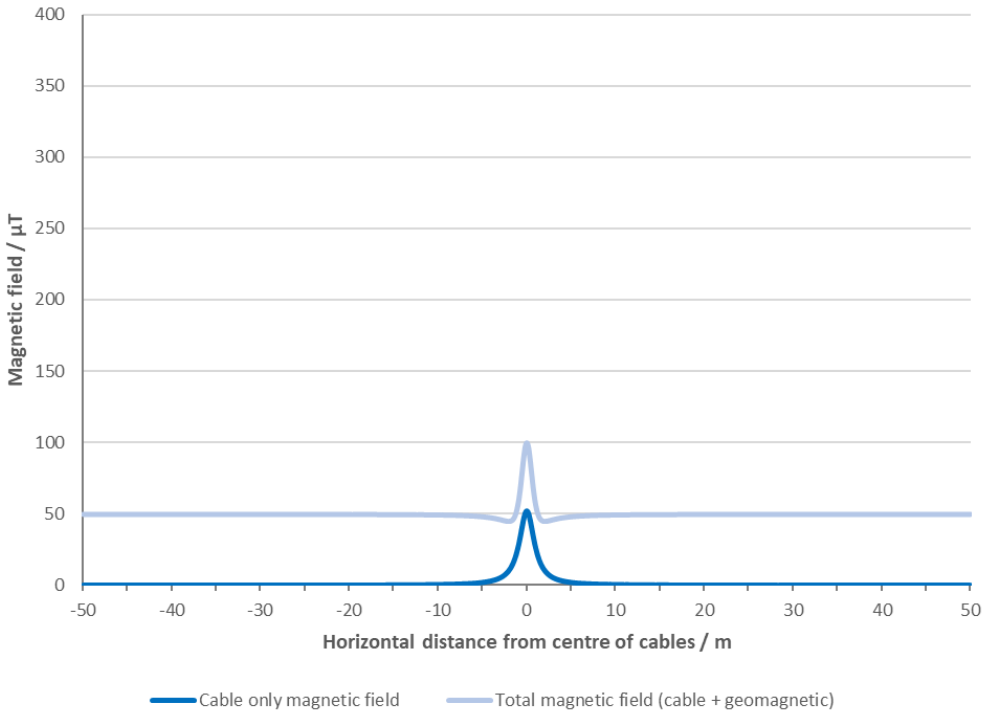
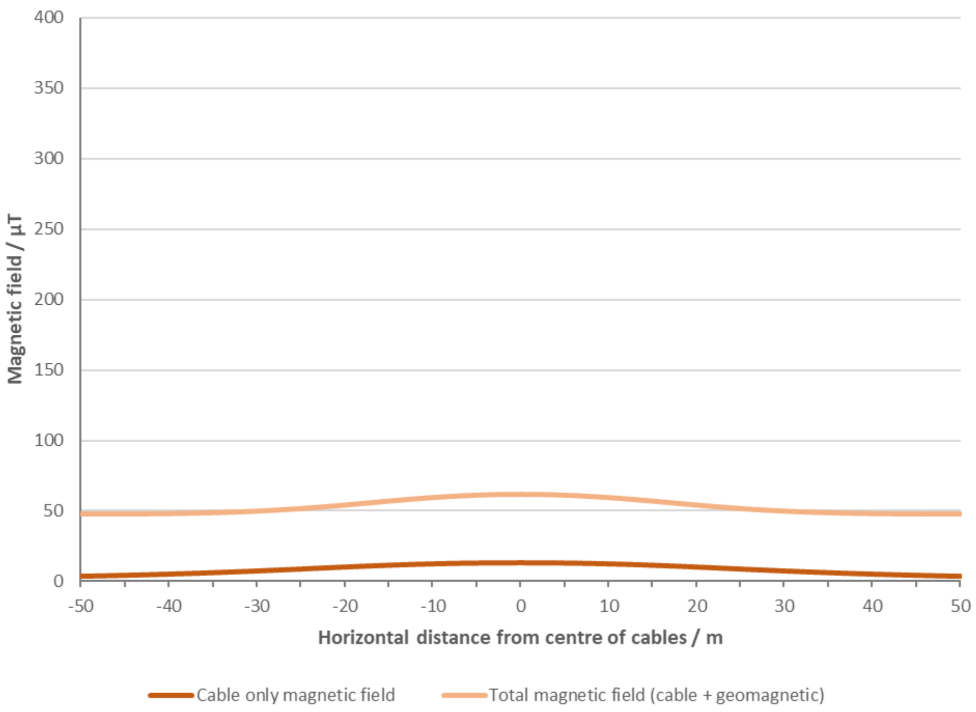


Figure 5.3: Calculated maximum magnetic fields horizontally along the seabed for option 2: 30m separated metallic return: Monopole operation. The dark green line shows the maximum magnetic field from the cables only. The light green line shows the total magnetic field when combined with the earths geomagnetic field.



5.2.5. The calculated magnetic fields are greatest on the seabed and reduce rapidly with vertical and horizontal distance from the circuits (Table 5.2 to 5.5 and Figure 5.2 to 5.3). The highest magnetic fields were observed from design option 1 and both bipole and monopole operation were the same. The maximum magnetic field would be 51.3 μT from the cables and 99.3 μT when combined with the earths geomagnetic field. The maximum magnetic fields calculated for normal bipole operation were 51.9 μT when cables are bundled and 13.4 μT when installed using HDD.

5.3. Cumulative effect of LionLink, Norfolk Vanguard and Norfolk Boreas projects

5.3.1. Due to the complex nature of the cable crossings, the option which gave the highest magnetic fields was modelled. Bundled and 30 m separated cables were modelled to cross the third-party assets, which will give a best and worst-case assumption when LionLink circuits are operational. The project does not cross third party wind farm assets where HDD installation is considered.

5.3.2. Results will be demonstrated as contour 2D graphs and 1D graphs demonstrating the magnetic field reduction with distance at each crossing point. In all instances, the cables running North-South are the LionLink cables and those running East-West are the third-party assets.

Norfolk Vanguard and Norfolk Boreas Wind Farm Projects

5.3.3. The proposed Norfolk Vanguard and Norfolk Boreas export cable circuits are to be crossed at as near to 90° as possible by the LionLink cable circuit. The crossing point was modelled using EFC-400[9]. Each modelled LionLink option crossed the existing cable locations on the seabed, approximately 1 m above the existing circuits.

5.3.4. The Norfolk Vanguard wind farm consists of two HVDC circuits (four cables in total) which have a maximum capacity of 450 MW per circuit. Each circuit has a 125 m separation distance. Where the LionLink cables cross the existing export cables, there would be a vertical separation layer that would be agreed with the asset owner. The LionLink cable would then have an additional rock protection berm installed up to approximately 1.8m in height. All calculations have been made at 1.8 m from the LionLink cable circuits.

5.3.5. The Norfolk Boreas wind farm export cables are the same design as Norfolk Vanguard, so the calculations are representative of both crossings.

5.3.6. Figure 5.5 shows a 2D plot of the magnetic fields from the crossing points of LionLink with bundled cables and either the Norfolk Vanguard or Boreas cable circuits. This represents the normal operation of Design option 1 and 2. Figure 5.6 shows the total magnetic fields along the LionLink cables.

5.3.7. Figure 5.6 demonstrates a small increase in magnetic fields where the cable circuits cross Lion Link cable design 1 and 2 during normal operation, which persists for approximately 6 m either side of the crossing point. The maximum magnetic field above the bundled LionLink cables where it crosses the Norfolk Vanguard or Boreas circuits was 17.2 μT, compared to 51.9 μT when cables are trenched and not crossing assets. The reduction in magnetic field is due to the increased separation of 0.8 m between the LionLink cables and wind farm export cables due to the rock coverage.

[9] Commercially available electric and magnetic field calculation software package from Narda

Figure 5.5 Calculated DC Magnetic Fields from LionLink bundled cable circuits above Norfolk Vanguard's proposed HVDC cable circuits with 90-degree crossing angle: Cable circuits running East are LionLink circuits which are above Norfolk Vanguard circuits running North-South. Colour bands represent magnetic field levels in microtesla with scale given below.

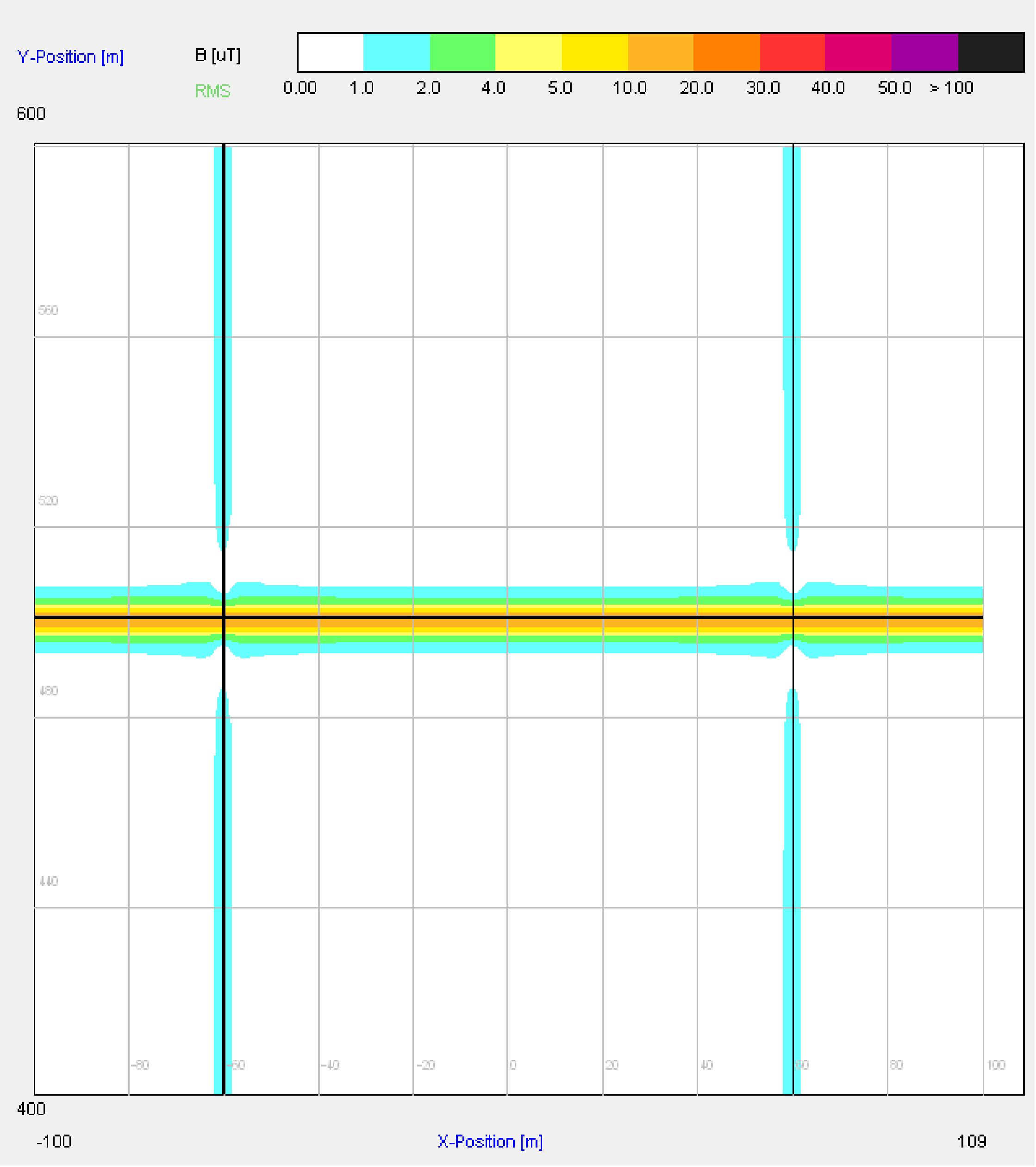
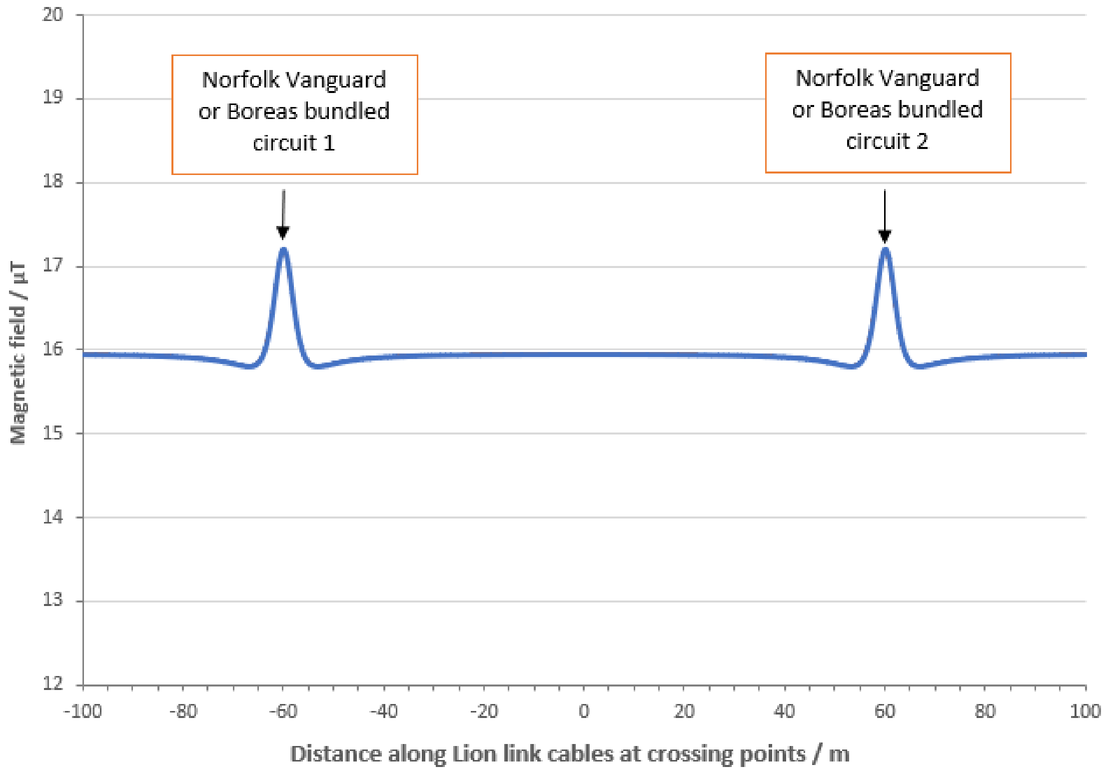


Figure 5.6: Calculated magnetic fields along the Lion Link circuit where the Proposed Norfolk Vanguard cable circuits cross. As the design is the same for the Proposed Norfolk Boreas is the same design, this would represent that situation also. Arrows indicate where the Proposed Norfolk Vanguard circuits cross the proposed LionLink circuit at a 90° angle. Calculations are for cable magnetic field only.



Norfolk Vanguard and Boreas crossing summary

5.3.8. Where LionLink cables cross third-party electricity assets, rock coverage increases the physical separation to the cables resulting in similar or reduced magnetic fields, compared to trenched installation, despite the cumulative magnetic fields.

5.4. Induced electric fields

5.4.1. The HVDC cable will produce a magnetic field which decreases with distance from the cables. The movement of sea water through the magnetic field will result in a small localised electric field being produced. A background electric field will be present in the sea due to the geo-magnetic field and localised magnetic anomalies. The strength of this field varies continuously due to the strength, speed and directions of the tide.

5.4.2. The convention for calculating induced electric fields for the Basslink, BritNed HVDC and Western Link connections is:

Induced electric field (µV/m) = Velocity (m/s) x Magnetic field (µT)

5.4.3. This is a vector cross product which means that the strength of the electric field is proportional to the component of the velocity perpendicular to the magnetic field and is in a direction perpendicular to both. The tidal velocities for LionLink are evaluated for values up to 1.3 m/s, to represent a very worst-case situation.

5.4.4. The average geomagnetic field along the LionLink route is approximately 49.9 µT, which is used for the calculations of background induced electric field. This background magnetic field induces an electric field that could range between 4.9 and 62 µV/m in tidal velocities between 0.5 m/s and 1.3 m/s. This does not take account of localised magnetic anomalies, which could result in higher localised electric fields, or of greater tidal velocities.

5.4.5. Table A2 in Appendix A gives the calculated induced electric field for each of the two designs.

5.4.6. These simplistic calculations are an overestimate of the induced electric field present close to the seabed. Water velocity distribution is non uniform due to friction that occurs at the seabed, where the magnetic field is greatest, which will reduce the resulting induced electric field.

5.5. Compass deviations along route

5.5.1. The magnetic field from the cables, if large enough, will combine with the earth's magnetic field causing a compass to indicate north in a different direction to the magnetic north pole.

5.5.2. It is the horizontal component of the geomagnetic field that is used for navigation, and this varies between 49.92 µT at the border of UK waters and 49.36 µT in the Leiston area. A value of 49.64 µT is used for the studies here.

5.5.3. MMO have previously provided the following guidance for other offshore cabling projects:

"In relation to Electromagnetic deviation on ships' compasses, the MMO would be willing to accept a three-degree deviation for 95% of the cable route. For the remaining 5% of the cable route no more than five degrees will be attained. The MMO would however expect a deviation survey post the cable being laid; this will confirm conformity with the consent condition. This data must be provided to the UKHO via a hydrographic note (H102), as they may want a precautionary notation on the appropriate Admiralty Charts."

5.5.4. The magnetic fields and compass deviation at the sea's surface were calculated for the LionLink cable route for each of the proposed design options. The assessments were performed using cable orientation and depth from bathymetry data. The orientation of the cables to north, separation and depth, as well as the current flowing in the cable, will all impact the extent a compass is deviated from the earth's magnetic north.

5.5.5. The maximum compass deviation for each of the designs and route has been calculated along its entire length for the maximum current in the cable. The results are shown in Figure B1 and B2 in Appendix B. The compass deviation is shown as a green line, with angle of cable to north as a red line and sea depth along route as a blue line.

5.5.6. The compass deviation calculations assume that the cable is buried 1m below the seabed. The compass deviation calculation results are calculated at the sea surface. In practice the draft of any vessels will limit the sea depth that applies, and the compass is likely to be situated above the water line, both of which will reduce the compass deviation that will be found in practice.

5.5.7. Table 5.6 gives the percentage of the LionLink route that would meet the MMO requirements stated in 5.5.3 for each of the cable design options. The change in compass deviation along the route for each design is provided in Appendix B, Figures B1 and B2.

Table 5.6: Percentage of the LionLink route resulting in compass deviations of less than 3° and 5° variations.

	Proportion of route within compass deviation threshold
	Design option 1: Bundled **Design option 2: Cables separated by 30 m**
Option 1 – bundled cables	
Less than 3° deviation	99.9%
Less than 5° deviation	100%
Option 2 – HDD transition to onshore	**300m from shoreline only**
Less than 3° deviation	0%
Less than 5° deviation	0%

Option 1 – Normal operation: Bundled design (2 cables 0.136 m apart): Very low compass deviation occurs over the majority of the route. Will meet MMO compass requirements for all normal common modes of operation.

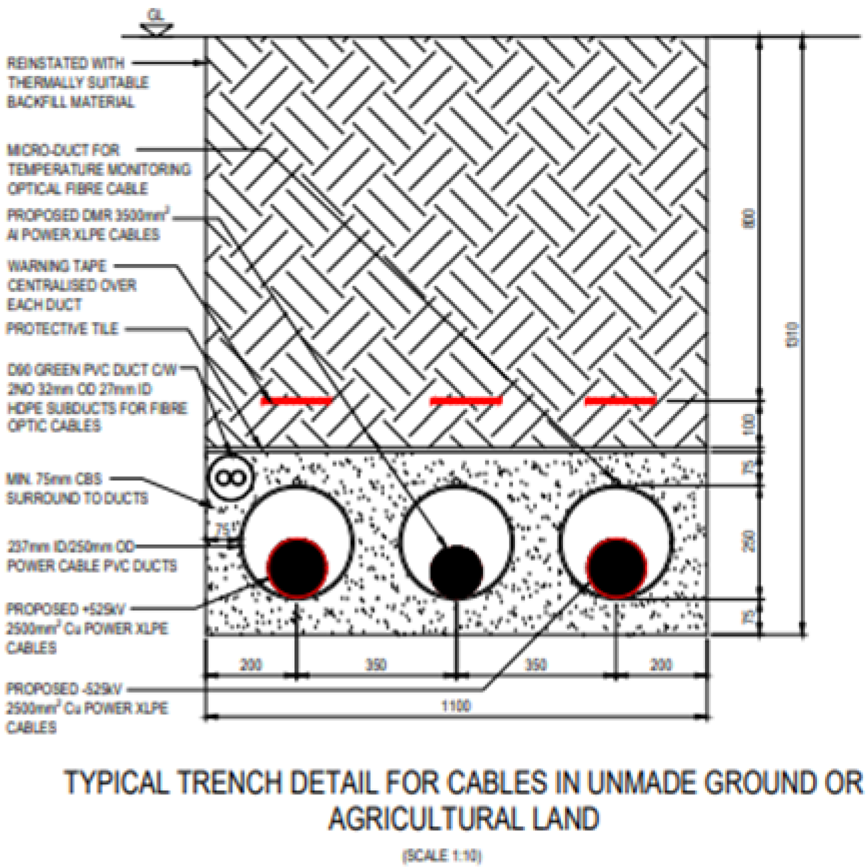
Option 2 - **HDD installation** (2 cables 30 m apart, 25 m deep). Due to the shallow water depth and cable separation, compass deviations in the near shore exceed the MMO requirements. However, the sea depth is on average around 3 m in this area, and compass deviations for the entire length are 7.8 to 8.5 degrees.

6. Onshore assessment

6.1. DC cables

6.1.1. There is one onshore HVDC circuit proposed which consists of two cables and a third metallic return. The indicative cable layout is shown in Figure 6.1. This installation design was assessed for typical bipole operation and monopole operation, where the metallic return will be used as a current return path.

Figure 6.1: Typical onshore HVDC cable layout with bipole cables and metallic return.



6.1.2. As the cables operate as a bipole system, the current in each cable runs in opposition to the other leading to a significant cancellation of the magnetic field. The magnetic field for each design has been calculated using the maximum current rating of the cable and at 1m above ground.

6.1.3. 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 no external electric field will be emitted. The proposed underground cables produce no external electric fields, so are not considered further.

6.1.4. The DC magnetic fields from the cable itself and the combined fields from the cable and geomagnetic field were calculated in accordance with the provisions of the Code of Practice and a presented in Table 6.1 and Figures 6.2 and 6.3. All calculations were performed assuming maximum load, minimum cable separation and minimum burial depth, giving a worst-case scenario.

Figure 6.2: Maximum calculated magnetic fields from onshore HVDC cable circuits during normal operation. The magnetic field from the cable alone is demonstrated by the dark blue line and the total combined field with the geomagnetic field shown by the light blue line. The dotted black line represents the minimum threshold for potential effects on pacemakers.

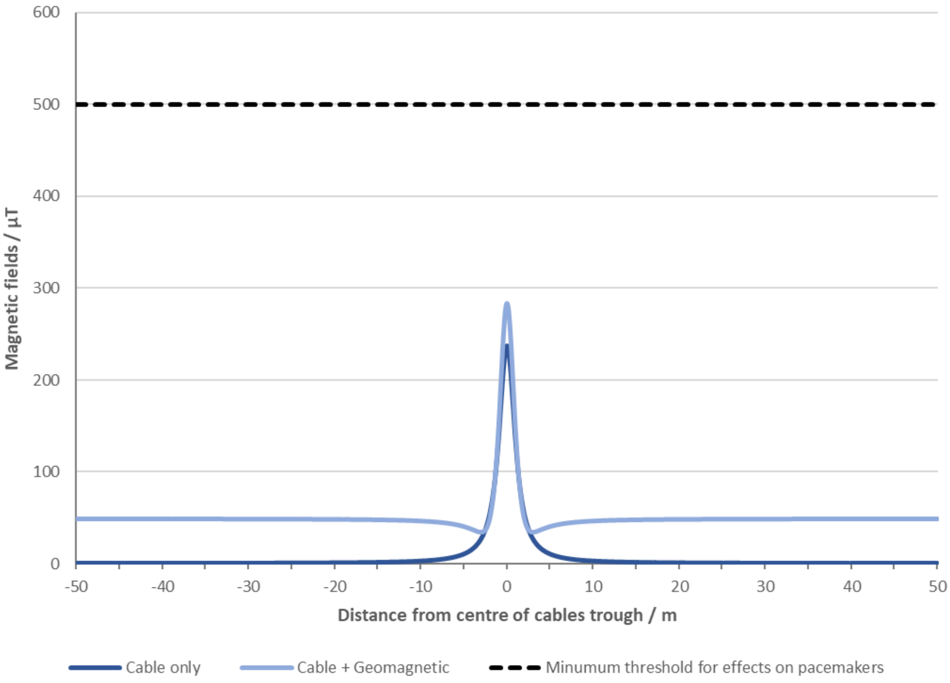


Figure 6.3: Maximum calculated magnetic fields from onshore HVDC cable circuits during normal operation. The magnetic field from the cable alone is demonstrated by the dark green line and the total combined field with the geomagnetic field shown by the light green line. The dotted black line represents the minimum threshold for potential effects on pacemakers.

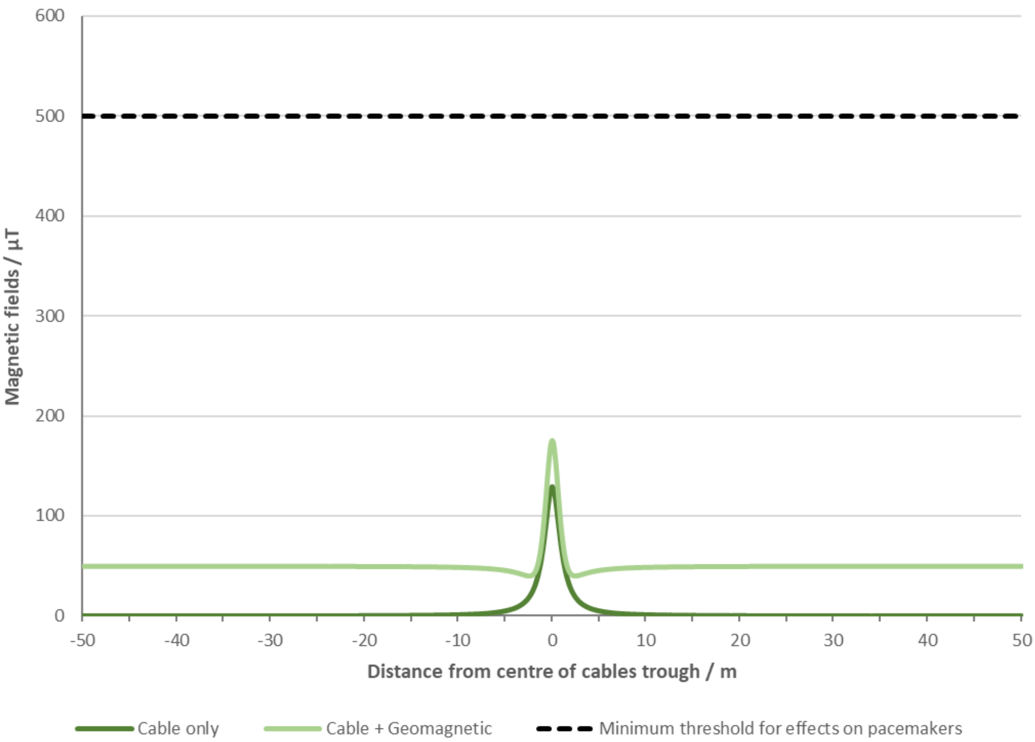


Table 6.1: Maximum calculated magnetic fields form onshore DC cables during normal and monopole operation. 0m represents directly on top of cables.

	Magnetic field (µT)					
	ICNIRP exposure limits	**0 m**	**5 m**	**10 m**	**25 m**	**50 m**
DC cable: normal operation	40 000	237.5	10.3	2.64	0.43	0.11
DC cable: monopole operation	40 000	129.3	5.13	1.32	0.21	0.05

6.1.5. The maximum calculated magnetic fields were 237.5 µT from the cable and 283.6 µT when combined with the earth's geomagnetic field during normal operation. When operating as a monopole the maximum calculated magnetic fields were 129.3 µT from the cable and 175.9 µT when combined with the earth's geomagnetic field These magnetic fields are compliant with ICNIRP 1994 public static magnetic field exposure limits (40 000 µT). The magnetic fields reduced quickly with distance from the cables as shown in Figures 6.2 and 6.3. Where the magnetic field from the cable combines with the earth's geomagnetic field, the resultant magnetic field is only elevated 2m either side of the cable during bipole operation and 1m either side during monopole operation, resulting in very localised fields.

6.1.6. For indirect effects such as on implanted medical devices ICNIRP suggest restrictions as low as 500 µT. The maximum magnetic field produced by the cables are significantly below this level, even when operation at maximum load.

6.2. Horizontally Directional Drilling River Crossing Cable Assessment

6.2.1. The onshore HVDC cables will cross a number of rivers using HDD. The cables will cross the river perpendicularly and installed at minimum depth of 5 m below the riverbed using HDD. The two HVDC cables and metallic return will be installed 5 m apart with the metallic return located centrally. The river depth and widths vary, with the maximum river depth being 2m.

6.2.2. Calculations of the magnetic fields have been performed at the riverbed, 0.2m, 0.5m, 1m and 2m above the riverbed for normal and monopole operations. Table 6.2 gives the maximum magnetic fields from the proposed DC cables at 100% current rating and the percentage net change from the background earths geomagnetic field. Table 6.3 gives the magnetic fields that will be present when combined with the earth's geomagnetic field.

6.2.3. No induced electric fields will occur as this is a freshwater river. Induced electric fields result from a conductive sea water moving through the magnetic fields inducing a charge. This does not occur in fresh water due to the low conductivity.

Table 6.2: Maximum magnetic field calculations for proposed river crossing DC cables- Cables only. Values are also presented of the percentage net change from the earths geomagnetic field background.

	Magnetic field (μT)				
	Riverbed	**0.2 m**	**0.5 m**	**1 m**	**2 m**
DC cable: normal operation	76.2	73.2	68.9	62.4	51.5
% above earths geomagnetic field	34.5%	31.8%	27.6%	20.0%	3.1%
DC cable: monopole operation	60.9	57.2	52.2	45.1	34.5
% above earths geomagnetic field	18.1%	12.8%	4.4%	0%	0%

Table 6.3: Maximum magnetic field calculations for proposed river crossing DC cables- Cables and geomagnetic field combined.

	Magnetic field (μT)				
	Riverbed	**0.2 m**	**0.5 m**	**1 m**	**2 m**
DC cable: normal operation	123.9	120.9	68.9	62.4	99.5
DC cable: monopole operation	108.9	105.2	100.2	93.3	82.9

6.2.4. Tables 6.2 and 6.3 provide the maximum magnetic fields for normal and monopole operation. When operating as a monopole the magnetic fields will be decreases slightly due to the metallic return being closer to the pole cable.

6.3. Converter station

6.3.1. The proposed Converter Station will use Voltage Source Converter technology. The proposed Converter Station will contain air-cored reactive equipment and as such compliance with the ICNIRP public exposure guidelines needs to be demonstrated, as per the Code of Practice. Specific EMF design criteria were incorporated into the proposed Converter Station's technical specification to ensure that the finalised design is compliant with public exposure limits at and beyond the Converter Station boundary. These specifications will ensure the following criteria are employed in the design:

- Static magnetic fields at the boundary fence of the proposed Converter Station site will not exceed the ICNIRP public exposure limits defined above; and
- AC magnetic fields at the boundary fence of the proposed Converter Station site shall not exceed the general public exposure limit defined above.

6.3.2. The proposed Converter Station may have some bare conductors in the central portion of the site which will operate at 50 Hz. These will produce an electric field which will diminish quickly increasing with distance from source. The palisade security fencing and buildings, however, will screen the electric field at the boundary of the site. These types of bare conductors have been demonstrated to be inherently compliant with exposure guidelines. The convertor building itself will shield any 50 Hz electric fields from equipment housed within it. As such, electric fields have not been considered further in the assessment.

7. Conclusions

Offshore

5.1.1. National Policy Statement EN-3 states that "*Where it is proposed that mitigation measures of the type set out in paragraph 2.6.76 below are applied to offshore export cables to reduce electromagnetic fields (EMF) the residual effects of EMF on sensitive species from cable infrastructure during operation are not likely to be significant. Once installed, operational EMF impacts are unlikely to be of sufficient range or strength to create a barrier to fish movement*"

5.1.2. The LionLink project proposes to use armoured cables which mitigates both the direct electric fields and to an extent the magnetic fields. Cables are expected to be buried to a depth of 1 m below the seabed, which further reduces the magnetic fields and is a suggested mitigation technique in NPS EN-3.

5.1.3. Bundled cables produced the lowest magnetic fields and is the most effective mitigation for the total route length, except for a very short length where cables transition to land. In this location cables are installed via a trenchless technique to come ashore, the magnetic fields at the seabed are similar to those of bundled cables due to the additional burial depth. As electric fields are proportional to the magnetic fields produced by the cables, the above statements also apply to the induced electric fields for both installation techniques

5.1.4. Bundled cable designs result in very low compass deviation compass deviations to occur across the entire route considered which meets the MMO requirements set out in Section 5.5.3. The entire length of HDD cabling would likely result in compass deviations that exceed the MMO's requirements. The deviation for the HDD section are all less than 9 degrees for this short section, this is due to the cable separation and the shallow waters (<3 m deep).

5.1.5. The LionLink cables use armoured cables and cable burial to mitigate the impacts of EMF on marine life. The cables are also proposed to be bundled to reduce the magnetic fields.

5.1.6. There are no formal limits for EMF exposure which apply to the marine environment, but the proposed bundled design reduces magnetic fields significantly compared to other installation method.

Onshore

5.1.7. For onshore HVDC cables, the maximum magnetic fields produced is less than the relevant ICNIRP exposure limit detailed in Section 2.1. Therefore, all installation options are compliant with the policies in place in the UK to protect public health and are assessed as having no significant adverse effects.

5.1.8. All of the HVAC electrical connection options assessed produced magnetic fields significantly below the ICNIRP public exposure limits. Under maximum normal loading conditions, the maximum calculated magnetic fields were less than 1% of the exposure limit. All other operating conditions result in lower magnetic fields.

5.1.9. All magnetic fields produced by the project will be significantly below the interference thresholds for active implantable medical devices, such as pacemakers.

5.1.10. The Government, acting on the advice of authoritative scientific bodies, has put in place appropriate measures to protect the public from EMFs. These measures comprise compliance with the relevant exposure limits, and one additional precautionary measure, optimum phasing, applying only to high-voltage overhead power lines. These measures are set out in a Written Ministerial Statement, National Policy statement EN-5, and various Codes of Practice.

5.1.11. All of the proposed onshore LionLink cable designs and convertor station would be fully compliant with the Government policy. Specifically, all the fields produced would be below the relevant exposure limits. Therefore, there would be no significant EMF effects resulting from this proposed development.

5.1.12. No mitigation measures for this cable design are necessary as both technology options have been demonstrated to comply with the current public exposure guidelines as detailed in NPS EN-5[1]. If these requirements are met NPS EN-5[1] states that *"no further mitigation should be necessary."*

5.1.13. There are no corresponding limits for non-human exposure in freshwater environments. The magnetic field exposures from river crossings assessed in Section 6.2 demonstrates the levels are a maximum of 34.5 % above the ambient background fields on the riverbed reducing with distance during normal operation of the cable. For monopolar operation the magnetic field is less than in normal operation, due to the cable design.

APPENDIX A

Table A1: Calculated magnetic field at 50% load for the for offshore HVDC design options for the LionLink project. Calculations are provided for increasing vertical distance from the seabed and maximum current load. All calculations were performed for a minimum burial depth of 1 m, except the HDD installation which has a burial depth of 25m.

	Maximum magnetic field: cable magnetic field only					
Distance above seabed	**At seabed**	**0.5m**	**1m**	**5m**	**10m**	**20m**
Bundled pair	26.0	11.6	6.5	0.73	0.22	0.06
HDD installation	6.7	6.6	6.4	5.1	4.0	2.6

Table A2: Calculated induced electric field for each cable design using the calculated magnetic fields provided in Tables 5.2 and 5.3. The induced electric field was calculated for a range of tidal velocities at increasing vertical distances from the cables.

Induced electric field (μV/m)						
Tidal velocity	**Distance above seabed**	**Field μT**	**0.5 m/s**	**0.75 m/s**	**1.0 m/s**	**1.3 m/s**
Bundled pair, both bipole and monopole operation	Seabed	51.90	25.95	38.93	51.90	67.47
	0.5 m	23.10	11.55	17.33	23.10	30.03
	1 m	13.00	6.50	9.75	13.00	16.90
	5 m	1.45	0.73	1.09	1.45	1.89
	10 m	0.43	0.22	0.32	0.43	0.56
	20 m	0.12	0.06	0.09	0.12	0.16
HDD separated by 30m, 25m deep	Seabed	13.40	6.70	10.05	13.40	17.42
	0.5 m	13.10	6.55	9.83	13.10	17.03
	1 m	12.80	6.40	9.60	12.80	16.64
	5 m	10.20	5.10	7.65	10.20	13.26
	10 m	7.90	3.95	5.93	7.90	10.27
	20 m	5.10	2.55	3.83	5.10	6.63

APPENDIX B- Compass deviations calculations

Figure B1: Calculated compass deviations for LionLink with bundled design. Compass deviations at sea level were calculated along the entire route using the depth to seabed and cable angle to vertical for each station mark.

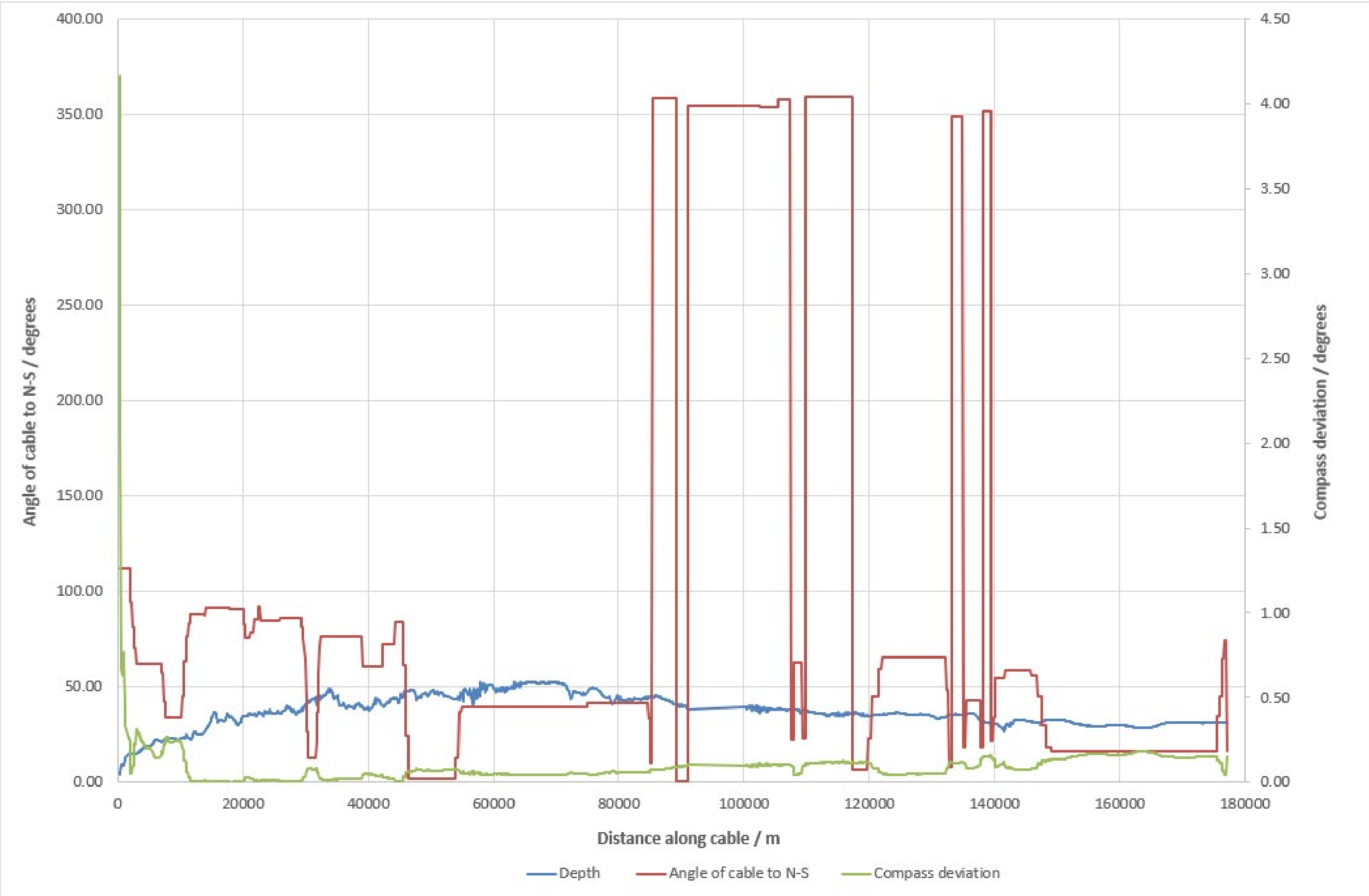


Figure B2: Calculated compass deviations for LionLink HDD cable design. Compass deviations at sea level were calculated in the near shore environment, 30m from the shoreline using the depth to seabed and cable angle to vertical for each station mark.