The Great Grid Upgrade

Eastern Green Link 3 (EGL 3) and
Eastern Green Link 4 (EGL 4)

Preliminary environmental information report (PEIR)

Volume 2, Part 1, Appendix 1.4.A Electromagnetic Fields (EMF) Assessment

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nationalgrid

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1.4.A Electromagnetic Field (EMF) Assessment

1.4.A.1 Overview

1.4.A.1.1 The following technical report has been prepared by National Grid Electricity Transmission plc (NGET) to inform the preliminary environmental assessments for the development of the English Onshore Scheme and English Offshore Scheme.

Contents

Abbreviations

AC	Alternating Current
DC	Direct Current
EGL	Eastern Green Link
EIA	Environmental Impact Assessment
ELF	Extremely Low Frequency
EMF	Electric and Magnetic Field
EU	the European Union
GIS	Gas Insulated Switchgear
Hz	Hertz
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 metre
NPS	National Policy Statement
NRPB	National Radiological Protection Board
MMO	Marine Management Organisation
PEIR	Preliminary Environmental Information Report
PHE	Public Health England
UKHO	UK Hydrographic Office
VSC	Voltage Source Converters
WHO	World Health Organisation
µT	Microtesla

1. Introduction

1.1.1. This document provides an assessment of electric and magnetic fields (EMFs) associated with the proposed Eastern Green Link (EGL) 3 and 4 projects. The EGL 3 and 4 projects are needed to increase network capability to connect the numerous new offshore wind farms that are being developed, and transport new clean green energy to the homes and businesses where it is needed.

1.1.2. Each project is a transmission reinforcement electrical link between Scotland and England, with associated onshore infrastructure allowing this to connect to the existing transmission infrastructure. The connection points for each of the projects are:

- EGL 3: HVDC link between Peterhead, Aberdeenshire, and the south Lincolnshire/West Norfolk area
- EGL 4: HVDC link from Kinghorn, Fife, also to the south Lincolnshire/West Norfolk area

1.1.3. This report describes Electric and Magnetic Fields (EMFs) produced by the operation of the proposed converter stations, the associated High Voltage Direct Current (HVDC) bipole cables and 50 Hz underground Alternating Current (AC) cables connecting the proposed converter stations to the existing National Grid 400kV Substation, in the onshore and offshore environments.

1.1.4. All equipment that generates, transmits, distributes or uses electricity produces EMFs. In the UK electricity is normally generated, transmitted, distributed and consumed as AC. The UK power frequency for AC is 50 Hertz (Hz), which is therefore the principal frequency of the EMFs produced, also known as Extremely Low Frequency (ELF) EMFs. The EGL 3 and 4 will use DC transmission which has a frequency of zero Hertz (0 Hz) and will produce static EMFs. The proposed converter stations will then convert DC transmission to AC 50 Hz transmission which can be connected to the existing National Grid transmission system.

1.1.5. The key English elements of our proposals for consultation include:

- two subsea cable circuits to each landfall location, whereby only the English aspects are being consulted on;
    - EGL 3: from Sandford Bay in Peterhead to a common landfall with EGL 4 at Anderby Creek in Lincolnshire
    - EGL 4: from Kinghorn in Fife to a common landfall with EGL 3 at Anderby Creek in Lincolnshire
- two co-located HVDC underground cable routes, from the Anderby Creek landfall on the Lincolnshire coastline;
- from landfall, the underground HVDC cable circuits would run to the two proposed new converter stations in the Walpole area, of Kings Lynn & West Norfolk;
- one new converter station;
- the route of two separate HVAC underground cables to connect the proposed converter stations to the new Walpole 400kV substation, and into the electricity transmission network;
- one new substation in the Walpole area (also proposed as part of NGET's Grimsby to Walpole project); and,
- potential converter station design approaches that we could consider during the later design stages.

1.1.6. 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.

Electric fields

1.1.7. 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.

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

1.1.9. 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 5.3.

Magnetic fields

1.1.10. 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.

1.1.11. 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.

1.1.12. The earth also produces its own DC magnetic field, which in the UK is around 50 μT, but this can vary due to geomagnetic material such as rocks.

1.1.13. 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 steady EMFs that always point in the same direction. There will also be approximately 5 km of AC cables installed between the proposed converter station and Walpole Substation which will operate at 50 Hz.

1.1.14. The proposed converter station will contain specialist electrical equipment which will produce both DC and AC fields which are assessed in this report.

1.1.15. EGL 3 and 4 will be developed as HVDC cable circuits. Where the cables come onshore, convertor stations and HVAC cabling and substations will be required to enable the power to connect to the existing transmission system.

1.1.16. This report will assess the EMF from the project and any mitigation to be considered.

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. Government has a clear policy on the exposure limits and other policies they expect to see applied, restated in January 2024 and incorporated in NPS EN-5[1]. 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. In the absence of any specific Scottish Government guidelines, those set by the UK Government remain applicable for the EGL 3 and 4 Projects. 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:

[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.

"…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 for uniform exposure 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 40,000μT (40 millitesla). However, ICNIRP's 1994 guidance[5], states that there are potential indirect effects, such as injuries due to flying ferromagnetic objects and potential interactions with implantable medical devices which could occur at levels below the exposure limits. These limits are detailed in Table 2.1.

2.1.6. Therefore, a lower restriction of 500 μT should be considered where indirect effects may be an issue. 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'.

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**

*No DC electric field limits are provided in the guidelines, but 20 kV/m is recommended by the IEEE to prevent spark discharges[6]

[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.
[6] IEEE standard for safety levels with respect to human exposure to radio frequency electromagnetic fields, 0 Hz to 300 GHz, IEEE-C95.1, NY, USA, 2019

2.2. Policy Framework for the Protection of marine life

2.2.1. National Policy Statement EN-3[7] 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 inter-array and export cables. Armoured cables are proposed for the EGL 3 and 4 project. Burial depth can reduce the magnetic fields at distance but to a lesser extent than cable bundling or compact phase arrangements. Therefore, mitigation of EMF from offshore cables can also occur by reducing the separation of the cables in each bipole system. 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 assessments.

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. This is a potential issue with direct current (DC) conductors or cables, which produce a static magnetic field that perturbs the geomagnetic field. These are assessed in Section 5.4.

2.3.3. High voltage AC cables produce 50 Hz magnetic fields. These oscillate far too quickly (50 times per second) for a magnetic compass needle to be affected. Fluxgate magnetometers are capable of responding to 50 Hz fields, but, when used as a compass, always have filtering to eliminate unwanted frequencies including 50 Hz. They can cease working correctly if saturated by a high-enough field, but the field required is orders of magnitude higher than would be produced by the Project. Magnetic compass impacts do not occur where AC cables are installed, so there will be no impact from these assets.

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 50 μT in the UK. This field may be distorted locally by ferrous minerals or by steelwork such as in buildings or bridges.

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

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.

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.

Offshore

3.1.5. The current offshore environment where the EGL 3 and 4 cables are proposed, has naturally occurring DC magnetic fields, which again is around 50 μT.

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. Given the background geomagnetic field of around 50 μT, the background induced electric field could range between 4.9 and 61.3 μV/m in tidal velocities ranging between 0.1 m/s and 1.25 m/s.

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[2]. 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 substation 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 stations 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 stations and substations 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. Assessment of Effects

4.2.1. The onshore EGL 3 and 4 projects would be assessed as having an adverse effect if non-compliance with the EMF exposure limits was demonstrated, using the principles set out in Codes of Practice2. Conversely, as specified in NPS EN-51 if the proposed projects comply with the exposure limits, EMF effects are assessed as not significant, and no mitigation is necessary.

4.2.2. 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. The impact of EMF on marine life will be covered within Volume 1, Part 3, Chapter 19 Intertidal and Subtidal Benthic Ecology, and Volume 1, Part 3 Chapter 20 Fish and Shellfish of the Preliminary Environmental Information Report (PEIR) and Environmental Statement (ES). The impact of EMF on the freshwater environment will be covered within Volume 1, Part 2, Chapter 6 Biodiversity of the PEIR and ES.

5. Assessment of Offshore EMF

5.1.1. EGL 3 and 4 will be formed of two new primarily offshore High Voltage Direct Current (HVDC) electrical links operating at 0 Hz (DC). Each transmission link will consist of a bipole system with 2 cables, each taking a different route offshore.

5.1.2. The installation and electrical design of the transmission links will impact the EMFs produced. The vast majority of the route will be a bundled bipole design. Where cables transition to land, cables are installed via a trenchless solution such as Horizontal Directional Drilling. The design for each of the two transmission circuits is included in Table 5.1 and has been used for the EMF assessment. For the HDD design, the largest cable separation has been considered which represents the worst-case design in EMF terms.

5.1.3. Design 1 has a bundled pair of cables which are assumed to have a 0.2 m separation in a single trench. Design 2, each cable has a 20 m separation and is a minimum of 21 m deep.

Table 5.1: EGL 3 and 4 cable geometries and calculation parameters for all electrical designs

Design option	Cable configuration	No. cables	No. trenches	Power per cable	Current per cable	Voltage
1	**Bundled**	2	1	1 GW	1930A	± 525kV
2	**Horizontal Directional Drill**	2	One cable per duct	1 GW	1930A	± 525kV

5.1.4. The magnetic field produced by the cables 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.

5.1.5. The magnetic field produced by the cables will in turn induce electric fields in sea water passing through the field, due to the sea waters conductivity. This will be proportional to the magnetic field and the velocity of the water.

5.2. Magnetic field assessment

5.2.1. All calculations were performed assuming the maximum circuit separation and minimum burial depth, and 100% load giving a worst-case scenario provided in Table 5.2 for cable only magnetic fields. The magnetic field from the cables will also combine with the earths geomagnetic field and these combined fields are provided in Table 5.3 and 5.5. 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 both projects was calculated at vertical distances of 0 to 20 m from the seabed, and horizontal drop off along the seabed. A minimum burial depth of 1 m was used for all bundled cables and 21 m burial depth for the HDD cables.

5.2.3. Table 5.2 gives the maximum magnetic field at vertical distances from the cables from both installation methods. Table 5.2 also gives the distance from the cables that the magnetic field produced by the cables reduces to below 49.6 μT, the earths geomagnetic field in the area.

5.2.4. Figures 5.2 to 5.4 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 5.3 gives the total magnetic field when combined with the geomagnetic field for the bundled and HDD cables.

Table 5.2: Calculated maximum cable magnetic fields at vertical distances from the seabed for the buried offshore cable circuit design options. Bundled cables are buried 1 m below the seabed and the HDD design has a burial depth of 21 m. 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	
Bundled cables	76.4	34.2	19.3	8.6	2.1	0.6	0.2	0.25 m above seabed
HDD	14.3	13.7	13.2	12.3	9.9	7.3	4.3	None above

Table 5.3: Calculated maximum cable magnetic fields at vertical distances from the seabed for the buried offshore cable circuit options during normal operation combined with the earths geomagnetic field. Bundled cables are buried 1 m below the seabed except option 3, which has a burial depth of 25 m.

	Magnetic field (μT)						
	Distance above seabed (m)						
	Seabed	0.5 m	1 m	2 m	5 m	10 m	20 m
Bundled cables	123.8	82.2	67.8	57.6	51.6	50.2	49.7
HDD	63.0	62.5	62.0	61.1	58.9	56.4	53.6

Figure 5.1: Calculated maximum magnetic fields horizontally along the seabed for bundled cable design. The light blue line shows the maximum magnetic field from the cables only. The dark blue line shows the total magnetic field when the magnetic field from the cables is combined with the Earth's geomagnetic field.

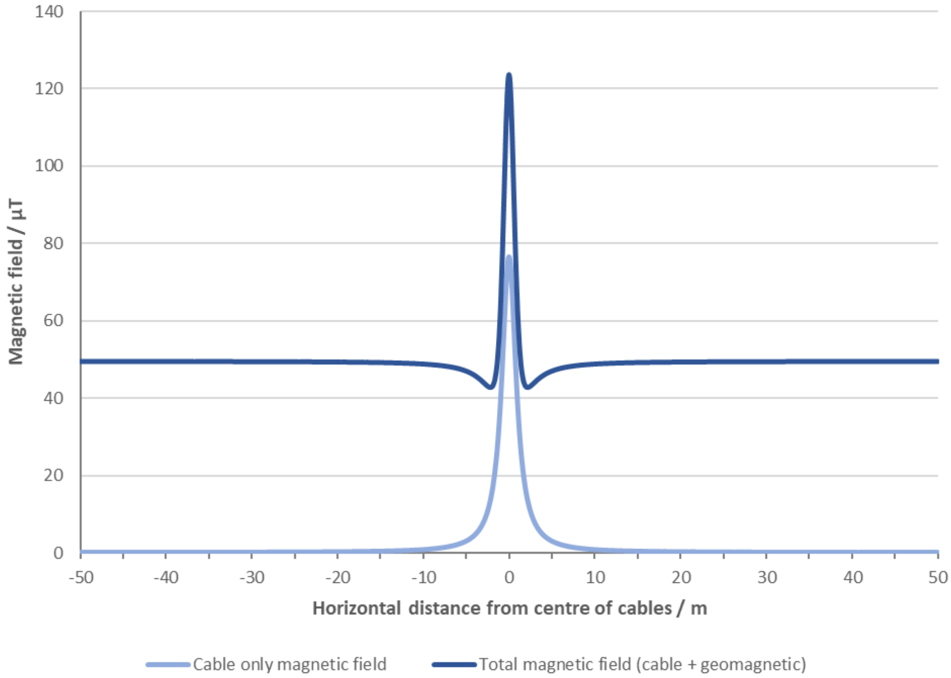
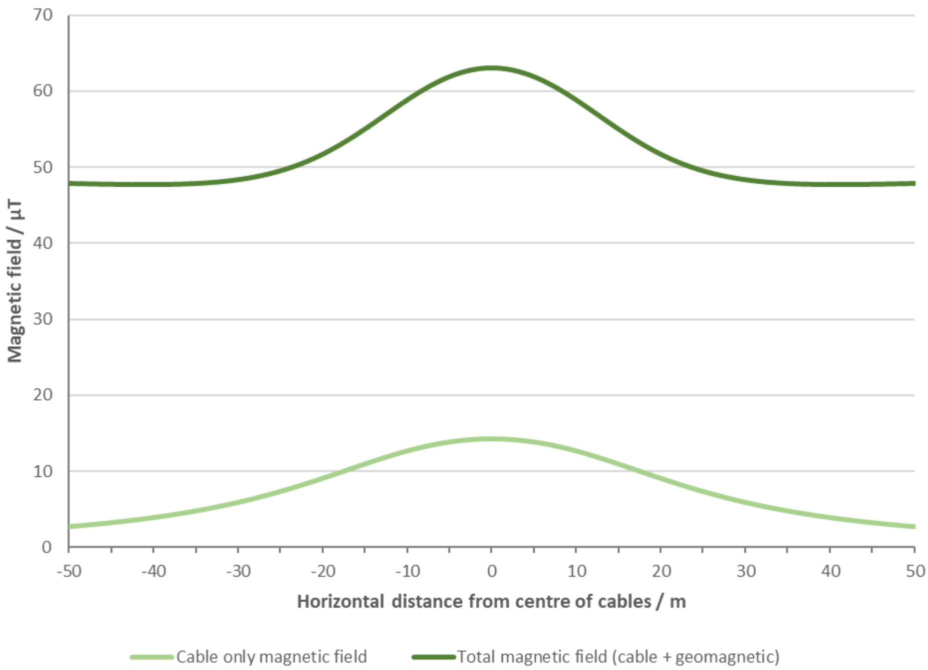


Figure 5.2: Calculated maximum magnetic fields horizontally along the seabed for HDD cable design. The light green line shows the maximum magnetic field from the cables only. The dark green line shows the total magnetic field when the magnetic field from the cables is combined with the Earth's geomagnetic 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 5.1 and Figures 5.1 and 5.2). The maximum magnetic fields calculated at the seabed were 76.4 μT for bundled cables and 14.3 μT when installed using HDD. It is important to note that these levels do not take account of shielding factors of the cable sheath which would further reduce the fields.

5.3. Induced electric fields

5.3.1. The HVDC cable will produce a magnetic field which decreases with distance from the cables and current flowing through the cables. The movement of the sea 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 geomagnetic field and localised magnetic anomalies. The strength of this field varies continuously due to the strength, speed and direction of the tide.

5.3.2. 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)

5.3.3. 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. In the absence of information of tidal velocity at the cable's locations, calculations are evaluated for values up to 1.25 m/s, as was used for the Western Link cable assessment.

5.3.4. The average geomagnetic field along the EGL 3 and 4 routes is approximately 50 μT, which is used to calculate the background induced electric field. This background magnetic field induces an electric field that could range between 5.0 and 65.0 μV/m in tidal velocities ranging between 0.1 m/s and 1.35 m/s. This does not take account of localised magnetic anomalies, which could result in higher localised electric fields, or of greater tidal velocities. Direction of water flow is also an important consideration, which has been assumed to be in the worst-case scenario for calculations.

5.3.5. Table A2 in Appendix A gives the calculated induced electric field for the two cable designs at four representative tidal velocities.

5.3.6. Calculations indicate the electric field is highly dependent on the tidal velocity and that the effects around the cables are localised. For both cable installation methods, the induced electric field are a similar magnitude to that occurring naturally. Magnetic fields are highest closest to the seabed, here water velocity will be lower due to friction, so calculations at maximum velocities would not occur in practice.

5.4. Compass deviations along route

5.4.1. 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.

5.4.2. It is the horizontal component of the geomagnetic field that is used for navigation, and this varies between 49.62 μT in East Scotland area and 49.57 μT in the Lincolnshire area[8]. A value of 49.6 μT is used for the studies here.

5.4.3. The Marine Management Organisation (MMO) have previously provided the following guidance for projects with a similar design:

"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 (UK Hydrographic Office) via a hydrographic note (H102), as they may want a precautionary notation on the appropriate Admiralty Charts."

[8] Taken from British Geological Society website
https://geomag.bgs.ac.uk/data_service/models_compass/wmm_calc.html

5.4.4. The magnetic fields and compass deviation at the sea's surface were calculated for both EGL 3 and EGL 4 cable routes 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, sea 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.

5.4.5. The maximum compass deviation for each route has been calculated along its entire length for the maximum circuit current. The results are shown in Figure B1 and B2 in Appendix B. The compass deviation is shown as a solid purple line for the main route. If the EGL 3 and 4 projects are not operating at full capacity, the compass deviation will be smaller. The depth of the cables from the water surface is shown as the red line.

5.4.6. The depth of the cable, used for the calculation of compass deviation, is deeper than the seabed depth by the 1 m burial depth. The compass deviation is calculated at the level of the sea surface. In practice the draught 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 found in practice.

5.4.7. Table 5.4 gives the percentage of the EGL 3 and 4 routes resulting in compass deviations at the sea surface of less than 3° and 5°. For this aspect, the parts of the cable which come ashore, where depth of the seabed becomes zero or negative, are excluded. The change in compass deviation along each route is provided in Appendix B, Figures B1 and B2.

Table 5.4: Percentage of the EGL 3 and 4 routes resulting in compass deviations of less than 3° and 5° variations.

	Proportion of route within compass deviation threshold
	Bundled cable design
EGL 3 route	
Less than 3° deviation	99.6%
Less than 5° deviation	99.7%
EGL 4 route	
Less than 3° deviation	99.5%
Less than 5° deviation	99.7%

EGL 3 and 4 Routes

Very low compass deviation occurs over the vast majority of the route. Both EGL 3 and 4 cable routes will meet MMO compass requirements of less than 5% of route causing deviations of less than 3 degrees. Due to the shallow water depth and cable separation, compass deviations in the section of cable installed using HDD exceed 5 degrees. However, the sea depth is less than 3 m deep in these areas, and most often much shallower.

6. Onshore assessment

6.1. DC cables

6.1.1. There are two lands based HVDC circuits proposed for the projects, each consisting of two cables which operate as a bipole system. Where the EGL 3 and 4 projects come ashore in England, they will be co-located for parts of the route near one another. This installation design was assessed as a worst-case situation. Where the circuits diverge or where they connect at different locations in Scotland, the EMF will be lower.

6.1.2. Where cables are collocated each circuit will be installed in a separate trench 14m apart. The cables for each bipole will be installed in each trench at a minimum burial depth of 1m and cables a maximum of 1m apart.

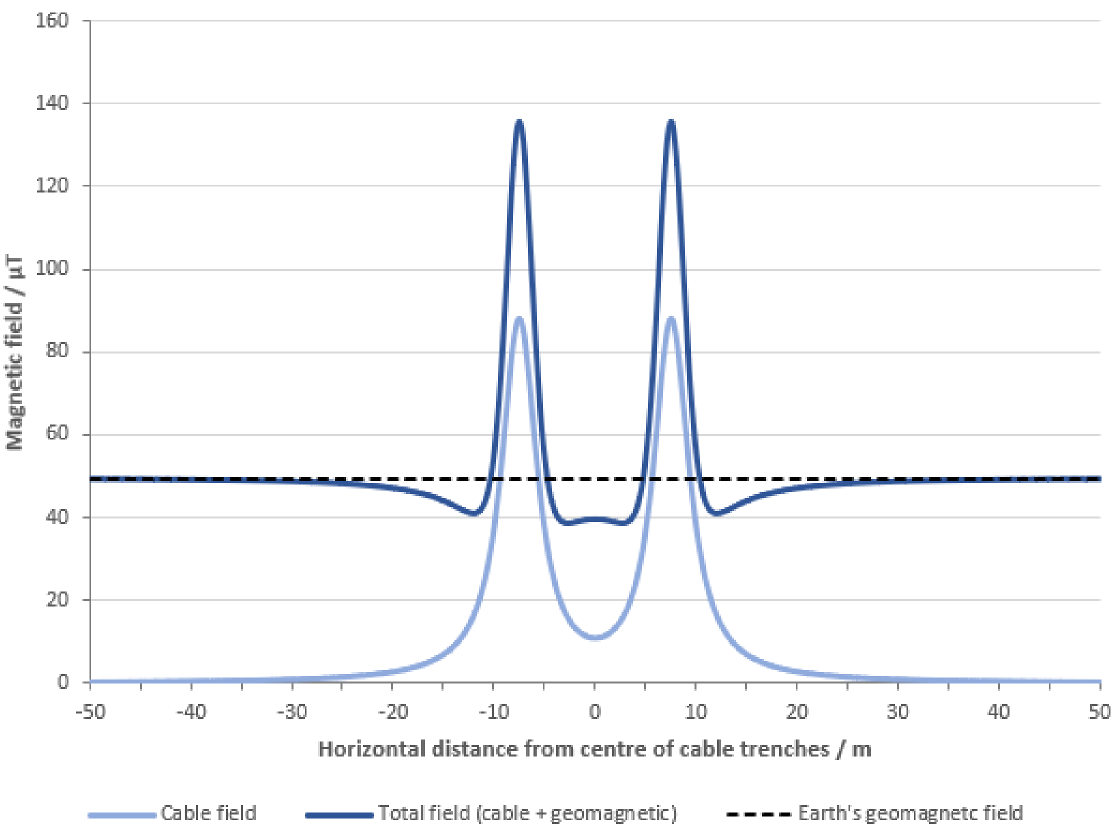
6.1.3. As the cables operate as a bipole system, the current in each cable runs in opposition to the other leading to a significant cancellation of the magnetic field. The magnetic field for each design has been calculated using the maximum current rating of the cable and at 1m above ground.

6.1.4. 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.

6.1.5. 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 Figure 6.1. All calculations were performed assuming maximum load, minimum cable separation and minimum burial depth, giving a worst-case scenario.

6.1.6. The maximum magnetic field calculated at 1m above ground for the cable itself and its combination with the earth's geomagnetic field is 88.0 μT and 135.6 μT respectively.

Figure 6.1: Maximum calculated magnetic fields from onshore HVDC cable circuits. The magnetic field from the cable alone is demonstrated by the light blue line and the total combined field with the geomagnetic field shown by the dark blue line. The dotted black line represents the background geomagnetic field.



6.1.7. The maximum calculated magnetic fields were 88.0 μT from the cable and 135.6 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 Figure 6.1.

6.1.8. For indirect effects such as on implanted medical devices or forces on ferromagnetic objects ICNIRP suggest restrictions as low as 500 μT. The maximum magnetic field produced by the cables are significantly below this level.

6.2. AC cables

6.2.1. Two 400 kV 50 Hz underground cable circuits will be installed at a minimum burial depth of 1 m. Each circuit will have 1 cable per phase, three cables in total with 0.5m phase separation and a minimum of 5m circuit separation (centre to centre). The HVAC cables will connect between the convertor stations to the proposed substation

6.2.2. The magnetic field for each design has been calculated using the maximum continuous current rating of the cable (1550 Amps) and at 1 m above ground. The maximum magnetic field calculated at 1m above ground is 71.6 μT directly above the cables. Magnetic fields reduce quickly with distance from source and Table 6.1 sets out the magnetic field strength at various distances from source. Figure 6.2 shows the magnetic field at 1m above ground fand how the magnetic fields reduce with distance from the cables.

Figure 6.2: Maximum calculated magnetic fields from onshore 400 kV cable circuits. Two peaks represent each of the cable circuits**.**

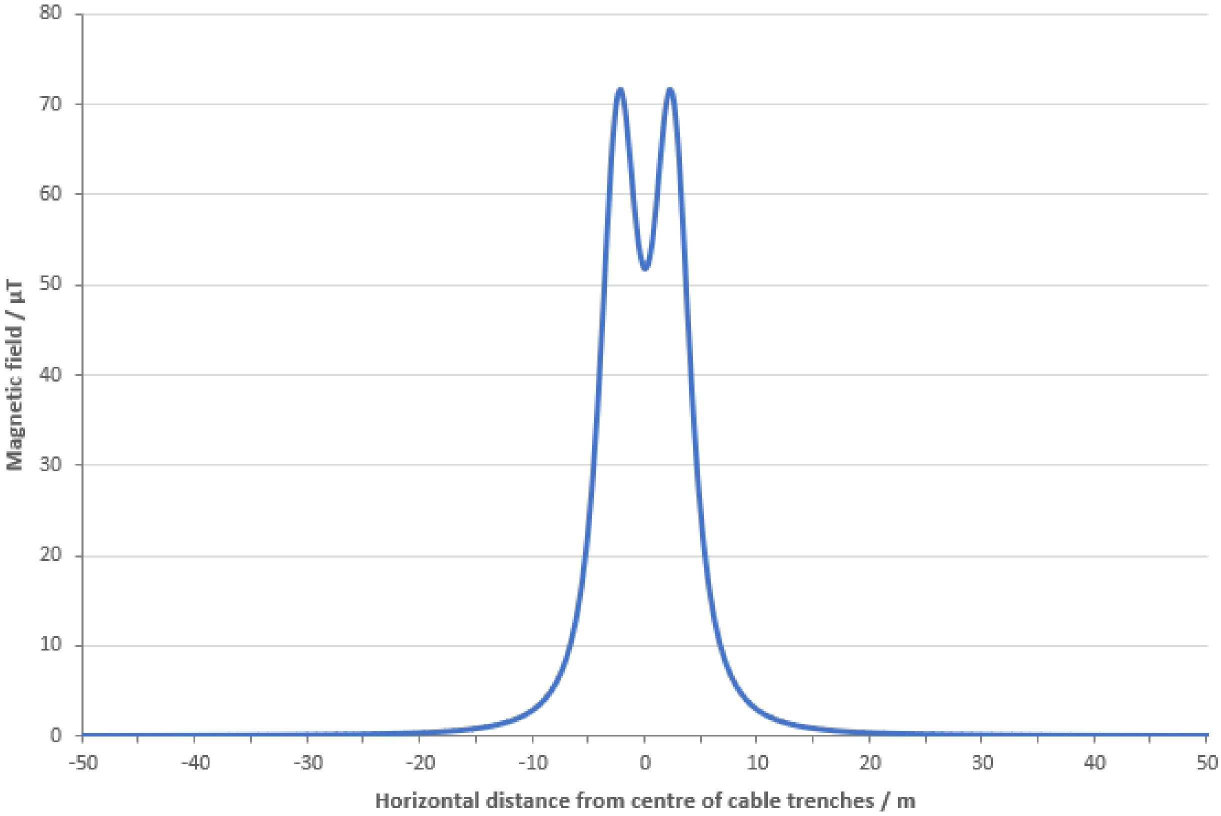


Table 6.1: **Maximum calculated magnetic fields form onshore AC and DC cables only.** 0m represents directly on top of cables.

		Magnetic field (µT)				
	ICNIRP Exposure Limits	**0 m**	**5 m**	**10 m**	**25 m**	**50 m**
AC onshore cables	360 µT	71.6	23.7	2.86	0.17	0.02
DC onshore cables	40 000 µT	88.0	14.0	4.26	0.84	0.30

6.3. Converter stations

6.3.1. The proposed Converter Stations will use Voltage Source Converter (VSC) 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. 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 EGL 3 and 4 projects propose 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 (other than areas where surface lay may with rock protection be required due to geological conditions), 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 lengths where cables transition to land. In these locations cables are installed via a trenchless technique to come ashore, the magnetic fields at the seabed are lower than 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. The cable designs proposed result in very low compass deviation compass deviations to occur across the majority of both the EGL 3 and 4 routes. For both the EGL 3 and 4 routes over 99.5 of the route resulted in compass deviations of less than 3 degrees, meeting MMO's requirements (Section 5.4.3). Small sections in the near shore area of each route exceed 3 degrees, due to the shallow water depth. These deviations occur in sea depths of less than 3 m.

5.1.5. The EGL 3 and 4 projects 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 methods.

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 cable designs and convertor stations 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[2]. If these requirements are met NPS EN-5 states that “no further mitigation should be necessary.”

APPENDIX A

Table A1: Calculated magnetic field at 50% load for the two offshore HVDC design options for EGL 3 and 4. 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.

	Maximum magnetic field: cable magnetic field only					
Distance above seabed	**At seabed**	**0.5m**	**1m**	**5m**	**10m**	**20m**
Bundled pair	38.2	17.1	9.65	1.05	0.3	0.09
HDD	7.15	6.85	6.6	4.95	3.65	2.15

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

Induced electric field (μV/m)						
Tidal velocity	**Distance above seabed**	**Field μT**	**0.1 m/s**	**0.3 m/s**	**0.75 m/s**	**1.35 m/s**
Bundled pair	Seabed	76.4	7.64	22.92	57.3	103.14
	0.5 m	34.2	34.2	10.26	25.65	46.17
	1 m	19.3	1.93	5.79	14.48	26.06
	5 m	2.1	0.21	0.63	1.58	2.84
	10 m	0.6	0.06	0.18	0.45	0.81
	20 m	0.2	0.02	0.06	0.15	0.27
HDD	Seabed	14.3	1.43	4.29	10.73	19.31
	0.5 m	13.7	1.37	4.11	10.28	18.50
	1 m	13.2	1.32	3.96	9.90	17.82
	5 m	9.9	0.99	2.97	7.43	13.37
	10 m	7.3	0.73	2.19	5.48	9.86
	20 m	4.3	0.43	1.29	3.23	5.81

APPENDIX B- Compass deviations calculations

Figure B1: Calculated compass deviations for EGL 3 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, excluding areas where no sea water was present.

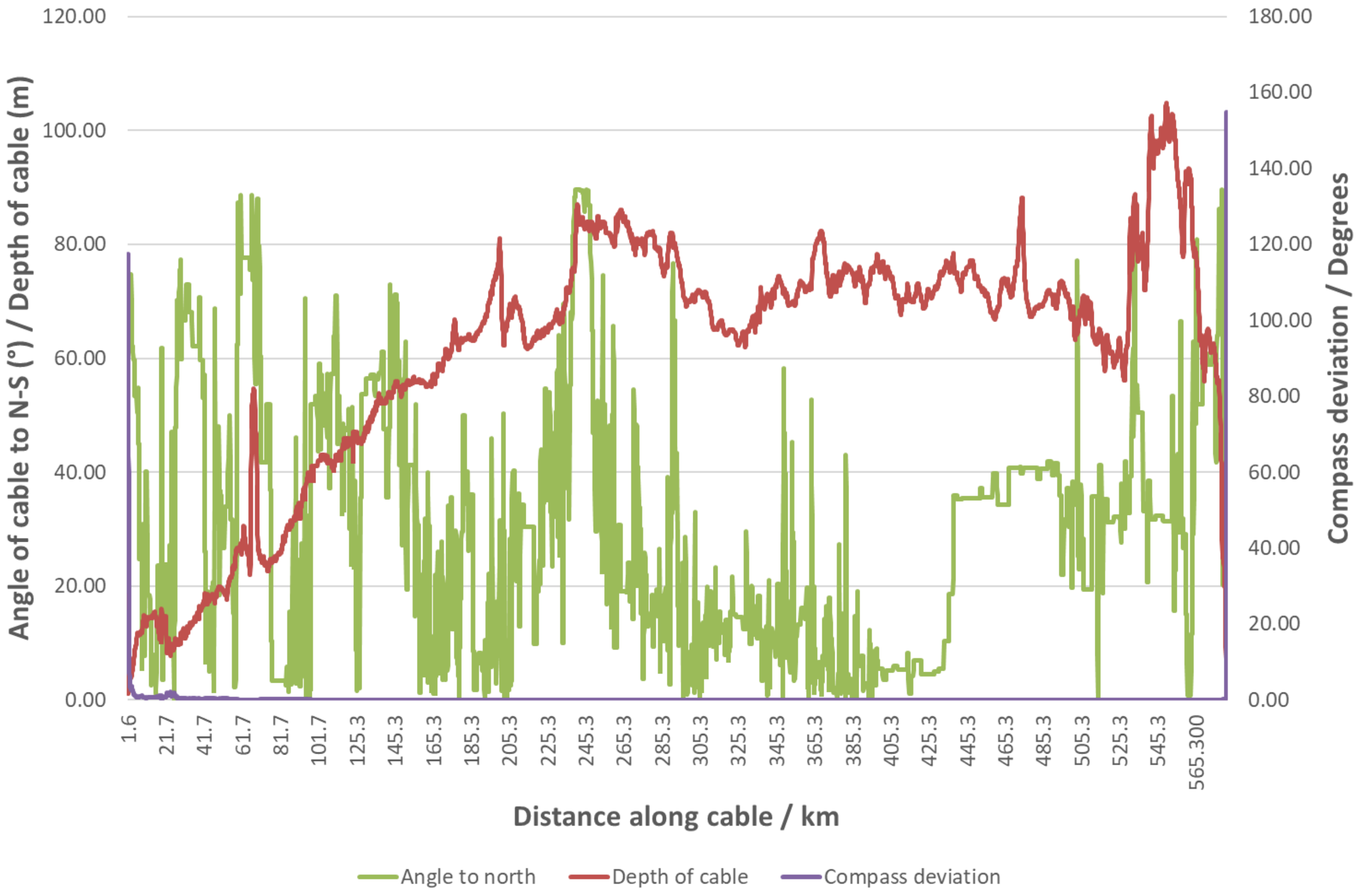
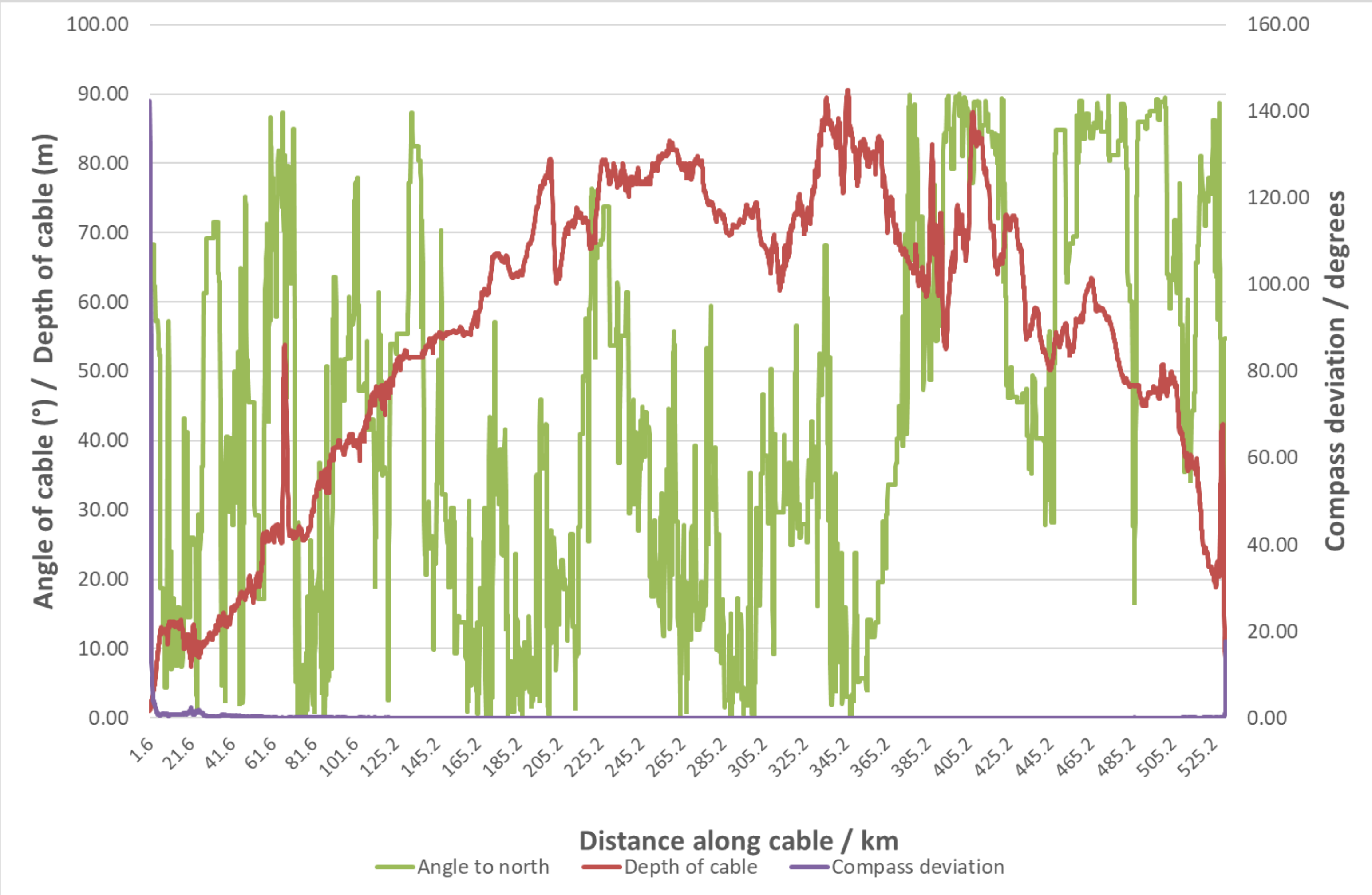


Figure B2: Calculated compass deviations for EGL 4 with bundled design. Compass deviations at sea level were calculated along the entire route using the depth to seabed and cable angle to vertical for each station mark, excluding areas where no sea water was present.



Angle of cable (°) / Depth of cable (m)
100.00
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
Compass deviation / degrees
160.00
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
1.6
21.6
41.6
61.6
81.6
101.6
125.2
145.2
165.2
185.2
205.2
225.2
245.2
265.2
285.2
305.2
325.2
345.2
365.2
385.2
405.2
425.2
445.2
465.2
485.2
505.2
525.2
Distance along cable / km
Angle to north
Depth of cable
Compass deviation

National Grid plc
National Grid House,
Warwick Technology Park,
Gallows Hill, Warwick.
CV34 6DA United Kingdom

Registered in England and Wales
No. 4031152
nationalgrid.com