GREEN VOLT

Technical Appendix 9.2

EMF Assessment Report

Offshore EIA Report: Volume 2

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nationalgrid

Green Volt Project EMF assessment

Document Control			
Document Properties			
Organisation	National Grid		
Author			
Title	Green Volt EMF Assessment		
Document Reference	EEN/472/NOTE2022		
Version History			
Date	**Version**	**Status**	**Description/Changes**
08/06/22	V1	Draft	Draft for Floatation Energy

Contents

Abbreviations

AC	Alternating Current
DC	Direct Current
EIA	Environmental Impact Assessment
ELF	Extremely Low Frequency
EMF	Electric and Magnetic Field
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 meter
NPS	National Policy Statement
NRPB	National Radiological Protection Board
PHE	Public Health England
WHO	World Health Organisation
μT	Microtesla

1. Introduction

1.1. Project description

1.1.1. This document provides an assessment of electric and magnetic fields (EMFs) associated with the proposed Green Volt project. Green Volt will use a grid-connected offshore windfarm to provide 100% of the power required by one of the largest oil and gas platforms in the North Sea as well as providing power to the UK grid.

1.1.2. Green Volt is at a development stage, where a range of electrical connection designs are being considered. There are two connection routes, one from the windfarm to the oil field, and one from the windfarm which transitions onshore and connects to the existing transmission system, described below:

- Ettrick and Blackbird, former oil-field sites to the Peterhead area: two offshore circuits approximately 120km in length transitioning to one circuit onshore connecting to the existing electricity transmission system.
- Ettrick and Blackbird former oil-field Field to the Buzzard oil platform: two circuits approximately 33km in length.

1.1.3. Green Volt will be developed as High Voltage Alternating Current (HVAC) cable circuits operating at 50 hertz (Hz). Each offshore circuit will consist of a single 3-core cable, but when the circuit comes onshore, three single-phase cables will be used per circuit.

1.1.4. Due to the geographical location of the connections, the offshore cable circuits are likely to be installed in close proximity to the North Connect high voltage direct current (HVDC) interconnector between Scotland and Norway. This assessment includes consideration of the cumulative impact of both projects.

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

1.2. Electric and Magnetic Fields

1.2.1. Electric and magnetic fields and the electromagnetic forces they represent are an essential part of the physical world. Their sources are the charged fundamental particles of matter (principally electrons and protons). EMFs occur naturally within the body in association with nerve and muscle activity, allowing these functions to happen. Humans also experience the natural static magnetic field of the Earth (to which a magnetic compass responds) and natural static electric fields in the atmosphere.

1.2.2. Electric and magnetic fields occur in the natural world, and people have been exposed to them for the whole of human evolution. The advent of modern technology and the wider use of electricity and electrical devices have inevitably introduced changes to the naturally occurring EMF patterns. Energised high-voltage power-transmission equipment, along with all other uses of electricity, is a source of EMFs.

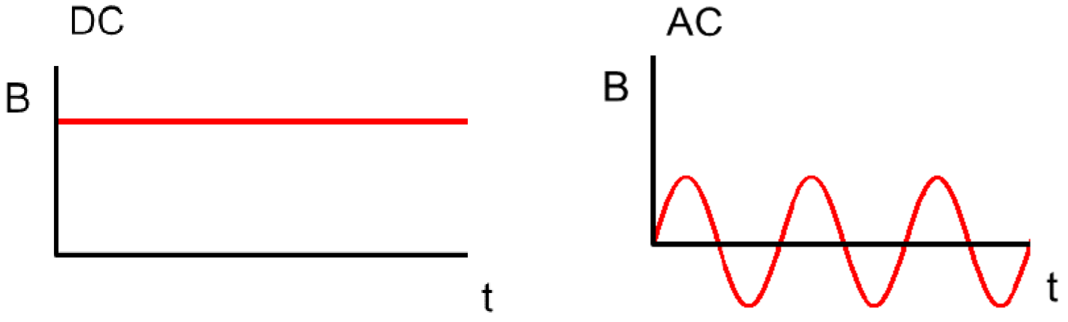
1.2.3. These EMFs have the same frequency as the voltages and currents that produce them. Power cables can be either alternating current or direct current. This project is proposing to install HVAC onshore and offshore connections, with a primary frequency of 50 Hz and these fields are described as power-frequency or extremely-low-frequency (ELF) alternating EMFs. There are areas where the proposed connections could be in close proximity to High Voltage Direct Current (HVDC) circuits which operate at a frequency of zero hertz (0 Hz).

1.2.4. A key characteristic of EMFs is their frequency. They always have the same frequency as the electricity that produced them. Most electricity supply in the UK is alternating current (AC) with a frequency of 50 cycles per second or 50 Hz. So, the EMFs it produces also alternate with a frequency of 50 Hz. However, there are an increasing number of electrical connections using direct current (DC) technology, so they will produce steady EMFs that always point in the same direction. (A different set of EMFs again are produced by radiofrequency electricity such as TV, radio and mobile communications – these have frequencies of typically hundreds of millions of Hz.)

1.2.5. The current in HVAC cables will periodically reverse direction with a frequency of 50 Hz (Fig. 1.2). The Earth has no natural AC fields, only those that result from man-made sources, such as those proposed here.

1.2.6. The current from HVDC cables flows in the same constant direction (Fig. 1.2). This will add to the Earth's natural magnetic field, meaning magnetic fields from DC cables have the potential to interfere with magnetic compasses.

Figure 1.2: Direction of AC and DC magnetic fields: Current from DC cables will flow in the same constant direction. Current in AC cables will periodically reverse direction with a frequency of 50 Hz.



Magnetic fields

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

Electric fields

1.2.8. Electric fields depend on the operating voltage of the equipment producing them and are measured in volts per metre (V/m). The operating voltage of most 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.

1.2.9. As a consequence of their design, some types of equipment do not produce an external electric field. Neither the offshore nor the onshore cables proposed here will emit electric fields, because the metal sheath surrounding the cable ensures the electric field is confined within the cable.

1.2.10. The Earth's magnetic field can induce an electric field in moving sea water. The movement of the sea through the magnetic field will result in a small localised electric field being produced. AC magnetic fields will similarly induce an electric field within a marine organism moving through the field, which is an important consideration for biological impacts[1].

[1] Normandeau, Exponent, T. Tricas, and A. Gill. 2011. Effects of EMFs from Undersea Power Cables on Elasmobranchs and other Marines Species. U.S.Dept. of the Interior, Bureau of Ocean Energy Management, Regulation and Enforcement, Pacific OCS Region, Camarillo, CA. OCS Study BOEMRE 2011-09.

2. Legislation and Policy

2.1. Policy Framework 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 October 2009 and incorporated in NPS EN-5[2], 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[3] 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 Green Volt Project. UK Government policy on EMF requirements for all electricity infrastructure projects is given in NPS EN-5[2].

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. 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."*

2.2. Exposure Limits

2.2.1. In March 2004, the NRPB provided new advice to the Government, replacing previous advice from 1993, and recommending the adoption in the UK of guidelines published in 1998 by the ICNIRP[4] The Government subsequently adopted this recommendation, saying that limits for public exposures should be applied in the terms of the 1999 EU Recommendation[5]. Table 2.1 summarises the recommended values.

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/m^2**	
Reference level (external unperturbed field)	**5,000 V/m**	**100 μT**
Field corresponding to the basic restriction	**9,000 V/m**	**360 μT**

2.2.2. In recommending these levels, the NRPB considered the evidence for all suggested effects of EMFs. It concluded that the evidence for effects on the nervous system of currents induced by the fields was sufficient to justify setting exposure limits, and this is the basis of their quantitative

[2] Department of Energy and Climate Change. National Policy Statement for Electricity Network Infrastructure (EN-5). London: The Stationary Office, 2011.

[3] Department of Energy and Climate Change. Power Lines: Demonstrating compliance with EMF public exposure guidelines. A voluntary Code of Practice. London, 2012.

[4] International Commission on Non-Ionizing Radiation Protection. Guidelines for Limiting Exposure to Time-Varying Electric, Magnetic and Electromagnetic Fields. Health Physics, 1998, 74 (4), p.494

[5] European Union Council. Recommendation of 12 July 1999 on the limitation of exposure of the general public to electromagnetic fields (0 Hz to 300 GHz) (1999/519/EC). Brussels, 1999.

recommendations[6]. It concluded that the evidence for effects at lower fields, for example the evidence relating to childhood leukaemia (discussed further below), was not sufficient to justify setting exposure limits, but was sufficient to justify recommending that the Government consider possible precautionary actions. Precautionary measures are considered in more detail below.

2.2.3. The EMF limits are documented in NPS EN-5[2] and practical details of their application are explained in the Code of Practice, 'Power Lines: Demonstrating compliance with EMF public exposure guidelines – a voluntary Code of Practice'[3] published by the then Department of Energy and Climate Change (DECC). It is the electricity industry's policy to comply with the Government limits on EMF, and this Code of Practice forms an integral part of this policy.

2.2.4. The ICNIRP guidelines[4] are set so as to prevent external exposure to EMFs that could cause currents to be induced in the body large enough to cause effects on nerves, with a substantial safety margin. These induced currents can be expressed as a current density, and it is on current density that the guidelines are based. The ICNIRP guidelines recommend that the general public are not exposed to levels of EMFs able to cause a current density of more than 2 milliAmps per metre squared (mA/m^2) within the human central nervous system, as shown in Table 2.1 above. This recommendation is described as the "basic restriction". The external fields that have to be applied to the body to cause this current density, have to be calculated by numerical dosimetry, since in-vivo measurements of current density are not practical.

2.2.5. The ICNIRP guidelines also contain values of the external fields called "reference levels". For the public, the reference level for electric fields is 5 kV/m, and the reference level for magnetic fields is 100 µT. The 1999 EU Recommendation[5] uses the same values as ICNIRP[4].

2.2.6. In the ICNIRP guidelines and the EU Recommendation, the actual limit is the basic restriction. The reference levels are not limits but are guides to when detailed investigation of compliance with the actual limit, the basic restriction, is required. If the reference level is not exceeded, the basic restriction cannot be exceeded, and no further investigation is needed. If the reference level is exceeded, the basic restriction may or may not be exceeded.

2.2.7. The Code of Practice on compliance[3] endorses this approach and gives the values of field corresponding to the basic restriction, stating:

"The 1998 ICNIRP exposure guidelines specify a basic restriction for the public which is that the induced current density in the central nervous system should not exceed 2mA m^{-2}. The Health Protection Agency specify that this induced current density equates to uniform unperturbed fields of 360µT for magnetic fields and 9.0kV m-1 for electric fields. Where the field is not uniform, more detailed investigation is needed. Accordingly, these are the field levels with which overhead power lines (which produce essentially uniform fields near ground level) shall comply where necessary. For other equipment, such as underground cables, which produce non-uniform fields, the equivalent figures will never be lower but may be higher and will need establishing on a case-by-case basis in accordance with the procedures specified by HPA. Further explanation of basic restrictions, reference levels etc is given by the Health Protection Agency."

2.2.8. The Code of Practice[3] also specifies the land uses where exposure is deemed to be for potentially a significant period of time and therefore where the public guidelines apply. These land uses are, broadly, residential uses and schools.

2.2.9. Therefore, if the EMFs produced by an item of equipment are lower than 9 kV/m and 360 µT, the fields corresponding to the ICNIRP basic restriction, it is compliant with the ICNIRP guidelines and hence with PHE recommendations and Government policy. If the fields are greater than these values, the equipment is still compliant with Government policy if the land use falls outside the residential and other uses specified in the Code of Practice[3] and it may still be compliant if the fields are non-uniform.

2.2.10. This makes it clear that the Government has not introduced any restrictions on constructing new high-voltage equipment close to existing properties on grounds of safety or health risks, and neither is it appropriate for individual local authorities to do so. Therefore, no additional measures or precautions are necessary or appropriate beyond the exposure guidelines and, for overhead lines, the policy on optimum phasing.

[6] National Radiological Protection Board. Review of the scientific evidence for limiting exposure to electromagnetic fields (0-300 GHz). Doc NRPB, 2004, 15(3), p.1

2.3. Summary of Policy

2.3.1. The EMF policies applying to high-voltage electricity equipment comprise compliance with the exposure guidelines; for overhead lines, the policy on optimum phasing; the policy on indirect effects expressed in the code of practice; but no other policies. If a development complies with these policies, adequate protection for the public is ensured.

2.4. Effects on magnetic compasses

2.4.1. 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.

2.4.2. This is a potential issue with direct current (DC) conductors or cables, which produce a static magnetic field that perturbs the geomagnetic field. However, there are no DC cables proposed for use in the project and no DC fields could be produced.

2.4.3. The magnetic fields produced by this project would be 50 Hz 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.

2.4.4. Therefore, this project would have no significant effect on magnetic compasses.

2.5. Policy Framework for the Protection of marine life

2.5.1. 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.

2.5.2. The key provision in Paragraph 2.6.75 states:

> *"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"* [8]

2.5.3. The mitigation methods suggested in NPS EN-3 include the use of armoured cables for interarray and export cables, and that cables should be buried at sufficient depths. 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 the arrangements of the phases in each circuit. The closer the phases in a circuit, the more cancellation of the field occurs and the lower the fields. The use of single 3-core armoured cables, such as proposed for this project, ensures that the phases are in very close proximity, reducing the fields significantly.

Mechanisms of action between EMF and marine species

2.5.4. A general commentary on the effects of EMF on marine species is included. There are no defined limits in terms of EMF to which the cables need to comply in regard to effects on marine life. The research area is relatively new and there is great deal of uncertainty in the science. A review of the impacts of the EMF assessed in this report should be sought from a marine specialist.

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[7] Department of Energy and Climate Change. National Policy Statement for Renewable Energy Structure (EN-3). London: The Stationary Office, 2011

[8] Bio/Consult, 2005. Infauna monitoring. Horns Rev Offshore Wind Farm. Annual Status Report, 2004, npower Renewables Limited, 2003. Baseline Monitoring Report. North Hoyle Offshore Wind Farm

2.5.5. There are two fields produced by the cables, a magnetic field which in turn causes an induced electric field. The Earth has its own geomagnetic field meaning that these fields are always naturally present. It has been shown that certain species use these natural fields to aid a number of physiological processes.

2.5.6. Marine species have specialised physiology to detect EMF, but the exact mechanisms of detection are complex, and not fully understood[8]. There are no limits above or below which marine AC EMF are known to have a detrimental impact on marine life and a full impact assessment should be considered.

Magnetic fields

2.5.7. Marine organisms can detect magnetic fields directly or indirectly through induced electric field detection. Species with the ability to detect magnetic fields directly do so through the forces on specialied particles called magnetite. Species with magnetite are sensitive to the geomagnetic field and use it for navigation. Examples of these types of species include salmon, lobsters, crabs, and bivalve molluscs.

2.5.8. Some research papers report that AC fields fluctuate too rapidly for the magnetite to respond mechanically to the imposed force, and that magnetite-based receptor systems may not respond to weak AC magnetic fields[1].

2.5.9. A comprehensive literature review commissioned by Scottish Natural Heritage (SNH) in 2010[9] revealed that EMFs from subsea cables may interact with eels if migration routes take them over cables in shallow water but no evidence of deviation from migration routes was recorded. They concluded that:

“Current knowledge suggests that EMFs from subsea cables and cabling orientation may interact with migrating eels (and possibly salmonids) if their migration or movement routes take them over the cables, particularly in shallow waters (<20m). The effects, if any, could be a relatively trivial temporary change in swimming.”

2.5.10. Some species that are able to detect the geomagnetic field not through magnetite, but through induced electric fields, are described as electrosensitive. These species are able to detect the presence of magnetic fields from electric fields induced by movement of an object or water through the magnetic field. The main species that uses this mechanism is Elasmobranchs. It is generally assumed that the induced electric field mode of detection is used for navigation.

2.5.11. The few studies that have looked at the potential effects of the emitted magnetic fields suggest that migratory fish do not deviate from their normal migration path[10, 11].

Electric fields

2.5.12. Some species, mainly Elasmobranchs, have specialist electroreceptive organs which allow them to sense voltage gradient changes. Sensing the induced electric field is mainly used for prey detection and is highly sensitive allowing very weak voltage gradients to be detected, as low as 5 to 20 nV/m. The electroreceptive organs are only used in close proximity to the prey and are highly tuned for the final stages of feeding or detecting others[12]. From the limited research investigating the potential effects of induced electric fields on various species three area of concerns have arisen:

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[9] Gill, A.B. & Bartlett, M. (2010). Literature review on the potential effects of electromagnetic fields and subsea noise from marine renewable energy developments on Atlantic salmon, sea trout and European eel. Scottish Natural Heritage Commissioned Report No.401.

[10] Westerberg, H & Begout-Anras, M.L. (2000) Orientation of silver eel (Anguilla anguilla) in a disturbed geomagnetic field. Advances in Fish Telemetry. Proceedings of the Third Conference on Fish Telemetry in Europe, Norwich, England, June 1999. Eds. Moore, A. & Russel, I. CEFAS Lowestoft.

[11] Westerberg, H. (2000) Effect of HVDC cables on eel orientation. In Merck, T & von Nordheim, H (eds). Technishe Eingriffe in marine Lebensraume. Published by Bundesamt fur Naturschutz.

[12] Centre for Marine and Coastal Studies Ltd. (CMACS). (2011) West Coast HVDC Link environmental Appraisal-Assessment of EMF effects on sub tidal marine ecology. Internal report

- Repulsion
- Confusion with bioelectric fields
- Physiological effects

2.5.13. Precisely what magnitude of electric field induces an avoidance / repulsion response in Elasmobranchs is uncertain, however current research suggests that the threshold electric field between attraction and avoidance lies somewhere between approximately[12] 400 and 1000 μV/m. It is not clear from the literature which frequencies these apply to or if there are effects outside this range.

2.5.14. A comprehensive review of EMF marine impacts[1] concluded:

"Most marine species may not sense very low intensity electric or magnetic fields at AC power transmission frequencies, AC magnetic fields at intensities below 5 μT may not be sensed by magnetite-based systems (e.g., mammals, turtles, fish, invertebrates), although this AC threshold is theoretical and remains to be confirmed experimentally. Low intensity AC electric fields induced by power cables may not be sensed directly at distances of more than a few meters by the low-frequency-sensitive ampullary systems of electrosensitive fishes."

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. At the Earth's surface there is also a natural electric field, created by electric charges high up in the ionosphere, of approximately 100 V/m in fine weather and more in stormy weather.

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 not close to 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[13].

3.1.4. Along the proposed cable circuit route there is existing electrical infrastructure which will produce localised 50 Hz EMF.

Offshore

3.1.5. The current offshore environment where the Green Volt export 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. The background geomagnetic field in the area is around 48 µT. Given this, the background induced electric field could range between 4.8 and 60 µV/m in tidal velocities ranging between 0.1 m/s and 1.25 m/s.

3.1.7. This project operates using AC technology and will not add or subtract to these natural DC fields. AC magnetic fields will, however, induce an electric field within a marine organism located in or moving through the AC magnetic field produced by the cable, which is the important consideration for biological impacts[1]. The induced electric field will depend on the size of the organism, its orientation or direction of travel in the field and how close it is to the cable. These effects tend to be highly localised as magnetic fields from cables reduce quickly with distance from source. The lower the magnetic field, the lower the induced electric field. The effect is greatest when organisms are traveling along the length of the cables. If the organism is at a different angle to the cables or offset to the side of the cables, the induced electric field will be lower because the magnetic fields will be lower.

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

4. Description of Green Volt

4.1.1. Green Volt will be developed as HVAC cable circuits operating at 50 Hz. The electrical design parameters of the project are not finalised, but a worst-case scenario in EMF terms has been assessed. Each circuit has been modelled using the maximum current rating for the cables installed, which gives a greater capacity than the project requires, resulting in higher calculated fields.

4.1.2. There are two offshore routes, the first consisting of a maximum of two circuits operating at 66 kV between the platform and windfarm and the second also consisting of a maximum of two circuits, operating at 275 kV between the windfarm and connecting to the existing transmission system near Peterhead. Where the circuits come onshore, only a single circuit is required, but will consist of three individual conductors for each phase, as opposed to the offshore cables which will be a single cable with 3-cores. Descriptions of both offshore routes and the onshore components are provided below and summarised in Table 4.1.

4.1.3. If the voltage of the proposed circuits were to change but the maximum current in the circuits remained the same or lower, these results would remain valid. It is the current which determines the magnetic field and the voltage, in this situation has no bearing on the results.

4.2. Offshore route 1: 66 kV between Ettrick and Blackbird field to the Buzzard Platform

4.2.1. Consists of two 66 kV single 3-phase 1000 mm^2 export cable circuits installed with a 50 m separation. The maximum current capacity of each circuit is 825 A. Each circuit will have a minimum burial depth of 0.6 m.

4.3. Offshore route 2: 275 kV between Ettrick and Blackbird field to Land fall

4.3.1. Consists of two 275 kV single 3-phase 2000 mm^2 export cable circuits, each with a maximum circuit rating of 1024 A. Each circuit will have a minimum circuit separation of 50 m and a minimum burial depth of 0.6 m

4.4. Onshore section: Land fall to existing transmission system in Peterhead area

4.4.1. The onshore route will consist of one 275 kV 3-phase circuit with a maximum capacity of 1024 A. There are different installation techniques which could be used, each influences the magnetic fields produced; both are described below.

Option A- Flat formation

4.4.2. Cables will be buried to a minimum of 0.9 m, with a horizontal phase separation of 0.25 m.

Option B- Trefoil formation

4.4.3. Cables will be arranged in a triangle formation, with a 0.2 m phase separation and a minimum burial depth of 0.9 m.

Table 4.1: Volt Green cable geometries and calculation parameters for all electrical designs

	Cable circuit route designs			
	Offshore Route 1	**Offshore Route 2**	**Onshore flat design**	**Onshore trefoil design**
No. of circuits	Two 3-cored cables	Two 3-cored cables	One 3-phase circuit	One 3-phase circuit
Operating voltage	66 kV	275 kV	275 kV	275 kV
Cable design	1 x 3-cored 1000mm^2	1 x 3-cored 1000mm^2	3 x Single cored	3 x Single cored
Maximum current	825 A	1024 A	1024 A	1024 A
Minimum burial depth	0.6 m	0.6 m	0.9 m	0.9 m
Circuit separation	50 m	50 m	N/A	N/A
Phase arrangement	N/A	N/A	Flat horizontally spaced	Triangular
Phase separation	N/A	N/A	0.25 m	0.2 m

5. Assessment methodology

5.1. Predicted Field Levels

5.1.1. The magnetic field produced by the currents in an electrical circuit falls with distance from the circuit. The magnetic field is highest at the closest point to the conductors and falls rapidly with distance.

5.1.2. For sources of fields with a simple, defined geometry, such as underground cables, calculations are the best way of assessing fields and are acceptably accurate. The calculations of fields presented here follow the provisions specified in the Code of Practice on Compliance[3] and were performed using specialised computer software that has been validated against direct measurement[14] and commercially available software package EFC-400 (Narda).

5.1.3. Calculations from overhead lines and cables usually assume that the line or cables are infinitely long and straight, known as a two-dimensional calculation. The Code of Practice specifies that such calculations are always acceptable.

5.1.4. Since field strengths are constantly varying, they are usually described by reference to an averaging calculation known as the "root mean square" or RMS. Future mention of power-frequency field strengths in this chapter will mean the RMS amplitude of the power-frequency modulation of the total field, which is the conventional scientific way of expressing these quantities.

5.1.5. A qualitative assessment of offshore EMF emissions has been performed for the specific cable designs considered and burial depths.

5.1.6. To assess compliance with exposure limits for the onshore sections of cable, the Code of Practice on Compliance[3] specifies that the maximum fields the installation is capable of producing should be calculated using the following conditions (other conditions in the Code of Practice apply only to overhead lines and are not reproduced here):

- magnetic fields: for the highest rating that can be applied continuously in an intact system (i.e. including ratings which apply only in cold weather, but not including short-term ratings or ratings which apply only for the duration of a fault elsewhere in the electricity system); and
- electric and magnetic fields: for 1 m above ground level, of the unperturbed field, of the 50 Hz component ignoring harmonics, ignoring zero-sequence currents and voltages and currents induced in the ground or earth wire.

5.1.7. These provisions ensure that the calculations for each of the cable design options represent worst-case conditions. These parameters were used for both the onshore and offshore calculations. The circuits will not always operate at this maximum rating, therefore resulting in lower magnetic fields for some of the time, but compliance is assessed for the worst-case conditions.

5.1.8. 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. Finally, the effect of the cable armouring (ferromagnetic shielding) to reduce the magnetic field outside the cable was not included. Complex modelling of similar cables demonstrated that the armour cable in fact accounted for a 2-fold reduction in the magnetic field[15]. The modelling assumptions were made to ensure that the calculated magnetic-field levels will overestimate the actual field level at any specified loading.

[14] J. Swanson, Magnetic fields from transmission lines: Comparison of calculations and measurements, IEE Proceedings.-Generator Transmission Distribution, 1995, 142 (5), p481.

[15] M. Silva, E. Zaffanella and J. Daigle. 2006 EMF Study: Long Island Power Authority (LIPA), Offshore Wind Project.

5.2. Combining fields from different sources

5.2.1. 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 their differing frequencies (Section 1.2) and should be considered separately.

5.2.2. The offshore Green Volt circuits may be installed close to the proposed North Connect high voltage direct current (HVDC) interconnector between Scotland and Norway. There will be no interaction or cumulative impact of these two projects as AC and DC fields do not combine. The impact of each can be considered separately and the High Connect project will not be considered further.

5.3. Assessment of Effects

5.3.1. The onshore Green Volt export cables 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 Practice[3]. Conversely, as specified in NPS EN-5[2], if the proposed projects comply with the exposure limits, EMF effects are assessed as not significant, and no mitigation is necessary.

5.3.2. For the marine environments, total field values are produced and compared to the requirements of NPS EN-3. For interpretation of the potential impacts on marine life physiology, a marine specialist will need to be consulted.

6. Assessment of EMF from Green Volt

6.1. Offshore options

6.1.1. The earthed metallic shield that is applied over the insulation of HVAC cables ensures that the electric field will be contained entirely within the insulation, and no external electric field will be emitted.

6.1.2. Magnetic fields are not shielded in the same way as electric fields and will be produced outside the cables, and this has been assessed for each cable route below.

6.1.3. All proposed offshore cable designs consist of two 3-core conductor cables, which vary in cross-sectional area, depending on the required rating. Within each single cable, the 3 conductors vary with distance from one another, which can influence the magnetic field produced. In each scenario the worst-case option was considered.

6.1.4. The magnetic field produced by the cables will in turn induce electric fields in organisms passing through the field. This will be proportional to the magnetic field and the size of the organism. The direction of travel and location over the cables will also be considered.

6.1.5. Magnetic field intensities reduce as a function of distance from the source and are highly localised.

Magnetic fields

6.1.6. Based on the cable design parameters provided by Floatation Energy (Table 4.1) and performed according to the provisions of the Code of Practice, the AC magnetic fields from each of the proposed offshore export options were calculated. All calculations were performed assuming maximum load, minimum circuit separation and minimum burial depth, giving a worst-case scenario.

6.1.7. Table 6.1 demonstrates the maximum magnetic field for each option at the seabed and with increasing vertical distance. Figure 6.1 shows the magnetic field along the seabed in a horizontal plane for the 66 kV and 275 kV routes. Figure 6.2 demonstrates the vertical reduction in magnetic field from the two offshore routes. Figures 6.3a and 6.3b demonstrate the reduction of magnetic fields with both vertical and horizontal distance from the cable circuits for both routes.

Table 6.1: Calculated maximum magnetic fields for offshore Green Volt export cable circuits options. Cables are buried with the top of the cable 0.6 m below the seabed

	Magnetic field (μT)						
	Distance above seabed (m)						
	Seabed	**0.5 m**	**1 m**	**2 m**	**5 m**	**10 m**	**20 m**
Offshore route 1- 66 kV	35.1	12.3	6.17	2.47	0.55	0.15	0.04
Offshore route 2- 275 kV	54.7	19.5	9.90	3.99	0.90	0.25	0.06

Figure 6.1: Calculated maximum magnetic fields for the 66kV (left hand graph- blue) and 275 kV (right hand graph- green) offshore circuits. Magnetic fields calculated along the seabed perpendicular to the cable circuits.

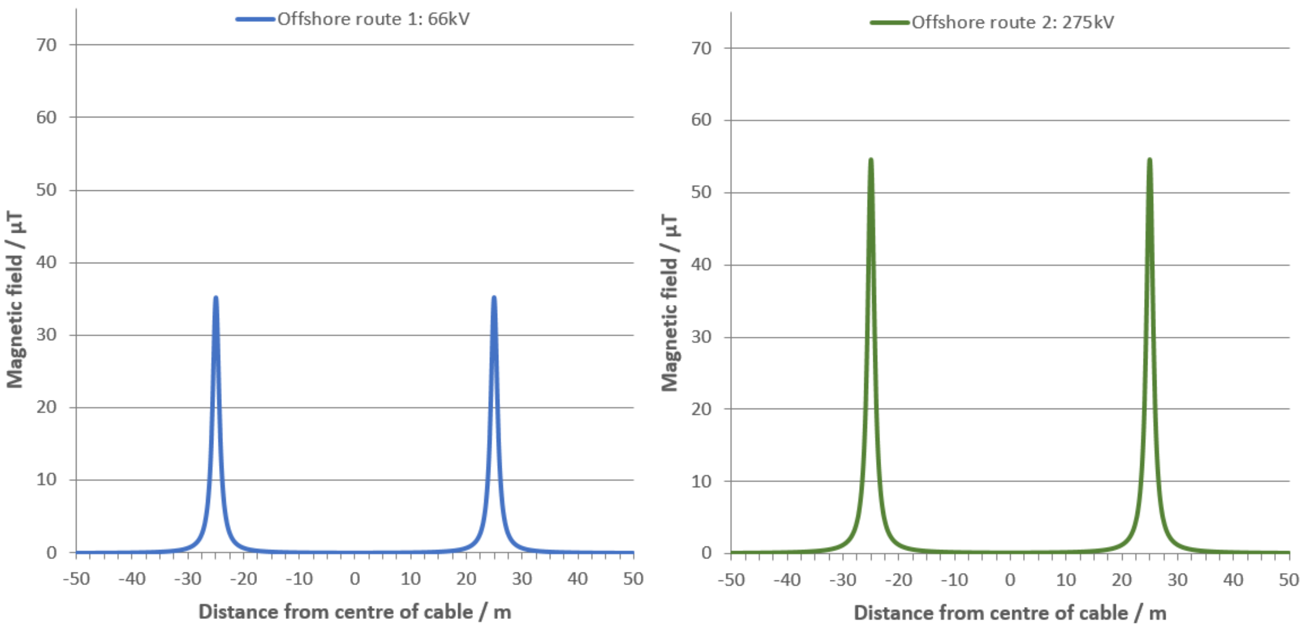


Figure 6.2: Calculated magnetic fields for the 66 kV and 275 kV offshore circuits with increasing distance from seabed.

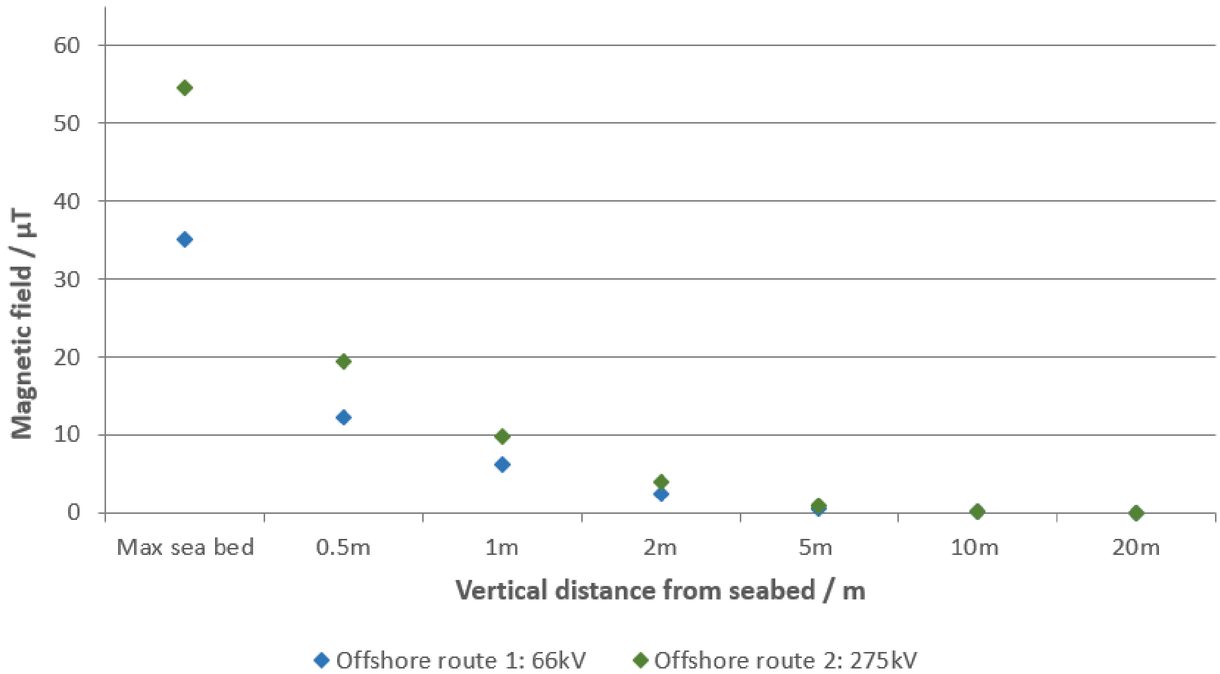


Figure 6.3a: Calculated AC Magnetic Fields from offshore route 1- 66 kV cable circuit: The hashed line running horizontally at 0 on the z-axis represents the seabed location. Colour bands represent magnetic field levels in microtesla with scale given below

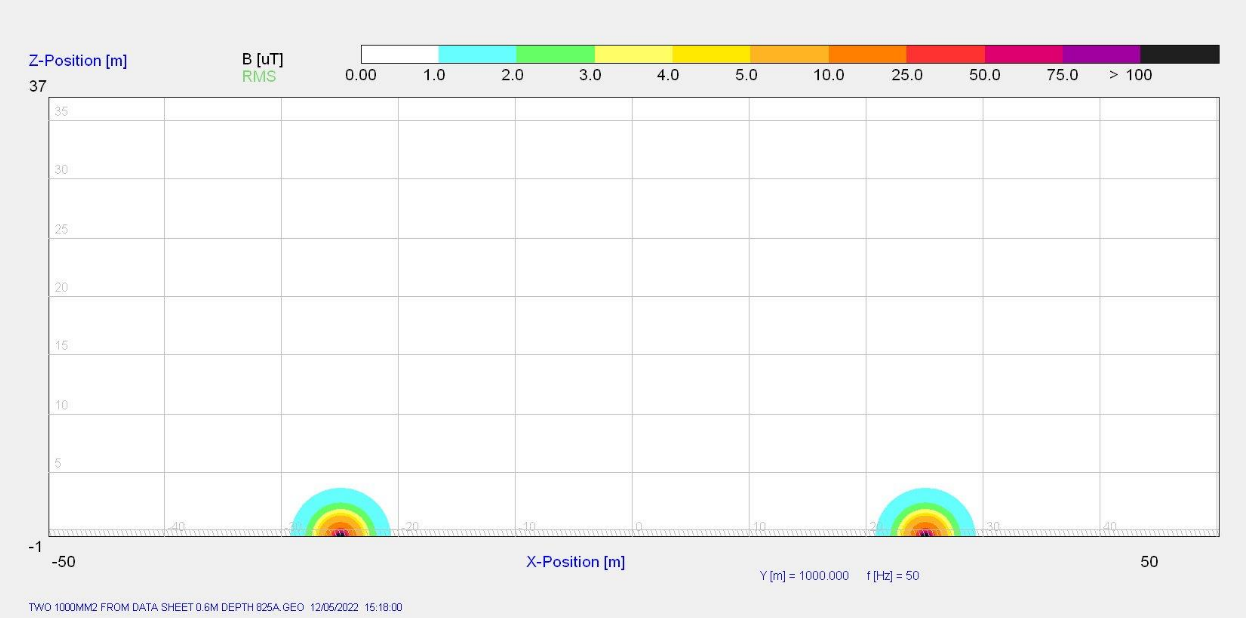
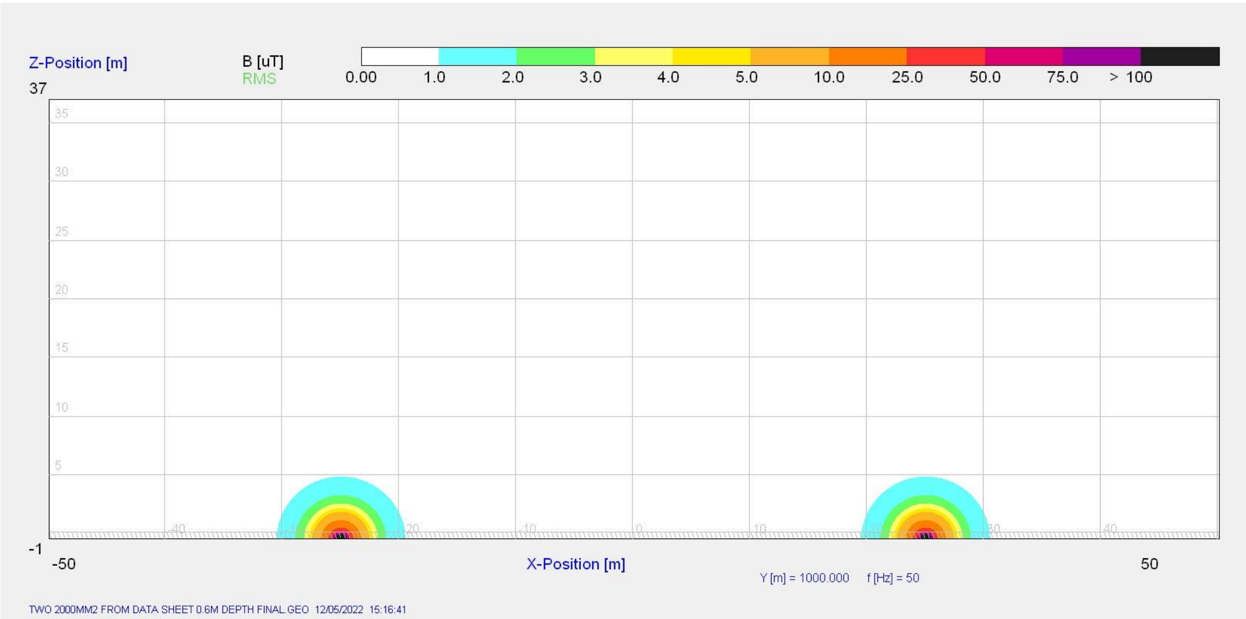


Figure 6.3b: Calculated AC Magnetic Fields from offshore route 2- 275 kV cable circuit: The hashed line running horizontally at 0 on the z-axis represents the seabed location. Colour bands represent magnetic field levels in microtesla with scale given below



6.1.8. Unlike DC magnetic fields produced by DC cables, the fields produced by HVAC cables do not combine with the geomagnetic field. The calculations provided are for the total magnetic field without the need to account for the Earth's natural DC field.

6.1.9. The calculated magnetic fields are greatest on the seabed and reduce rapidly with vertical and horizontal distance from the circuits (Figure 6.1, 6.2 and 6.3). The highest magnetic fields were observed from offshore route 2, operating at 275kV, as these circuits carry a greater current. The maximum magnetic fields calculated for offshore routes 1 and 2 at the seabed were 35.1 µT and 54.7 µT respectively. The magnetic fields from all options reduced to very low levels within a few metres from the circuits. The magnetic fields halved in value 0.8m from the seabed and reduced to below 1µT, 5m from the seabed. 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.

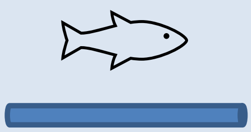
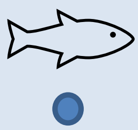
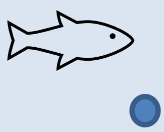
Induced electric fields

6.1.10. The induced electric field within an organism is directly related to the size of the magnetic field, the size of the organism and, for large organisms, orientation over the cables. The method used to calculate the induced electric field is that noted in the BOEMRE report[1] and derived from Reilly[16].

6.1.11. Reilly's[16] method is used to calculate the induced electric field in the elliptical cross-sectional area of the organism as a function of the uniform magnetic field, the dimensions of the ellipse and the location within the ellipse. The induced electric field is calculated in vertical and horizontal layers through the organism. The important quantity that determines the induced electric field is the total magnetic flux through that cross section. Near to cables, the magnetic field is very non-uniform. Where an organism is small (say <10cm) this is not an issue because the magnetic field does not vary significantly over the entire volume of the organism. However, where an organism is large, the average magnetic field over the cross-section of the organism is used to represent the uniform magnetic field of the Reilly model. For this, averages of the magnetic field over the vertical cross-sections of all the organisms were calculated and these were averaged over the width of the organism. This model calculated the induced electric field for the average magnetic field over the entire organism. This is an approximation and leaves the possibility of that the variation of field across the organism results in a local increase of induced electric field. If there is a specific area of the organism where results should be focused, further calculations would be necessary.

6.1.12. For larger organisms, three orientations relative to the cable where considered, described in Table 6.2.

Table 6.2: Modelled organism orientations relative to the cable.

	1	2	3
Direction of travel	Along cable	Perpendicular to cable	Perpendicular to cable
Location relative to cable	Centred	Centred	Offset- one end of organism directly above cable
Diagrammatic representation of organism location			

[16] P. Reilly. 1991. Magnetic field excitation of peripheral nerves and the heart: a comparison of thresholds. Ned. & Biol. Eng. & Comput., 28: 571-579.

Table 6.3: Marine species modelled for induced electric field effects. The maximum dimensions of each species used are included. **Bottlenose Dolphin height excludes fin*

	Species Dimensions		
	Length (cm)	Width (cm)	Height (cm)
Mammals			
Harbour porpoise	190	35	35
Bottlenose dolphin	300	80	80*
Minke whale	850	400	400
Fish and Shellfish			
Common ray	285	200	70
Brown crab	10	25	5
Salmon	100	11.5	23

6.1.13. The modelled induced electric field was assessed for three marine mammals, two fish and one representative shellfish. These modelled induced electric fields were calculated considering the orientation and proximity of the organism to the cables, as described in Table 6.2 and the dimensions of each organism, noted in Table 6.3. Appropriate magnetic field values or averages were then calculated depending on the organism's size at various vertical distances from the cables. Calculations of induced electric fields are presented for each route and each species considered, along with orientation of travel, in Tables 6.4 and 6.5.

6.1.14. As the induced electric fields are directly proportional to the magnetic field, as expected the greatest induced electric fields were observed when considering the 275 kV circuits. The induced electric field reduced with vertical and horizontal distance from the cable circuits. The induced electric fields are also highest when the organisms are positioned along the length of the cables, rather than perpendicular.

6.1.15. The predicted induced electric field was greatest in the Common Ray, where it was located along the cables at the seabed. At this location, the induced electric field reached a maximum of 4.6 mV/m. This reduced to 3.9 and 2.5 mV/m when the Common Ray was orientated perpendicular to the cables. Increasing its vertical height above the cables also significantly reduced the predicted induced electric field. In the worst-case orientation, i.e., along the cables, the induced electric fields reduce by more than a factor of three at 1 m above the cables, from 4.6 mV/m to 1.4 mV/m. At 5 m from the cables, the induced electric field had reduced significantly, ranging between 11 and 57 times smaller than the induced electric field at the seabed, depending on the species. These reductions at vertical and horizontal distance were observed in all species. The smaller the species the smaller the predicted induced electric field.

6.1.16. The induced electric field would also only persist whilst the organism is within the magnetic field. For comparison, the public exposure limit for induced electric fields in humans is 20mV/m in the head and 400 mV/m for the whole body.

Table 6.4: Modelled maximum induced electric field (µV/m) in six species at various distances above Route 1: 66 kV cable circuits.

Electric field (µV/m)							
	Distance above seabed (m)						
Organism orientation (Table 6.2)	**Seabed**	**0.5 m**	**1 m**	**2 m**	**5 m**	**10 m**	**20 m**
Harbour porpoise							
1	1272	509	273	116	27.7	7.9	2.0
2	930	437	250	112	27.4	7.9	2.0
3	641	339	209	102	26.6	7.7	2.0
Bottlenose dolphin							
1	1,871	853	489	222	56.7	16.7	4.3
2	1,279	687	426	208	55.7	16.6	4.3
3	832	492	329	177	52.7	16.2	4.2
Minke whale							
1	1,832	1165	819	473	162	56.2	16.5
2	1,183	822	617	390	150	54.6	16.3
3	705	513	403	275	122	48.4	14.7
Common ray							
1	2,911	1445	857	399	103	30.1	7.8
2	2,423	1286	792	383	102	30.0	7.8
3	1,564	916	610	326	95.9	29.2	7.6
Brown crab							
1	178	63.8	32.5	13.1	3.0	0.8	0.2
2	178	63.8	32.5	13.1	3.0	0.8	0.2
3	178	63.8	32.5	13.1	3.0	0.8	0.2
Salmon							
1	469	183	96.2	40.3	9.5	2.7	0.7
2	418	173	93.7	39.8	9.5	2.7	0.7
3	340	156	87.9	38.7	9.4	2.7	0.7

Table 6.5: Modelled maximum induced electric field (µV/m) in six species at various distances above Route 2: 275kV cable circuits.

Electric field (µV/m)							
	Distance above seabed (m)						
Organism orientation (Table 6.2)	Seabed	0.5 m	1 m	2 m	5 m	10 m	20 m
Harbour porpoise							
1	1996	812	439	188	45.2	12.9	3.3
2	1474	699	403	181	44.7	12.8	3.3
3	1021	544	338	165	43.5	12.7	3.2
Bottlenose dolphin							
1	2,958	1,366	788	361	92.6	27.3	7.1
2	2,041	1,104	688	337	90.9	27.1	7.1
3	1,333	794	533	288	86.0	26.4	6.9
Minke whale							
1	2,946	1,884	1327	769	265	92.0	27.0
2	1,910	1,332	1003	636	245	89.4	26.7
3	1,140	834	656	448	200	79.3	24.0
Common ray							
1	4,627	2,318	1,381	646	167	49.3	12.8
2	3,863	2,067	1,279	621	166	49.1	12.8
3	2,505	1,478	987	529	157	47.9	12.5
Brown crab							
1	278	102	52.1	21.2	4.8	1.3	0.3
2	278	102	52.1	21.2	4.8	1.3	0.3
3	278	102	52.1	21.2	4.8	1.3	0.3
Salmon							
1	735	290	155	65.2	15.5	4.4	1.1
2	657	277	151	64.5	15.5	4.4	1.1
3	539	249	142	62.7	15.4	4.3	1.1

6.2. Onshore circuits assessment

6.2.1. The earthed metallic shield that is applied over the insulation of HVAC cables ensures that the electric field will be contained entirely within the insulation, and no external electric field will be emitted.

6.2.2. Magnetic fields are not shielded in the same way as electric fields and will be produced outside the cables, and this has been assessed for each technology option and installation scenario below.

Electric fields

6.2.3. The earthed metallic shield that is applied over the insulation of the AC cables, which is an inherent part of the cable design, ensures that the electric field is contained within the cable, not leaking out.

6.2.4. The proposed underground cables produce no external electric fields, so are not considered further.

Magnetic fields

6.2.5. The AC magnetic fields from the two potential installation techniques were calculated based on the cable design parameters provided by Flotation Energy (Table 4.1) and in accordance with the provisions of the Code of Practice. All calculations were performed assuming maximum load, minimum phase separation and minimum burial depth, giving a worst-case scenario.

6.2.6. Figure 6.4 shows the magnetic field at 1m above ground for the flat and trefoil formation designs considered for the onshore route. Figure 6.5 shows the same calculated field as in Figure 6.4, but with the addition of the Government public exposure limit.

Figure 6.4: Maximum calculated magnetic fields from onshore 275 kV cable circuit. Two installation techniques were calculated for a flat formation (red) and trefoil formation (orange) design.

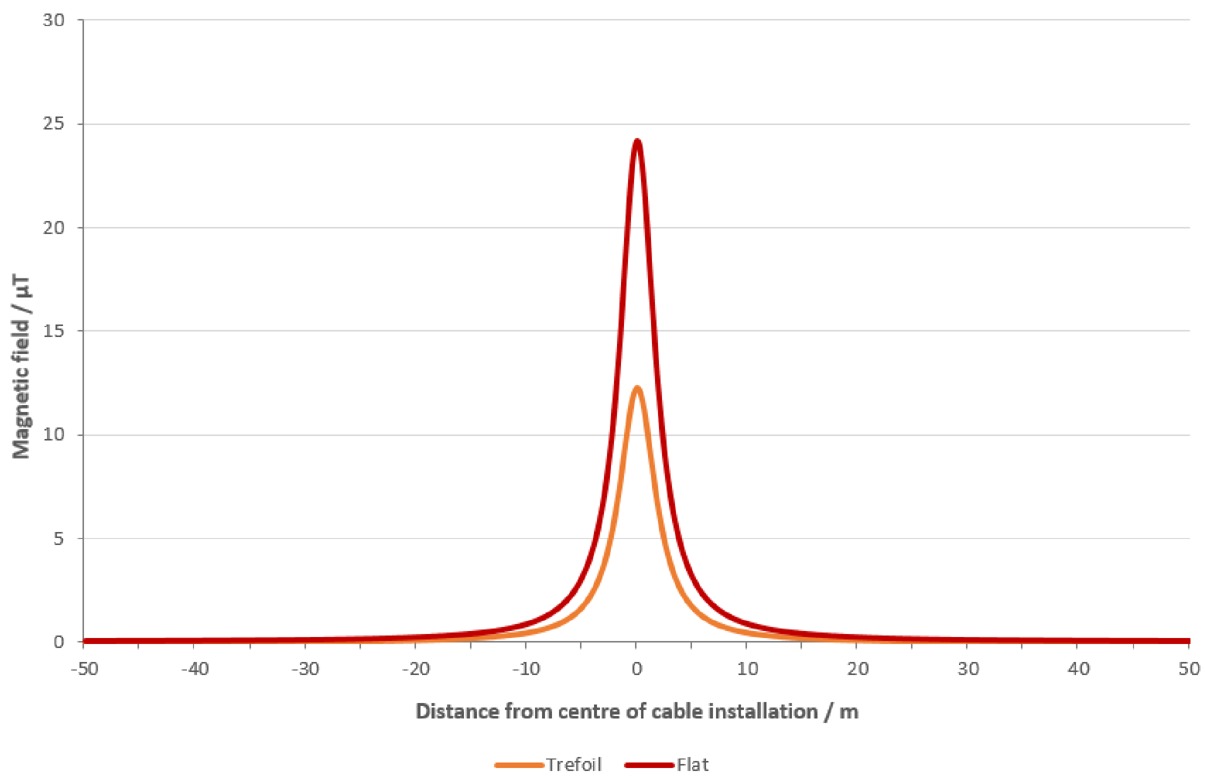
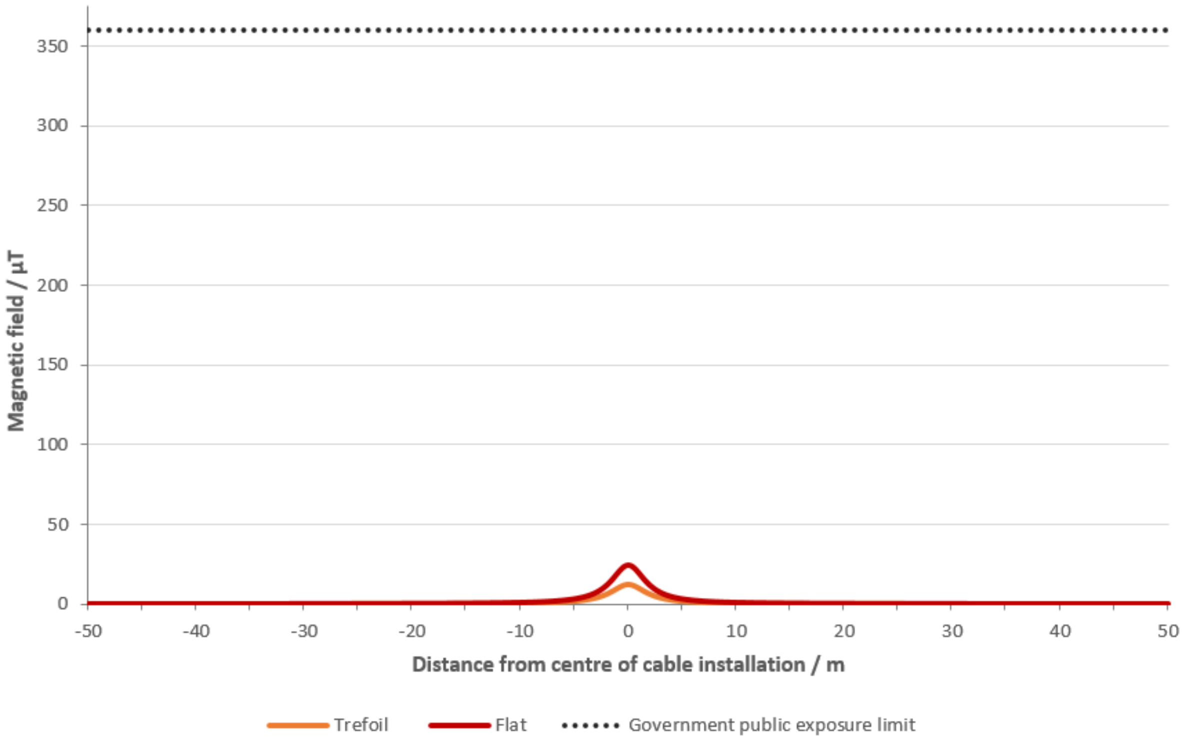


Figure 6.5: Maximum calculated magnetic fields from onshore 275 kV cable circuit. Two installation techniques were calculated for a flat formation (red) and trefoil formation (orange) design. The Government public exposure limit is marked as a dotted black line.



6.2.7. Figure 6.4 shows the maximum calculated magnetic field at 1 m above ground and how the field reduces with distance for the two installation options. Installing the circuit in flat formation results in slightly higher magnetic fields which reduce less quickly than if the circuit was installed in a trefoil formation. The maximum magnetic field from the trefoil installation was 12.3 µT compared to 24.2 µT in a flat formation.

6.2.8. The magnetic fields from both trefoil and flat installations reduce quickly with distance. Even using worst-case conditions, the fields have reduced to a background field level 16m from the trefoil arrangement and 21m from the flat formation installation.

6.3. Summary of Assessment

Offshore summary

6.3.1. The magnetic fields produced by both cable routes were highly localised, reducing rapidly from the source due to the singe 3-core cables used. The decrease in magnetic fields occurs both in the vertical water column and horizontally along the seabed. The magnetic fields reduced to below 1 µT at a distance of 5.5 m for the 275 kV cables and 4.3 m from the 66 kV cables.

6.3.2. AC magnetic fields induce electric fields within organisms, which vary with the size of the organism, orientation and magnetic field strength. The impact of external electric fields, especially those induced by AC fields is unclear, but using worst-case assumptions, the maximum predicted induced electric field of 4.6 mV/m was observed in the Common Ray orientated along the cables at the seabed.

Onshore summary

6.3.3. For onshore power-frequency (AC) fields, the maximum EMF produced is less than the relevant exposure limit. 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.

6.3.4. All of the electrical connection options assessed produced magnetic fields significantly below the ICNIRP public exposure limits. Under maximum loading conditions and a flat formation installation, the maximum calculated magnetic fields were less than 7% of the exposure limit.

7. Additional Mitigation

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 Green Volt project proposes to use armoured cables which mitigates both the electric and to an extent the magnetic fields. Cables have also been buried to a depth of 0.6 m, which again reduces the magnetic fields and is a suggested mitigation technique in NPS EN-3.

5.1.3. NPS EN-3 states a recommended burial depth of 1.5 m to mitigate against EMF impacts, which could be considered. However, the use of single 3-core cables ensures magnetic fields reduce very quickly with distance and ensures that the fields remain highly localised.

Onshore

5.1.4. 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[2] states that *"no further mitigation should be necessary."*

8. Conclusions

Offshore

5.1.5. There are no formal limits for EMF exposure which apply to the marine environment. The Green Volt offshore export circuits use armoured cables and cable burial to mitigate the impacts of EMF on marine life. The use of single 3-core cables, compacting the circuit phases, also reduces and localises the EMFs significantly.

5.1.6. The mitigation techniques employed by the project should be sufficient to reduce the impacts of EMF on marine life. The opinions of a marine specialist should be sought.

Onshore

5.1.7. 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.

5.1.8. All of the proposed onshore Green Volt cable designs 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.

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GREEN VOLT

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