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Land Use Consultants

Neart Na Gaoithe Wind Development

EMF Assessment

June, 2012

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ADMINISTRATION PAGE

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EXECUTIVE SUMMARY

The UK guidelines relating to health concerns associated with electromagnetic fields (EMFs) have been comprehensively reviewed.

Various health concerns relating to EMFs exist, including effects on the nervous system and childhood leukaemia. The World Health Organisation (WHO) has classified magnetic fields as "possibly carcinogenic".

The UK guidelines are based on the 1998 International Commission on Non-Ionizing Radiation Protection (ICNIRP) guidelines. These define the following reference levels for magnetic and electric fields:

- 100 micro Teslas (μT, magnetic fields)
- 5 kilo Volts per metre (kVm^{-1}, electric fields)

These are also referred to as 'investigation levels', as any field strengths above these levels require further investigation.

The potential fields associated with the Neart Na Gaoithe underground cable have been modelled using Opera v.14 software, which models the fields by means of Finite Element Analysis (FEA). Twenty locations along the cable route have been chosen for assessment. These are mostly residences and public footpaths, as these are the areas where significant exposure to the fields would be expected. The analysis is based on the cables carrying power at full load.

The anticipated magnetic and electric field strengths associated with the underground cable are below the reference levels advised by UK government policy.

The field levels immediately above the cable are predicted to be:

- below 3 μT (magnetic fields)
- 0 kVm^{-1} (electric fields)

The magnetic field levels drop sharply with distance from the horizontal centre of the cables. None of the identified residences are likely to be within even 1% of the reference levels relating to health concerns.

The model suggests that the electric field will be entirely contained within the shielding layers surrounding the conductors.

All calculations have assumed the cables are operating at peak capacity. In reality it is likely that average power values in the cable will be below this.

Available information regarding fields surrounding substations suggests that these fall away within a few metres of the substation. There are no residences within one kilometre of the substation location near Friardykes Dod.

No impact relating to EMFs is therefore anticipated. Therefore, it is unlikely that there will be any significant impact on human health.

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1 INTRODUCTION

1.1 Purpose of the Study

This report concerns the potential health issues associated with the underground cable for the Neart Na Gaoithe offshore wind development (hereinafter referred to as the 'onshore works'). The electromagnetic fields produced by the cable, based on the available information, have been modelled by means of two-dimensional Finite Element Analysis (FEA). The magnetic and electric field strength have been compared with published safe levels for human exposure in order to quantify the potential impact.

Unless stated otherwise, all co-ordinates within this report are British National Grid (BNG) Ordnance Survey of Great Britain 1936 datum (OSGB 36).

1.2 Electromagnetism

The movement of electric charge causes electric and magnetic fields to be produced in the space surrounding the charge. Human exposure to such fields can cause health problems. The magnitude of the effects is dependent on both the field strength and the exposure time.

1.3 Health Concerns – Potential Effects

The potential effects on human health caused by time varying magnetic fields, such as those generated by AC[1] cables, are due to induced current on functions of the central nervous system. There are various international bodies which provide maximum safe exposure levels to time varying electromagnetic fields.

Various sources of information relating to safe exposure levels have been reviewed as part of this study. The most relevant resource consulted is the EMFs.info webpage, where the National Grid have collected the relevant studies pertaining to safe limits on exposure in the UK and elsewhere in the world. The relevant sections are analysed in the next chapter.

[1] Alternating Current

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2 EMFS.INFO (NATIONAL GRID)

2.1 Overview

National Grid provides a comprehensive overview of electromagnetic fields (EMFs) and the issues associated with these on their webpage. This was consulted in July 2011 for the purposes of this study. Regarding health issues caused by EMFs they state the following:

However, there are suggestions that magnetic fields may cause other diseases, principally childhood leukaemia, at levels below these limits. The evidence for this comes from epidemiology studies, which have found a statistical association - an apparent two-fold increase in leukaemia incidence, from about 1 in 24,000 per year up to 1 in 12,000 per year, for the children with the top half percent of exposures. The evidence is strong enough for magnetic fields to be classified by the World Health Organization as "possibly carcinogenic". But because these studies only show statistical associations and do not demonstrate causation, and because the evidence from the laboratory is against, the risk is not established, it remains only a possibility.

Regarding the legal standpoint on exposure limits, a comprehensive overview of the situation in various countries is given by the National Grid on their website. We shall focus on the UK specific guidance as this is relevant for the onshore works associated with this project.

2.2 Exposure limits in the UK

National Grid states that there are no statutory exposure limits in the UK, and that limits which do apply are a matter of Government policy. The UK policy for public exposure[2] is to comply with the 1998 International Commission on Non-Ionizing Radiation Protection (ICNIRP) guidelines which define three things:

i) Basic Restrictions

These are the levels at which radiation is potentially harmful to humans. This is a current density[3] given in mA m^{-2}.

ii) Reference Level (Investigation Level)

National Grid states that:

These are not the actual limits, they are simply guidance figures for when it is necessary to investigate the basic restriction.

Therefore, field values below the investigation level will automatically ensure the current density values below the basic restriction.

iii) Field Actually Required

This is the field strength at which the basic restriction is likely to be exceeded.

The values for the above stated in the ICNIRP 1998 paper are shown in the table below. It is UK Government policy to adhere to these values. These are the public exposure values, not the occupational exposure values – the former is more conservative than the latter by a factor of five.

[2] The limits are sometimes different for Occupational Exposure. Public Exposure limits are never less conservative than Occupational Exposure limits.
[3] Current density is the amount of electric current flowing through a unit area.

ICNIRP 1998 – Current UK Government Policy – Public Exposure Limits				
Basic Restriction (mA m^{-2})	Magnetic Fields Reference Level (µT)	Electric Fields Reference Level (kV m^{-1})	Magnetic Field Actually Required (µT)	Electric Field Actually Required (kV m^{-1})
2	100	5	360	9

Table 1 ICNIRP Exposure Limits 1998 (Current UK Government Policy)

The values above are also used in the EU Recommendation on Public Exposure (1999), which the UK Government follows. The EU recommendation also has provisos including one which states that the limits should be introduced where the time of exposure is significant.

2.3 Updated Guidance – 2009

National Grid state on their website that:

In July 2009 ICNIRP published a consultation draft of new guidelines covering 1 Hz to 100 kHz. They had previously published new guidelines on static fields and intend to revise the guidelines for the higher frequencies later. The consultation ran until October, after which the document was withdrawn from the ICNIRP site.

Because this is only a draft for consultation, it has no force. It would not come into effect in the UK unless and until it is adopted by ICNIRP and then incorporated into EU provisions and then in turn implemented in the UK.

The relevant difference between the 1998 paper and the 2009 update is the change in the basic restriction. This changes from 2 mA m^{-2} to 20 mV m^{-1} for public exposure. The investigation levels do not change.

2.4 Updated Guidance – 2010

In 2010 the ICNIRP released more updated guidance. In this document, the distinction was made between basic restrictions for the head and basic restrictions for the rest of the body. The table below shows the guidance for public exposure detailed in the 2010 update. Pager Power's source for this information is the EMFs.info online recourse.

ICNIRP 2010 – Public Exposure Limits				
Basic Restriction (mV m^{-1})	Magnetic Fields Reference Level (µT)	Electric Fields Reference Level (kV m^{-1})	Magnetic Field Actually Required (µT)	Electric Field Actually Required (kV m^{-1})
Head: 20 Body: 400	200	5	606	9.9

Table 2 ICNIRP Exposure Limits 2010

It should be stressed once again that the above limits are not part of UK or EU guidance. They will, however, be considered as part of the analysis for the Neart Na Gaoithe cable for completeness.

2.5 Height Above Ground Used for Testing Compliance

The National Grid specifically states the below with regard to the height to be used to test compliance:

The standard height for measuring fields, especially from power lines, is 1 m above ground level. This is the height specified in the UK Code of Practice on compliance. This isn't just because it's a convenient round number, it's because roughly half way up the height of a standing person is actually the height that gives the best approximation to the induced current in the body.

2.6 Safe Levels – Summary

The values of interest are those shown in table one. Effectively, this means that in locations of significant exposure time, such as residences, levels should be below:

- 100µT (magnetic fields)
- 5kV m^{-1} (electric fields)

Values exceeding the limits above, at one metre above ground level, would suggest that further investigation is required.

3 NEART NA GAOITHE UNDERGROUND CABLE

3.1 Technical Parameters

The table below shows the technical parameters that have been received by Pager Power relating to the underground cable. Unless stated otherwise, all values were given by LUC or Xero Energy.

Parameter	Value	Unit	Notes
Voltage	220	kilo-Volt (kV)	Two trefoil AC cables.
Voltage per conductor	127	kilo-Volt (kV)	Determined using standard calculation for 3-phase transmission.[4]
Separation between cables	1	metre (m)	Estimated.
Depth of cables	1.1	metre (m)	The layers above the cable will be[5]: • 300mm of stabilised material; • concrete covers of unknown thickness; • 500mm of backfill/native material; • 300mm of topsoil.
Power	450	mega-Watt (MW)	Maximum value
Conductor Diameter	33.9	millimetre (mm)	This is an aluminium conductor.
Insulation Diameter	79.9	millimetre (mm)	
Screen Sheath Diameter	85.9	millimetre (mm)	The metallic screen is made of copper.
Cable Diameter	94.1	millimetre (mm)	This includes the outer thickness.
Power Factor (PF)	0.9	*dimensionless quantity*	Assumed. The Power Factor is normally likely to be close to 1. It indicates the time relationship between voltage and current in the cable.
Current Density in Each Conductor	0.727	Ampere per square millimetre (A mm^{-1})	This has been calculated assuming maximum power divided evenly between the two trefoil cables, using the formula[6] $P = I*V_{conductor}*PF$ and the geometry of each conductor.

Table 3 Cable Parameters

3.2 Cable Route

The map below shows the planned route of the cable (indicated by the dark yellow line.

[4] The voltage on each conductor ($V_{conductor}$) is 220kV divided by √3 = 127V
[5] The electrical properties of these materials have not been differentiated, with one set being used for ground.

[6] P = Power in Watts, I = Current in Amperes, V = Voltage in Volts and PF = Power Factor.

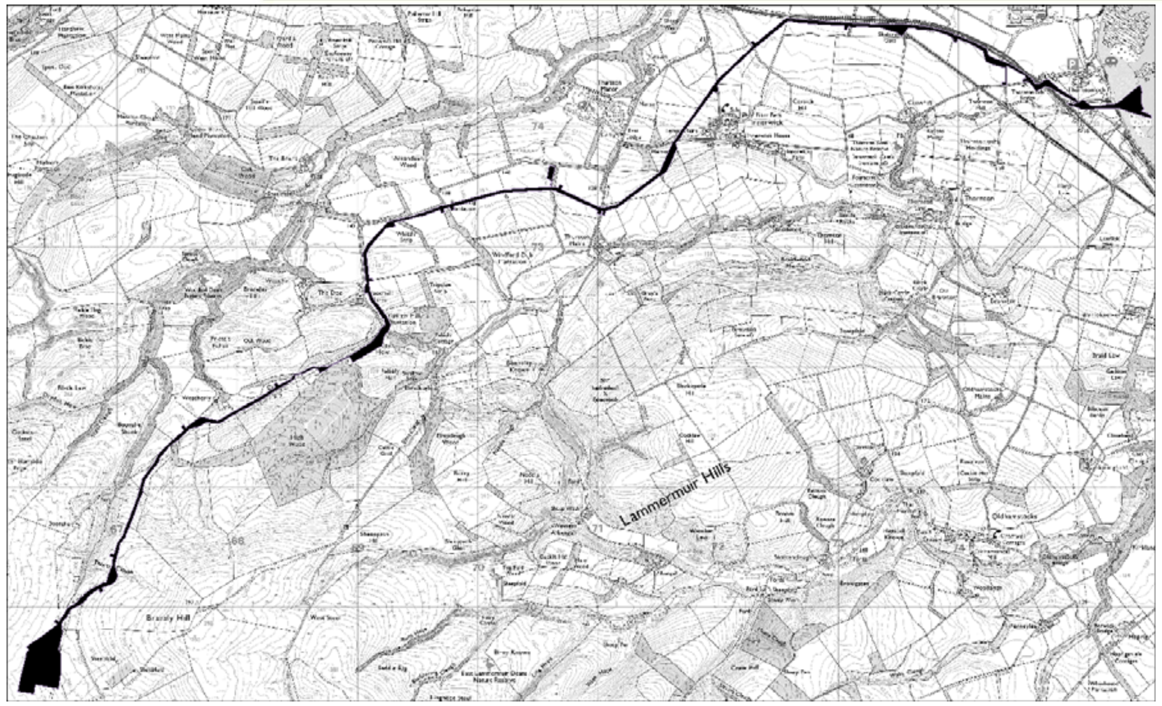

Figure 1 – Planned Cable Route.

Locations for assessment have been chosen based on their proximity to inhabited areas, i.e. residences and roads. The areas of interest are listed and described in the table below. The horizontal distance from the cable has been extrapolated from mapping. The locations of the buildings were extrapolated from 1:10,000 maps and the location of the cable was taken from geo-referenced maps such as the one shown in the figure above. The distance values in the table blow are given to 5 metre precision, which is not indicative of the accuracy for an individual case. However, the large number of locations considered, at various distances from the cable route, means the results taken as a whole are meaningful.

Location #	Easting	Northing	Horizontal Distance from Cable (m)	Notes
01	375330	674015	155	Building in Thornly
02	375015	674345	125	Residence in south Thortonloch
03	374680	674415	65	Residence west of Thorntonloch
04	374570	674345	40	Thorntonloch Bridge
05	374130	674330	280	Station House east of Crowhill
06	373410	675075	245	Residence at Skateraw
07	373565	674755	65	Residence at Skateraw Gate
08	371640	674555	380	Thurston Home Farm Cottages
09	371895	674050	105	Residence in west Innerwick
10	371885	673930	165	Temple Mains Building
11	371190	673939	430	East Lodge
12	371220	673850	360	Smithy Row
13	371005	673080	235	Thurston Mains
14	371080	673490	105	Ogle Lodge
15	369700	673365	25	Road near Birky Bog Plantation
16	368845	673235	330	Footpath north of Woodhall Farm
17	369020	672550	95	Woodhall Farm
18	369730	672150	515	Falsely Cottage
19	368585	671725	215	Footpath in High Wood
20	367830	671705	130	Farm Building in Weatherly

Table 4 Assessed Locations

The figure below shows the cable route with the considered locations shown as round icons, numbered in accordance with the table above.

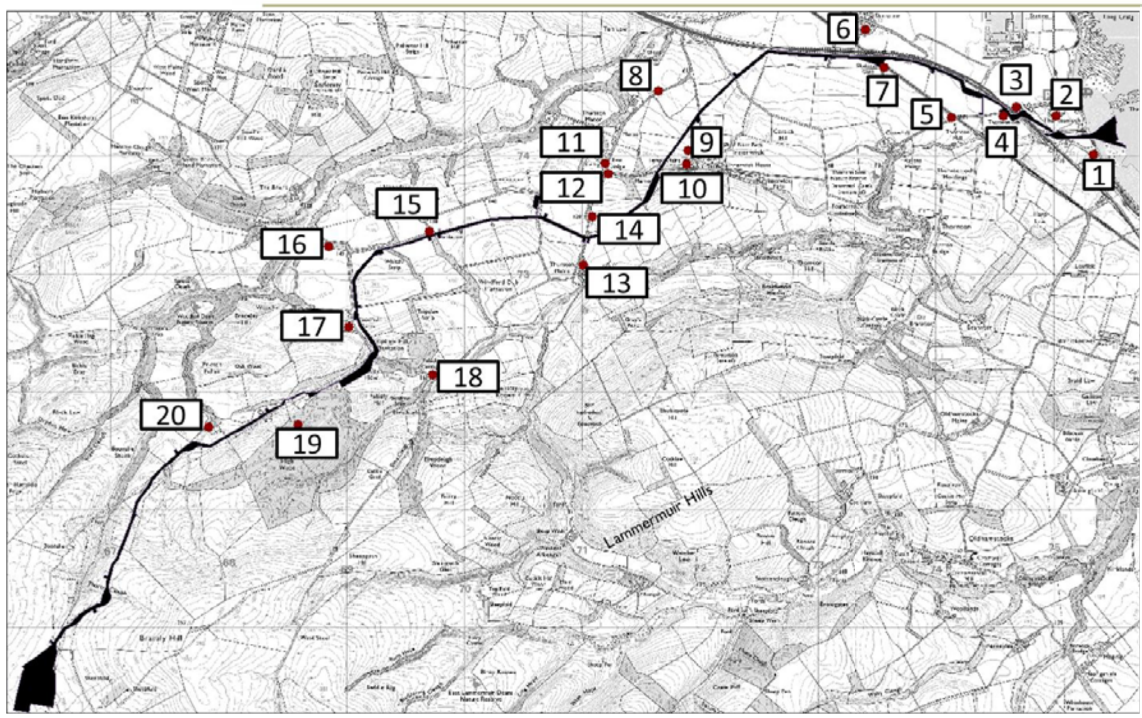

Figure 2 – Planned Cable Route with Considered Locations.

4 ANALYSIS

4.1 Model

The magnetic and electric fields at ground level have been modelled using Opera v.14 software. This is a software package based on Finite Element Analysis (FEA), which is widely considered[7] to be the most effective method for analysing problems related to electromagnetic fields. The analysis is two-dimensional.

The model incorporates the geometry of the cable as well as all the technical parameters described in section three. Some input parameters have been assumed or approximated, these are described below.

4.2 Magnetic Permeability (μ)

This is a quantity defined as the ratio of the magnetic flux density in a substance to the external field strength. The magnetic permeability of a material has a bearing on the extent to which it acts to shield a magnetic field. Therefore, the permeability of the cable, cable insulation and all the materials between the cable and the ground will affect the magnetic field strength at ground level. Precise values for all these materials are not available, and have been approximated based on available literature.

4.3 Electrical Permittivity (ε)

This is a quantity defined as the ratio of the electric displacement in a medium to the intensity of the electric field producing it. The value of electrical permittivity for a material will affect the extent to which it shields an electric field. The permittivity of the materials between the cable and the ground will therefore impact on the predicted electric field strength at ground level due to the cable. Precise values for all these materials are not available, and are not required for the modelling method employed for electric fields. The values found in the available literature have been included for completeness.

4.4 Electrical Conductivity (σ)

This is a measure of how well a material conducts electricity. The distribution of the electric current in a system will influence the surrounding electric field.

4.5 Values Used

The table below shows the values for magnetic permeability μ and electrical permittivity ε for each of the materials. It should be noted that the values shown in the table are actually for *relative*[8] permeability and permittivity, as these are the inputs for the model.

In many cases the values of the parameters are negligibly small (approximated as zero) or extremely close to unity (approximated as 1).

---

[7] The Electromagnetic Fields of Energised Transmission Circuits and Substations – C.P. Riley and A.M. Michaelides - 1998

[8] The relative permeability of a material is defined as the ratio of its permeability to that of free space. Algebraically, this is written $\mu_r = \mu/\mu_0$ where μ_r = relative permeability and μ_0 = permeability of free space (a constant). The same principle applies to electrical permittivity.

Material	Value of μ_r	Value[9] of ε_r	Value of σ (Sm^{-1})	Source	Notes
Aluminium Core	1	1000	3.5×10^7	μ_r: I.S. Grant and W.R. Phillips Electro-magnetism, Second Edition, John Wiley and Sons Ltd. ε_r: Value for metals in this model[10]. σ: Serway, Raymond A. (1998). Principles of Physics (2nd ed.). Fort Worth, Texas; London: Saunders College Pub. p. 602.	Values of relative magnetic permeability derived from values of magnetic susceptibility given in the source using: $\mu_r = (1 - \chi_B)$. where χ_B is magnetic susceptibility. This yields a value which are not exactly unity but can be considered to be 1 for modelling purposes.
Insulation	1	2.3	1×10^{-15}	μ_r: Assumed for insulating material in this model. ε_r: Typical value for Polyethylene from I.S. Grant and W.R. Phillips Electro-magnetism, Second Edition, John Wiley and Sons Ltd. σ: Assumed for insulating material.	It is not known what the material of the insulation is. Typical materials for such insulation include Cross-linked Polyethylene (XLPE). The conductivity will in reality be non-zero but negligibly small.

[9] These values have been included for completeness, however the modelling of electric fields was based on a fixed voltage of 220kV within the conductor which merely requires this value to be sufficiently high.
[10] For the model to give meaningful results the key is for this value to be very high for the conductors compared to the other materials. This is not necessarily representative of ε_r in any other context.

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Material	Value of μ_r	Value[9] of ε_r	Value of σ (Sm^{-1})	Source	Notes
Copper Screen Sheath	1	1000	5.9×10^7	μ_r: I.S. Grant and W.R. Phillips Electro-magnetism, Second Edition, John Wiley and Sons Ltd. ε_r: Value for metals in this model. σ: Value given for Copper, I.S. Grant and W.R. Phillips Electro-magnetism, Second Edition, John Wiley and Sons Ltd.	Values of relative magnetic permeability derived from values of magnetic susceptibility given in the source using: $\mu_r = (1 - \chi_B)$. where χ_B is magnetic susceptibility. This yields a value which are not exactly unity but can be considered to be 1 for modelling purposes.
Outer Layer	1	2.3	1×10^{-15}	μ_r: Assumed for insulating material in this model. ε_r: Typical value for Polyethylene from I.S. Grant and W.R. Phillips Electro-magnetism, Second Edition, John Wiley and Sons Ltd. σ: Assumed for insulating material.	It is not known what the material of the insulation is. For the purposes of this analysis the same parameters have been used for this layer as for the insulating layer.

Material	Value of μ_r	Value[9] of ε_r	Value of σ (Sm^{-1})	Source	Notes
Ground	1	3.4	2.4×10^{-3}	μ_r: Assumed. ε_r: Arthur R. von Hippel, ed.: "Dielectric Materials and Applications", M.I.T. Press, Cambridge, MA, 1954. σ: EON Earthing Manual Section E3 Soil Resistivity Measurements	The values for the ground should be considered indicative only. The value for relative permeability of the ground is highly sensitive to the type of soil, its constituent materials, its water content and various other parameters. The same is true of the conductivity. The value used for conductivity is calculated based on values of resistivity given in the source document mentioned. There is a wide range of values for various scenarios, and therefore the value used here should be considered indicative.

Material	Value of μ_r	Value[9] of ε_r	Value of σ (Sm^{-1})	Source	Notes
Air	1	1	0	μ_r: B. D. Cullity and C. D. Graham (2008), Introduction to Magnetic Materials, 2nd edition, 568 pp., p.16 ε_r: I.S. Grant and W.R. Phillips Electro-magnetism, Second Edition, John Wiley and Sons Ltd. σ: Assumed.	

Table 5 Conductivity, Permittivity and Permeability Values

The figure below shows a cross sectional view of a single phase of the cable, i.e. one of the three conductors in each of the two groups of three, for illustration purposes.

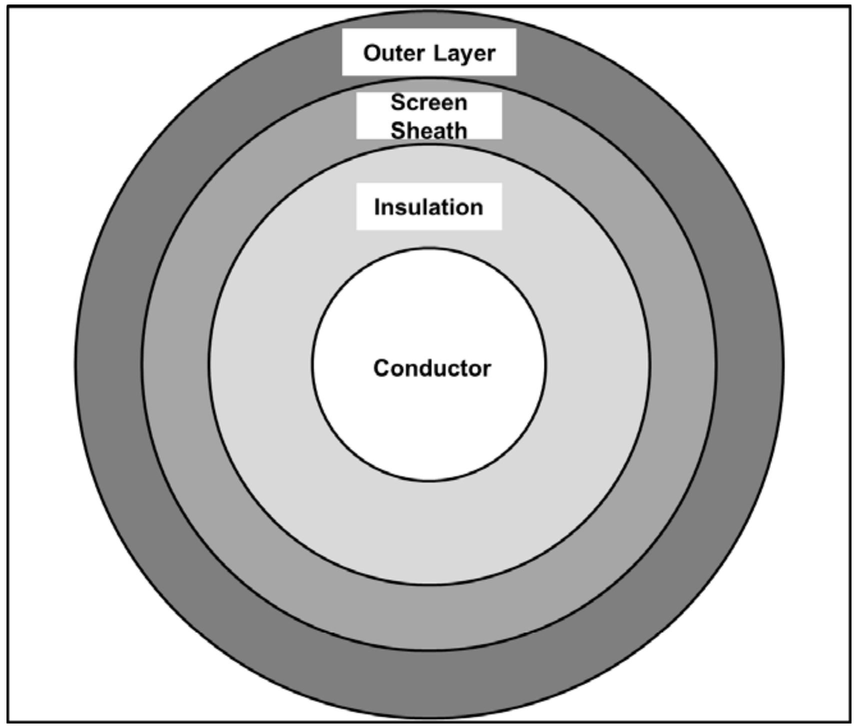

Figure 3 – Cable Cross Section (not to scale).

4.6 Model Outputs

There are two outputs of the model. These are:

- A plot of the magnetic field at ground level in the vicinity of the cable;
- A plot of the electric field at ground level in the vicinity of the cable.

Both of these plots show the field values with varying distances on either side of the cable. The distance of each assessed location from the cable route therefore dictates the predicted field values at that location.

5 RESULTS

5.1 Boundary Conditions

When modelling fields in this way, it is necessary to set a boundary condition where the field is defined as zero. This needs to be set at a distance where the field strength will be sufficiently low for this approximation to yield meaningful results. Initially, this distance was to be set at 500m to incorporate all the locations identified. However, a preliminary analysis with the field set to zero at 25m revealed that the field drops to negligible values within a much shorter distance than this. Therefore, the results have been generated with a boundary condition setting the field values to zero at 25m from the cable (horizontally). Whilst this does mean that field values for many of the locations of concern are zero by construction, this is thought to be a valid approximation and does not compromise the validity of the results.

5.2 Magnetic Field

The figure below shows the predicted magnetic field strength at one metre above ground level above the underground cable out to 25 metres from the cable location.

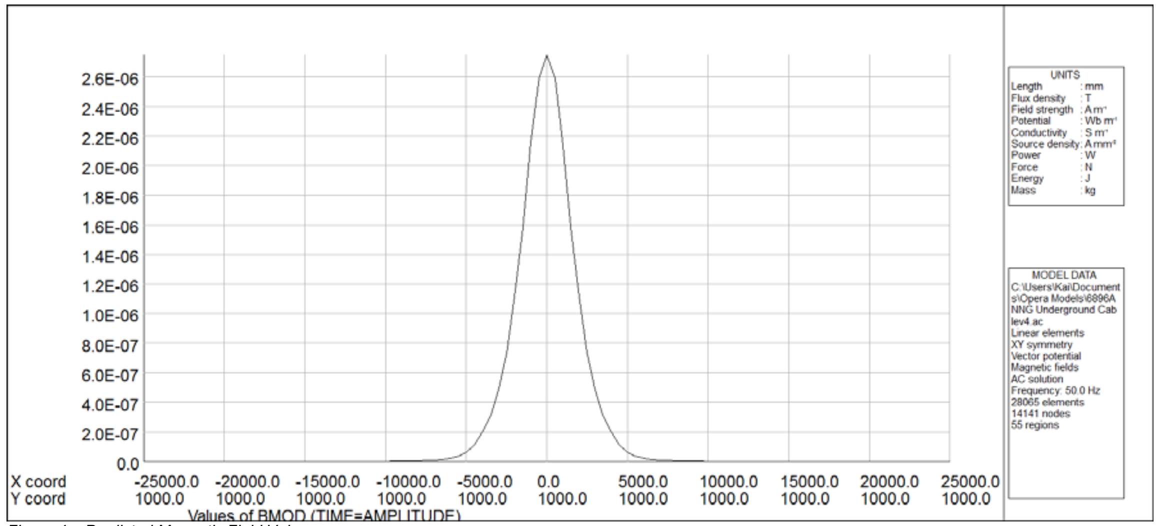

Figure 4 – Predicted Magnetic Field Values.

The figure shows that:

- The magnetic field is highest directly above the cable[11];
- The maximum field strength is less than 3µT and therefore less than 3% of the reference level;
- The field strength falls to half this value at approximately 2m from the cable.

The figure below illustrates the level at which the field strength would require further investigation relative the field strength predicted by the model.

[11] It should be noted that the phase ordering of the cables has not been established and therefore the pattern of the field may be altered slightly (e.g. there may be a dip at the centre due to the phases cancelling one another out. This is not important as we are considering the maximum field values, which are unlikely to be significantly affected by the phase ordering of the cable. This is true of the electric field plots also.

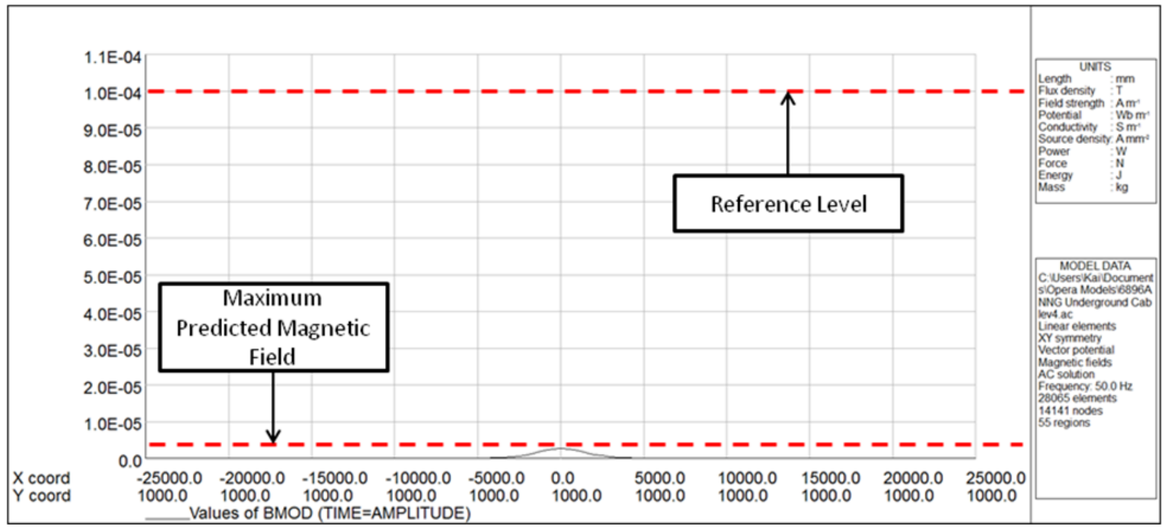

Figure 5 – Predicted Magnetic Field Values and Reference Level for Magnetic Fields.

The modelling has assumed a balanced load spread across all the conductors. This may not be the case at all times, and slight bias towards one phase may alter the result to a degree. However, large imbalances are not anticipated[12]. Given the large gap between predicted field strength and the reference level, it can be concluded that there will be no significant risk with regard to magnetic field strength.

5.3 Electric Field

The figure below shows the predicted electric field strength at one metre above ground level above the underground cable out to 25 metres from the cable location.

[12] Large imbalances could occur under fault conditions. However, this would be expected cause a spike in the field level for less than one second, and would therefore not be considered 'continuous exposure' even if the investigation levels were breached. As stated in section 3.2 of this document, one of the provisos in the EU recommendation is that limits be imposed where exposure time is significant.

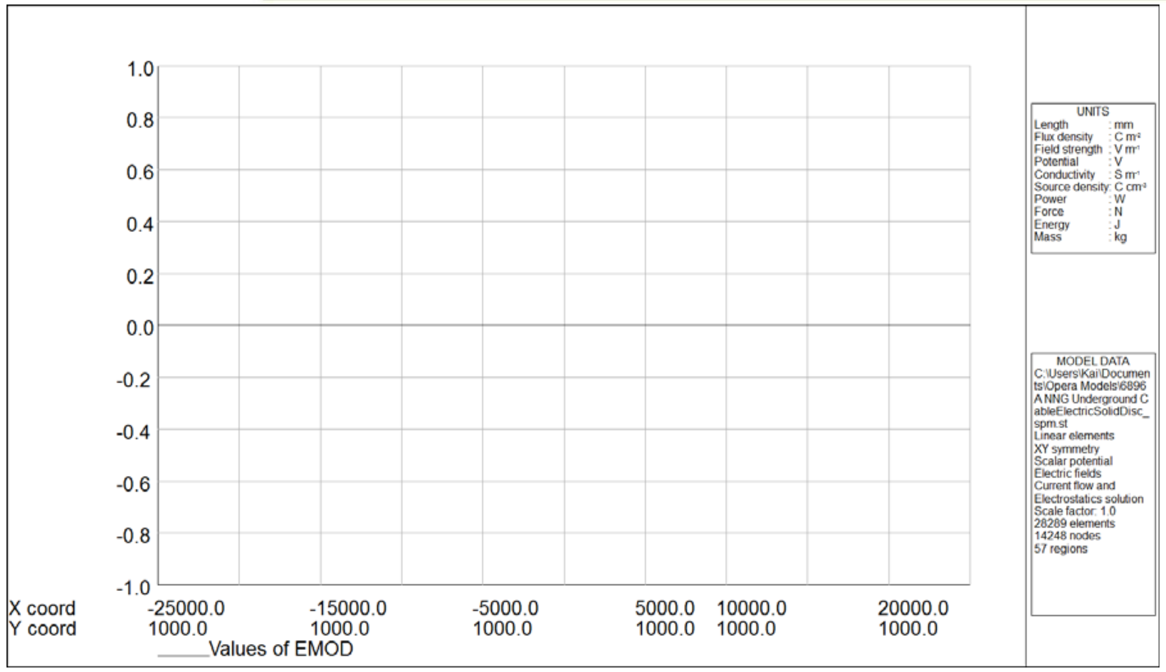

Figure 6 – Predicted Electric Field Values.

The figure shows no anticipated electric field at 1m above ground level. This is likely to be due in part to the high conductivity of the copper shielding, which will contain a high electric field within it as shown in the figure below, which is a contour plot of the electric field for a cross section of the cables. The bright coloured zones surrounding the cables represent high electric field values with the ground outside the remaining unaffected.

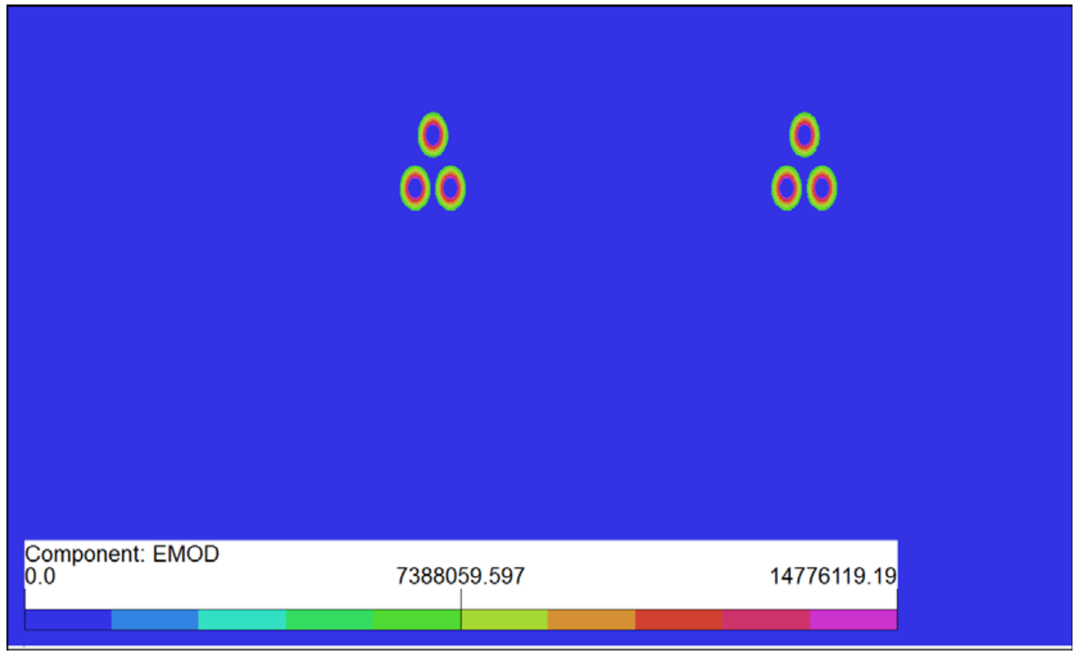

Figure 7 – Electric Field Values. The layers surrounding the cable hold high electric field levels.

It should be noted that the copper shielding has been modelled as a solid disc, which may not be the case[13]. However, even if the effective area and conductivity of this shield are significantly lower, potentially harmful levels at ground level would not be anticipated.

5.4 Field Strength at Considered Locations

The table below shows the values of magnetic and electric field strength at each of the locations detailed in section 3 of this report.

Location #	Horizontal Distance from Cable (m)	Predicted Magnetic Field Strength (μT)[14]	Magnetic Field Strength Percentage of Reference Level (%)	Predicted Electric Field Strength (Vm^{-1})	Electric Field Strength Percentage of Safe Level (%)
01	155	0	0	0	0

[13] Details of the kind of shielding have not been provided. This could be in the form of a folded screen or braided wires etc.

[14] Values will always be above zero, however a value of zero is given when the field strength is considered negligibly small based on the plots shown in the previous section.

Location #	Horizontal Distance from Cable (m)	Predicted Magnetic Field Strength (μT)[14]	Magnetic Field Strength Percentage of Reference Level (%)	Predicted Electric Field Strength (Vm^{-1})	Electric Field Strength Percentage of Safe Level (%)
02	125	0	0	0	0
03	65	0	0	0	0
04	40	0	0	0	0
05	280	0	0	0	0
06	245	0	0	0	0
07	65	0	0	0	0
08	380	0	0	0	0
09	105	0	0	0	0
10	165	0	0	0	0
11	430	0	0	0	0
12	360	0	0	0	0
13	235	0	0	0	0
14	105	0	0	0	0
15	25	0	0	0	0
16	330	0	0	0	0
17	95	0	0	0	0
18	515	0	0	0	0
19	215	0	0	0	0
20	130	0	0	0	0

Table 6 Assessed Locations

5.5 Substation

The fields associated with the substation have not been explicitly modelled. However, the substation is due to be located near Friardykes Dod, more than a kilometre from any dwellings. The National Grid guidance regarding substations states the following:

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Substations are where electricity lines are connected and switched and where the voltage is changed by transformers. They range from the very large to the very small - see below for a guide. But in nearly all cases, the highest field is usually produced by the lines and cables supplying the substation and not by the equipment inside the substation itself. If the substation itself produces a field outside its perimeter, it usually falls away over the first few metres.

Any issues due to the substation are considered negligible.

6 REMARKS

All efforts have been made to ensure the modelling undertaken is accurate and that the results are meaningful. The following should be noted:

- Assumptions have been made relating to the specific electrical properties of some of the materials. Every effort has been made to state these assumptions within this report;
- The locations for assessment and their distances from the cable have been extrapolated from mapping;
- Other parameters may affect the results which cannot be meaningfully accounted for at the modelling stage. This includes existing EMFs at any locations and conducting materials such as copper pipes which may already exist in the vicinity of the cable;
- Calculations have assumed the cable is operating at peak capacity. This is a worst case scenario and is unlikely to be the case in the real world;
- Consideration of more accurate parameters for some materials and the phase ordering of the cables once this is known could alter the results. It is Pager Power's view that the conclusion of this report, which is that harmful EMFs as defined by the appropriate authorities, will not be caused by the underground cable, would remain unchanged even if more detailed modelling were to be undertaken.

7 CONCLUSIONS

The anticipated magnetic and electric field strengths associated with the underground cable are below the reference levels advised by UK government policy.

Peak power conditions have been assumed for all calculations.

Magnetic Fields

The field levels drop sharply with distance from the horizontal centre of the cables. None of the identified residences are likely to be within even 1% of the reference levels relating to health concerns.

Electric Fields

The model does not predict measurable electric fields at one metre above ground level, even directly above the cable.

Substation

Available information regarding fields surrounding substations suggests that these fall away within a few metres of the substation. There are no residences within one kilometre of the substation location near Friardykes Dod.

No impact relating to EMFs is anticipated.