NAVITUS BAY WIND PARK

TECHNICAL APPENDIX

VOLUME B - OFFSHORE
CHAPTER 2 - OFFSHORE PROJECT DESCRIPTION
APPENDIX 2.1 - EMF CALCULATIONS REPORT

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Report On

Electromagnetic Field Calculations
For PMSS & Navitus Bay Development
Navitus Bay Windfarm

Document 75926004 Report 01 Issue 1

March 2014

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REPORT ON	EMF Calculations PMSS & Navitus Bay Development Navitus Bay Windfarm Document 75926004 Report 01 Issue 1 March 2014
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1 INTRODUCTION

1.1 This report provides a briefing paper providing details of the range of electromagnetic field (EMF) emissions that could be expected from the inter array and export cables for Navitus Bay Wind Park to inform relevant chapters of the environmental impact assessment.

1.2 The EMF calculations were undertaken in accordance with requirement document 31211 120808 CTR EMF and with reference to the descriptions contained in document Navitus Bay OFFSHORE PDS.

1.3 The calculations were undertaken by TÜV SÜD Product Service for PMSS under PO 1229 on behalf of Navitus Bay Development Limited under PO 3-1648.

1.4 Electromagnetic fields from submarine power cables may be significant for electrically and magnetically sensitive marine organisms if they can detect them. This report is only concerned with a calculation of the magnitude of the electromagnetic fields.

2 REFERENCES

2.1 31211 120808 CTR EMF draft RM (PMSS Cost/Time/Resource Schedule for preparation of briefing paper on EMF emissions for Navitus Bay Wind Park)

2.2 Navitus Bay OFFSHORE PDS Issue 3_29 June 2012 FINAL

2.3 Extremely low frequency fields environmental health criteria monograph No. 238, World Health Organisation

2.4 OCS Study – Effects of EMFs from undersea power cables on elasmobranchs and other marine species, 2011-09, US Dept of Interior

2.5 Oregon Wave Energy Electromagnetic Field Study 0905-00-007 Sept 2010

2.6 Vattenfall – Impact of electric and magnetic fields from submarine cables on marine organisms 3080100, Nov 2010

2.7 Sweden Offshore - Electromagnetic simulations of 135kV three-phase submarine power cables, University of Liverpool

2.8 COWRIE-EMF-01-2002 – A baseline assessment of electromagnetic fields generated by offshore windfarm cables, University of Liverpool

2.9 COWRIE 1.5 Electromagnetic Fields Review Final Report, July 2005

2.10 COWRIE 2.0 Electromagnetic Fields (EMF) Phase 2, EP-2054-ABG, 2009

3 ABBREVIATIONS

AC	Alternating Current
Al	Aluminium
A/m	Amps per Metre
B	Magnetic Flux Density
Cu	Copper
DC	Direct Current
E	Electric Field
Est	Estimate
EMF	Electromagnetic field
H	Magnetic Field (Strength)
kV	Kilovolt
I	Current
m	Metre
mm	Millimetre
MVA	Megavoltamp
RMS	Root Mean Square
TÜV SÜD PS	TÜV SÜD Product Service
µT	Microtesla
µV/m	Microvolt per Metre
V	Volt
V/m	Volts per Metre
WHO	World Health Organisation

4 ELECTRIC AND MAGNETIC FIELDS FROM SUBMARINE CABLES

4.1 Figure 1 shows the general relationship between a submarine cable and the electric and magnetic fields produced.

4.2 Electric fields are created by differences in voltage: the higher the voltage, the stronger will be the resultant field. Magnetic fields are created when electric current flows: the greater the current, the stronger the magnetic field. An electric field will exist even when there is no current flowing. If current does flow, the strength of the magnetic field will vary with power consumption but the electric field strength will be constant.

4.3 The strength of the electric field (E) is measured in volts per metre (V/m). Electric fields are strongest close to a charge or charged conductor, and their strength rapidly diminishes with distance from it. Conductors such as metal shield them very effectively. Therefore submarine cables with an earthed metal shield around the conductors do not produce a direct electric field outside the cable. For Navitus Bay, the proposed cables are shielded and therefore the direct electric field will be negligible and need not be considered further. However the magnetic field can produce an induced electric field described below.

4.4 The strength of the magnetic field (H) is measured in amperes per meter (A/m); more commonly in electromagnetic field research at low frequencies, a related quantity, the flux density (B in microtesla, µT) is used instead. The relationship between magnetic field strength and magnetic flux density is constant in air as well as non-magnetic materials including seawater, seabed and biological organisms. This results in the relationship 1µT = 0.79A/m.

The magnetic field outside a submarine cable is a function of current flow on the cable conductors, distance from the cable, and the arrangement of the conductors within the cable. For the Navitus Bay Windfarm all cables will contain three phase conductors arranged in triangular or trefoil geometry.

4.5 An induced electric field results from a changing magnetic field where there is a conducting medium such as seawater or an organism. From Faraday's law of induction; the magnetic field causes an induced electromotive force in the electrically conducting medium and this electromotive force in turn, causes an electric field. In a marine environment induced electric fields can exist due to the following reasons:

1) A sub-sea cable carrying an AC-current.

2) Moving water (e.g. tidal water) in the presence of the earth's geomagnetic field.

3) Moving water (e.g. tidal water) crossing a cable carrying a DC-current.

4) Earth's geomagnetic field variations, inducing electric and magnetic field.

2) and 4) are natural sources. For Navitus Bay we are only concerned with 1) a submarine cable carrying an AC current as there is no DC cable. The induced electric field depends on the distance from the cable, the electrical conductivity of the medium, the separation between the conductors and the load current in the cable and is independent of the voltage. Further, the induced electric field depends upon the size of the conducting object (e.g. organism) (Ref 2.3).

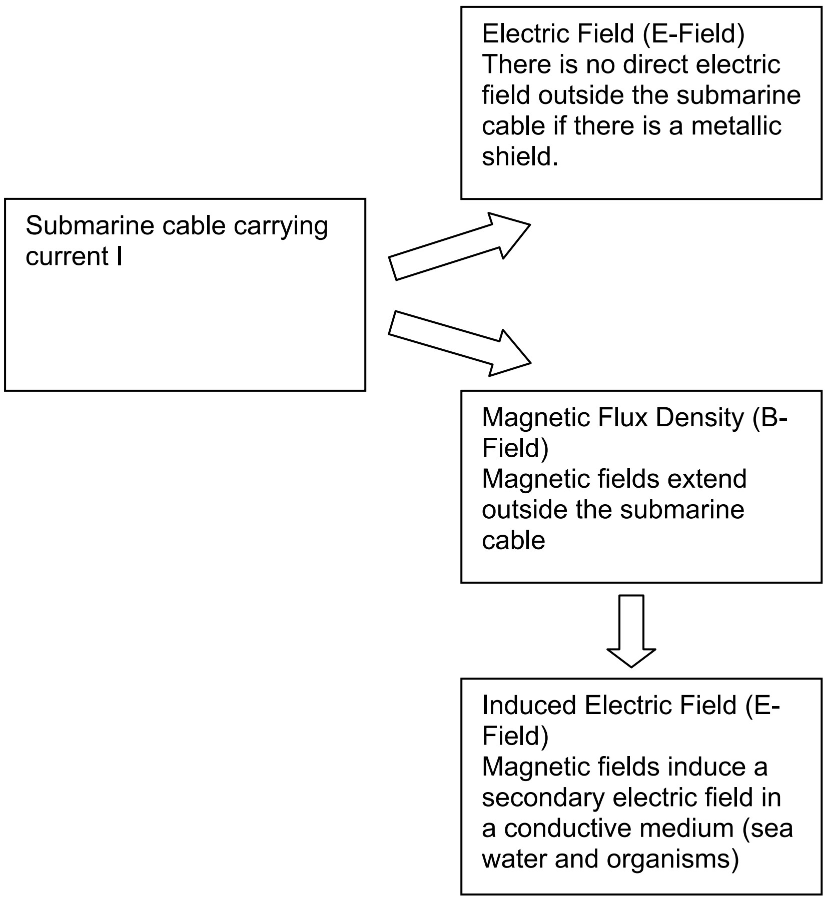

Figure 1 – Electromagnetic Fields Associated with Submarine Cables

5 ASSUMPTIONS

5.1 All cables will contain three phase conductors arranged in a triangular geometry.

5.2 All conductors are shielded. Shielded cables produce negligible direct electric field. As a consequence, the cable voltage is not relevant, only the current that produces the magnetic field and resultant induced electric field.

5.3 The reduction in magnetic field due to cable armouring is not included in the calculation. The magnetic fields (and resultant induced electric fields) would be reduced further by the presence of cable armouring. It is understood that for the Navitus Bay project Submarine Cables will be armoured.

5.4 The sea, seabed and any organism is non-metallic and has a relative permeability of 1 and therefore does not influence the magnetic field.

5.5 The induced electric field resulting from the magnetic field is also dependent on the radius of loop formed by a body (of an organism). The worst case induced electric field occurs for the largest body of interest. For this study the loop radius assumed is 0.5m.

6 EMF CALCULATION METHOD

6.1 An excel spreadsheet has been used to perform calculations of magnetic field and induced electric field from AC submarine cables. The spreadsheet has been used by PMSS on previous projects and has been adapted for the Navitus Bay Windfarm cables.

6.2 The data required for the spreadsheet is:

Parameter	Units	Source
Conductor core cross section	mm^2	From cable specification.
Conductor sheath outer diameter	m	From cable specification.
Cable outer diameter	m	From cable specification.
Cable burial depth (d)	m	0m and 1.5m required by Ref 2.1.
Frequency	Hz	UK location. 50Hz AC for all cables
Load	A	Derived from Ref 2.1 power data, see 7.1.
Radius z of organism for induced field	m	Used to calculate induced electric field. Assumed max 0.5m
Distance along seabed (x)	m	0m required by Ref 2.1 for worst case plus graph as x varies.

Table 1 - EMF Input Data

6.3 The physical parameters are shown below. The scenario for the submarine cable is that it is either on the seabed or buried. When on the seabed (d = 0), the calculation position 'x' is taken as equal to the radius of the cable (otherwise the calculation refers to the interior of the cable). For the buried case, results are required directly above the cable (x = 0) plus a graph showing the field attenuation (as x increases). The distance from the point of interest to the cable is r.

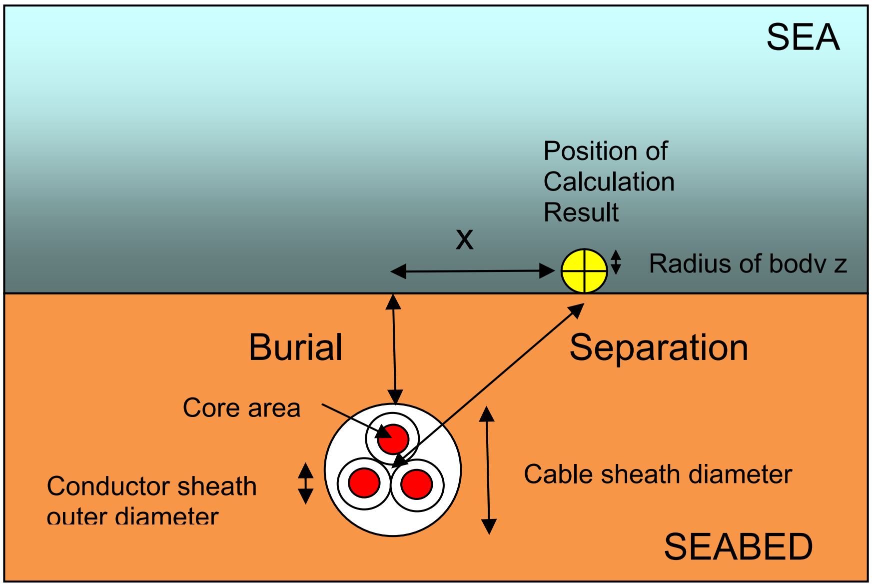

Figure 2 – Physical Scenario

6.4 The magnetic field at the position of interest is calculated for each of the 3 conductors and the resultant field calculated. The magnetic field due to current I in an infinite conductor is given by the Biot-Savart Law:

$B = \mu_r \mu_o I / (2 \pi r)$

Where:

B	Magnetic flux density Tesla
μ_r	Relative permeability (1)
μ_o	Permeability of free space (constant $4\pi \times 10^{-7}$)
I	Current amps
r	distance m

For each time step over an AC cycle, the instantaneous current I is calculated for each of the 3 conductor phases. The contributions from each conductor are added to give a resultant instantaneous vertical and horizontal component of magnetic field. The total instantaneous magnetic field is then calculated from Pythagoras Theorm ($A^2 = B^2 + C^2$).

The root mean square (RMS) value of magnetic field over the AC cycle is then calculated.

6.5 The induced electric field at the position of interest depends on the magnetic field calculated and the size of the body into which the electric field is induced. The World Health Organisation (Ref 2.3) provides guidance on human and animal magnetic field dosimetry. In the simplest model the induced electric field is given by the relationship:

$E = \pi f z B$

Where:

f	Frequency Hz (50Hz)
z	Loop radius of body m

B Magnetic flux density (calculated above)

Since the induced electric field depends upon the size of the body, it can be seen that the larger the loop radius z, the larger the induced electric field. Therefore the worst case field will result from the largest body of interest. For this study a loop radius of z = 0.5m has been used. This equates approximately to the area of a 'generic small shark' as described in OCS Study for US Dept of Interior, Ref. 2.4. For smaller organisms the induced electric field will be less.

It was noted that some previous studies of EMFs due to submarine cables had used a similar method but other studies used a different approach to calculating induced electric field at a point that did not require knowledge of the size of the organism and had found differing results.

7 CABLE PARAMETERS

7.1 The requirement document 31211 120808 CTR EMF specifies the range of cables for the Inter Array Power and for the Export Power functions. The cable parameters are shown below. Conductor material is either copper (Cu) or aluminium (Al).

Note: The phase current in a three phase cable is given by:

$I = S_{MVA} / \sqrt{3}\, U_v$

Where:

S_{MVA} Power MVA
U_v Voltage V

Further detail of cable parameters was obtained from the cable manufacturers website; nexans.co.uk. Where specific data was not available an estimate was made as indicated by 'est' in the tables.

Function	Conductor Type	Voltage kV	Power MVA	Phase current A	Cable Diameter m	Conductor Diameter m	Core Area mm^2
Export power	Cu	132	240	1050	0.22	0.092	1000
Export power	Al	132	240	1050	0.225	0.106	1600
Export power	Cu	150	290	1116	0.225 est	0.097	1000
Export power	Al	150	290	1116	0.247 est	0.107	1600
Export power	Cu	220	450	1181	0.259	0.1	1000
Export power	Al	220	450	1181	0.264	0.114	1600
Export power	Cu	275	570	1196	0.250 est	0.108	1000
Export power	Al	275	570	1196	0.283 est	0.122	1600

Table 2 – Export Power Cable Data

Function	Conductor Type	Voltage kV	Power MVA	Phase current A	Cable Diameter m	Conductor Diameter m	Core Area mm^2
Inter Array power	Cu	11	15	788	0.157 est	0.070 est	800 est
Inter Array power	Cu	33	40	700	0.129	0.047 est	400
Inter Array power	Cu	33	40	700	0.144	0.052 est	630
Inter Array power	Al	66	70	612	0.141	0.067	400
Inter Array power	Al	66	70	612	0.167	0.081	800

Table 3 – Inter Array Cable Data

8 EMF CALCULATION RESULTS

8.1 The magnetic and induced electric field results are shown for each cable type in the table below. Graphs showing how the fields attenuate with distance along the seabed are shown in Annex A for the worst case Export and Inter Array cables identified for 0m and 1.5m burial as highlighted below.

Note: The levels calculated for 0m burial assume the organism is directly against the cable, i.e. no separation due to cable burial or a covering of ‘rock armour’. The levels are theoretical worst case and do not take account of any reduction if EMF due to cable armouring. See Section 9 for mitigation of EMF.

Function	Conductor Type	Voltage kV	Core Area mm^2	Magnetic Field B μT 0m Burial	Magnetic Field B μT 1.5m Burial	Induced Electric Field E mV/m 0m Burial	Induced Electric Field E mV/m 1.5m Burial
Export power	Cu	132	1000	1007	9.14	79.126	0.717
Export power	Al	132	1600	1112	10.5	87.340	0.824
Export power	Cu	150	1000	1080	10.2	84.828	0.802
Export power	Al	150	1600	989	11.1	77.654	0.872
Export power	Cu	220	1000	887	10.9	69.661	0.856
Export power	Al	220	1600	975	12.4	76.636	0.974
Export power	Cu	275	1000	1044	12.0	81.991	0.942
Export power	Al	275	1600	920	13.3	72.275	1.043
Inter Array power	Cu	11	800	1131	5.43	88.832	0.426
Inter Array power	Cu	33	400	994	3.29	78.104	0.259
Inter Array power	Cu	33	630	883	3.61	69.331	0.283
Inter Array power	Al	66	400	1043	4.07	81.943	0.320
Inter Array power	Al	66	800	899	4.85	70.631	0.381

Table 4 – EMF Calculation Results – Theoretical Worst case

9 MITIGATION OF EMF

9.1 Cable Armouring

The addition of cable armouring will reduce the magnetic field depending on the magnetic permeability of the material and thickness of the armouring material.

- Steel wires or tape armouring have a high permeability (e.g. Steel wire = 300, Steel Tape = 3000).
- Stainless steel, copper or lead armouring will have a permeability of 1 and will not provide any additional reduction in magnetic field.

It is understood that for the Navitus Bay project Submarine Cables will be steel wire armoured. The EMF calculations in this report do not take account of any reduction due to cable armouring. Other studies have considered the reduction due to cable armouring and these are outlined below for magnetic field. The induced electric field is also reduced by the same factors as it is proportional to the magnetic field:

Example #1: Oregon Wave Energy Electromagnetic Field Study 0905-00-007 Sept 2010, Ref. 2.5:

Data from this study is summarized to show the effect of cable armouring:

Study Figure Reference	Magnetic Field at 1m
Figure 21 Trefoil cable (no armouring)	30nT/A
Figure 24 Trefoil cable (Single outer shield armouring)	7nT/A
Relative Reduction in Magnetic Field	4.3 times reduction

Table 5 - OCS Study Effect of Cable Armouring

Example #2: Sweden Offshore - Electromagnetic simulations of 135kV three-phase submarine power cables, University of Liverpool, Ref. 2.7:

Data from this study is summarized to show the effect of cable armouring:

Study Figure Reference	Magnetic Field at 1m
Figure 3.5 Trefoil Cable B-Field Contours (Without steel armouring)	1180 to 2570μT (at cable surface)
Figure 3.4 Trefoil Cable B-Field Contours (Steel armouring)	11.7 to 21.7μT (at cable surface)
Relative Reduction in Magnetic Field	101 to 118 times reduction

Table 6 – Sweden Offshore Study Effect of Cable Armouring

9.2 Cable Burial and Rock Armouring

It is understood that for the Navitus Bay project Submarine Cables will be buried or covered with rock armour. The effect of cable burial is to enforce a separation between the organism and the cable and results in a reduction of the EMF as shown in Table 4 for cable burial of 1.5m. The reduction is between 80 and 300 times reduction (depending on the cable construction geometry).

The same reduction would be obtained by covering the cable with the equivalent thickness of ‘rock armour’. Here the cable remains on the surface of the seabed but is buried with the addition of a rock material forming a mound over the cable.

10 CONCLUSIONS AND RECOMMENDATIONS

10.1 The worst case magnetic field and induced electric fields for Export Power cables and Inter Array cables have been calculated.

10.2 The magnetic fields for 1.5m cable burial (or additional rock armour) are reduced and range up to 13.3μT for Export Power cables and 5.43μT for Inter Array Power cables.

10.3 The induced electric fields for 1.5m cable burial (or additional rock armour) are reduced and range up to 1.043mV/m for Export Power cables and 0.426mV/m for Inter Array Power cables (assuming a large organism of 0.5m radius – these levels would be reduced for smaller organisms).

10.4 The above levels would be further reduced for cables with cable armouring of steel wires or tapes. The reduction factor depends on the magnetic permeability and thickness of the armouring. Previous studies have found reductions ranging from 4.3 to 118 times reduction.

10.5 The simplified spreadsheet calculations in this report provide an indication of the magnitude of magnetic field and induced electric field based on a range of assumptions as stated. To provide a more in-depth analysis, detailed specific cable parameters would be required to create a model in suitable software tools for electromagnetic field and cable simulation.

ANNEX A
EMF Graphs

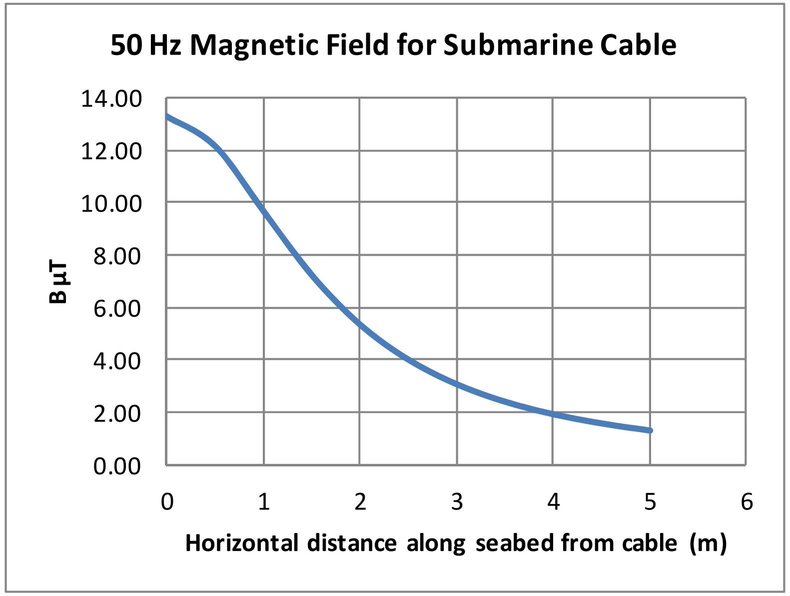

Figure 3 - Export Power, 275kV Al Cable, 1.5m Burial, Magnetic Field

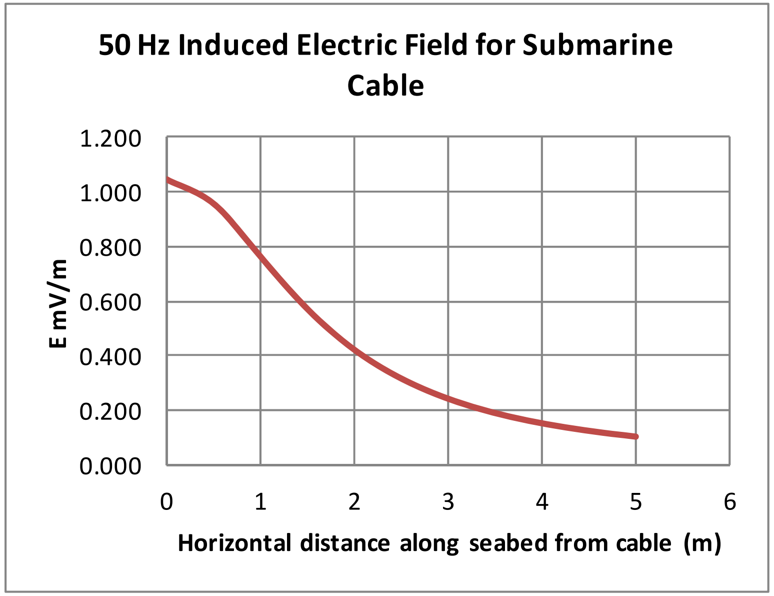

Figure 4 - Export Power, 275kV Al Cable, 1.5m Burial, Induced Electric Field

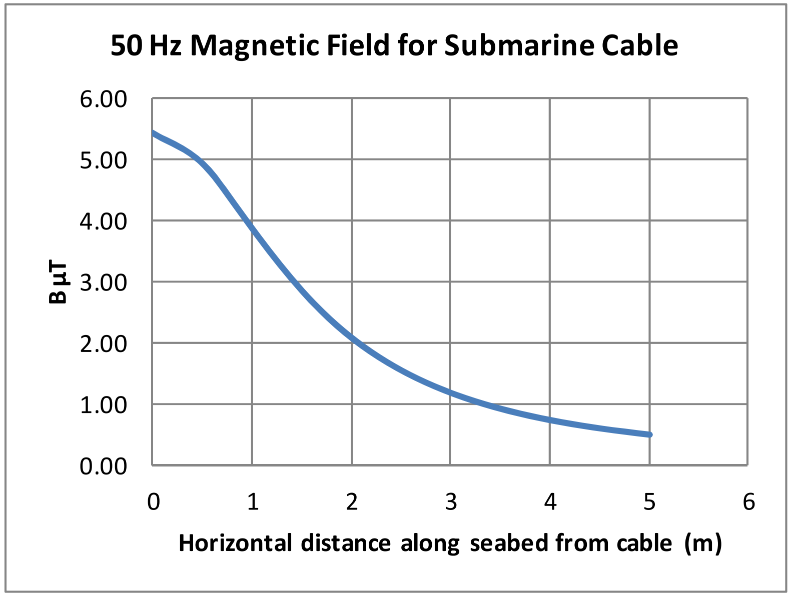

Figure 5 – Inter Array Power, 11kV Cu Cable, 1.5m Burial, Magnetic Field

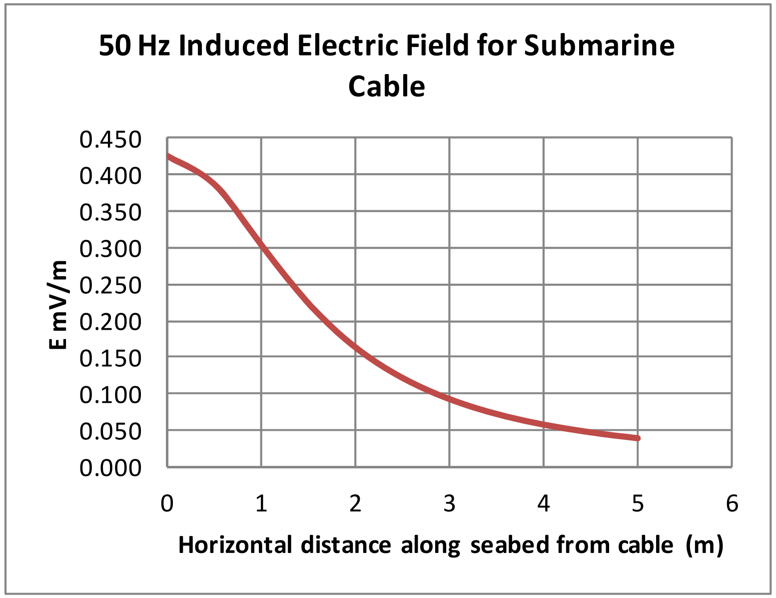

Figure 6 - Inter Array Power, 11kV Cu Cable, 1.5m Burial, Induced Electric Field