

Appendix 19 - Human Health Assessment (EMF)



Bullawah Wind Farm Project

Bullawah Wind Farm – EMF Study



Client: Umwelt (Australia) Pty Ltd

Revision: 2

Project: Bullawah Wind Farm – Electromagnetic Field / Human Health Assessment

Doc no: 23048-E-RPT-0002

DRAFT



Revision control

Revision	Date	Description	Prepared by	Reviewed by	Approved by
A	20.10.23	Issued for Review	Ramez Barakat	Eric Bendtsen	Timothy Cervenjak
1	27.06.24	Final Issue	Ramez Barakat	Eric Bendtsen	Alex Low
2	02.07.24	Final Re-issue	Ramez Barakat	Eric Bendtsen	Alex Low

Disclaimer

This document has been prepared by Middleton Group Engineering Pty Ltd solely for the exclusive use of Umwelt (Australia) Pty Ltd. This document is not intended to be and should not be used or relied upon by anyone else. Middleton Group Engineering Pty Ltd does not accept any duty of care or liability to any other person or entity other than Umwelt (Australia) Pty Ltd. Users of this document should exercise their own skill and care or seek professional advice in the use of the document.

The opinions, conclusions and any recommendations in this report are necessarily based on assumptions made by Middleton Group Engineering Pty Ltd, as described in this report. To the extent the report makes assumptions, these can give rise to discrepancies to the extent that they may or may not represent actual existing circumstances or eventuate to be correct assumptions. Middleton Group Engineering Pty Ltd disclaims liability arising as a result of such discrepancies to the extent such assumptions are such that Middleton Group Engineering Pty Ltd can reasonably be expected to make in accordance with sound professional principles.

Executive Summary

Middleton Group Engineering (MGE) has been engaged by Umwelt (Australia) Pty Ltd to undertake an Electromagnetic Field (EMF) desktop study for the Bullawah Wind Farm Project (the Project), located approximately 36 km south east of Hay, within the South West Renewable Energy Zone. The Project Area is located within the Hay Shire, Murrumbidgee and Edward River Local Government Areas (LGAs).

The Project will include the installation, operation, maintenance and decommissioning of up to 143 wind turbine generators (WTGs), battery storage, ancillary infrastructure and temporary facilities associated with construction of the Project. The Project design incorporates up to 143 wind turbines, with a maximum blade-tip height of 300 m above ground level, and an installed capacity of up to 815.1 megawatts (MW).

Methodology

The study has been undertaken to address the hazards element of the NSW Planning Secretary's Environmental Assessment Requirements (SEARs) for the Project (SSD-50505215), specifically to provide:

an assessment of potential hazards and risks, including electromagnetic fields or the proposed grid connection infrastructure against the International Commission on Non-Ionizing Radiation Protection (ICNIRP) Guidelines for limiting exposure to Time-varying Electric, Magnetic and Electromagnetic Fields.

EMF limits for this study are taken from the International Commission on Non-Ionising Radiation Protection (ICNIRP). The limit of magnetic field strength to protect human health as determined by the ICNIRP is 200 μ T (micro-Tesla).

The software package (Current Distribution, Electromagnetic Fields, Grounding and Soil Structure Analysis) CDEGS was utilised to model the proposed overhead lines for the Project. The HIFREQ module was utilised to capture the magnetic and electric field strengths applicable for the Project.

In CDEGS, models of the conductor configurations was built using the following inputs:

- Provided proposed conductor arrangements.
- Underground cable and transmission line tower installation details as per AS 7000 [1] and as per typical industry values.
- Current and voltage magnitude as per design inputs.

Assessment Overview

The EMF emitted by the proposed electrical power infrastructure for the Project is estimated to be below the acceptable exposure limit as per the ICNIRP. These limits are summarised as follows:

- Magnetic field strength: 200 μ T limit, at four (4) m above ground level.
- Electric field strength: 5 (kilovolts per metre) (kV/m) for general public and 10 kV/m for occupational personnel, at four (4) m above ground level.

Under worst case scenarios, the magnetic field emitted is 40 μ T while the electric field strength is 4 kV/m for the proposed single circuit 330 kV transmission line, four (4) metres (m) above ground level.

A summary of measurements is detailed in Table 1 and 2.

Table 1: Magnetic field strength results summary

Installation Method	Observation Location	Field Strength (in Micro-tesla (μT))	Pass / Fail
Underground Cable	1.5 m above ground (standard height)	<10	PASS
	1 m above ground (lowest height of impact when standing)	<10	PASS
	Ground level (person lying on the ground)	<50	PASS
Overhead 220 kV Single Transmission Line	4 m above ground (person sitting in heavy vehicle)	<40	PASS
	1.5 m above ground (standing height)	<30	PASS
Overhead 330 kV Single Transmission Line	4 m above ground (person sitting in heavy vehicle)	<40	PASS
	1.5 m above ground (standing height)	<20	PASS

The limit of electric field strength to protect human health is determined by ICNIRP as 5 kV/m for general public and 10 kV/m for occupational personnel. The worst-case scenario of the 330 kV transmission line was assessed. These results are summarised in Table 2 below.

Table 2: Electric field strength results summary

Installation Method	Observation Location	Field Strength (kV/m)	Pass / Fail
Overhead Single 330 kV Transmission Line 8 m height	4 m above ground (person sitting in heavy vehicle)	<4	PASS
	1.5 m above ground (standing height)	<1	PASS

This study finds the risk to human health due to emitted EMF is negligible when the recommended clearance (8 m) to the 330 kV transmission line is maintained.

The actual conductor arrangements are likely to differ from this modelled scenario. The difference is assumed to be minimal. The corresponding difference in magnetic field emissions is expected to be marginal and is unlikely to affect the EMF safety compliance performance of the transmission lines.

Contents

1	Introduction	1
1.1	Background	1
1.2	Purpose	1
1.3	Scope	1
1.4	Design Inputs	2
2	Definitions	3
3	Basis	4
4	Methodology	5
4.1	Assessment Criterion	5
4.2	Assessed Area	7
4.3	CDEGS Model	8
4.3.1	Modelled Electrical Installations	8
4.3.2	Underground 33 kV Cable Concept Design	9
4.3.3	Overhead 220 kV Transmission Line Concept Design	10
4.3.4	Overhead 330 kV Transmission Line Concept Design	12
5	Results	13
5.1	Underground Cable	13
5.2	220 kV Overhead Transmission Lines	14
5.3	330 kV Overhead Transmission Lines	15
5.4	Electric Field	16
5.5	Cumulative Impacts	17
6	Mitigation Measures	18
7	Conclusion	19
7.1.1	Magnetic Field Assessment	19
7.1.2	Electric Field Assessment	20
8	References	21
Appendix A	EMF Theory	22
Appendix B	Overhead line concept design	24
Appendix C	OLEX catalogue	27

Tables

Table 1: Magnetic field strength results summary	iii
Table 2: Electric field strength results summary	iii

Table 3: Assessment locations	7
Table 4: Modelled scenarios	8
Table 5: Magnetic field strength results summary	19
Table 6: Electric field strength results summary	20
Table 7: 33 kV Overhead Line conductor horizontal separation calculation	25
Table 8: 220 kV Transmission line conductor separation calculation	25
Table 9: 330 kV Transmission line conductor separation calculation	26

Figures

Figure 1: Project Overview	2
Figure 2: Magnetic field limits for public exposure	5
Figure 3: Electric field limits for public and occupational exposure	6
Figure 4: Underground cable installation concept design	9
Figure 5: 220 kV Transmission Tower Concept Design	10
Figure 6: 220 kV Transmission Lines Sag	11
Figure 7 330 kV Transmission Tower Concept Design	12
Figure 8 330 kV Transmission Lines Sag	12
Figure 9: Magnetic field strength from three (3) x single core underground cables each carrying 584 A	13
Figure 10: Magnetic field strength from three (3) x conductors each carrying 1017 A	14
Figure 11: Magnetic field strength from three (3) x conductors each carrying 993 A	15
Figure 12: Electric field strength directly below 8 m high 330 kV overhead transmission lines	16
Figure 13: Magnetic field around a conductor	22

1 Introduction

1.1 Background

Middleton Group Engineering (MGE) has been engaged by Umwelt (Australia) Pty Ltd to undertake an Electromagnetic Field desktop study for the Bullawah Wind Farm Project (the Project), located approximately 36 km south east of Hay, within the South West Renewable Energy Zone. The Project Area is located within the Hay Shire, Murrumbidgee and Edward River Local Government Areas (LGAs).

The Project will include the installation, operation, maintenance and decommissioning of up to 143 wind turbine generators (WTGs), battery storage, ancillary infrastructure and temporary facilities associated with construction of the Project. The Project design incorporates up to 143 wind turbines, with a maximum blade-tip height of 300 m above ground level, and an installed capacity of up to 815.1 megawatts (MW).

1.2 Purpose

The purpose of this report is to estimate the electric and magnetic fields that will be emitted by the conductors assess the impact on human health.

The study has been undertaken to address the hazards element of the NSW Planning Secretary's Environmental Assessment Requirements (SEARs) for the Project, specifically to provide:

an assessment of potential hazards and risks, including electromagnetic fields or the proposed grid connection infrastructure against the International Commission on Non-Ionizing Radiation Protection (ICNIRP) Guidelines for limiting exposure to Time-varying Electric, Magnetic and Electromagnetic Fields.

1.3 Scope

The scope of this study includes:

- Identify and model electromagnetic field emitters to be constructed under the Bullawah Wind Farm.
- Assess impact of the EMF emitters on human health.

The study bounds are defined as:

- EMF from the proposed 33 kV underground wires.
- EMF from the proposed 220 kV transmission line.
- EMF from the proposed 330 kV transmission line.

The Conductor lines are represented in the extract of the project overview in Figure 1.

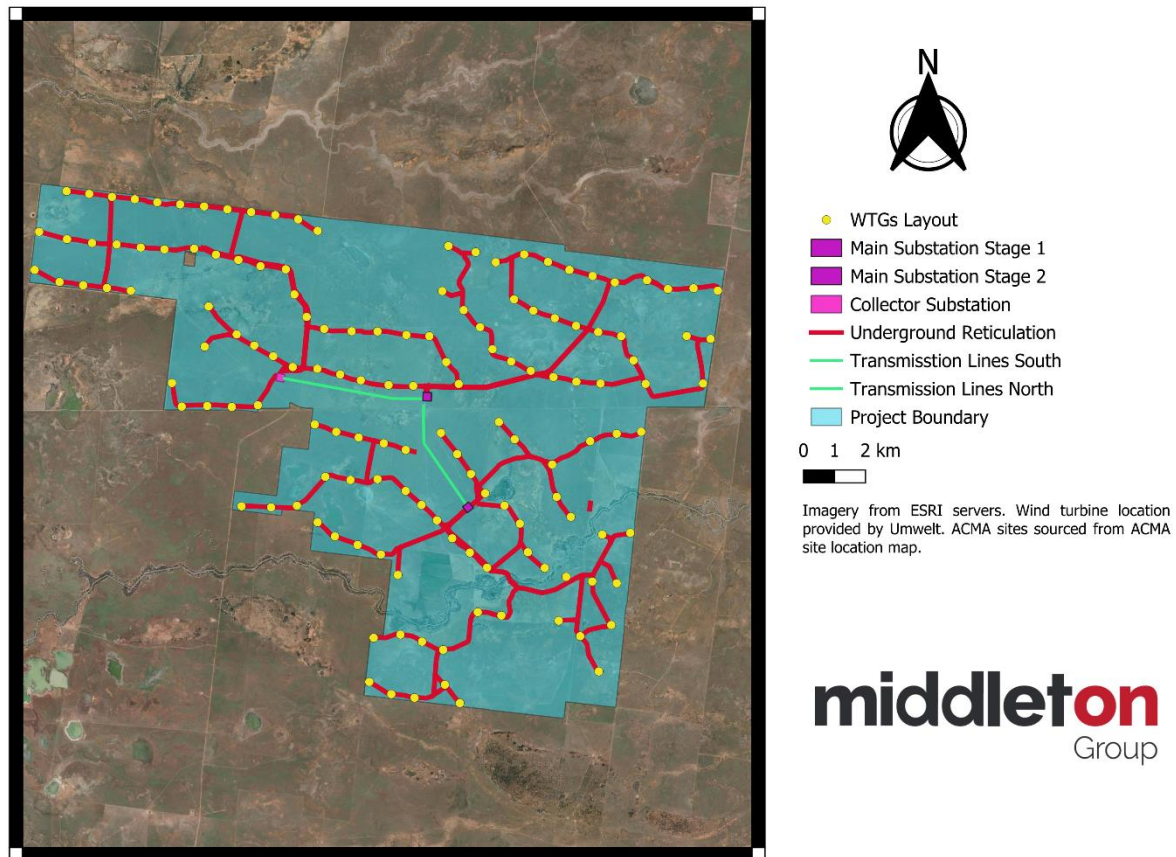


Figure 1: Project Overview

1.4 Design Inputs

The following information was used to form the basis of the design:

- Proposed conductor arrangements as provided by Bullawah Wind Farm Pty Ltd.
- Underground cable and transmission line tower installation details as per AS 7000 [1] and as per typical industry values.
- Current and voltage magnitude as per design inputs provided by Bullawah Wind Farm Pty Ltd.

2 Definitions

Term	Definition
ARPANSA	Australian Radiation Protection and Nuclear Safety Agency
CDEGS	Current Distribution Electromagnetic Fields, Ground and Soil Structure Analysis. Software developed by SES & Technologies Ltd.
EMF	Electro-magnetic field
ICNIRP	International Commission on Non-Ionising Radiation Protection
kV	kilovolt
Magnetic Flux Density / Magnetic Field Strength	Terms used interchangeably to describe magnetic field
MW	Megawatt
Tesla	A measure of magnetic flux density. One Tesla = Newton / (Amp * metre).

3 Basis

The following parameters have been applied to form the basis of this study.

Electrical Network

1. Electrical installation in line with Australian Standards, *Overhead line design (AS 7000)* in particular: height and configuration of overhead powerlines
2. Underground cables are buried at 800 mm. This is a typical minimum depth, although cables can be as shallow as 750 mm as per AS2067 clause 4.2.9.1.a.
3. All equipment (inverters, BESS systems, transformers, switchgear etc.) meets Australian and International Standards for electromagnetic compatibility and therefore does not meaningfully contribute to EMF risk.
4. Current carrying capacity for conductors have been applied to the modelling scenarios.
5. Maximum power on a single transmission line is 345 MW.

WTG Parameters

6. WTG size = 6.0164 MW with power factor of 0.9. This equates to 6.68 megavolt-amperes (MVA).
7. WTGs are compliant to applicable electromagnetic compatibility standards.

Scenario Limitations

8. Substations and collector stations excluded as the general public do not have access to these areas.
9. Background EMF on site is considered negligible. Background measurements have not been included in this assessment. However, given the remote location of the Project Area and absence of nearby electrical equipment, the background magnetic field strength along the majority of the route is expected to be negligible.
10. Fault conditions are not modelled in this assessment. A fault event is expected to last no longer than two (2) seconds and is very unlikely to introduce human health risk due to EMF exposure.

4 Methodology

4.1 Assessment Criterion

EMF limits for this study are taken from the ICNIRP. The limit is specified below, based on review of the relevant Australian guidelines and health advice.

The advice of the National Health and Medical Research Council (NHMRC) with regards to EMF exposure has been withdrawn. Responsibility for review of the radiation health series publications has been handed to Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) [2]. The EMF exposure guidelines from ARPANSA now explicitly refer to ICNIRP [3].

Furthermore, the Energy Networks Association (ENA) EMF Handbook [4] also refers to ICNIRP for determining the human health limit of magnetic field exposure.

The limit for magnetic and electric field exposure to the general public is specified in the ICNIRP General Public Health Physics publication 99(6):818-836 [5].

The red box highlights in Figure 2 shows the magnetic flux density for the frequencies emitted from the transmission lines. The peak field strength from the transmission lines will be at 50Hz. The pass/fail criterion for the general public for this study is 2000 milli Gauss (200 μ Tesla).

Figure 3 shows the electric field strength limits at 50 Hz, which will have the peak field strength from the transmission lines. The pass/fail criterion for the general public will be 5 kilovolts per m (kV/m) and 10 kV/m for occupational exposures to personnel.

Table 4. Reference levels for general public exposure to time-varying electric and magnetic fields (unperturbed rms values).

Frequency range	E-field strength E (kV m ⁻¹)	Magnetic field strength H (A m ⁻¹)	Magnetic flux density B (T)
1 Hz–8 Hz	5	$3.2 \times 10^4/f^2$	$4 \times 10^{-2}/f^2$
8 Hz–25 Hz	5	$4 \times 10^3/f$	$5 \times 10^{-3}/f$
25 Hz–50 Hz	5	1.6×10^2	2×10^{-4}
50 Hz–400 Hz	$2.5 \times 10^2/f$	1.6×10^2	2×10^{-4}
400 Hz–3 kHz	$2.5 \times 10^2/f$	$6.4 \times 10^4/f$	$8 \times 10^{-2}/f$
3 kHz–10 MHz	8.3×10^{-2}	21	2.7×10^{-5}

Notes:

- f in Hz.
- See separate sections below for advice on non sinusoidal and multiple frequency exposure.
- In the frequency range above 100 kHz, RF specific reference levels need to be considered additionally.

Figure 2: Magnetic field limits for public exposure

**TABLE 5-3 ELECTRIC FIELD REFERENCE LEVELS
AT 50HZ FOR IEEE AND ICNIRP**

	IEEE 2002	ICNIRP 2010
GENERAL PUBLIC		
Exposure	5 kV/m 10kV /m (within right of way)	5 kV/m
OCCUPATIONAL		
Exposure	10 kV/m 20kV /m (within right of way)	10 kV/m

Figure 3: Electric field limits for public and occupational exposure

4.2 Assessed Area

The assessed locations are specified in Table 3. All locations are directly underneath the overhead line, or directly above the underground cable(s).

Table 3: Assessment locations

Assessment Location	Scenario
Ground Level	Person lying on the ground
1 m above ground level	Lowest height impact for person standing
1.5 m above ground level	Typical height of impact for person standing
4 m above ground level	Person in heavy vehicle (truck, tractor etc.) Applies to kV overhead transmission line only

Any closer than 2.5 m above ground level introduces risk of breaching safe clearance between person/vehicle and live conductor as per AS2067:2016. Refer Table 3.1 of AS2067 for safe clearances for operational purposes and maintenance work.

Should the magnetic field and electric field strength at the assessment locations in Table 3 pass the assessment criteria, then the magnetic field and electric field strength at all other areas further away from the electrical installation will also pass. This includes the following:

- Host residences
- Non-associated residences
- All public locations (such as roads, parks, roadside stops)

This is supported by the modelling which aligns with fundamental theory of electromagnetism which dictates that the magnetic field strength diminishes with distance from the source. See Appendix A for detail.

4.3 CDEGS Model

The SES software package CDEGS (Current Distribution, Electromagnetic Fields, Grounding and Soil Structure Analysis) was used to model the underground cables and overhead lines. The HIFREQ module was utilised to capture the magnetic and electric field strengths.

4.3.1 Modelled Electrical Installations

The scenarios identified as likely to create the greatest impact are identified in Table 4.

Table 4: Modelled scenarios

No.	Conductor Description	Voltage	WTGs Connected	Current in each conductor
1	Single circuit underground lines	33 kV	5	584 A
2	Single circuit overhead transmission line	220 kV	58	1017 A
3	Single circuit overhead transmission lines	330 kV	85	993 A

Scenarios not modelled will radiate lower magnetic fields due to lower current in conductors (see Appendix A for how lower current results in lower magnetic field). These include:

- Underground cables with fewer than four (5) WTGs connected.
- Single circuit overhead 220 kV line with less than 58 WTGs connected.
- Single circuit overhead 300 kV line with less than 85 WTGs connected.

Impacts associated with the scenarios listed above are not anticipated.

4.3.2 Underground 33 kV Cable Concept Design

The underground cabling which connects the WTGs will have up to five (5) WTGs connected in series. The cables are expected to be single core 1000 square millimetres (mm²), installed underground.

The concept design considers the cables will be buried at 800 millimetres (mm). This is a typical minimum depth, although cables can be as shallow as 750 mm as per AS2067 clause 4.2.9.1.a.

The concept design considers that the cables will be installed in individual conduits, as this is the most likely scenario given the cable size. Furthermore, to accommodate the current produced from five (5) WTGs in series, the individual cables are installed with no spacing between them. The conduits considered are 150 mm in diameter (typical size for the 1000 mm² cables).

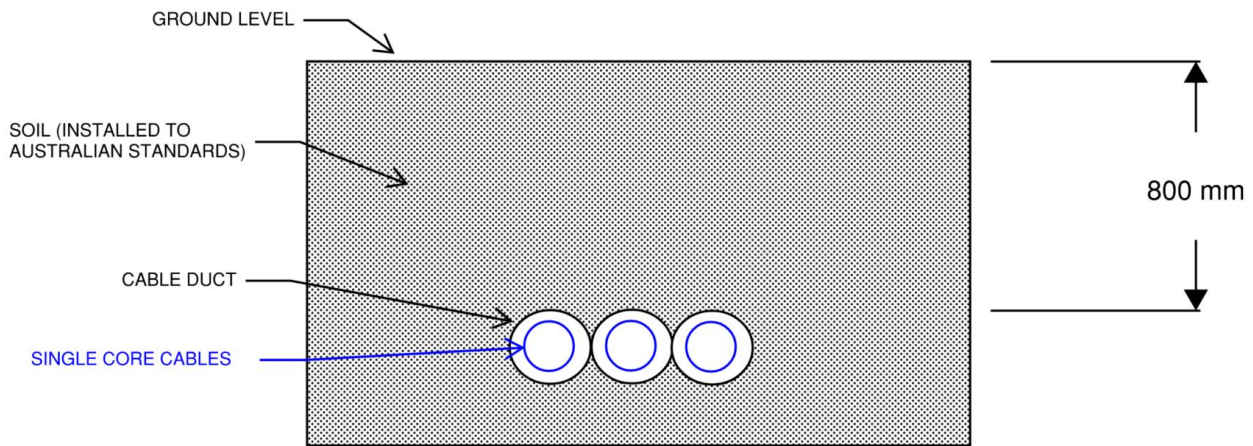


Figure 4: Underground cable installation concept design

4.3.3 Overhead 220 kV Transmission Line Concept Design

The overhead single 220 kV line is proposed to be a vertical separated transmission tower that will carry up to 58 wind turbines connected in series. These have been modelled in accordance with AS 7000 [1]. The concept design currently considers three (3) vertically spaced conductors, with a separation distance of 3.5 m between each conductor. The height of the transmission line is 7.5 m above the ground.

Figure 5 shows a cross-section of the transmission lines and poles, the transmission lines in practice sag as seen in Figure 6. This study considers the minimum height required to adhere to AS7000 including the line sag.

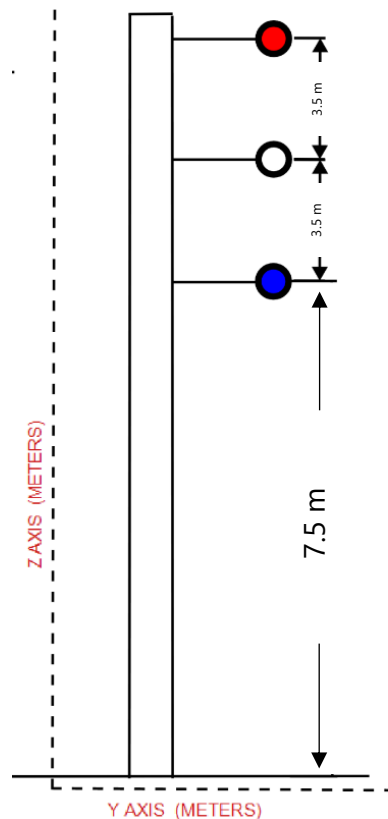


Figure 5: 220 kV Transmission Tower Concept Design

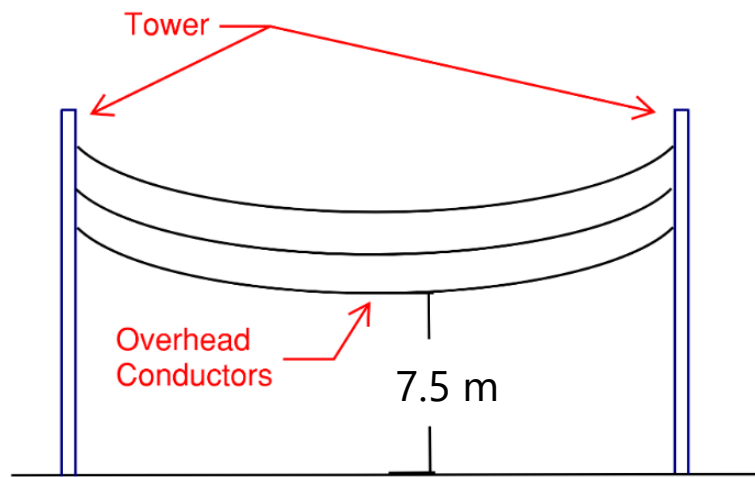


Figure 6: 220 kV Transmission Lines Sag

4.3.4 Overhead 330 kV Transmission Line Concept Design

The proposed overhead 330 kV power line will be supported by line poles, vertical flat conductors' arrangement, designed to accommodate a maximum of 85 wind turbines connected in series. These towers have been modelled in accordance with AS 7000 [1].

As per the concept design, each 330 kV line pole will feature three (3) vertically spaced conductors. The separation distance between each conductor will be 4 metres, and the conductors will be strung such that the lowest sag on any sections of the line crossing the roadway will be above 8 m safety clearance specified in Table 3.5 of AS/NSZ 7000:2016.

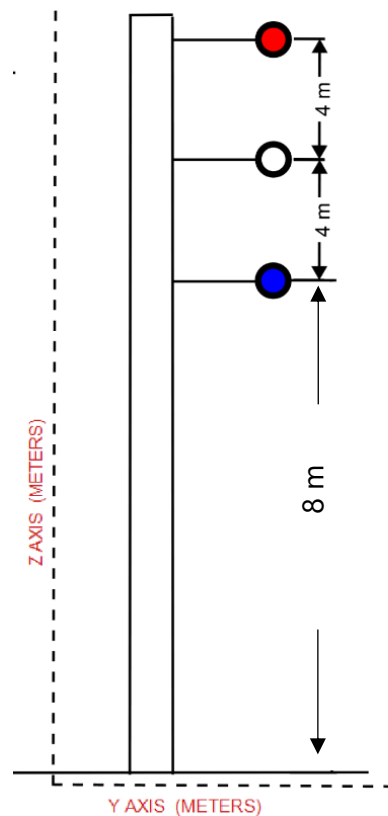


Figure 7 330 kV Transmission Tower Concept Design

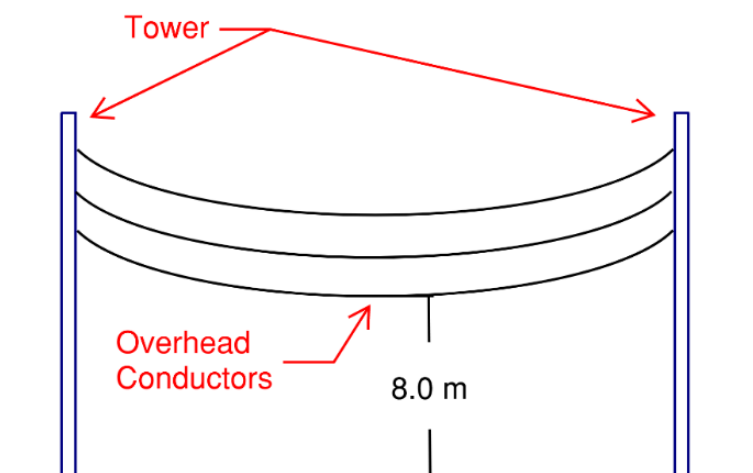


Figure 8 330 kV Transmission Lines Sag

5 Results

5.1 Underground Cable

The three (3) 1000 mm² cable circuit installed at an 800 mm depth will carry a maximum of 584 A in each cable. At ground level the magnetic field strength emitted from the cables reaches a maximum of 50 µT.

The required current per cable to exceed the 200 µT safe exposure limit (specified by Figure 2 in Section 4.1) at ground level is greater than 800 A. This will exceed the current carrying capability of the cable. The maximum current allowable in 33 kV 1000 mm² copper cables installed in underground ducts is 661 A in the modelled installation method.

Figure 9 shows the magnetic field strength emitted from the cable in the Y-Z plane. Ground level is marked as 0 m with a dashed line. Magnetic field strength for a person is usually measured at 1 m, accordingly no impacts are anticipated.

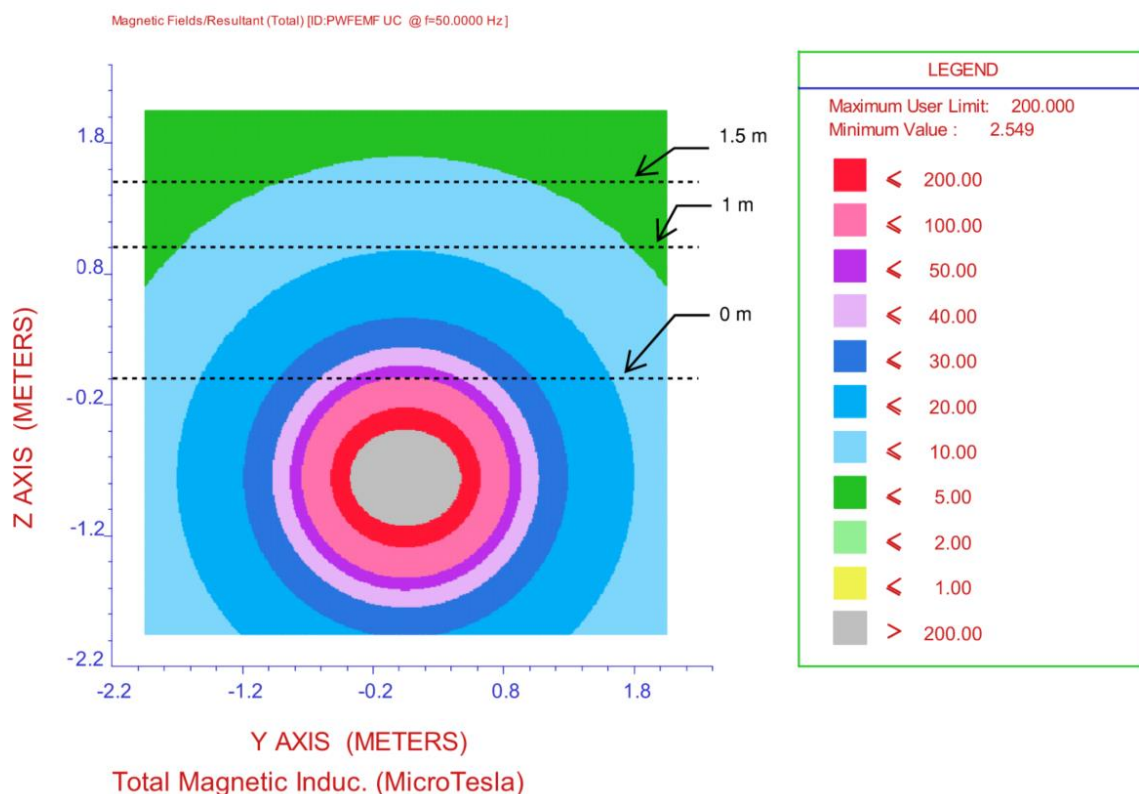


Figure 9: Magnetic field strength (µT) from three (3) x single core underground cables each carrying 584 A

5.2 220 kV Overhead Transmission Lines

The proposed overhead 220 kV transmission line will be supported by line poles, vertical flat conductors' arrangement, designed to accommodate a maximum of 58 wind turbines connected in series. These towers have been modelled in accordance with AS 7000 [1].

The three (3) parallel conductors will carry a maximum of 1017 A each. At four (4) m above ground level the magnetic field strength emitted from the conductors reaches a maximum value of 40 μ T. Figure 10 provides the magnetic field strength emitted from the cable in the Y-Z plane, with height levels indicated by dashed lines.

The result of CDEGS-HIFREQ modelling indicates that across the 220 kV power line, the magnetic field strengths at 1 m, 1.8 m and 4 m height due to the overhead line conductors are within the 200 μ T safe exposure limit specified in Section 4.1, Figure 2.

To breach the 200 μ T limit at four (4) m above ground level, the required current in each conductor must be greater than 5000 A. This is a significant deviation from the intended design. Consequently, the Proponent will not proceed with such an approach.

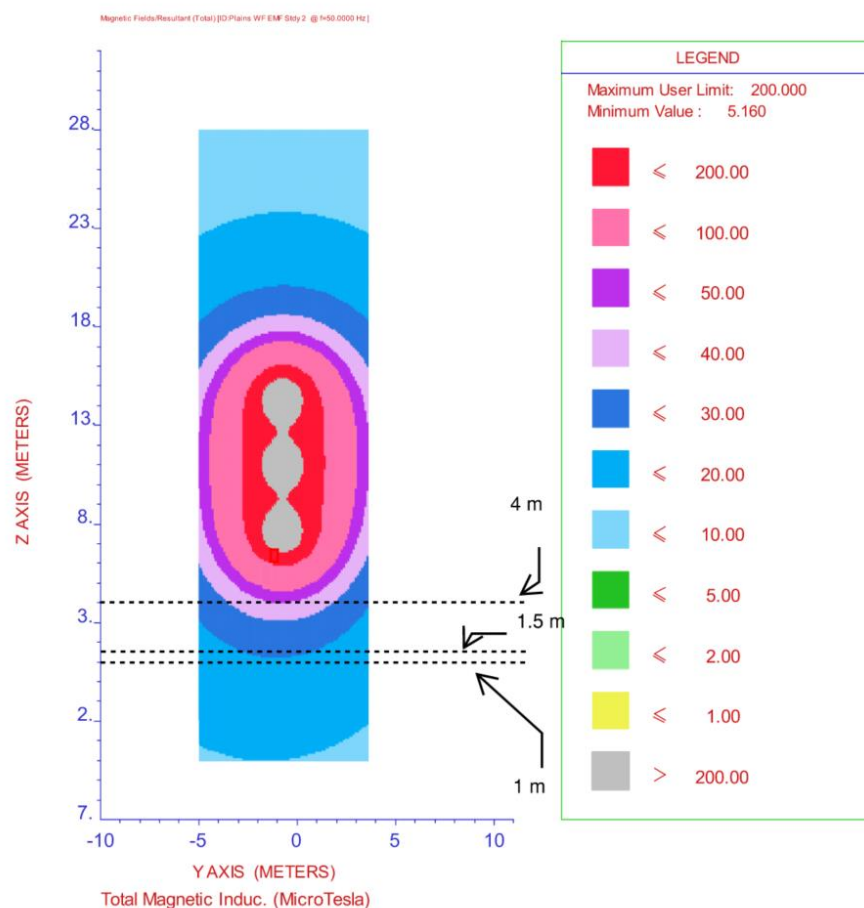


Figure 10: Magnetic field strength (μ T) from three (3) x conductors each carrying 1017 A

5.3 330 kV Overhead Transmission Lines

The proposed overhead 330 kV transmission line will be supported by line poles, vertical flat conductors' arrangement, designed to accommodate a maximum of 85 wind turbines connected in series. These towers have been modelled in accordance with AS 7000 [1].

The three (3) parallel conductors will carry a maximum of 993 A each. At four (4) m above ground level the magnetic field strength emitted from the conductors reaches a maximum value of less than 40 μ T. Figure 11 provides the magnetic field strength emitted from the cable in the Y-Z plane, with height levels indicated by dashed lines.

The result of CDEGS-HIFREQ modelling indicates that across the 330 kV power line, the magnetic field strengths at 1 m, 1.8 m and 4 m height due to the overhead line conductors are within the 200 μ T safe exposure limit specified in Section 4.1, Figure 2.

To breach the 200 μ T limit at four (4) m above ground level, the required current in each conductor must be greater than 4900 A. This is a significant deviation from the intended design. Consequently, the Proponent will not proceed with such an approach.

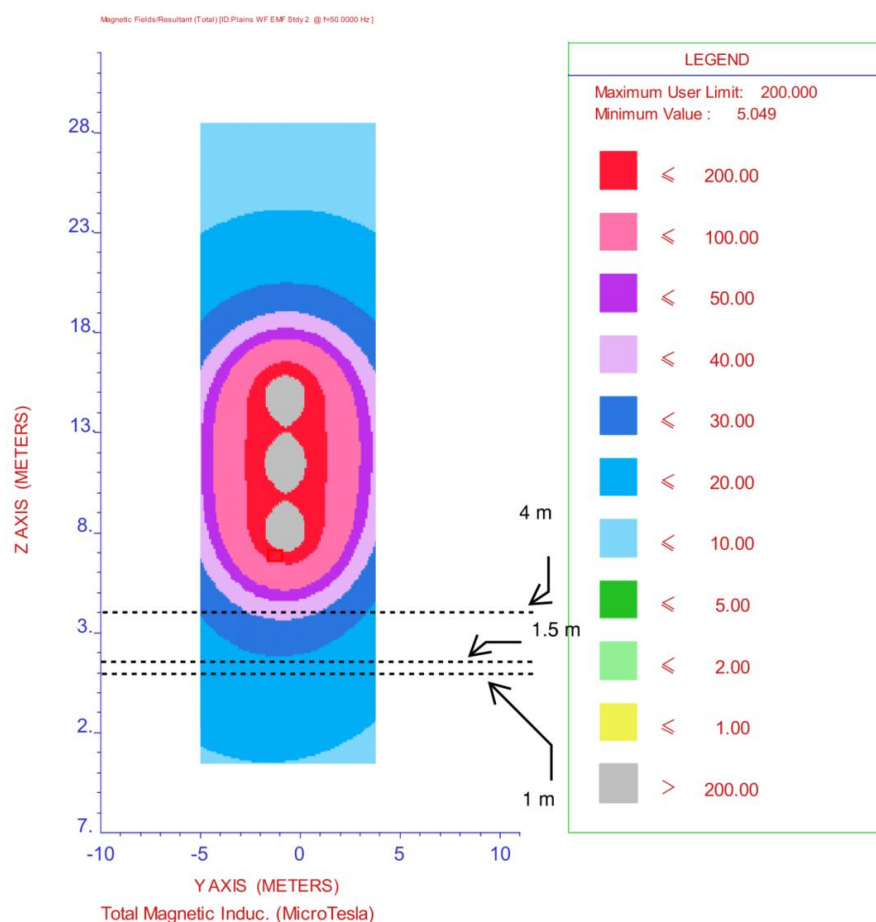


Figure 11: Magnetic field strength from three (3) x conductors each carrying 993 A

5.4 Electric Field

An electric field assessment has been completed for the worst-case scenario only. This is the highest voltage scenario in which a person is directly underneath the 330 kV overhead transmission lines.

As seen in Figure 12, at four (4) m, 1.5 m and one (1) m above ground, the electric field strength is below the public and occupational exposure limit (specified by Figure 3 in Section 4.1) of five (5) and ten (10) kV/m, respectively [4].

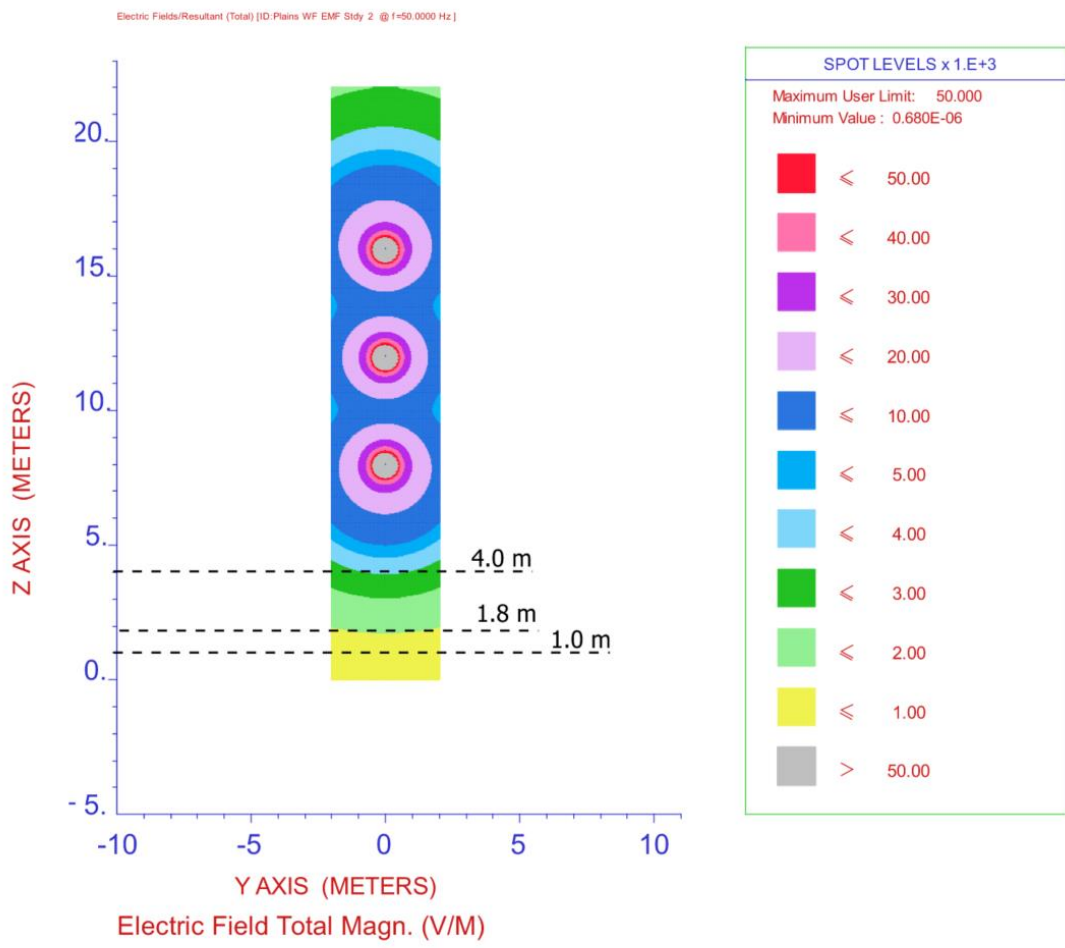


Figure 12: Electric field strength directly below 8 m high 330 kV overhead transmission lines

5.5 Cumulative Impacts

NSW Government – EnergyCo seeks to maximise opportunities created by the transformation of the NSW electricity system by coordinating investment in Renewable Energy Zones (REZs) across NSW. A REZ is the equivalent of modern-day power stations, combining new renewable energy infrastructure, including generators (such as solar and wind farms), storage (such as batteries and pumped hydro) and then high-voltage transmission infrastructure. Five (5) dedicated REZs have already been identified in NSW.

The Project is located wholly within the South West REZ.

Because of this, and the REZ benefits anticipated by NSW Government – EnergyCo, the South West REZ has the potential to see strong interest for renewable energy development.

Based on information available within the public domain, specifically the NSW Government – Major Projects website, the following developments are identified in the vicinity of the Project:

- Pottinger Solar Farm (SSD-59254709)
- Pottinger Wind Farm (SSD-59235464)
- Dinawan Wind Farm (SSD-50725708)
- Dinawan Solar Farm (SSD-50725959)
- Argoon Wind Farm (SSD-64935522)
- Conargo Wind Farm (SSD- 70611708)
- Booroorban (Saltbush) Wind Farm (SSD-70636459)
- Yanco Delta Wind Farm (SSD-41743746)
- The Plains Wind Farm (SSD-50629707)
- The Plains Solar Farm (SSD-51219280)
- Romani Solar Farm (SSD-67105475)
- Tchelery Wind Farm (SSD-59701722).

Based on the proximity of the above-mentioned developments to the Project, and the limited potential for interactions to occur with respect to EMF, cumulative impacts are considered highly unlikely to occur.

It is noted that because of the development activity in the South West REZ the above list may not address all potential sites being privately developed and not yet in the public domain. Information pertaining to any developments not yet in the public domain is therefore unavailable and excluded for this study.

6 Mitigation Measures

The Project design has avoided, minimised and mitigated risks and impacts associated with EMF. Accordingly, there are no project-specific recommendations required or provided by MGE, as relevant to the Project assessed in this study.

To safeguard against potential future impacts, identified as a result of any design changes, the following conceptual avoidance, minimisation and/or mitigation options may be considered:

- Confirm during detailed design that any change in EMF, as a result of any relevant design modification results in a risk and associated impact being maintained within suitable thresholds of acceptability.
- If required, modify the design to either relocate and/or remove infrastructure to avoid, minimise and/or mitigate any EMF issues, risks and impacts.

Where these options require future investigation, any interaction and/or cumulative impact as a result of the developments listed in Section 5.5 (or any additional developments that have entered the public domain since) should be considered.

No further recommendations and/or safeguards are warranted or provided in this report.

7 Conclusion

The concept design observations show that for each scenario, the magnetic field strength should be within ICNIRP guidelines at locations where personnel do not risk breaching AS 2067 requirements. The final design will differ from the concept design. Boundary conditions have been provided to enable electric and magnetic fields to comply to ICNIRP guidelines at the specified locations.

7.1.1 Magnetic Field Assessment

The result of CDEGS-HIFREQ modelling indicates that across all scenarios the magnetic field strengths at 1 m, 1.8 m and 4 m height due to all respective underground cables and overhead line conductors scenarios, are within the 200 μT safe exposure limit specified in Section 4.1, Figure 2. There are no unsafe magnetic field that the general public can be exposed to.

A summary of the results can be found in Table 5.

Table 5: Magnetic field strength results summary

Installation Method	Observation Location	Field Strength (in Micro-tesla (μT))	Pass / Fail
Underground Cable	1.5 m above ground (standard height)	<10	PASS
	1 m above ground (lowest height of impact when standing)	<10	PASS
	Ground level (person lying on the ground)	<50	PASS
Overhead 220 kV Single Transmission Line	4 m above ground (person sitting in heavy vehicle)	<40	PASS
	1.5 m above ground (standing height)	<30	PASS
Overhead 330 kV Single Transmission Line	4 m above ground (person sitting in heavy vehicle)	<40	PASS
	1.5 m above ground (standing height)	<20	PASS

7.1.2 Electric Field Assessment

The result of CDEGS-HIFREQ modelling indicates that across all scenarios the electric field strengths at 1 m, 1.8 m and 4 m height due to the 330 kV overhead transmission line conductors are within the 5kV/m safe exposure limit specified in Section 4.1, Figure 3. There are no unsafe electric field that the general public can be exposed to. Similarly, the 330 kV overhead transmission line conductors are within the 10kV/m safe exposure limit specified in Section 4.1, Figure 3 for occupational exposures, as applicable to personnel.

A summary of results can be found in Table 6.

Table 6: Electric field strength results summary

Installation Method	Observation Location	Field Strength (kV/m)	Pass / Fail
Overhead Single 330 kV Transmission Line 8 m height	4 m above ground (person sitting in heavy vehicle)	<4	PASS
	1.5 m above ground (standing height)	<1	PASS

Human health assessment

The concept design observations show that the 33 kV underground lines and overhead 220/330 kV transmission lines all meet ICNIRP guidelines for general and occupational exposure for both magnetic and electric field strengths at the modelled line arrangements.

Applications of these findings

The actual conductor arrangements are likely to differ from this modelled scenario. The difference is likely to be minimal and the corresponding difference in the magnetic field emissions is expected to be negligible. As such the finding of this report will apply for minor design changes.

8 References

- [1] International Commission on Non-Ionizing Radiation Protection, "ICNIRP Guidelines For Limiting Exposure to Time-Varying Electric and Magnetic Fields (1 Hz - 100 kHz)," *Health Physics*, vol. 99, pp. 818-836, 2010.
- [2] Standards Australia, *Overhead line design (AS 7000)*, SAI Global., 2016.
- [3] Australian Radiation Protection and Nuclear Safety Agency, "Radiation Health Series," 2023. [Online]. Available: <https://www.arpsa.gov.au/regulation-and-licensing/regulatory-publications/radiation-health-series>. [Accessed 21 03 2023].
- [4] Australia, Commonwealth of, "Electricity and Health," [Online]. Available: <https://www.arpsa.gov.au/understanding-radiation/radiation-sources/more-radiation-sources/electricity>.
- [5] Energy Network Association, *EMF Management Handbook*, 2016.
- [6] Standards Australia, *Substations and high voltage installations exceeding 1 kV a.c.*, Sai Global., 2016.

Appendix A EMF Theory

Overview

A current carrying conductor creates a magnetic field which circulates around the conductor as illustrated.

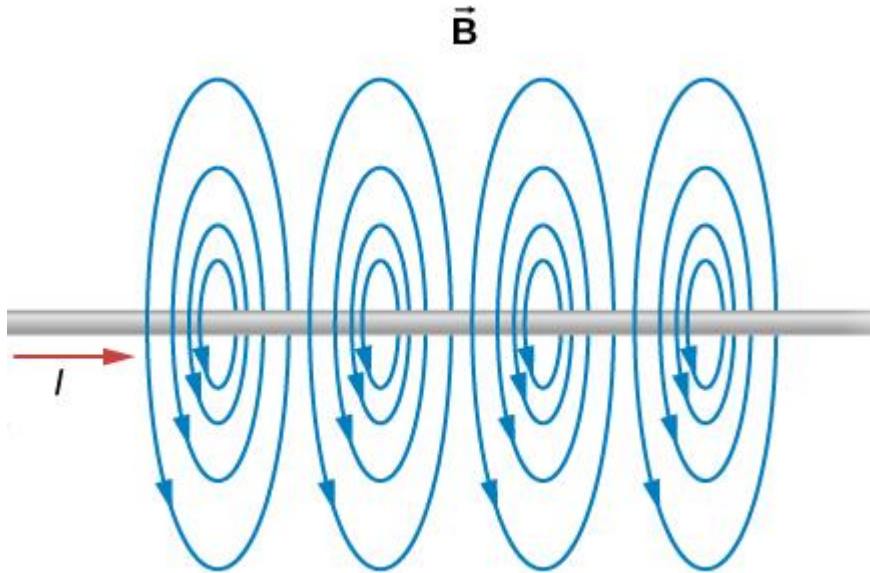


Figure 13: Magnetic field around a conductor

EMF from a single conductor

To calculate the magnetic field strength emitted from a conductor, one must apply the Biot-Savart law.

Application of this law finds that for an infinitely long conductor the field strength due to current I at a distance of R and is given by the formula in. For conductors of enough length, this formula can be used to provide an accurate approximation of the actual field strength.

$$B = \frac{\mu_0 I}{2\pi R}.$$

Where:

B = Magnetic field strength in Teslas, where Tesla = $N/(A \cdot m)$

μ_0 = permeability of free space

I = current in conductor

R = distance from conductor in a straight line

This tells us that magnetic field strength is inversely proportional to the distance from the conductor.

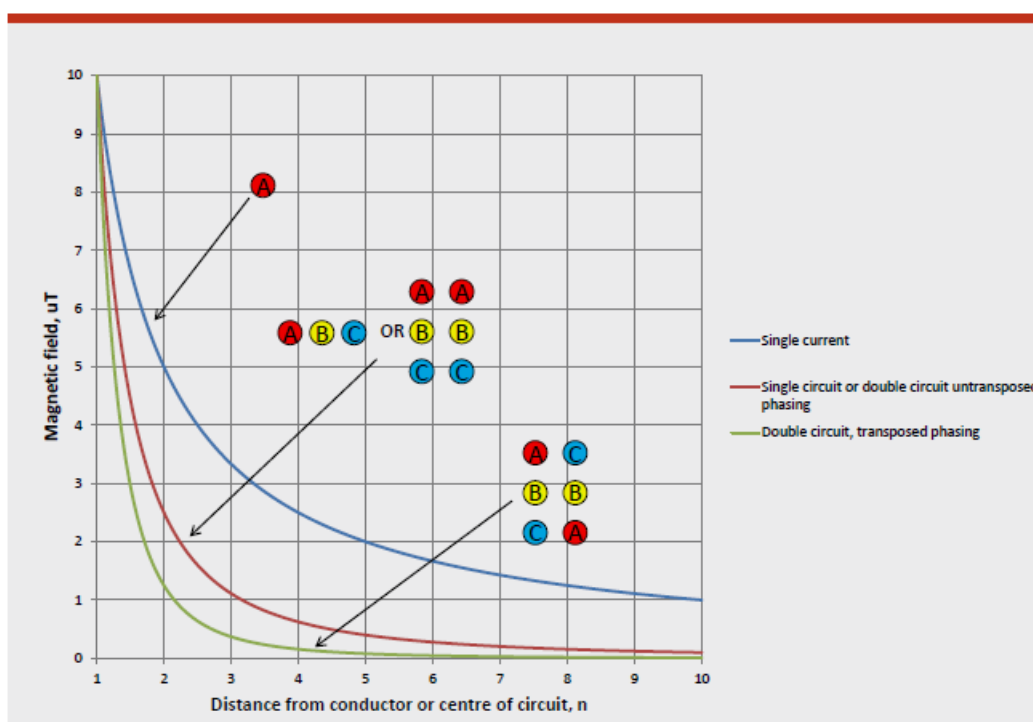
EMF from a three (3) phase system

The magnetic field at a point will be the vector sum of the fields from each conductor. In a balanced three (3) phase system, the phase angle of the magnetic field from the three (3) conductors will cancel out. However, any three (3) phase system will have a non-zero resultant field strength due to separation between the conductors. That is, at any given location the magnetic field emitted from the three (3) conductors will not be of equal magnitude, therefore not fully cancelling each other out.

Relationship of Field Strength to Distance from Source

As noted above, the magnetic field strength is inversely proportional to the distance from the conductor. However, there is some variability in the field strength reduction with distance from the source where that source is a 3 phase system. The extract from the ENA EMF Handbook below demonstrates this.

FIGURE 3.3 RATE OF DECREASE OF MAGNETIC FIELDS FROM DIFFERENT SOURCES



* Note: Hypothetical examples where magnetic fields are 10 μ T at 1m from the source.

Appendix B Overhead line concept design

The conductor separation of the transmission line is established in two (2) parts by the following section 3.7.3 of AS 7000-2016.

The first part considers the minimum mid-span conductor separation as per the image and formula given in the following extract:

The mid span conductor separation for a single circuit can be determined using Equation 3.1 and Figure 3.5.

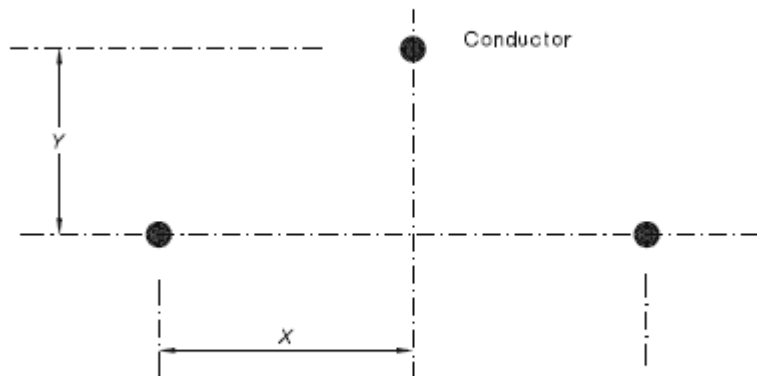


FIGURE 3.5 CONDUCTOR SEPARATION AT MID SPAN (ONE CIRCUIT)

$$\sqrt{X^2 + (1.2Y)^2} \geq \frac{U}{150} + k\sqrt{D + l_i} \quad \dots 3.1$$

In this, X is the horizontal distance between conductors. For this study, X = 0 as the transmission line concept design assumes that the conductors will be equal height above the ground.

Y is the vertical distance between conductors.

The remaining variables are defined below:

- U = is the r.m.s. vector difference in potential (kV) between the two conductors when each is operating at its nominal voltage. In determining the potential between conductors of different circuits or between an earthwire and an aerial phase conductor, regard shall be paid to any phase differences in the nominal voltages
- k = is a constant, normally equal to 0.4. Where experience has shown that other values are appropriate, these may be applied. See Note 5 to Figure 3.6.
- D = is the greater of the two conductor sags in metres at the centre of an equivalent level span and at a conductor temperature with electrical load (typically 50°C in still air). This may be higher for high temperature conductors
- l = is the length in metres of any free swing suspension insulator associated with either conductor. Zero for pin and post insulators

The second part of establishing conductor separation considers an allowance for wind loading. That is, the conductors may swing in the air. As such, they must be installed with enough separation at the towers that

the mid-span separation requirement described above is not breached. Two (2) m has been allowed for swinging conductors, based on typical industry application.

The calculation of the above two (2) parts is resolved in the below tables for 33 kV, 220 kV and 330 kV conductors respectively.

Table 7: 33 kV Overhead Line conductor horizontal separation calculation

Variable	Value	Unit	Comment
Y	0	m	No horizontal separation
U	57.1578	kV	Derived
k	0.4		As per standard
D	4	m	Typical industry value
li	2.4	m	Typical industry value
Results			
X (horizontal separation)	1.4	m	
Swinging conductor allowance	2	m	Typical industry value

Table 8: 220 kV Transmission line conductor separation calculation

Variable	Value	Unit	Comment
X	0	m	No horizontal separation
U	476.314	kV	Derived
k	0.4		As per standard
D	4	m	Typical industry value
li	2.4	m	Typical industry value
Results			
Y (Vertical separation)	3.5	m	
Swinging conductor allowance	2	m	Typical industry value

Table 9: 330 kV Transmission line conductor separation calculation

Variable	Value	Unit	Comment
X	0	m	No horizontal separation
U	476.314	kV	Derived
k	0.4		As per standard
D	4	m	Typical industry value
li	2.4	m	Typical industry value
Results			
Y (Vertical separation)	4	m	
Swinging conductor allowance	2	m	Typical industry value

Appendix C OLEX catalogue

The following is an extract of the Olex-Nexans cable catalogue. The maximum current rating for any 19 / 33 kV single core cable for the proposed installation is shown in red.

Derating factors including depth of burial, proximity of nearby cables, temperature, soil resistivity etc. may reduce this value.

It should be noted that a 1200mm² cable is an upper limit, not commonly installed.

19/33kV Single Core Screened & PVC Sheathed

Copper Conductors, up to 10kA Fault Level

Nominal conductor area	Nominal conductor diameter	Nominal insulation thickness	Nominal diameter over insulation	Nominal screen area on each core	Number and nominal diameter of screen wires	Nominal diameter over wire screen	Nominal overall diameter	Approx. mass	Product code	Max. pulling tension	Min. bending radius	Nominal duct diameter		
mm ²	mm	mm	mm	mm ²	no/mm	mm	mm	kg/100m		kN	During pulling mm	Set in position mm	mm	mm
50	8.0	8.0	25.5	48.7	34/1.35	29.8	34.3	170	XNHP19AA001	3.5	620	410	63	100
70	9.6	8.0	27.1	68.7	48/1.35	31.4	36.1	215	XNHP20AA001	4.9	650	430	63	100
95	11.5	8.0	29.0	68.7	48/1.35	33.3	38.0	245	XNHP22AA001	6.7	680	460	65	150
120	13.1	8.0	30.6	68.7	48/1.35	34.9	39.8	280	XNHP23AA001	8.4	720	480	65	150
150	14.5	8.0	32.0	68.7	48/1.35	36.5	41.4	310	XNHP24AA001	11	750	500	65	150
185	16.1	8.0	33.6	68.7	48/1.35	38.1	43.2	345	XNHP25AA001	13	780	520	65	150
240	18.5	8.0	36.0	68.7	48/1.35	40.5	45.9	410	XNHP26AA001	17	830	550	65	150
300	20.7	8.0	38.4	68.7	48/1.35	42.9	48.4	475	XNHP27AA001	21	870	580	80	150
400	23.6	8.0	41.3	68.7	48/1.35	45.8	51.5	575	XNHP28AA001	28	930	620	80	150
500	26.5	8.0	44.2	68.7	48/1.35	48.7	54.9	685	XNHP30AA001	35	990	660	80	200
630	29.9	8.0	47.9	68.7	48/1.35	52.4	58.8	815	XNHP32AA001	44	1060	710	100	200
800	35.9	8.0	54.0	68.7	48/1.35	58.5	65.3	1020	XNHP33AA001	56	1180	780	100	200
1000	40.2	8.0	59.5	68.7	48/1.35	64.0	71.0	1220	XNHP34AA001	70	1280	850	125	200
1200	43.8	8.0	63.5	68.7	48/1.35	68.0	75.2	1420	XNHP50AA001	84	1350	900	125	200

Current Ratings

Nominal conductor area mm ²	Continuous current-carrying capacity, A												Fault current carrying capacity for 1 second	
	In air						In ground							
	Solid Bond	Solid Bond	Solid Bond	Solid Bond	Solid Bond	Solid Bond	Solid Bond	Solid Bond	Solid Bond	Solid Bond	Solid Bond	Solid Bond	Cond. kA	Screen kA
50	224	250	210	221	160	208	209	205	187	186	185	174	7.15	7.22
70	276	306	259	273	202	251	249	249	223	219	223	216	10.0	10.1
95	333	369	315	332	242	297	292	297	265	258	267	258	13.6	10.1
120	381	420	361	381	276	335	327	336	296	287	300	292	17.1	10.2
150	429	469	407	430	308	372	359	375	327	313	333	325	21.4	10.2
185	485	527	463	490	348	414	397	421	362	343	372	366	26.4	10.2
240	563	605	542	574	402	471	444	485	408	382	425	420	34.3	10.2
300	634	674	616	653	452	521	485	542	446	413	471	469	42.9	10.2
400	719	756	706	750	533	579	531	610	492	449	526	547	57.2	10.2
500	807	837	803	854	600	637	574	682	539	484	585	611	71.5	10.2
630	902	924	911	969	672	697	619	759	576	513	635	680	90.0	10.2
800	1012	1026	1036	1103	748	756	664	838	630	552	705	748	114	10.2
1000	1160	1131	1219	1300	888	845	713	966	661	578	749	880	143	10.2
1200	1252	1204	1337	1426	963	896	745	1043	698	603	801	948	171	10.2

Z

Creating a sustainable energy future for our communities

Strategic consulting for



Industrial



Power utilities



Renewables



Water



Transport

middleton
Group

Melbourne

L13, 500 Collins Street
Melbourne VIC 3000

Sydney

Tower 2 Darling Park L20
201 Sussex Street, Sydney NSW 2000

www.middletongroup.com.au