Appendix

E

E.11 | Human Health Assessment

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Dinawan Wind Farm

EMF / Human Health Assessment

Client: **EMM Consulting**
Revision: B
Project: Dinawan Wind Farm
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DRAFT

Revision control

Revision	Date	Description	Prepared by	Reviewed by	Approved by
A	22.03.24	Issued for Review	Linh Vi Ramez Barakat	Elpidio Jayagan	Timothy Cervenjak
B	10.05.24	Added double circuit transmission line circuit	Ramez Barakat	Elpidio Jayagan	Alex Low
1	29.05.24	Final issue	Ramez Barakat	Elpidio Jayagan	Alex Low

Disclaimer

Executive Summary

The proposed electrical power infrastructure for the Dinawan Wind Farm project (The Project) is estimated to emit an electric and magnetic field (EMF) from the underground and overhead single-circuit 33 kV and 330kV overhead transmission line. The worst-case scenario modelled is the 330 kV overhead transmission line with a current of 1,567 A in a single circuit configuration and 784 A in a double circuit configuration.

- The primary design criterion for overhead lines is the minimum vertical clearance specified in AS/NZS 7000:2016, focusing on ensuring safety over roadways and public areas. This includes considering the lowest sag of the conductor and EMF levels at specified heights above ground in worst-case load condition, namely:
  - EMF for 4 m above ground over roadways and
  - EMF at 1.8 m and 1 m above ground for public domains.

The EMF strength was calculated using the HIFREQ module in the software package CDEGS. In CDEGS, the conductors were modelled using the following design basis:

- Proposed conductor arrangements as per Section 4.5.1.
- Current and voltage magnitude as per Section 1.2: Design Inputs.

The different environments with worst-case load condition for 330 kV overhead conductors occurs when the lowest sag of the bottom conductor is located at the roadway crossing.

AS/NZS 7000: Overhead line design, Table 3.5 specifies a minimum vertical clearance of 8 m above the finished ground level. The EMF model indicates that at 4 m high above ground level a driver sitting in a heavy vehicle can be exposed to a magnetic field strength of 100 microTesla (μT). This condition is permitted as the calculated EMF level is within the 200 microTesla (μT) exposure limit recommended for the general public, refer to Figure 2.

Accordingly, at 4 m high, the driver is exposed to an electric field strength of approximately 4 kiloVolt per metre (kV/m) which is within the 5 kV/m safe exposure limit specified in Figure 3.

A summary of the worst-case EMF measurements for the project is detailed in Table 1. The results indicate that the general public will not be exposed to unsafe EMF if:

- The 33 kV underground cable circuit is buried at a minimum depth of 800 mm and
- The lowest conductor sag of the 330 kV overhead line is at least 8 m above ground level.

Table 1 Electric and Magnetic Field Strength Results Summary

Installation Method	Observation Location	Field Strength Result (µT)	Field Strength Result (kV/m)	[1]Pass / Fail
Underground 33 kV Cable (at 800 mm underground)	1.8 m above ground (standard height)	<5	-	PASS
	1 m above ground (lowest height of impact when standing)	<5	-	PASS
	Ground level (person lying on the ground)	<20	-	PASS
Overhead 33 kV Power Line – Single Circuit (at 6.7 m height)	4 m above ground (person sitting in heavy vehicle)	<20	-	PASS
	1.8 m above ground (standing height)	<10	-	PASS
Overhead 330 kV Transmission Line – Single Circuit (at 8 m height)	4 m above ground (person sitting in heavy vehicle)	<100	<4	PASS
	1.8 m above ground (standing height)	<40	<1	PASS
Overhead 330 kV Transmission Line – Double Circuit (at 8 m height)	4 m above ground (person sitting in heavy vehicle)	<30	<4	PASS
	1.8 m above ground (standing height)	<20	<2	PASS

The International Commission on Non-Ionising Radiation Protection (ICNIRP) has set the threshold for protecting human health:

- 200 µT for Magnetic field strength and
- 5 kV/m (general public) or 10 kV/m (occupational personnel) for Electric field strength.

All calculated magnetic field strengths are below the threshold for all installation methods.

All calculated electric field strengths are below the threshold for all installation methods.

The findings of this study indicate that the risk to human health due to emitted EMF are within safe exposure limits if the lowest sag of the 330 kV overhead transmission line conductor is at least 8 m above ground level.

The actual conductor arrangements are likely to differ from the proposed modelled scenario. However, the difference is likely to be minimal, and any corresponding variance in the calculated magnetic field strength are expected to be within +/- 20% design tolerance.

[1] International Commission on Non-Ionising Radiation Protection (ICNIRP) Guidelines

Contents

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1 Introduction

Background

Spark Renewables Pty Limited (Spark Renewables) proposes to develop the Dinawan Wind Farm (the project). The project includes the installation, operation, maintenance and decommissioning of up to approximately 200 wind turbine generators (WTGs) and associated infrastructure.

The project is on the traditional lands of the Wiradjuri people and several smaller nations of the Murrumbidgee plains, about halfway between the towns of Coleambally and Jerilderie and lies within the Murrumbidgee and Edward River local government areas (LGAs) in New South Wales (NSW).

The project will have a generation capacity of approximately 1,200 MW (AC), equivalent to the need of 600,00 NSW households per year. It will assist in meeting NSW and Australian Government meeting their emissions reduction targets to abate approximately 3.2 million tonnes of greenhouse gases (GHG) annually.

The project is a State significant development (SSD) pursuant to schedule 1 of State Environmental Planning Policy (Planning Systems) 2021 (Planning Systems SEPP).

Middleton Group (MG) has been engaged by EMM consulting to undertake an Electromagnetic Field desktop study for inclusion in the Environmental Impact Statement (EIS).

Purpose

The purpose of this report is to estimate the electric and magnetic fields (EMF) emitted by the conductors, and then assess their potential impact on human health. This addresses the EMF aspect of the "Hazards and Risks" element outlined in the Planning Secretary's Environmental Assessment Requirements (SEARs) dated 14/12/2022. An extract of the SEARs specifying this report requirement is provided below:

"Health – consider and document any health issues having regard to the latest advice of the National Health and Medical Research Council, and identify potential hazards and risks associated with electric and magnetic fields (EMF) and demonstrate the application of the principles of prudent avoidance, including an assessment against the International Commission on Non-Ionizing Radiation Protection (ICNIRP) Guidelines for limiting exposure to Time-varying Electric, Magnetic and Electromagnetic Fields"

1.1 Scope

The scope of this study includes:

- Identify and model the sources of EMF such as underground cables and overhead line conductors to be constructed as part of the Dinawan Wind Farm.
- Calculate the levels of EMF that the general public will be exposed to, and then assess the exposure risk they pose to human health.

The study boundaries are defined as:

- EMF generated by proposed 33 kV underground cable – single circuit.
- EMF generated by the proposed 33 kV overhead power line – single circuit.

EMF generated by the proposed 330 kV transmission line – single circuit.

The proposed layout of WTGs, cable route of 33 kV (either underground or overhead) cable circuits and potential route options for 330 kV overhead transmission lines are represented in the extract of the project overview below.

Figure 1: Project Overview

1.2 Design Inputs

This assessment is based on the infrastructure assumptions specified in Table 2.

Table 2 Study Inputs – Project Infrastructure

Project Detail	Value
Proposed conductor arrangements	• 33 kV underground cable. • 33 kV overhead power line • 330 kV transmission lines As received from EMM Consulting (26.02.2024).
WTG Parameters	• Power 6.45 MW with power factor of 0.9. This equates to 7.16 MVA. • Maximum number of WTG per circuit: 6. • Total number of WTGs: 200. • WTGs compliant to standards.

2 Definitions

Term	Definition
ARPANSA	Australian Radiation Protection and Nuclear Safety Agency
CDEGS	Current Distribution Electromagnetic Fields, Ground and Soil Structure Analysis. A powerful piece of 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 References

[1] Standards Australia, *Overhead line design (AS 7000),* SAI Global., 2016.

[2] Australian Radiation Protection and Nuclear Safety Agency, "Radiation Health Series," 2023. [Online]. Available: https://www.arpansa.gov.au/regulation-and-licensing/regulatory-publications/radiation-health-series. [Accessed 21 03 2023].

[3] Australia, Commonwealth of, "Electricity and Health," [Online]. Available: https://www.arpansa.gov.au/understanding-radiation/radiation-sources/more-radiation-sources/electricity.

[4] Energy Network Association, EMF Management Handbook, 2016.

[5] 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.

[6] Standards Australia, *Substations and high voltage installations exceeding 1 kV a.c.,* Sai Global., 2016.

4 Methodology

4.1 Assumption

This study has been developed on the following basis:

1. Electrical installation in line with Australian Standards, in particular: height and configuration of overheard powerlines.
2. Underground cables are buried at 800 mm. This is a typical minimum depth.
3. All equipment (transformers, switchgear etc.) meets Australian and International Standards for electromagnetic compatibility and therefore does not meaningfully contribute to EMF risk.

4.2 Exclusion

1. Background EMF on site is considered negligible. Background measurements have not been included in this assessment. However, given the remote location of the site and absence of nearby electrical equipment, the background magnetic field strength within the project area and surrounds is expected to be negligible.
2. Fault conditions are not modelled in this assessment. A fault event is expected to last no longer than two seconds and is very unlikely to introduce human health risk due to EMF exposure.
3. Current carrying capacity for conductors has not been applied for any modelling.

4.3 Assessment Criterion

EMF limits for this study are taken from the International Commission on Non-Ionising Radiation Protection (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 in Figure 2 highlights magnetic flux density for the frequencies emitted from the transmission line. The peak field strength from the transmission lines will be at 50Hz. The Pass/Fail criterion applied for the general public as part of this assessment is 2,000 milli Gauss (200 μT).

Figure 3 shows the electric field strength limits at 50 Hz, which will be the peak field strength from the transmission lines. The Pass/Fail criterion applied for the general public as part of this assessment is 5 kV/m.

TABLE 5-2 MAGNETIC FIELD REFERENCE LEVELS AT 50HZ FOR IEEE AND ICNIRP.		
	IEEE 2002	ICNIRP 2010
GENERAL PUBLIC		
Exposure general	Not specified	200 µT*
Exposure to head and torso	904 µT	Not specified
Exposure to arms and legs	75,800 µT	Not specified
OCCUPATIONAL		
Exposure general	Not specified	1,000 uT*
Exposure to head and torso	2,710 µT	Not specified
Exposure to arms and legs	75,800 µT	Not specified

Figure 2: Magnetic Field Limits for Public and Occupational 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

4.4 Assessed Area

The assessed locations in this study are detailed 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
1.8 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 330 kV overhead transmission line only

Should the magnetic field and electric field strength calculations at the assessment locations listed in Table 3 meet the established criteria, it can be reasonably assumed that the magnetic and electric field strength at all other areas further away from the electrical installation will also meet the criteria. This includes the following:

- Associated houses
- Non-associated houses
- All public locations (such as roads, parks, roadside stops)

This conclusion is supported by modelling results, which aligns with the fundamental theory of electromagnetism dictating that magnetic field strength diminishes with distance from the source. For further details, please refer to Appendix A.

4.5 CDEGS Model

The SES software package CDEGS was used to model the underground cables and overhead transmission lines. The HIFREQ module was utilised to analyse the magnetic and electric field strengths.

4.5.1 Modelled Electrical Installations

The load scenarios, identified as having the potential to generate significant impact while still conforming to the EMF safety exposure limit for the general public and maintenance service crew, are outlined below:

Table 4: Modelled Scenarios

No.	Conductor Description	Voltage	WTGs Connected	Current in each conductor
1	2 Parallel Sets of 3 x 1 Core Underground 33 kV Cable – Single Circuit	33 kV	6 (3 WTGs per circuit)	376 A
2	Overhead 33 kV Power Line – Single Circuit	33 kV	6	754 A
3	Overhead 330 kV Transmission Line – Single Circuit	330 kV	125	1567 A
4	Overhead 330 kV Transmission Line – Double Circuit	330 kV	125 (Approx 62 per circuit)	784 A

Scenarios excluded in the modelling are anticipated to emit lower magnetic fields due to reduced load current in the conductors (see Appendix A for how lower current results in lower magnetic field). These scenarios include:

- Underground single-circuit 33 kV cables with less than 3 WTGs connected.
- Single-circuit 330 kV overhead transmission line with less than 125 WTGs connected.
- Overhead 330 kV overhead transmission line with less than 62 WTGs connected.

4.5.2 Underground 33 kV Cable Concept Design

The underground 33 kV cable reticulation connecting the WTGs with the 330/33 kV collector substation can only accommodate up to 6 WTGs. These underground cable circuits consist of 2 parallel circuits of three single-core cables, each conductor having a cross-sectional area of 240 mm^2.

As stated in Section 4.1, the concept design considers the cables will be buried at 800 mm. This is a typical minimum depth.

The concept design also includes the installation of each cable circuit within a single Φ150 mm HDuPVC conduit (see Appendix C). The separation between two cable circuits is typically 300 mm, as shown in Figure 4.

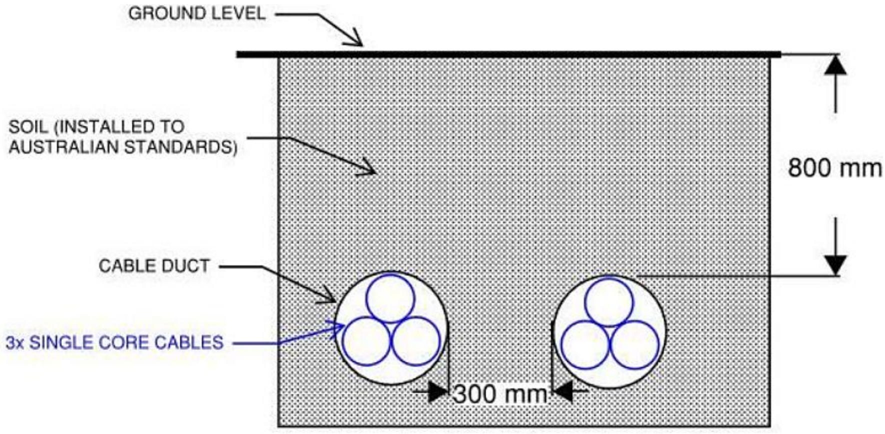


Figure 4: Underground Cable Installation Concept Design

4.5.3 Overhead 33 kV Power Line Concept Design

The proposed overhead 33 kV power line will be supported by line poles, vertical flat conductors' arrangement, designed to accommodate a maximum of 6 WTGs connected in series. These towers have been modelled in accordance with AS 7000 [1].

As per the concept design, each 33 kV line pole will feature three (3) vertically spaced conductors. The separation distance between each conductor will be 1.2 m, and the conductors will be strung such that the lowest sag on any sections of the line crossing a roadway will be above 6.7 m safety clearance as specified in Table 3.5 of AS/NSZ 7000:2016.

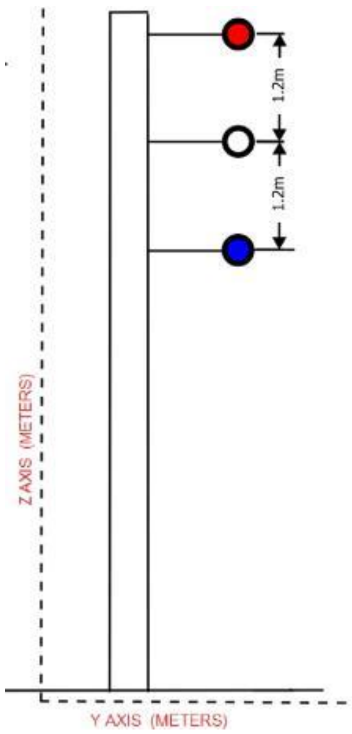


Figure 5: 33 kV Line Pole "Typical" Configuration

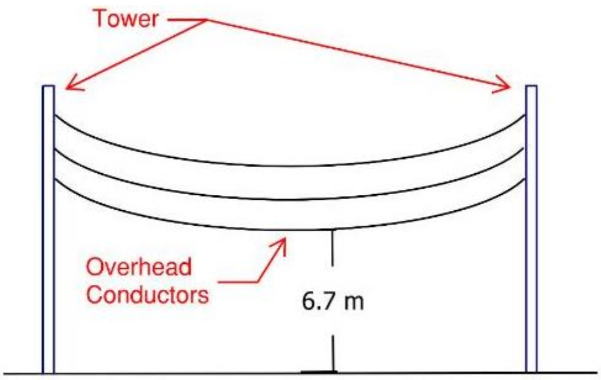


Figure 6 33 kV Power Lines

4.5.4 Overhead 330 kV Transmission Line Concept Design

The proposed overhead 330 kV transmission line will be supported by line poles, vertical flat conductors' arrangement, designed to accommodate a maximum of 125 WTGs 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 m, 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. This is shown below in Figure 7 (a).

The overhead double 330 kV line is proposed to be a vertical separated transmission tower that will carry up to 125 wind turbines connected in series. The horizontal separation distance between conductors used is 12 m. The height of the transmission line is 8 m above the ground with a separation distance of 4 m between conductors. These have been modelled in accordance with AS 7000 [1] and typical industry values. This is shown below in Figure 7 (b).

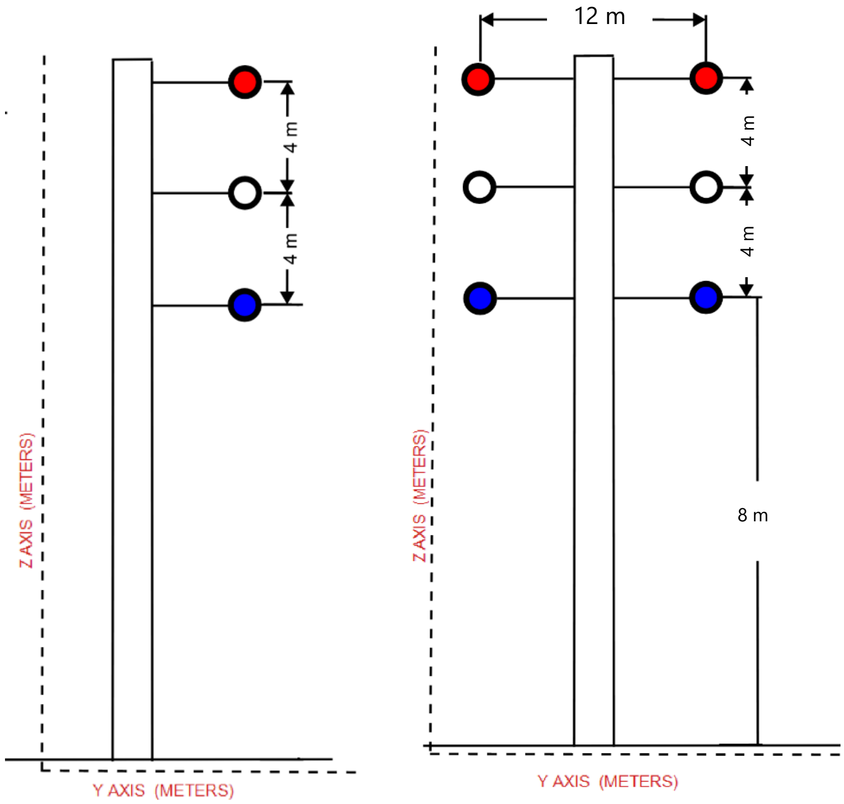


Figure 7 330 kV (a) Single Circuit Transmission Tower (b) Double Circuit Transmission Tower

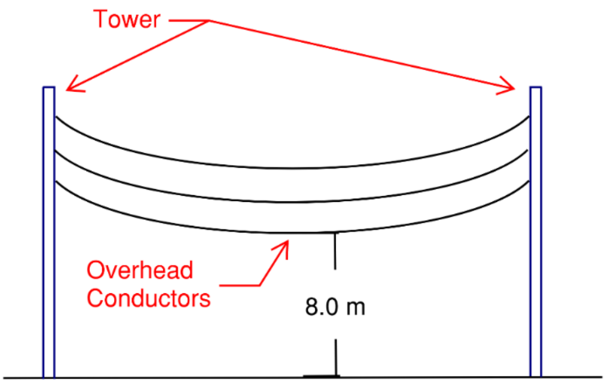


Figure 8 330 kV Transmission Lines

5 Results

5.1 33 kV Underground Cable

The worst-case 33 kV underground cable installation is shown in Figure 4. It comprises of two (2) circuits of three (3) x 240 mm^2 cables laid in single conduit each buried at a depth of 800 mm below ground. Each cable per phase is loaded to 376 A.

The CDEGS magnetic field model of the cables in the Y-Z plane, with height and depths of EMF observation points indicated by dashed lines, is detailed in Figure 9. The results indicate that at the ground surface level, the EMF values do not exceed 20 μT. Hence, there are no unsafe EMF that the general public can be exposed to due to 33 kV underground reticulation network. In the practical scenario, magnetic field strength measurements for individuals are taken at a distance of 1 m.

To exceed the 200 μT threshold at ground level, which poses a significant risk to human health, each cable would need to carry a current exceeding 3760 A, representing a significant deviation from the intended design. Consequently, Spark Renewables is unlikely to consider this approach as the current 33 kV cable available in the market does not include this type of cable at this voltage level.

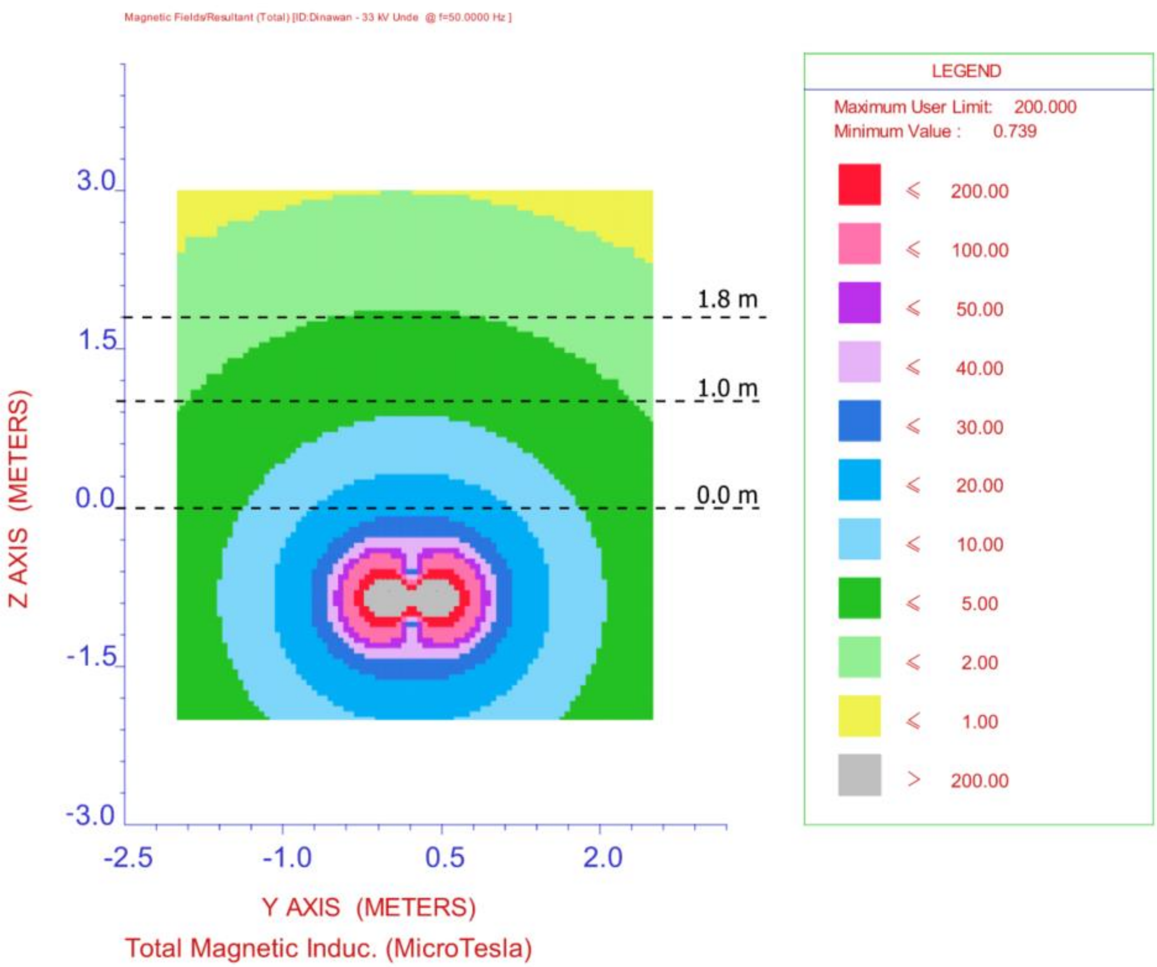


Figure 9 Magnetic Field Strength of 33 kV Underground Cables Carrying 376 A

5.2 33 kV Overhead Power Lines

The proposed overhead 33 kV power line will be supported by line poles, vertical flat conductors' arrangement, designed to accommodate a maximum of 6 WTGs connected in series. These towers have been modelled in accordance with AS 7000 [1].

As per the concept design, each 33 kV line pole will feature three (3) vertically spaced conductors. The separation distance between each conductor will be 1.2 m, and the conductors will be strung such that the lowest sag on any sections of the line crossing the roadway will be above 6.7 m safety clearance specified in Table 3.5 of AS/NSZ 7000:2016. Each conductor will carry a calculated current of 754 A.

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 33 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 µT safe exposure limit specified in Section 4.3, Figure 2.

To exceed the 200 µT threshold at 4 m, which poses a significant risk to human health, each cable would need to carry a current exceeding 7540 A, representing a significant deviation from the intended design. Consequently, Spark Renewables will not proceed with such an approach.

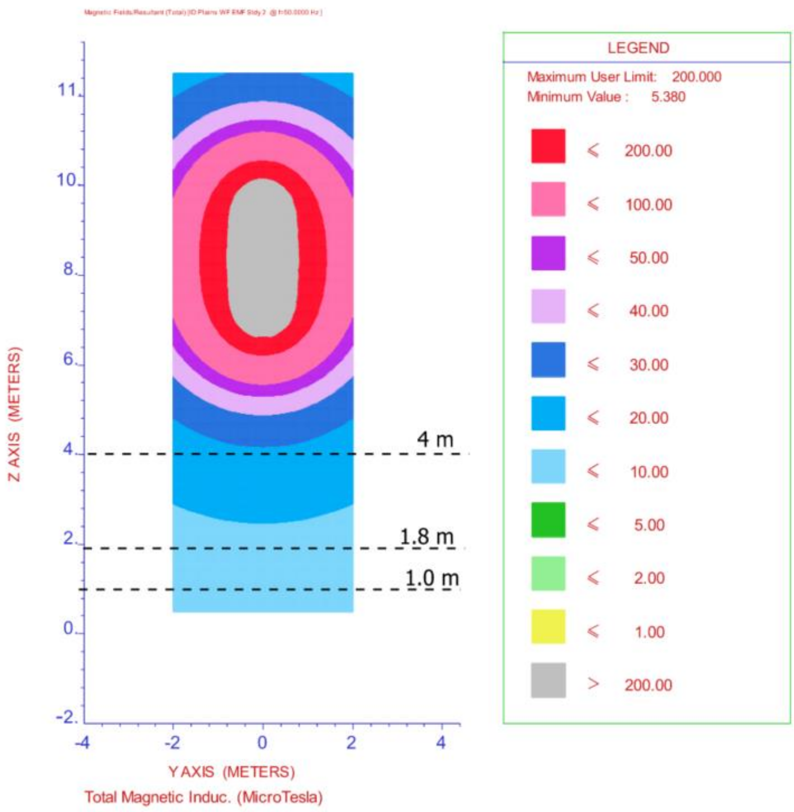


Figure 10 Magnetic Field Strength of 33 kV Overhead Power Lines Carrying 754 A

Figure 11 below shows the maximum allowed height before breaching the 200 µT limit. This shows a 6.7 m clearance must be maintained to remain within the safe magnetic field strength limits under the 33 kV power line.

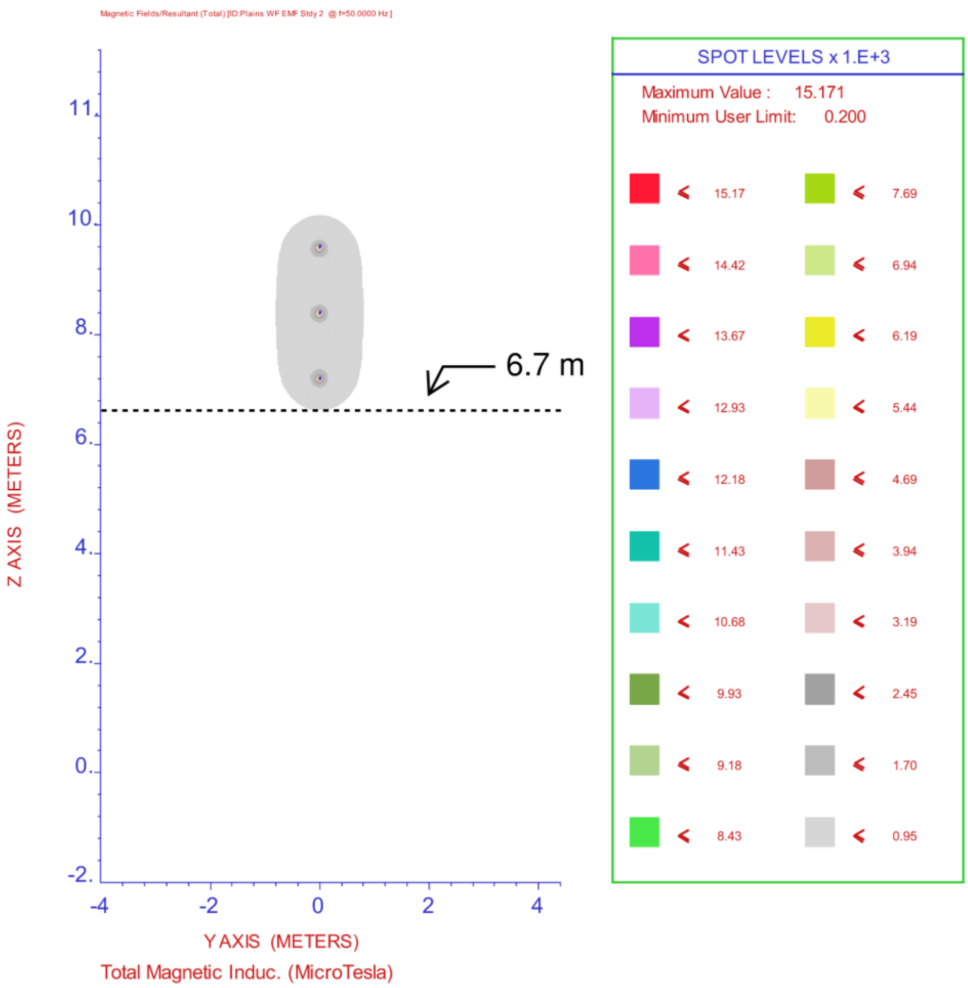


Figure 11: 200 µT cut-off height

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 125 WTGs connected in series. These towers have been modelled in accordance with AS 7000 [1].

5.3.1 Single Circuit

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 m, and the conductors will be strung such that the lowest sag on any sections of the line crossing a roadway will be above 8 m safety clearance specified in Table 3.5 of AS/NSZ 7000:2016. Each conductor will carry a calculated current of 1567 A.

Figure 12 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 µT safe exposure limit specified in Section 4.3, Figure 2

To exceed the 200 µT threshold at 4 m height, which poses a significant risk to human health, the lowest cable would need to carry a current exceeding 3134 A, representing a significant deviation from the intended design. Consequently, the Proponent will not proceed with such an approach.

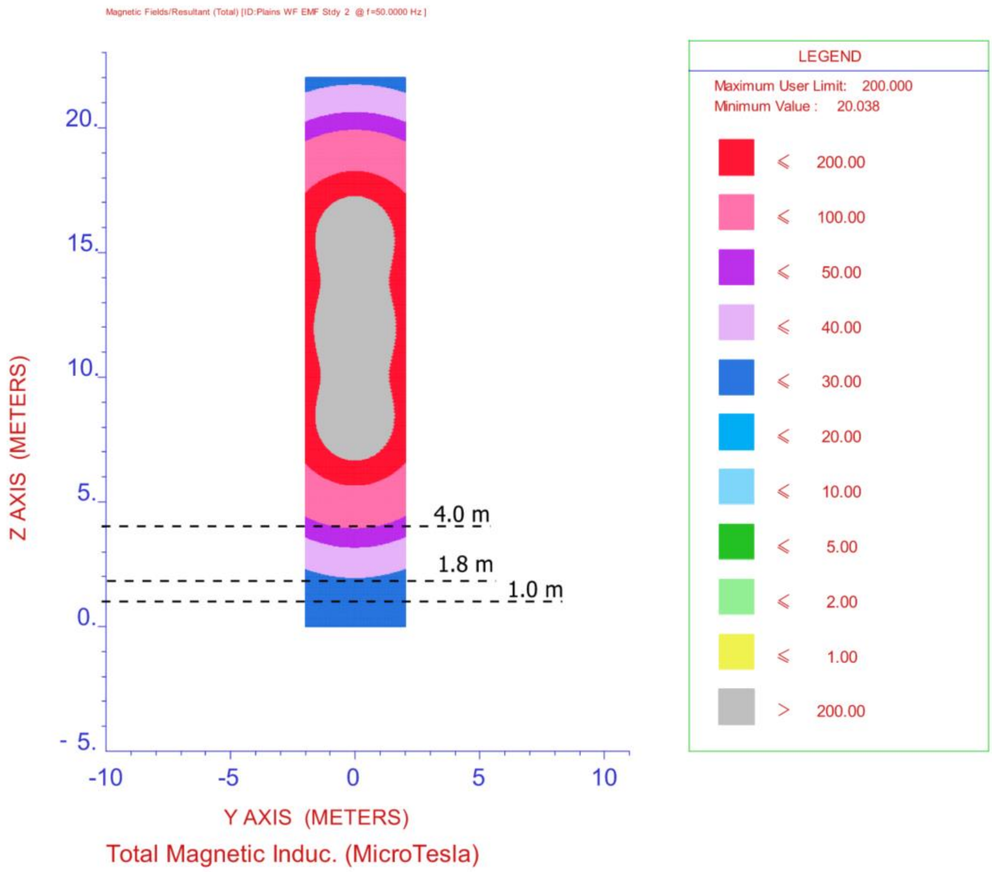


Figure 12: Magnetic Field Strength of 330 kV Overhead Transmission Lines Carrying 1567 A (At 8m Height)

Figure 13 below shows the maximum allowed height before breaching the 200 µT magnetic field strength limit. This shows a 6.9 m clearance must be maintained to remain within the safe magnetic field strength limits under the 330 kV transmission line.

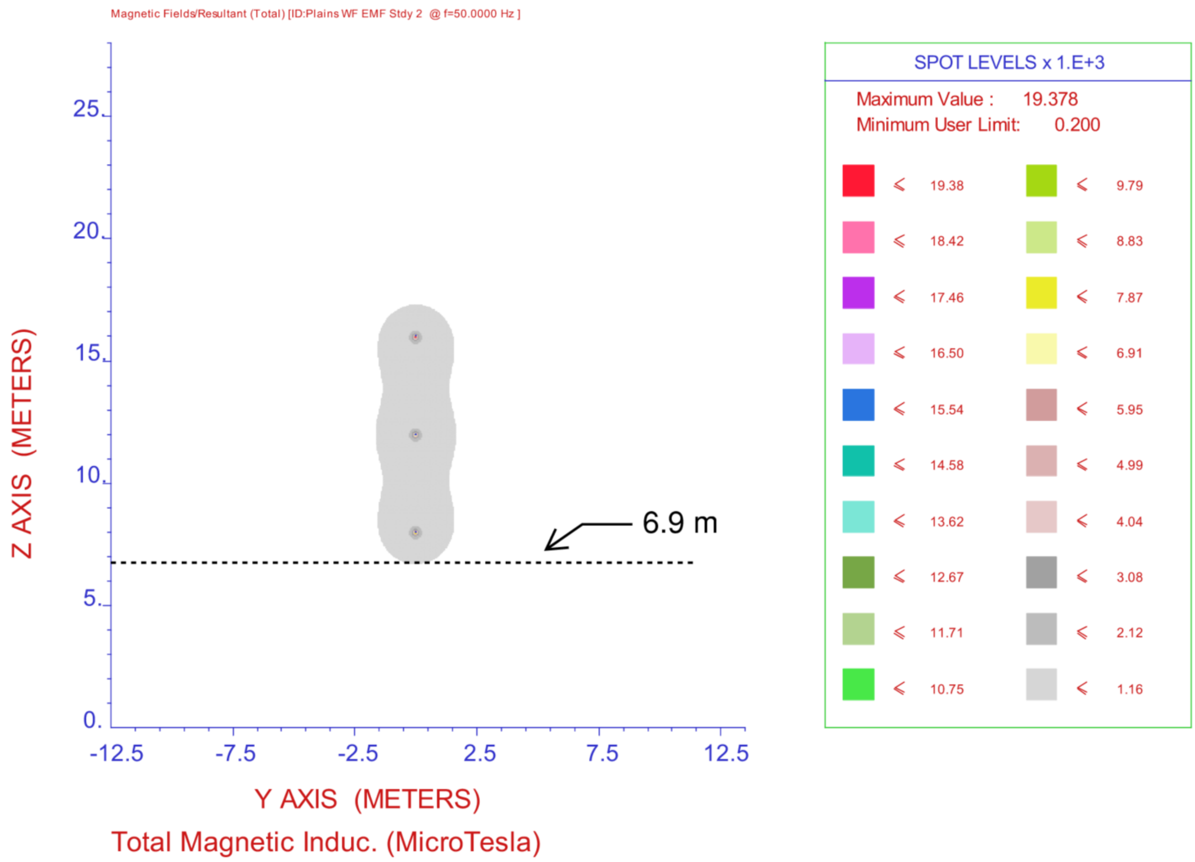


Figure 13: 200 µT cut-off height – Single 330 kV transmission line

5.3.2 Double Circuit

The overhead double 330 kV line is proposed to be a vertical double circuit transmission tower that will carry up to 125 wind turbines connected in series. The horizontal separation distance between conductors used in the analysis is 12 m. The height of the transmission line is 8 m above the ground with a vertical separation distance of 4 m between conductors. These have been modelled in accordance with AS 7000 [1] and typical industry values.

Figure 14 provides the magnetic field strength emitted from the overhead conductors in the Y-Z plane, with height levels indicated by dashed lines.

The result in CDEGS-HIFREQ modelling indicates that across the double 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 μT safe exposure limit specified in Section 4.3, Figure 2.

To exceed the 200 μT threshold at 4 m height, which poses a significant risk to human health, the lowest cable would need to carry a current exceeding 5,200 A, representing a significant deviation from the intended design. Consequently, the Proponent will not proceed with such an approach.

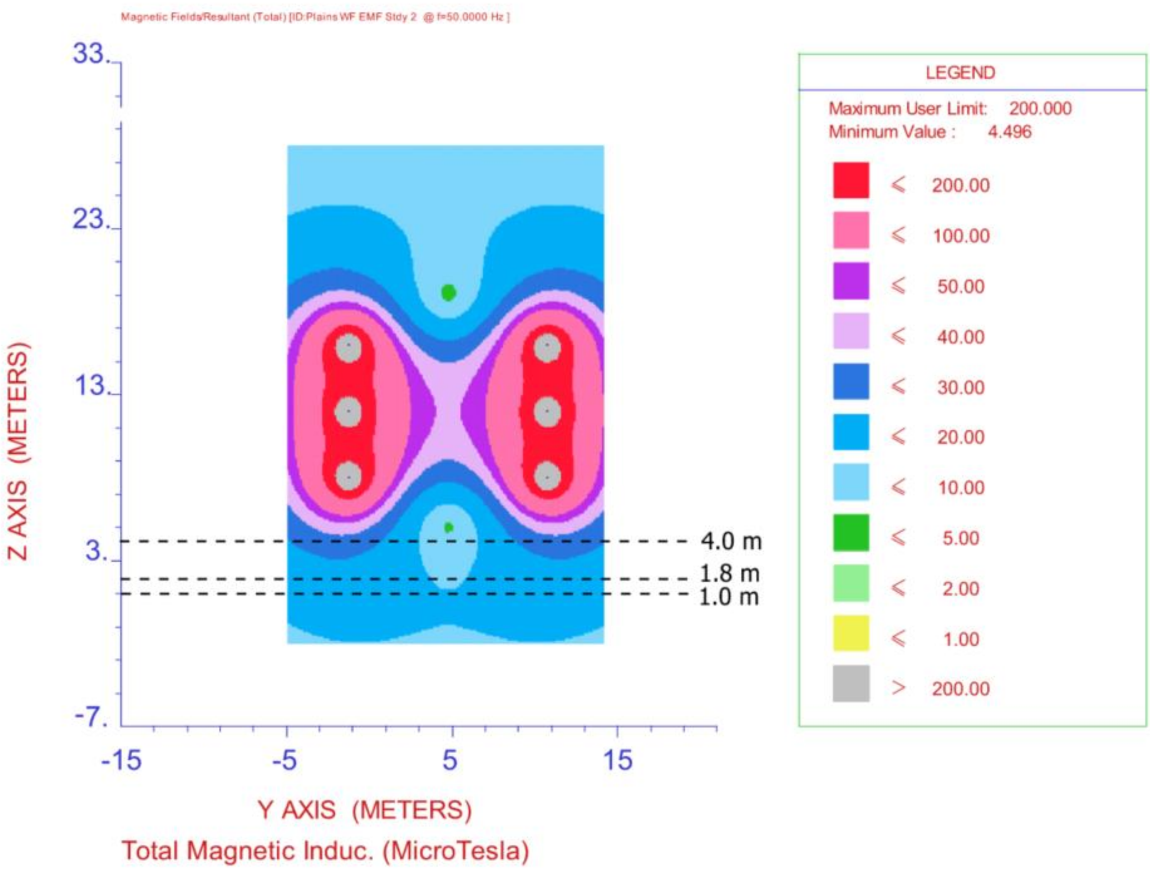


Figure 14: Magnetic Field Strength of 330 kV Overhead Double Transmission Lines Carrying 784 A (At 8m Height)

Figure 15 shows the maximum allowed height before breaching the 200 μT magnetic field strength limit. This implies the 7 m ground clearance must be maintained to remain within the safe magnetic field strength limits under the double 330 kV transmission line.

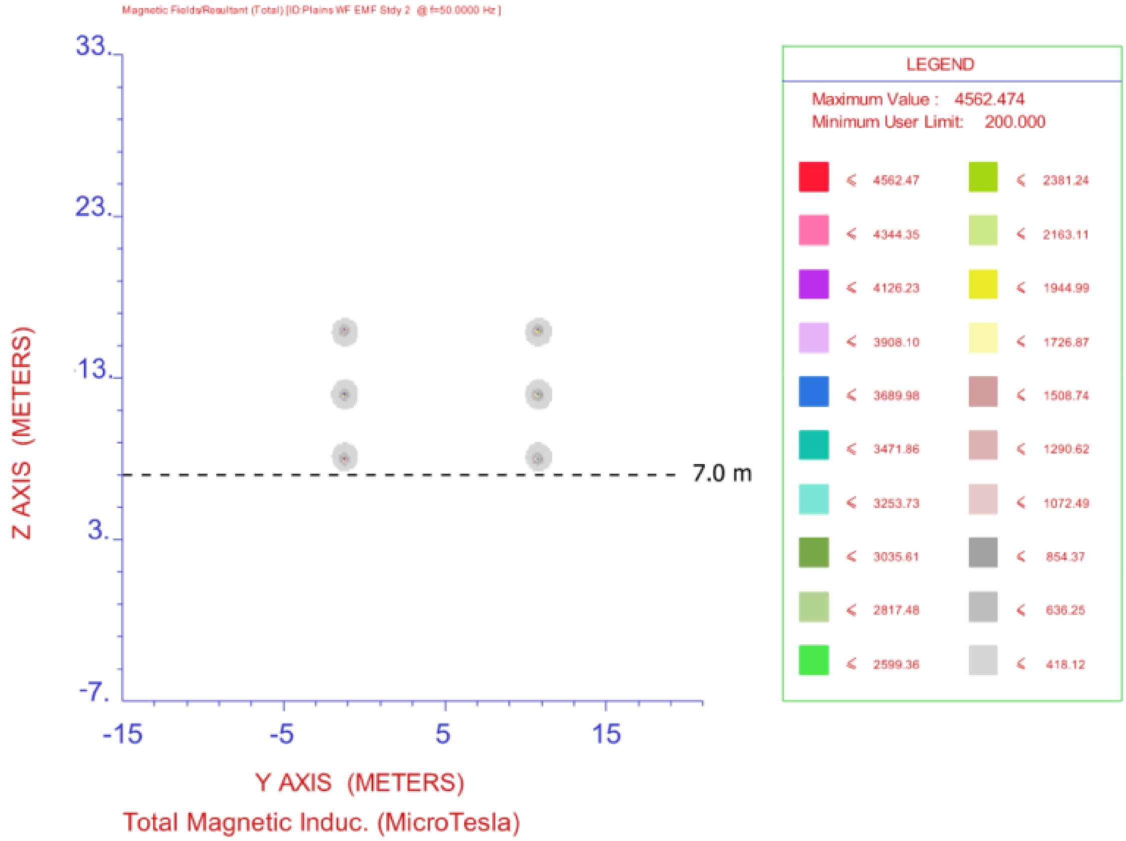


Figure 15: 200 μT cut-off height – Double 330 kV transmission line

5.4 Electric Field

5.4.1 33 kV Overhead Power Line

Due to the relatively low values of electric field strength from both the 33 kV overhead and underground power lines, a CDEGS model was not developed, and a study was not found necessary.

5.4.2 330 kV Overhead Transmission Line

The electric field assessment has been completed for the worst-case scenario only, representing the highest voltage scenario where a person is directly underneath an 8 m high 330 kV single and double overhead transmission line.

Figure 16 and Figure 17 show that at heights of 4 m, 1.5 m, and 1 m above ground, the electric field strengths do not exceed the public exposure limit of 5 kV per metre for both 330 kV circuit configurations [4].

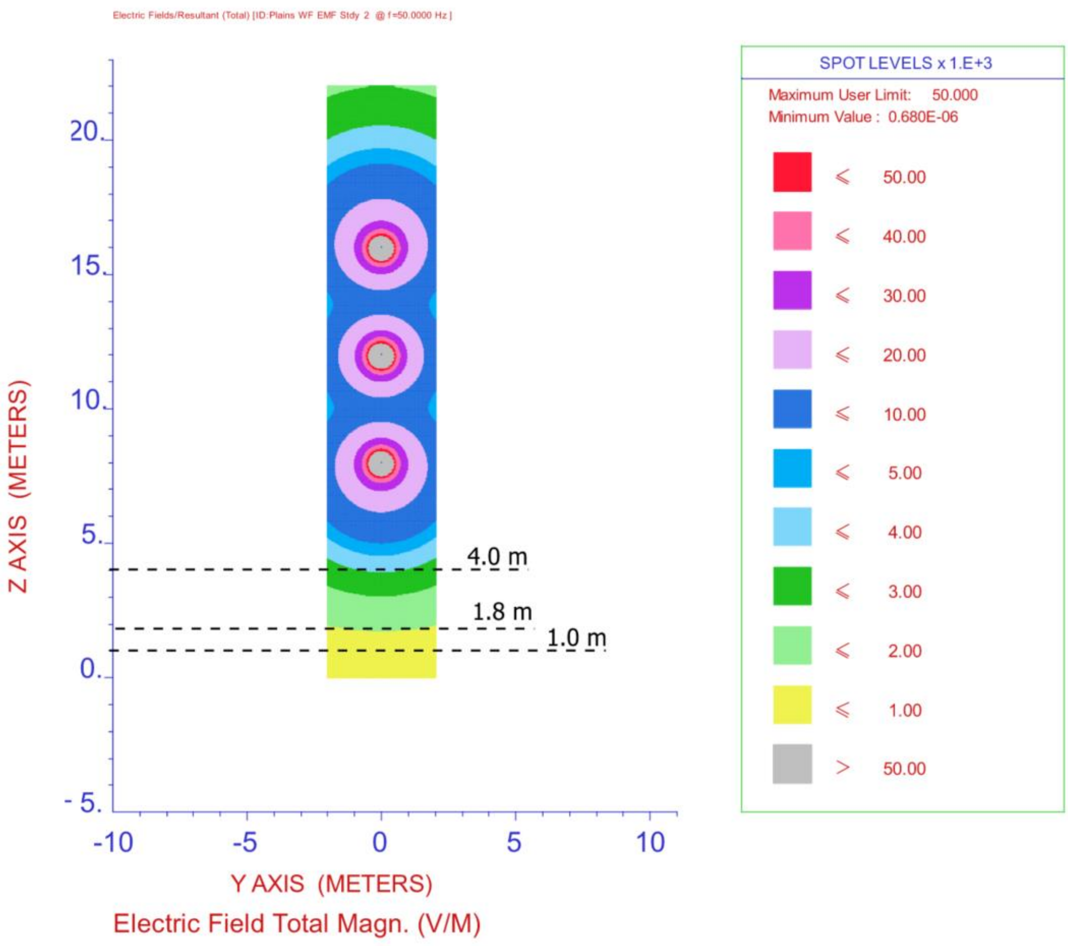


Figure 16: Electric Field Strength of 330 kV Overhead Transmission (At 8m Height)

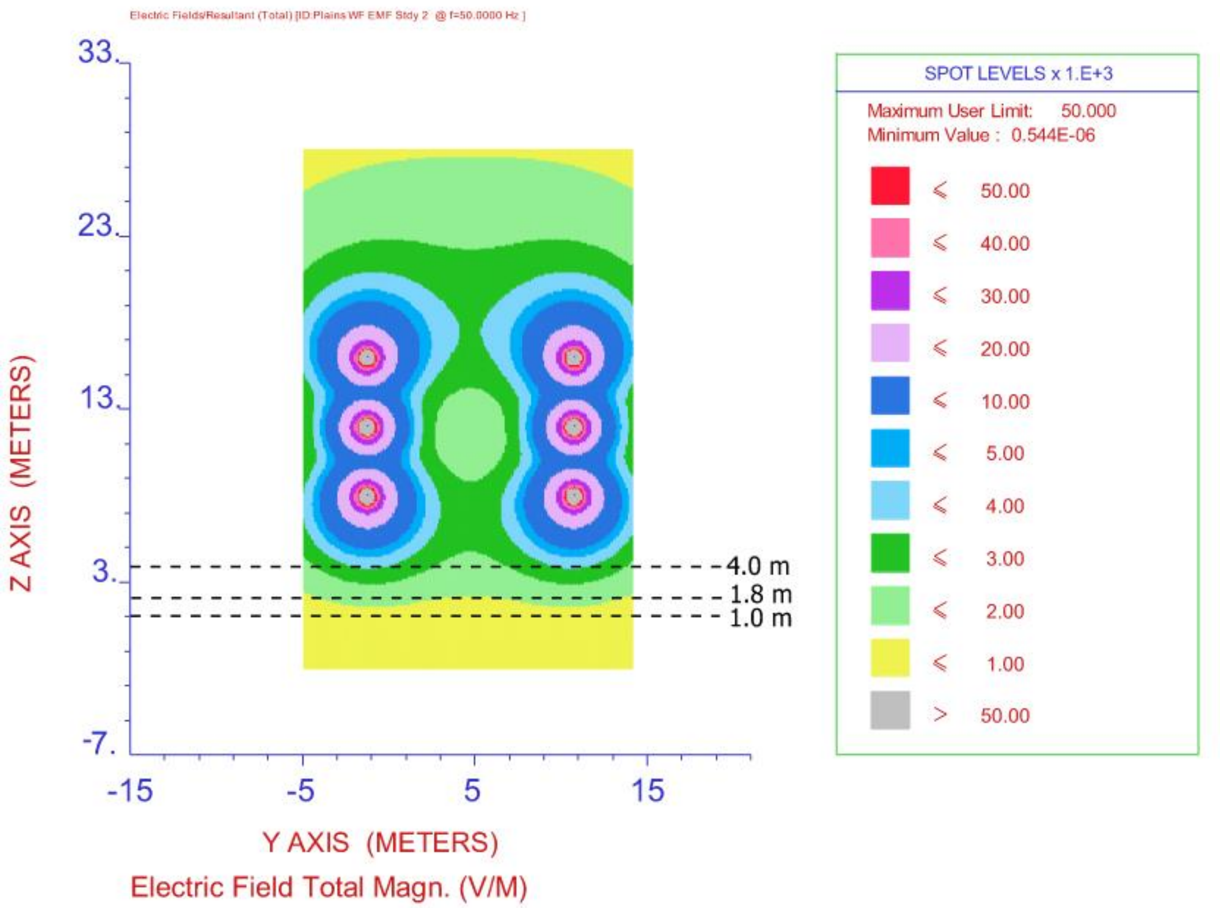


Figure 17: Electric Field Strength of 330 kV Double Overhead Transmission (At 8m Height)

6 Conclusion

6.1.1 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 both underground cables and overhead line conductors are within the 200 μT safe exposure limit specified in Section 4.3, Figure 2.

No unsafe magnetic fields that the general public can be exposed to have been identified.

The 7 m ground clearance must not be exceeded to remain within the safe magnetic field strength limits under the 330 kV transmission line.

The overhead conductors radiates a lower magnetic field strength in the double circuit scenario than a single circuit transmission line. This is due to the load current being split equally across two parallel circuits.

The summary of these results is detailed in Table 5.

Table 5 Magnetic Field Strength Results Summary

Installation Method	Observation Location	Field Strength Result (μT)	[2]Pass / Fail
Underground 33 kV Cable	1.8 m above ground (standard height)	<5	PASS
	1 m above ground (lowest height of impact when standing)	<5	PASS
	Ground level (person lying on the ground)	<20	PASS
Overhead 33 kV Power Line – Single Circuit	4 m above ground (person sitting in heavy vehicle)	<20	PASS
	1.8 m above ground (standing height)	<10	PASS
Overhead 330 kV Transmission Line – Single Circuit (at 8m Height)	4 m above ground (person sitting in heavy vehicle)	<100	PASS
	1.8 m above ground (standing height)	<40	PASS
Overhead 330 kV Transmission Line – Double Circuit (at 8m Height)	4 m above ground (person sitting in heavy vehicle)	<30	PASS
	1.8 m above ground (standing height)	<20	PASS

[2] International Commission on Non-Ionising Radiation Protection (ICNIRP) Guidelines

6.1.2 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 4.3, Figure 3.

No unsafe electric fields that the general public can be exposed to have been identified.

The 4.5 m and 4.8 m ground clearances must not bet exceeded to remain within the safe electric field strength limits under the single circuit and double circuit 330 kV transmission lines respectively. The double circuit line configuration has a slightly lower electric field strength due to the cancelling effects caused by the two parallel circuits.

A summary of results can be found in Table 6.

Table 6 Electric Field Strength Results Summary

Installation Method/	Observation Location	Field Strength Result (kV/m)	[3]Pass / Fail
Overhead 330 kV Transmission Line – Single Circuit (at 8m Height)	4 m above ground (person sitting in heavy vehicle)	<4	PASS
	1.5 m above ground (standing height)	<1	PASS
Overhead 330 kV Transmission Line – Double Circuit (at 8m Height)	4 m above ground (person sitting in heavy vehicle)	<4	PASS
	1.5 m above ground (standing height)	<2	PASS

6.1.3 Human Health Assessment

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

6.1.4 Applications of These Findings

The actual conductor arrangements are likely to differ from the proposed modelled scenario. However, the difference is likely to be minimal, and any corresponding variance in the magnetic field emissions is expected to be negligible. As such, the findings of this report are still considered applicable if minor design changes occur.

An existing 132 kV transmission line runs between the eastern and western wind areas. It is expected that the proposed conductor arrangements will be designed as per AS 7000 to maintain adequate clearances, as well as to mitigate the increased EMF risk due to the coexistence of multiple high-voltage transmission lines.

[3] International Commission on Non-Ionising Radiation Protection (ICNIRP) Guidelines

Appendix A EMF Theory

Overview

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

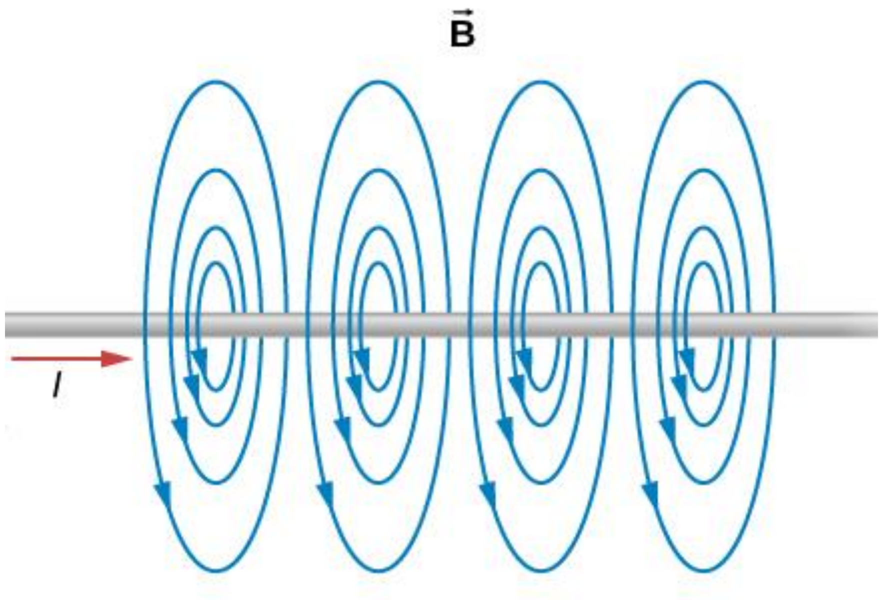


Figure 18 Magnetic Field Around a Conductor

EMF from a single conductor

To calculate the magnetic field strength emitted form 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 below.

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*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.

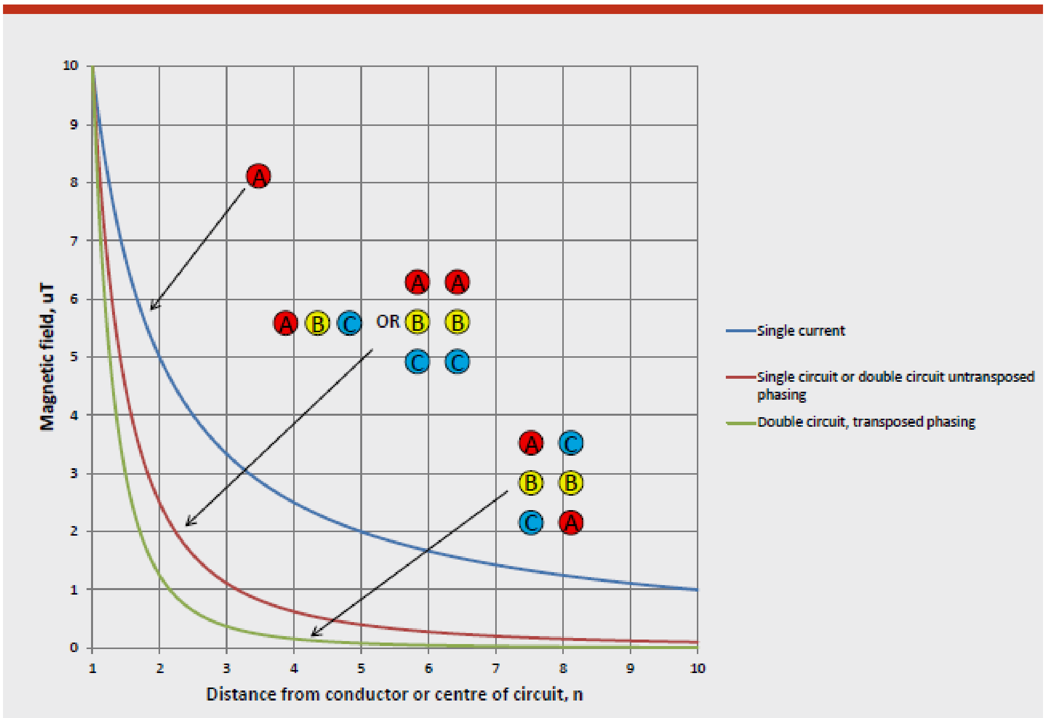
EMF from a three-phase system

The magnetic field at a point will be the vector sum of the fields from each conductor. In a balanced three phase system, the phase angle of the magnetic field from the three conductors will cancel out. However, any three 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 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 10µT at 1m from the source.

Appendix B Overhead line concept design

The conductor separation of the transmission line is established in two 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 3.1and Figure 3.5.

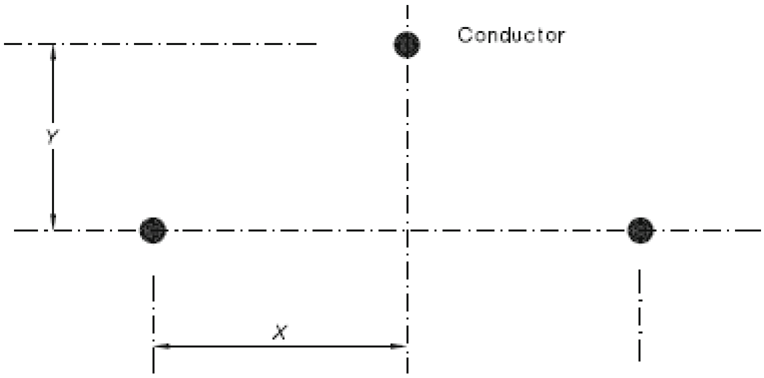


FIGURE 3.5 CONDUCTOR SEPARATION AT MID SPAN (ONE CIRCUIT)

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

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. 2 m has been allowed for swinging conductors, based on typical industry application.

The calculation of the above two parts is resolved in Table 7 and Table 9 for 33 kV and 330 kV conductors respectively.

Table 7 33 kV Overhead Line Conductor Vertical Separation Calculation

Variable	Value	Unit	Comment
X	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		
Y (Vertical separation)	1.16	m	
Swinging conductor allowance	2	m	Typical industry value

Table 8 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)	1.3930	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	571.5767	kV	Derived
k	0.4		As per standard
D	4	m	Typical industry value
li	2.4	m	Typical industry value
	Results		

Variable	Value	Unit	Comment
[4]Y (Vertical separation)	4.02	m	
Swinging conductor allowance	2	m	Typical industry value

[4]For double circuit 330 kV transmission tower the vertical separation Y is identical.

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, which is applicable to the project 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 1,200 mm^2 cable is an upper limit, not commonly installed.

19/33kV Single Core
Screened & PVC Sheathed

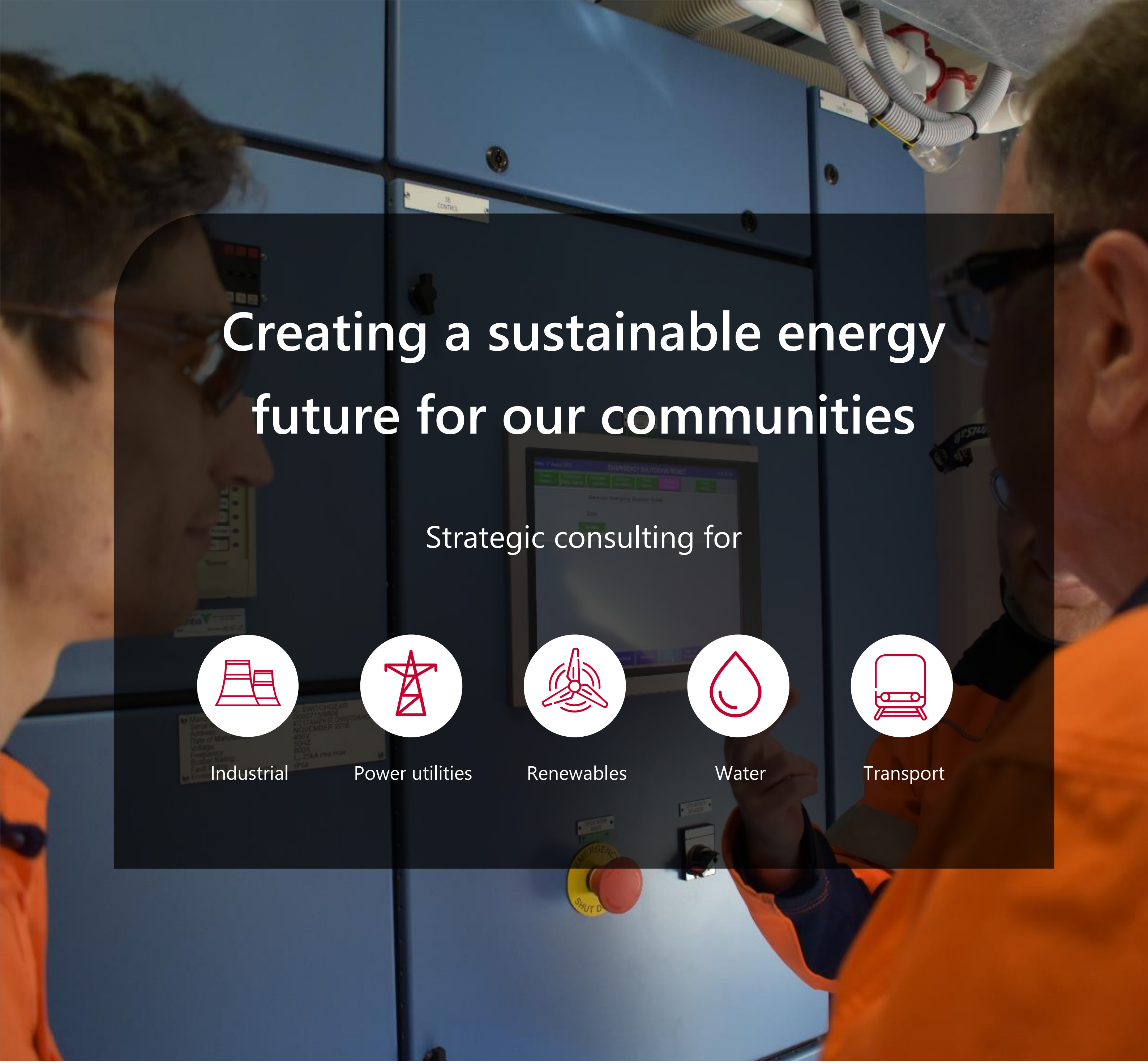
Copper Conductors, up to 10kA Fault Level

Nominal conductor area mm²	Nominal conductor diameter mm	Nominal insulation thickness mm	Nominal diameter over insulation mm	Nominal screen area on each core mm²	Number and nominal diameter of screen wires no/mm	Nominal diameter over wire screen mm	Nominal overall diameter mm	Approx. mass kg/100m	Product code	Max. pulling tension kN	Min. bending radius: During pulling mm	Min. bending radius: Set in position mm	Nominal duct diameter (trefoil) mm	Nominal duct diameter (single duct) 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

Continuous current-carrying capacity, A

Nominal conductor area mm²	In air: Solid Bond	In air: Solid Bond	In air: Solid Bond	In air: Solid Bond	In air: Solid Bond	In ground: Solid Bond	In ground: Solid Bond	In ground: Solid Bond	In underground ducts: Solid Bond	In underground ducts: Solid Bond	In underground ducts: Solid Bond	In underground ducts: Solid Bond	Fault current carrying capacity for 1 second: Cond. kA	Fault current carrying capacity for 1 second: 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



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