APPENDIX 14

Electromagnetic Fields Assessment

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Wattle Creek Solar Farm

SSD-63344210
EMF/Human Health Assessment

Client: **Umwelt Environmental & Social Consultants**
Revision: 4
Project: Wattle Creek Solar Farm EMF/ Human Health Assessment
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FINAL

Revision control

Revision	Date	Description	Prepared by	Reviewed by	Approved by
A	28.06.24	Issued for Review	Heshna Uppadoo	Elpidio Jayagan	Alex Low
B	20.09.24	Issued for Review Revised layout	Heshna Uppadoo	Eric Bendtsen	Craig Johnston
C	28.11.24	Issued for Review	Heshna Uppadoo	Eric Bendtsen	Craig Johnston
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3	22.01.25	Separate Projects	Heshna Uppadoo	Craig Johnston	Craig Johnston
4	12.03.25	Spark's Comments	Heshna Uppadoo	Craig Johnston	Craig Johnston

Disclaimer

Executive Summary

The proposed electrical power infrastructure for the Wattle Creek Solar Farm Project (the Project) is estimated to emit an electric and magnetic field (EMF) from the underground and overhead single-circuit 33 kV and 330 kV overhead transmission line.

This includes considering the lowest sag of the conductor and electromagnetic field (EMF) levels at specified heights above ground in worst-case load condition.

- EMF for 4 m above ground over roadways and
- EMF at 1.8 m and 1 m above ground for public domains.

The electric and magnetic field (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 5.3.1, which are in accordance with AS/NZS 7000, focusing on ensuring safety over roadways and public areas.
- Current and voltage magnitude as per Section 1.4: Design Inputs.

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

- Magnetic field strength at 200 μT, a level exceeding all calculated magnetic field strength scenarios.
- Electric field strength at 5 kV/m for general public and 10 kV/m for occupational personal, a level exceeding the worst anticipated electric field strength scenario (330 kV transmission line at 8 m height).

The summary of the worst-case EMF measurements is detailed in Table 1 and Table 2. The results indicate that the predicted EMF levels from the proposed electrical infrastructure are well within the allowable limits for all scenarios if the recommended ground clearance is maintained.

Cumulative effects & recommendations:

The results of the cumulative impact assessment for the Project and the proposed Wattle Creek Battery Energy Storage System project(SSD-63345458), also proposed on site along with approved and existing infrastructure, indicate that the general public will not be exposed to unsafe electric or magnetic fields at the recommended height. Likewise, the Project does not present a risk of unsafe EMF exposure at the nearby proposed gas fired power station.

At the crossover points of the proposed and existing 330 kV overhead transmission lines, the combined magnetic fields remain within safe exposure limits for both the general public and occupational personnel. However, the electric fields exceed the safety thresholds of 5 kV/m and 10 kV/m, respectively.

Table 1: Magnetic Strength Results Summary

Installation Method	Observation Location	Field Strength Result (μT)	Pass / Fail
Underground 33 kV Cable	1.8 m above ground (standard height)	<30	PASS
	1 m above ground (lowest height of impact when standing)	<30	PASS
	Ground level (person lying on the ground)	<40	PASS
Overhead 330 kV Transmission Line	4 m above ground (person sitting in heavy vehicle)	<20	PASS

Installation Method	Observation Location	Field Strength Result (μT)	Pass / Fail
	1.8 m above ground (standing height)	<10	PASS
Cumulative Impact: the Project and Wattle Creek BESS(SSD-63345458)			
Overhead 330 kV Transmission Line	4 m above ground (person sitting in heavy vehicle)	<50	PASS
	1.8 m above ground (standing height)	<30	PASS
Cumulative Impact: With Existing Infrastructure			
Single Circuit Overhead 330 kV Transmission Line	1 m above ground (lowest height of impact when standing)	<145	PASS
Double Circuit Overhead 330 kV Transmission Line	1 m above ground (lowest height of impact when standing)	<10.6	PASS

Table 2: Electric field strength Results Summary

Installation Method	Observation Location	Field Strength Result (kV/m)	Pass / Fail
Cumulative Impact			
Overhead 330 kV Transmission Line	4 m above ground. Ground clearance of 8 m.	<5.4	PASS*
	4 m above ground. Ground clearance of 8.5 m.	<4.7	PASS
	1 m above ground. Ground clearance of 8.5 m.	<2.8	PASS
Cumulative Impact: With existing infrastructure			
Single Circuit Overhead 330 kV Transmission Line	1 m above ground (lowest height of impact when standing)	<7.4	PASS**
Double Circuit Overhead 330 kV Transmission Line	1 m above ground (lowest height of impact when standing)	<7.3	PASS**

Note:

PASS*: The field strength will be within the safe exposure limit at the recommended ground clearance.

PASS**: The field strength is above the safe exposure limit for general public and within the safe exposure limit for occupational personnel.

It is recommended that further analysis be conducted during the detailed design phase, considering finalized parameters such as conductor specifications, structural arrangements, and conductor heights for both proposed and existing infrastructure. Restricting public access in the crossover area or adjusting the transmission crossover setup to meet established electric field limits must be considered following analysis in detailed design.

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1 Introduction

1.1 Background

Spark Renewables propose to develop the Wattle Creek Solar Farm Project (the Project) located on Arthursleigh Farm (Lot 3 of DP 1120270), approximately 80 kilometres (km) west of Wollongong and 15 km northwest of Marulan within the Upper Lachlan Shire Council Local Government Area (LGA) and abuts the Wingecarribee Shire LGA to the east, and Goulburn Mulwaree Shire Council LGA to the south.

The project includes a large-scale solar photovoltaic (PV) generation facility (265 MW(AC)) combined with a 100 MW solar hybrid battery energy storage system (BESS).

Spark renewables are also proposing the Wattle Creek Battery Energy Storage System (BESS) project (SSD-63345458) which has been assessed separately and will be progressed through separate approval applications and process and is considered from a cumulative impact perspective in this assessment.. This Electromagnetic Fields Desktop Study assesses the Project and associated cumulative impacts in Section 6.

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

1.2 Purpose

The purpose of this report is to estimate/calculate 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" element outlined in the Planning Secretary's Environmental Assessment Requirements (SEARs) dated 22/12/2023. An extract of the SEARs specifying this report requirement is provided below:

"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 the sources of EMF such as underground cables and overhead line conductors to be constructed under the Project.
- Calculate the levels of electric and magnetic fields 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 330 kV transmission line – single circuit.

The Proposed layout of Solar Panels and hybrid BESS are represented in the extract of the project overview in Figure 1.

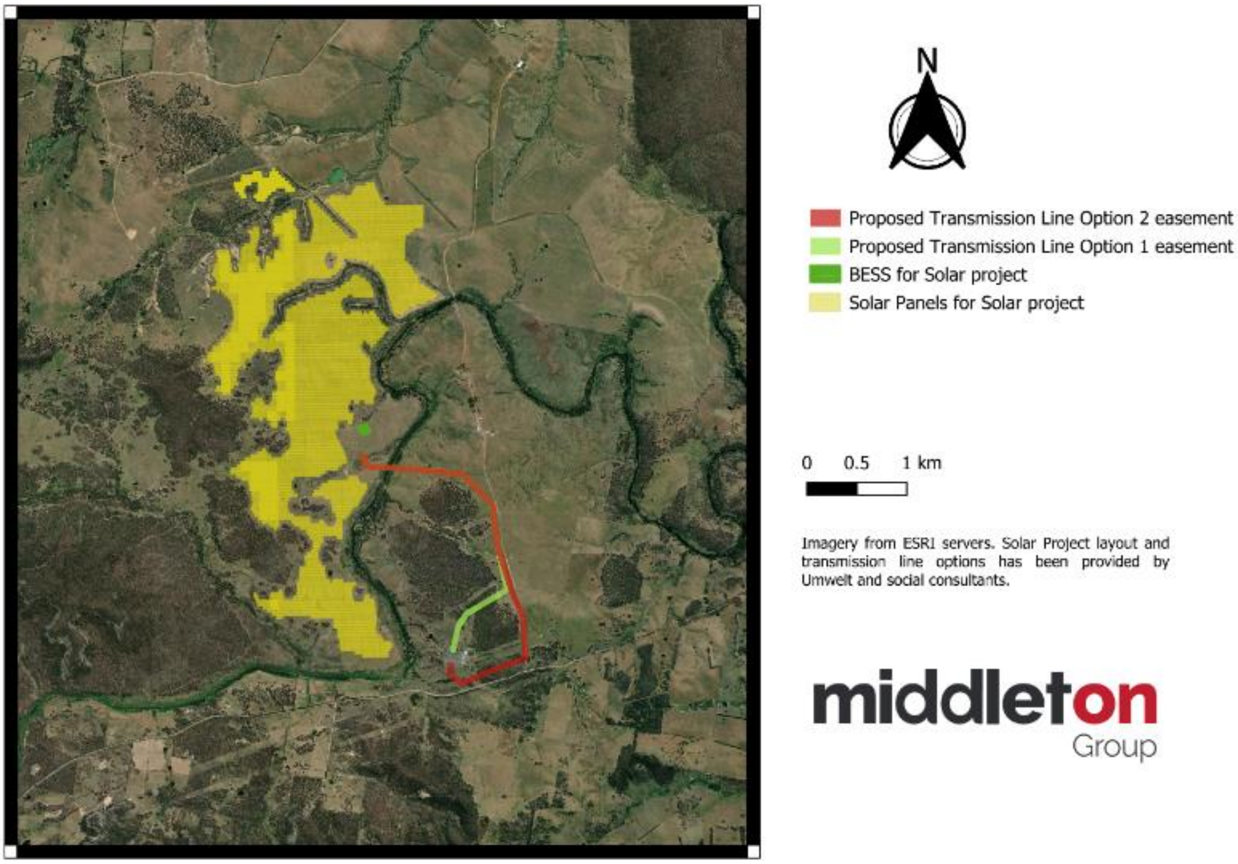


Figure 1: Project Overview

1.4 Design Inputs

This assessment is based on stakeholder infrastructures specified in Table 3.

Table 3: Study Inputs – Project Infrastructure

Project Detail	Value
Proposed conductor arrangements	As received from Umwelt and Social Consultants (02.08.2024).
System Parameters	Solar Project with a power generation and transmission capacity of 265 MW and storage capacity of 100 MW/200 MWh (2 hours storage capacity). Solar panels and hybrid BESS are 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] 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].

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

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

[4] 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.

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

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

4 Basis

This study has been developed on the following basis:

4.1 Electrical network

1. Electrical installation is in line with Australian Standards, in particular: height and configuration of overheard transmission lines.
2. Underground cables are buried at 800 mm below ground level. 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 (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 not been applied to the modelling scenarios.

4.2 Electrical Parameters

5. A reactive compensation factor of 0.395 is used as per the NER Clause s5.2.5.1.
6. The underground reticulation network is a single circuit with a trefoil conductor configuration.
7. It is assumed that the existing infrastructure has been constructed using standard TransGrid tower designs.

4.3 Exclusions

8. 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 facilities, the background magnetic field strength along the majority of the route is expected to be negligible.
9. 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.
10. Low frequency induction (LFI) study on existing metallic pipelines and metallic fenceline running parallel to the proposed 330 kV overhead transmission line is not included in this scope.
11. The underground cable circuitries between the solar panels and dc/ac inverters are direct current (dc). Inherently, these circuitries do not produce alternating magnetic field and are considered low voltage. So, there are excluded in the EMF study.

5 Methodology

5.1 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) [1]. The EMF exposure guidelines from ARPANSA now explicitly refer to ICNIRP [2].

Furthermore, the Energy Networks Association (ENA) EMF Handbook [3] 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 are specified in the ICNIRP General Public Health Physics publication 99(6):818-836 [4].

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 shall be based on Australian electrical network system frequency of 50 Hz. The Pass/Fail criterion for the general public for this study is 2,000 milli Gauss (200 μT).

Figure 3 shows the electric field strength limits at 50 Hz. Only the peak field strength generated by 330 kV transmission line is considered in the safety compliance analysis. The Pass/Fail criterion for the general public will be 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

5.2 Assessed Area

5.2.1 The Project

The assessed locations in this study are detailed in Table 4. All locations are directly underneath the overhead line, or directly above the underground cable(s).

Table 4: Assessment Locations

Assessment Location	Scenario
Ground Level	Person lying on the ground
1 m above ground level	Typical waist height of a person standing on ground level
1.8 m above ground level	Typical head and torso height of a person standing on ground level
4 m above ground level	Typical seating position of a person driving a heavy vehicle (truck, tractor etc.) Applies to 330 kV overhead transmission line only

5.2.2 Cumulative Impact with Existing infrastructure

The potential levels of EMF exposure associated with the existing infrastructure will be identified and evaluated at the cross-over point, taking into account the maximum sag and typical tower specification of single circuit[1] and double circuit[2] 330 kV transmission towers.

The existing sources of EMF in the surroundings of the Project Area have been identified as follows:

- Wattle Creek standalone BESS project
- Marulan Gas Fired Power Station (approved but not constructed)
- Existing 330 kV TransGrid single and double circuit transmission lines
- Existing 330 kV non-TransGrid single circuit transmission lines

[1] TransGrid Single Circuit 330 kV Tower
[2] TransGrid Double Circuit 330 kV Tower

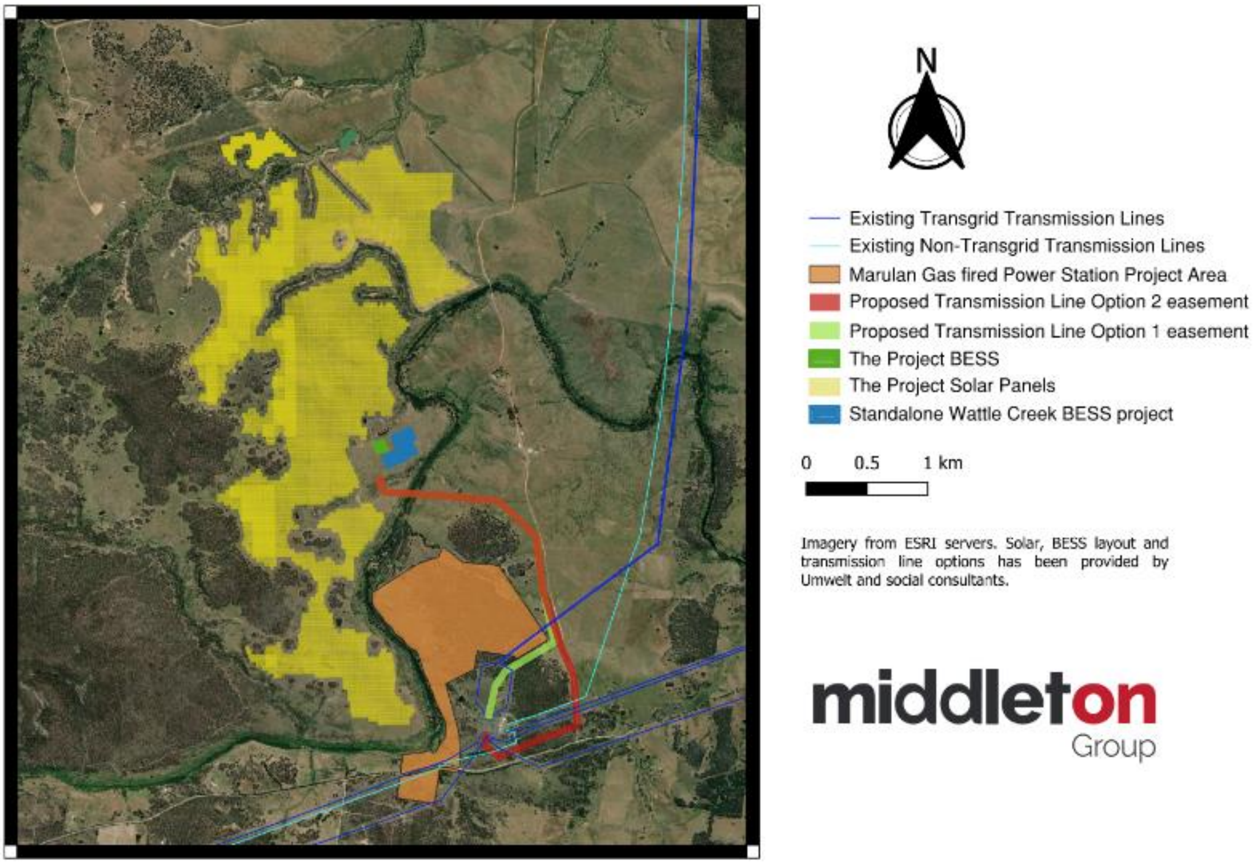


Figure 4: Existing Infrastructures

Assumptions have been made around the existing transmission lines, tower structure and arrangement and current carrying capacity of conductors based on the google maps imagery and typical TransGrid's Transmission Towers standard.

Should the magnetic field (MF) and electric field (EF) strength calculations at the assessment locations listed in Table 4 meet the specified safety exposure MF and EF limit criteria, it can be reasonably assumed that the magnetic and electric field strength at all other areas located further away from the electrical installation will also satisfy the exposure limit criteria. This includes the following:

- Associated residential houses
- Commercial and non-residential buildings
- All public areas such as roads, parks, roadside stops, footpath

This conclusion is supported by modelling results, which aligns with the fundamental theory of electromagnetism, that the electric and magnetic field strength diminishes as the object of observation is moving away from the source. For further details, please refer to Appendix A.

5.3 CDEGS Model

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

5.3.1 Modelled Electrical Installations

The load scenarios, identified as having the potential to generate significant impact on the EMF safety exposure limit of general public and maintenance service crew, are outlined in Table 5.

Table 5: Modelled Scenarios

No.	Conductor Description	Voltage [kV]	Number of circuits	Current in each conductor
1	8 Parallel Sets of 3 x 1 Core Underground 33 kV Cable – Single Circuit	33	8	623 A
2	Overhead 330 kV Transmission Line – Single Circuit	330	1	499 A
Cumulative Impact for the Project and Wattle Creek BESS Project				
3	Overhead 330 kV Transmission Line for both project – Single Circuit	330	1	1157 A

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

- Double circuit 330 kV overhead transmission line.
- Underground single circuit 33 kV cables with less solar panels and batteries connected.

5.3.2 Underground 33 kV Cable Concept Design

The underground 33 kV cable reticulation connects the Project to the 330/33 kV collector substation. These underground cable circuits consist of 8 parallel circuits of three single-core cables, each conductor having a cross-sectional area of 800 mm^2.

As stated in Section 4: Assumption, 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 Φ200 mm HDuPVC conduit (see Appendix C). The separation between two cable circuits is 450 mm, given the high number of conductors, as shown in Figure 5.

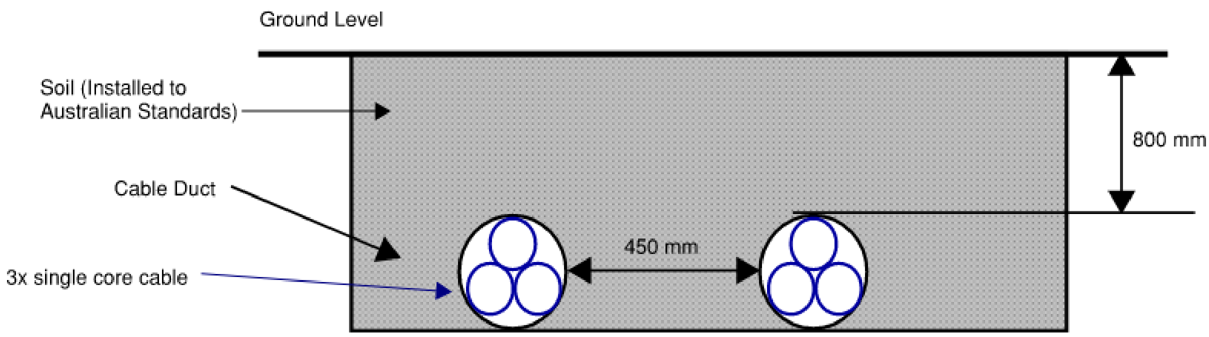


Figure 5: Underground Cable Installation Concept Design

5.3.3 Overhead 330 kV Transmission Line Concept Design

The proposed overhead 330 kV transmission lines will be supported by line poles, vertical flat conductors' arrangement designed to provide optionality for the connection of the Project. These towers have been modelled in accordance with AS 7000 [5].

As per the concept design, each 330 kV line pole will feature three vertically spaced conductors. The conductors are assumed to be Mango 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. This is shown in Figure 6 and Figure 7.

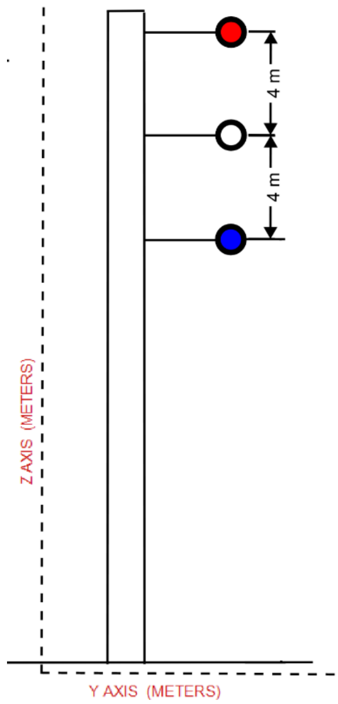


Figure 6: 330 kV Transmission Tower

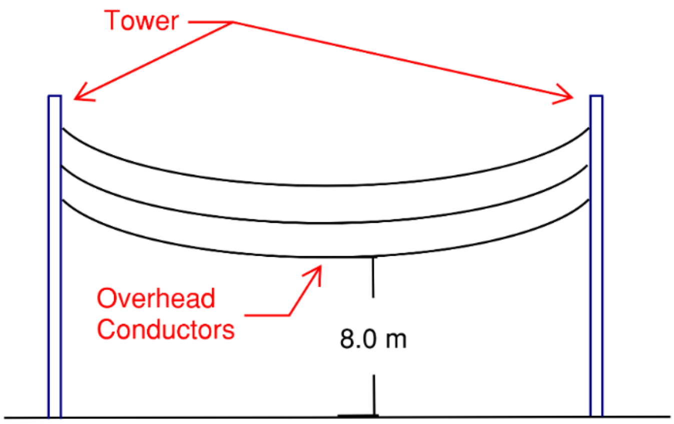


Figure 7: 330 kV Transmission Lines

6 Results

6.1 Magnetic Field

6.1.1 33 kV Underground Cable

The worst-case 33 kV underground cable installation is shown in Figure 5. It comprises of eight circuits of 3 x 800 mm^2 cables laid in single conduit each buried at a depth of 800 mm below ground. Each cable per phase is loaded to 623.1 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 8. The results indicate that at the ground surface level, the EMF values do not exceed 40 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 waist height of 1 metre.

To exceed the 200 µT threshold at ground level, which poses a risk to human health, each cable would need to carry a current exceeding 3115.5 A. This scenario cannot occur. The largest commercially available at this voltage level in the market is only 1,200 mm^2 conductor, which can only accommodate up to 948 A load current when buried below ground in conduit. Consequently, the Proponent will not consider this approach due to impractical application and technical challenges.

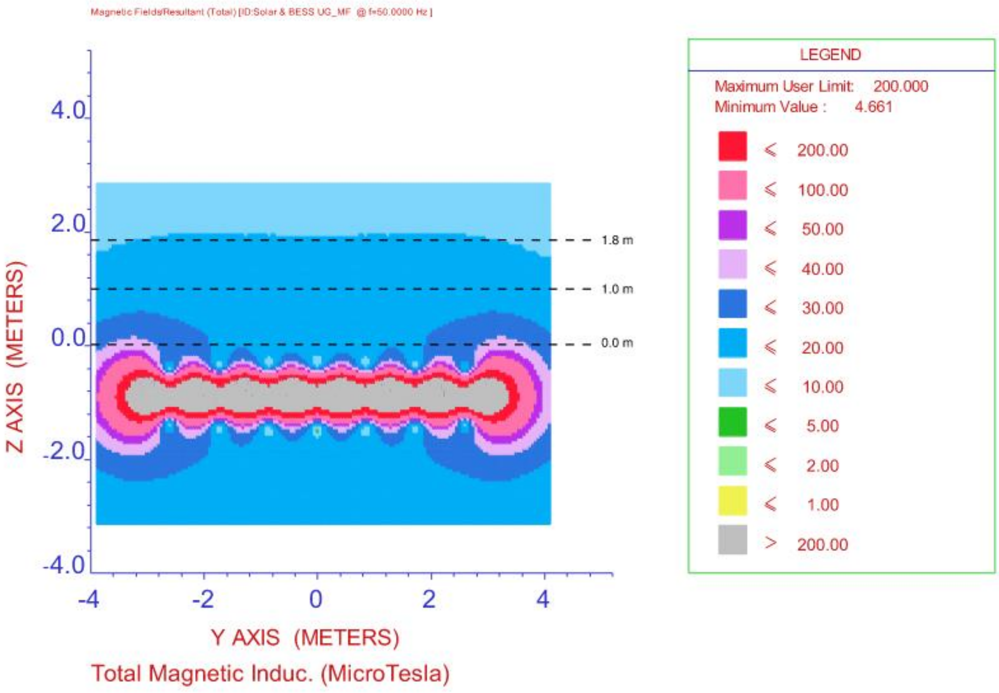


Figure 8: Magnetic Field Strength of 33 kV Underground Cables Carrying 623.1 A

6.1.2 330 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 export capacity of 265 MW. These towers have been modelled in accordance with AS 7000 [5].

The three parallel conductors will carry a maximum of 498.5 A each. At 4 m above ground level the magnetic field strength emitted from the conductors reaches a maximum value of less than 20 μT. Figure 9 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 Figure 2.

To breach the 200 μT limit at four (4) m above ground level, the required current in each conductor must be greater than 4985 A. This is a significant deviation from the intended design. Consequently, the Proponent will not proceed with such an approach.

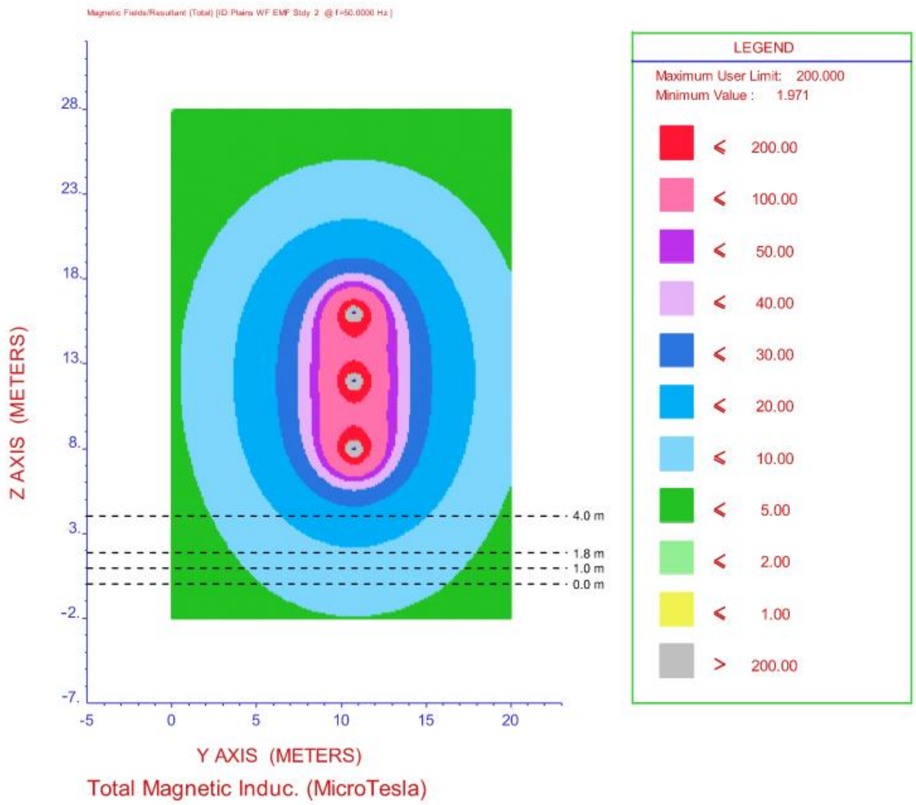


Figure 9: Magnetic Field Strength of 330 kV Overhead Transmission lines carrying 498.5 A

6.1.3 Electric Field

6.1.3.1 330 kV Overhead Transmission Lines

The electric field assessment is completed for the worst-case scenario only, representing the highest voltage scenario where a person is directly underneath the 330 kV overhead transmission line.

Figure 10 shows that at heights of 4 m above ground, the electric field strength is 5.4 kV/m at the midspan, exceeding the public exposure limit of 5 kV/m [3].

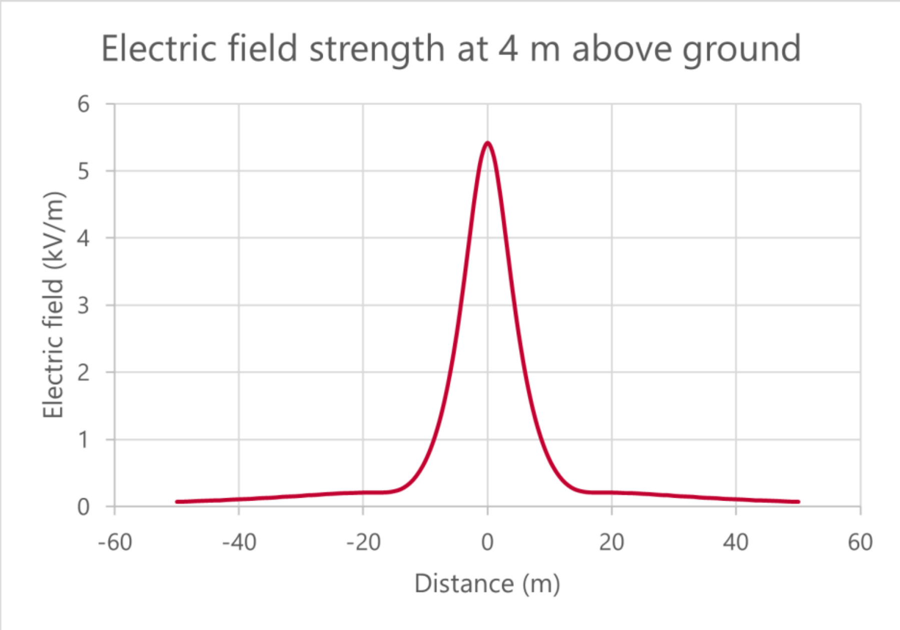


Figure 10: Electric Field strength of 330 kV Overhead Transmission lines with a ground clearance of 8 m

As such, a ground clearance of 8.5 m is recommended. When the overhead transmission line is elevated, the electric field strength at 4 m and 1 m above ground level are 4.7 kV/m and 2.8 kV/m, which are within the safe exposure limit as shown in Figure 11 and Figure 12.

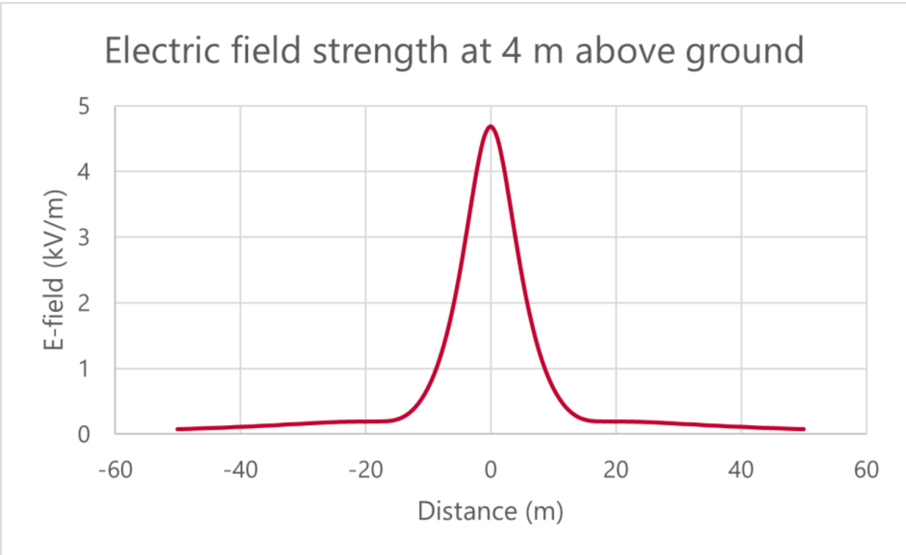


Figure 11: Electric Field strength of 330 kV Overhead Transmission lines with a ground clearance of 8.5 m

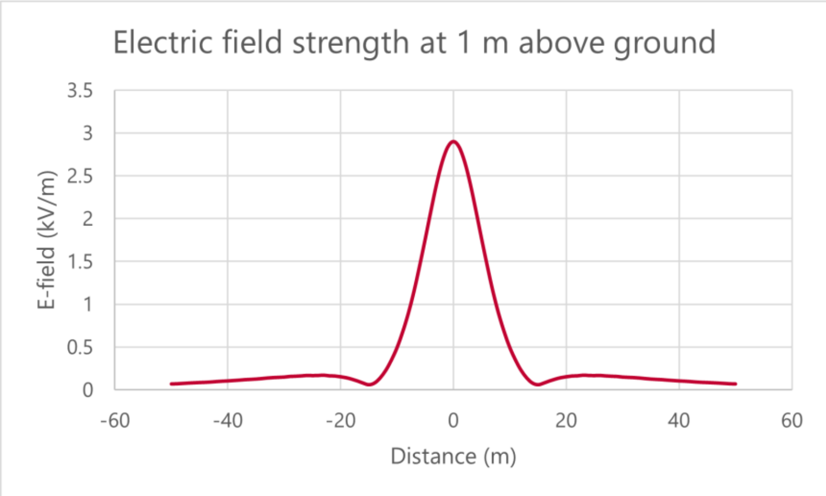


Figure 12: Electric Field strength of 330 kV Overhead Transmission lines with a ground clearance of 8.5 m

7 Cumulative Impact

7.1 Proposed Projects

The cumulative impact of implementing the Project and the Wattle Creek BESS project (SSD-63345458) (subject to separate assessment) on the same transmission overhead line has been evaluated.

7.1.1 Magnetic Field

The three parallel conductors will carry a maximum of 1157 A each. At 4 m above ground level the magnetic field strength emitted from the conductors reaches a maximum value of less than 50 μT. Figure 13 provides the magnetic field strength emitted from the transmission lines 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 Figure 2.

To breach the 200 μT limit at 4 m above ground level, the required current in each conductor must be greater than 4628 A. This is a significant deviation from the intended design. Consequently, the Proponent will not proceed with such an approach.

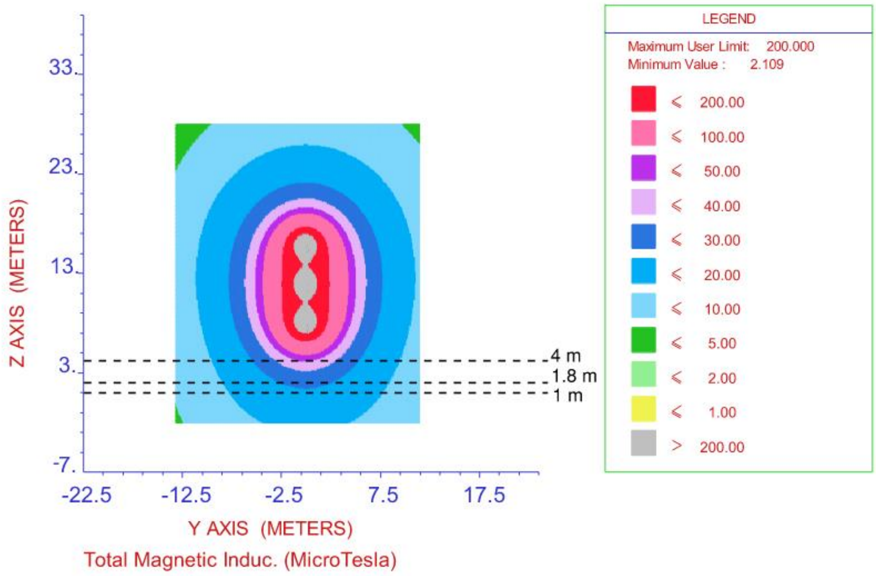


Figure 13: Magnetic Field Strength of 330 kV overhead transmission lines carrying 1157 A

7.1.2 Electric Field

The electric field strength is consistent with the values outlined in Section 6.1.3.1, since the electric field is dependent on voltage.

7.2 Project with Existing Infrastructure

The easement for a 330 kV transmission tower spans 60 meters in width. The Marulan Gas Fired Power Station project area is situated 14 m from the closest edge of the easement for Transmission Line Option 1 and 55 m from the nearest edge of the easement for Transmission Line Option 2.

Transmission Line Option 1 will intersect existing lines at two points, while Option 2 will cross at five. Both options cross both the single circuit and double circuit 330 kV lines.

7.2.1 Single circuit 330 kV

Magnetic field

The current flowing through the TransGrid and non-TransGrid's single circuit 330 kV transmission lines have been assumed to be 1147 A per phase, based on the current carrying capacity of a Mango conductor at a wind speed of 2 m/s.

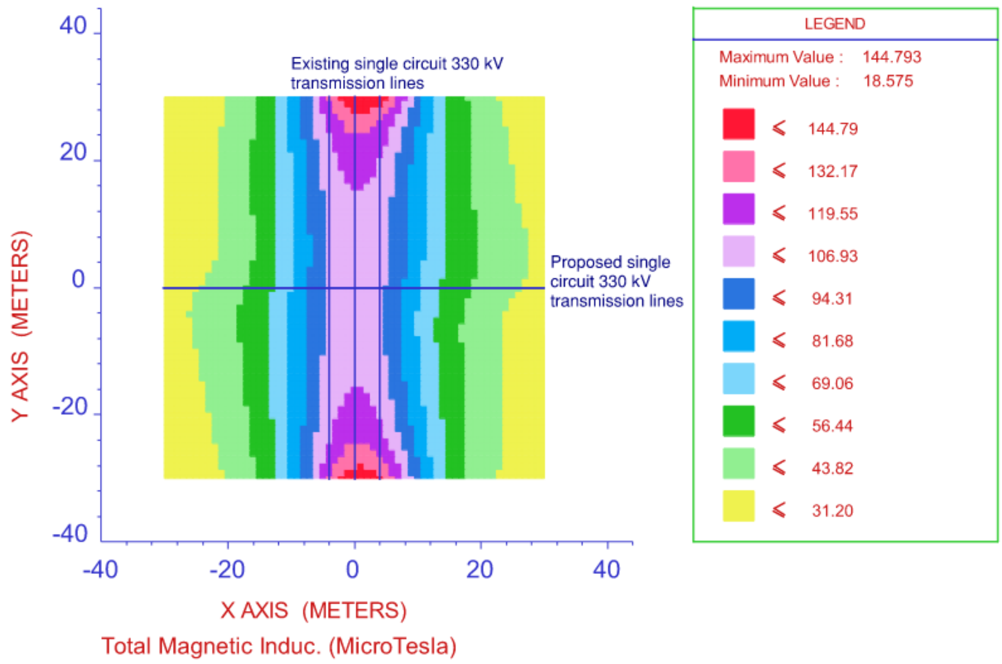


Figure 14: Cumulative Magnetic field strength of existing and proposed 330 kV lines

As shown in Figure 16, there is some cancellation between the 2 transmission lines. However, since a higher current flow through transmission lines tend to influence the field strength, the existing single circuit 330 kV is dominating the magnetic field strength directly under the transmission line. At 1 m above ground, the magnetic field strength reaches a maximum of 145 μT, within the 200 μT safe exposure limit.

Electric field

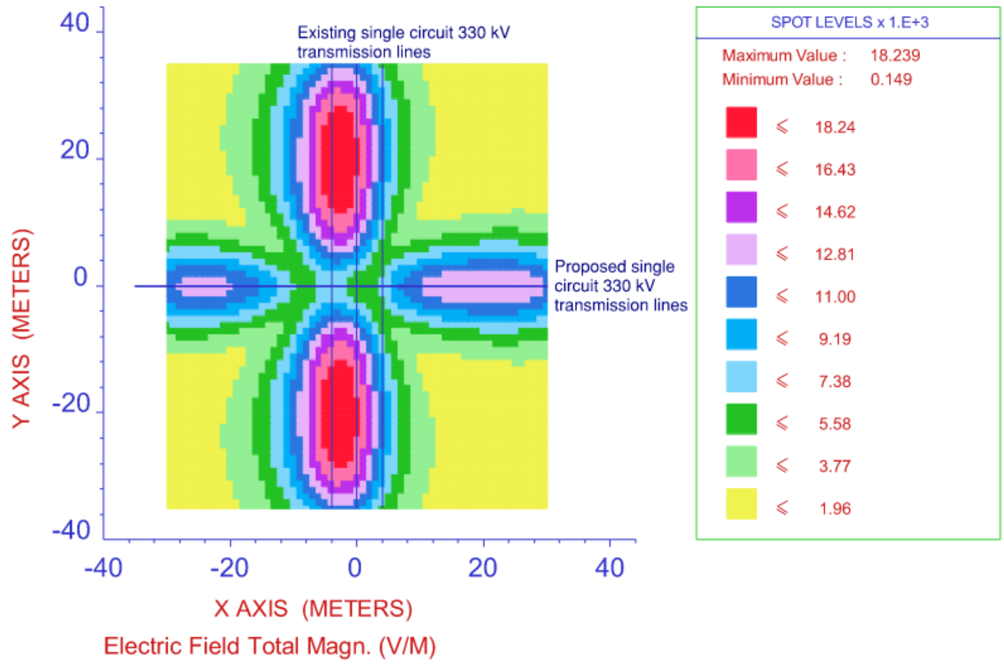


Figure 15: Cumulative Electric field strength of existing and proposed 330 kV lines

Similarly, higher voltage transmission lines generally affect field strength. However, since both lines have the same voltage, the voltage level itself doesn't impact field strength—instead, the tower structure does. Directly underneath the crossover, there is some cancellation due to both transmission lines and the electric field strength reaches a maximum of 7.4 kV/m, above the safe exposure limit for the general public and within the safe exposure limit of 10 kV/m for occupational personnel.

7.2.2 Double circuit 330 kV

The existing double circuit 330 kV transmission lines has been modelled according to TransGrid's specification[2]. The recommended ground clearance of 8.5 m has been considered for the proposed single circuit 330 kV transmission lines.

Magnetic field

The current flowing through TransGrid's double circuit 330 kV transmission lines have been assumed to be 1147 A per phase, based on the current carrying capacity of a Mango conductor at a wind speed of 2 m/s. A transposed phasing has been assumed for the existing double circuit.

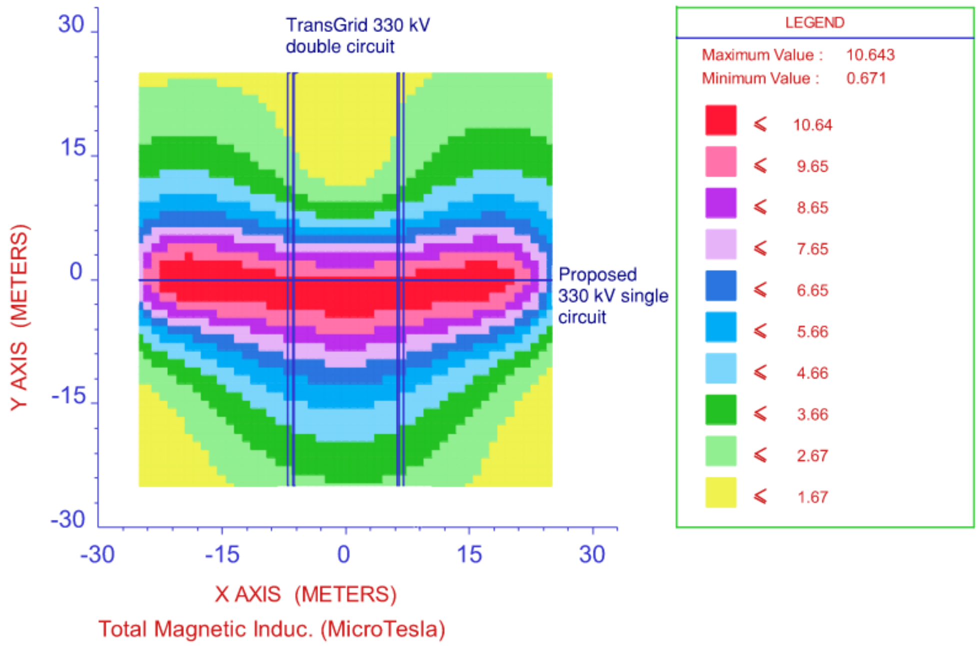


Figure 16: Cumulative Magnetic field strength of existing double circuit and proposed 330 kV lines

As shown in Figure 16, the magnetic field due to the transposed phasing of the double circuit 330 kV is reduced through mutual cancellation. At 1 m above ground, the magnetic field strength reaches a maximum of 10.6 μT, within the 200 μT safe exposure limit.

Electric field

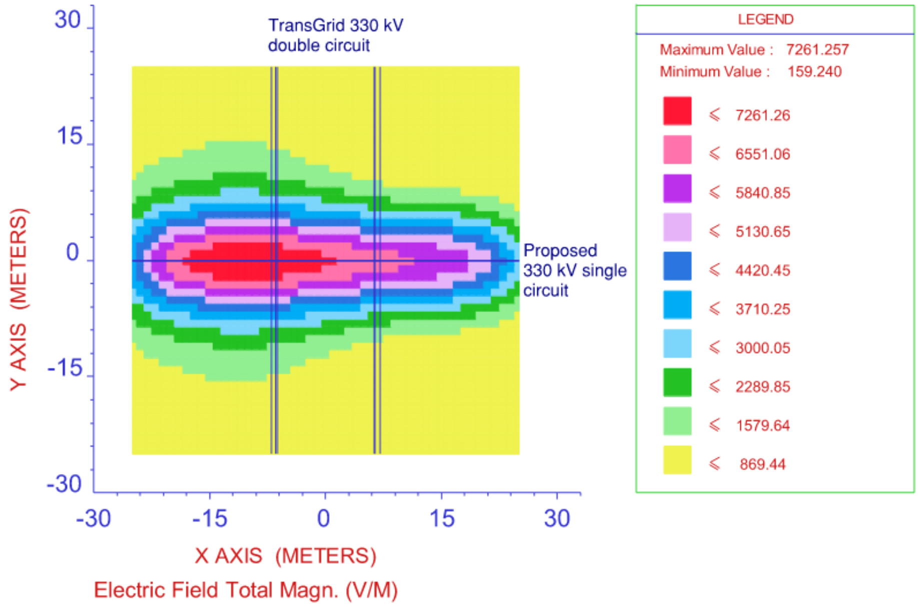


Figure 17: Cumulative Electric field strength of existing double circuit and proposed 330 kV lines

Similarly, the electric field strength is reduced through mutual cancellation due to the transposed phasing of the double circuit. As shown in Figure 17, the electric field reaches a maximum of 7.3 kV/m, exceeding the general public exposure limit of 5 kV/m but within the safe exposure limit of 10 kV/m for occupational personnel.

8 Conclusion

The concept design observations show that for each scenario, the magnetic field strength and electric field strength at the recommended height are within ICNIRP guidelines at locations where personnel do not risk breaching AS 2067 requirements.

8.1 Magnetic Field Assessment

The result of CDEGS-HIFREQ modelling for the Project and the associated cumulative impact indicates that across all scenarios the magnetic field strengths are within the 200 μT safe exposure limit specified in Figure 2. There are no unsafe magnetic field that the general public can be exposed to.

A summary of these results can be found in Table 6.

Table 6: Magnetic Field Strength Results Summary

Installation Method	Observation Location	Field Strength Result (µT)	Pass / Fail
Underground 33 kV Cable	1.8 m above ground (standard height)	<30	PASS
	1 m above ground (lowest height of impact when standing)	<30	PASS
	Ground level (person lying on the ground)	<40	PASS
Overhead 330 kV Transmission Line	4 m above ground (person sitting in heavy vehicle)	<20	PASS
	1.8 m above ground (standing height)	<10	PASS
Cumulative Impact: the Project and Wattle Creek BESS(SSD-63345458)			
Overhead 330 kV Transmission Line	4 m above ground (person sitting in heavy vehicle)	<50	PASS
	1.8 m above ground (standing height)	<30	PASS
Cumulative Impact: Project with approved and existing infrastructure			
Single Circuit Overhead 330 kV Transmission Line	1 m above ground (lowest height of impact when standing)	<145	PASS
Double Circuit Overhead 330 kV Transmission Line	1 m above ground (lowest height of impact when standing)	<10.6	PASS

8.2 Electric Field Assessment

The result of CDEGS-HIFREQ modelling indicates that across all scenarios the electric field strengths at minimum ground clearance due to the 330 kV overhead transmission line conductors are above the 5 kV/m safe exposure limit specified in Figure 3. Hence, a ground clearance of 8.5 m is recommended such that there are no unsafe electric field that the general public can be exposed to.

The electric field strength directly underneath the crossovers is above the safe exposure limit for general public and within the safe exposure limit for occupational personnel.

A summary of results can be found in Table 7.

Table 7: Electric Field Strength Results Summary

Installation Method	Observation Location	Field Strength Result (kV/m)	Pass / Fail
The Project and Cumulative Impact			
Overhead 330 kV Transmission Line	4 m above ground. Ground clearance of 8 m.	<5.4	PASS*
	4 m above ground. Ground clearance of 8.5 m.	<4.7	PASS
	1 m above ground. Ground clearance of 8.5 m.	<2.8	PASS
Cumulative Impact: With existing infrastructure			
Single Circuit Overhead 330 kV Transmission Line	1 m above ground (lowest height of impact when standing)	<7.4	PASS**
Double Circuit Overhead 330 kV Transmission Line	1 m above ground (lowest height of impact when standing)	<7.3	PASS**

Note:

PASS*: The field strength will be within the safe exposure limit at the recommended ground clearance.

PASS**: The field strength is above the safe exposure limit for general public and within the safe exposure limit for occupational personnel.

Human Health Assessment

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

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 applicable even in minor design changes.

It is expected that the proposed conductor arrangements for other underground lines and transmission lines are designed as per AS 7000 to maintain adequate clearances, as well as to mitigate the increased EMF risk due to coexistence of multiple high-voltage transmission lines.

Recommendations

We recommend that during detailed design further analysis is conducted once other parameters are finalised including conductors, structure arrangements and conductor height of proposed and existing infrastructures.

Restricting public access in the crossover area or adjusting the transmission crossover setup to meet established electric field limits must be considered following analysis in detailed design.

Appendix A EMF Theory

Overview

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

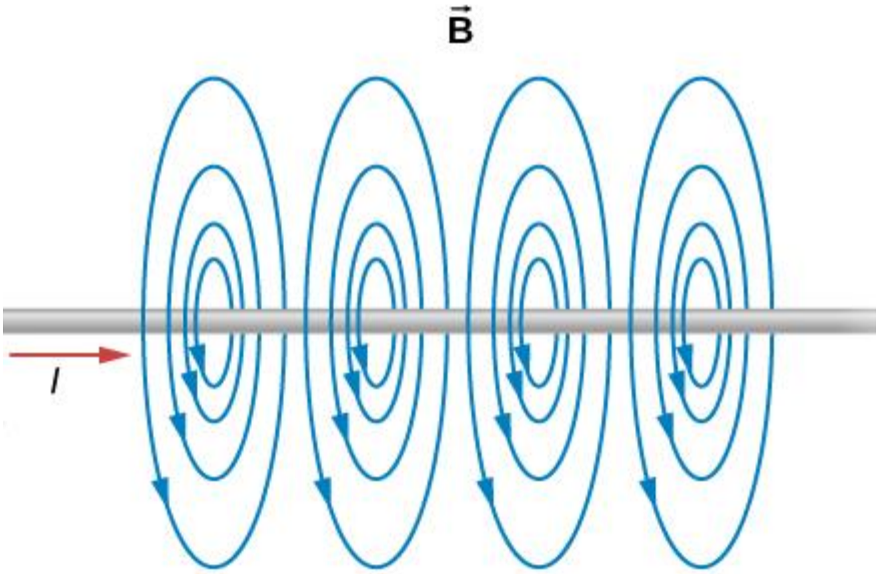


Figure 18: Magnetic Field Around a Conductor

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 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*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.

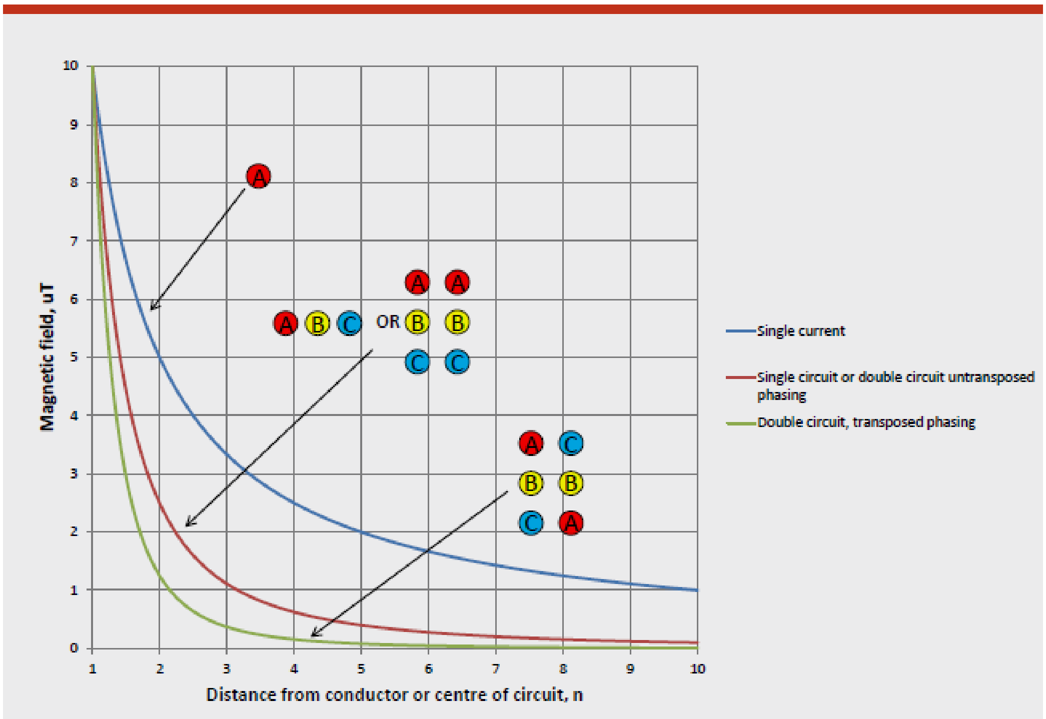
EMF from a three-phase system

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.

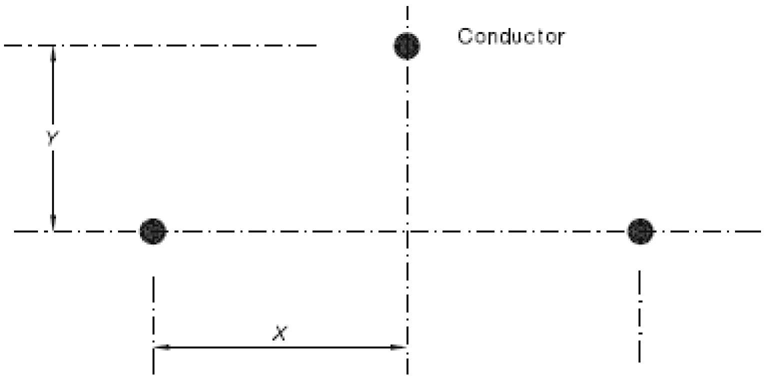


FIGURE 3.5 CONDUCTOR SEPARATION AT MID SPAN (ONE CIRCUIT)

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

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 8 and Table 9 for 330 kV conductors respectively.

Table 8: 330 kV Transmission line conductor vertical 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

Table 9: 330 kV Transmission line conductor horizontal separation calculation

Variable	Value	Unit	Comment
v	0	m	No vertical 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			
X (Horizontal separation)	4	m	
Swinging conductor allowance	2	m	Typical industry value

Appendix C OLEX catalogue

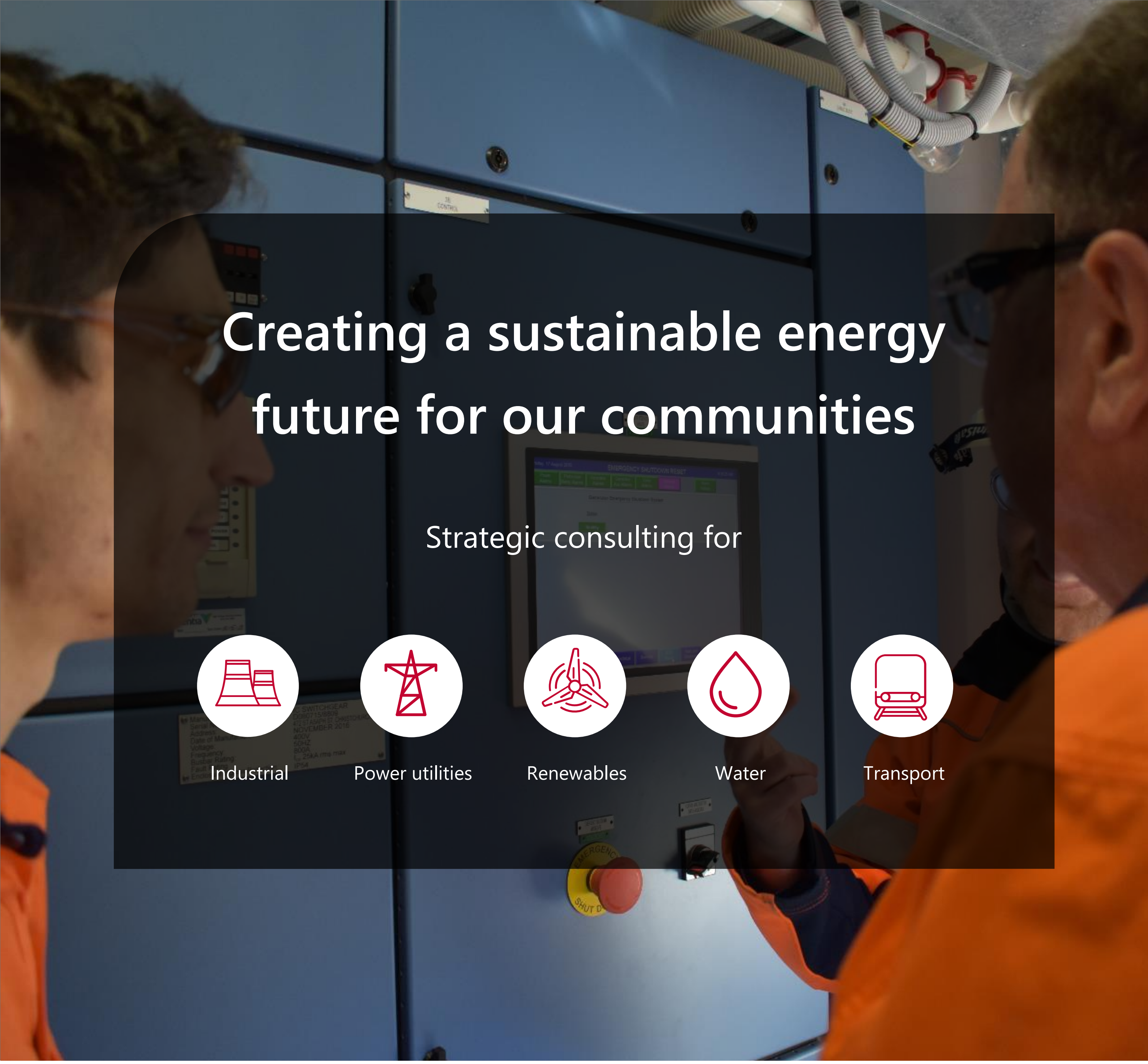
The following is an extract of the Olex-Nexans cable catalogue. The maximum current rating for any 19/33 kV single core cable for the proposed installation is shown in red.

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

It should be noted that a 1200 mm^2 cable is an upper limit, not commonly installed.

Current Ratings

Nominal conductor area	Continuous current-carrying capacity, A												Fault current carrying capacity for 1 second	
	In air					In ground			In underground ducts					
mm^2	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	Scr. kA
50	175	195	165	170	125	160	165	160	145	150	145	135	4.73	4.88
70	215	245	200	215	160	200	200	195	180	180	175	170	6.62	6.79
95	260	290	245	260	190	235	235	230	210	205	210	200	8.99	9.13
120	300	335	280	295	215	265	260	260	240	235	235	230	11.4	10.2
150	335	375	315	335	240	295	290	295	265	260	265	255	14.2	10.2
185	385	425	360	380	270	330	325	330	295	285	295	285	17.5	10.2
240	450	490	425	450	315	380	365	380	335	320	340	330	22.7	10.2
300	510	555	485	515	355	420	405	430	370	355	380	370	28.4	10.2
400	585	630	560	595	425	475	450	490	415	390	430	440	37.8	10.2
500	675	715	650	690	485	535	500	555	465	430	485	495	47.3	10.2
630	765	805	750	795	555	595	545	625	510	465	540	560	59.6	10.2
800	865	900	855	910	625	655	595	700	560	505	605	625	75.7	10.2
1000	1000	1010	1010	1070	735	735	650	800	620	550	685	730	94.6	10.2
1200	1090	1090	1110	1190	805	790	685	875	640	565	710	795	114	10.2



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