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Dinawan Wind Farm

EMF / Human Health Assessment

Client: **EMM Consulting**
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FINAL

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
0	10.05.24	Added double circuit 330 kV transmission line circuit – Final issue	Ramez Barakat	Elpidio Jayagan	Alex Low
1	14.02.25	Layout change	Heshna Uppadoo	Eric Bendtsen	Craig Johnston
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4	14.05.25	Missing Figure	Heshna Uppadoo	Craig Johnston	Craig Johnston

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Executive Summary

Middleton Group Engineering has been engaged by EMM Consulting to undertake an Electric and Magnetic Field (EMF) desktop study for the Dinawan Wind Farm (the Project).

The project would include the installation, operation, maintenance and decommissioning of up to approximately 200 wind turbine generators (WTGs) and associated infrastructure. The proposed electrical power infrastructure will emit EMF from the 33 kV and 330 kV transmission networks.

The study has been carried out to address the Hazards and Risks element of the NSW Planning Secretary's Environmental Assessment Requirements (SEARs) for the Project. The EMF assessment presented as part of the environmental impact statement (EIS) has been updated to consider the amendments to the project layout.

EMF limits for this study are taken from the International Commission on Non-Ionising Radiation Protection (ICNIRP). The limit of electric field strength and magnetic field strength to protect human health as determined by the ICNIRP are 5 kV/m and 200 μT, respectively.

Industry standard EMF modelling software CDEGS was used to predict the electric and magnetic fields associated with the proposed electrical infrastructure required for the project. The conductors were modelled on the following basis:

- Assumed conductor arrangements in accordance with industry practice and AS/NZS 7000.
- Voltage and current magnitude, derived from the power ratings proposed for the project.

A summary of the predicted maximum field strength levels is provided in Table 1 and Table 2 below for magnetic fields and electric fields, respectively.

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

The calculated electric field strength for the 330 kV double circuit overhead line is below the threshold. The electric field strength for the 330 kV single circuit overhead line is above the ICNIRP reference level, however, it is within TransGrid's commissioned modelling limits, based on a dosimetric analyses[1] of the internal fields [1].

The findings of this study indicate that the risk to human health due to emitted EMF are within safe exposure limits, noting that TransGrid's commissioned model for electric field exposure limits have been applied.

The actual conductor arrangements are likely to differ from the proposed modelled scenario because detailed design has not yet been undertaken.

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[1] Dosimetric analyses involves the measurement, calculation and assessment of the amount and distribution of electric field absorbed by an object, usually the human body.

Table 1 Electric and Magnetic Field Strength Results Summary

Installation Method	Observation Location	Field Strength Result (µT)	Field Strength Result (kV/m)	[2]Pass / Fail
Underground 33 kV Cable (at 800 mm depth)	1 m above ground	<10	-	PASS
Overhead 33 kV Power Line – Single Circuit (at 6.7 m height)	1 m above ground	<10	-	PASS
Overhead 330 kV Transmission Line – Single Circuit (at 8 m height)	1 m above ground	<31	<7.4	PASS*
Overhead 330 kV Transmission Line – Double Circuit (at 8 m height)	1 m above ground	<20	<3.9	PASS

*Passes TransGrid's limit but exceeds ICNIRP Guidelines for Public Exposure

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

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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 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.

Purpose

The purpose of this report is to estimate the electric and magnetic fields (EMF) generated by electrical 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".

The EMF assessment presented as part of the EIS has been updated to consider the amendments to the project layout.

1.1 Scope

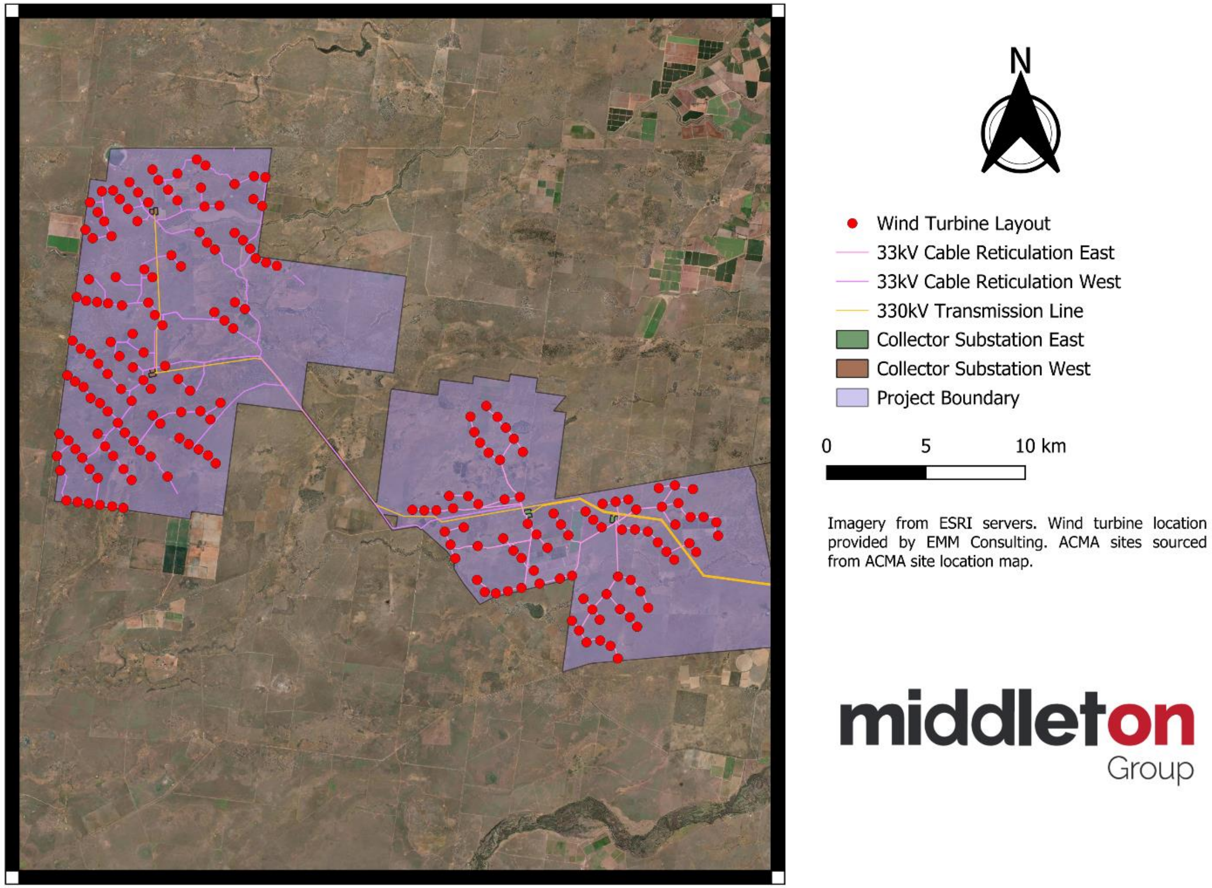
The scope of this study includes:

- Identification and modelling of sources of EMF such as underground cables and overhead line conductors to be constructed as part of the Dinawan Wind Farm.
- Calculation of the levels of EMF that the general public will be exposed to, and then assess the exposure risk those 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 and double 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.



Imagery from ESRI servers. Wind turbine location provided by EMM Consulting. ACMA sites sourced from ACMA site location map.

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 (18.11.24).
WTG Parameters	• Power 7.2 MW with power factor of 0.9. This equates to 8.0 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	Electric and Magnetic fields
ICNIRP	International Commission on Non-Ionising Radiation Protection
kV	kiloVolt
Magnetic Flux Density / Magnetic Field Strength	Terms used interchangeably to describe magnetic field magnitude
MW	Megawatt
Tesla	A measure of magnetic flux density. One Tesla = Newton / (Amp * metre).

3 References

[1] Beca Pty Ltd, “Project EnergyConnect Electric and Magnetic Field Study,” NSW, 202.

[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, *Overhead line design (AS 7000),* SAI Global., 2016.

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

4 Methodology

4.1 Assumptions

This study has been developed on the following basis:

1. Overhead lines will be in accordance with Australian Standard AS7000
2. Underground cables are buried at 800 mm. This is a typical minimum depth.
3. All other equipment (transformers, switchgear etc.) meets Australian and International Standards for electromagnetic compatibility and therefore does not meaningfully contribute to EMF risk.

4.2 Exclusions

1. Background EMF strengths on site are negligible because the site is remote. Background measurements have not been considered on this basis.
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. The existing 132 kV transmission line that runs between the eastern and western wind areas has not been modelled. 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.

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.

TransGrid adheres to ICNIRP guidelines and aims to maintain the general public reference level of 5 kV/m for electric fields where feasible. However, while 220 kV transmission lines typically comply without additional assessment, lines with voltage of 330 kV and above can exceed this limit in certain areas, requiring further evaluation. Consequently, for previous projects, TransGrid has commissioned a dosimetric analysis to evaluate compliance with safety standards for higher voltage overhead lines. This analysis utilized an anatomically accurate human body model positioned beneath the transmission line at midspan, where exposure to electric fields is at its highest. The assessment focused on internal electric fields, particularly within the central nerve stimulation tissue of the head, which has the most restrictive limit of 0.02 V/m. To ensure compliance with ICNIRP basic restrictions, the analysis determined that the external electric field should not exceed 9.1kV/m at a height of 1 m above the ground.

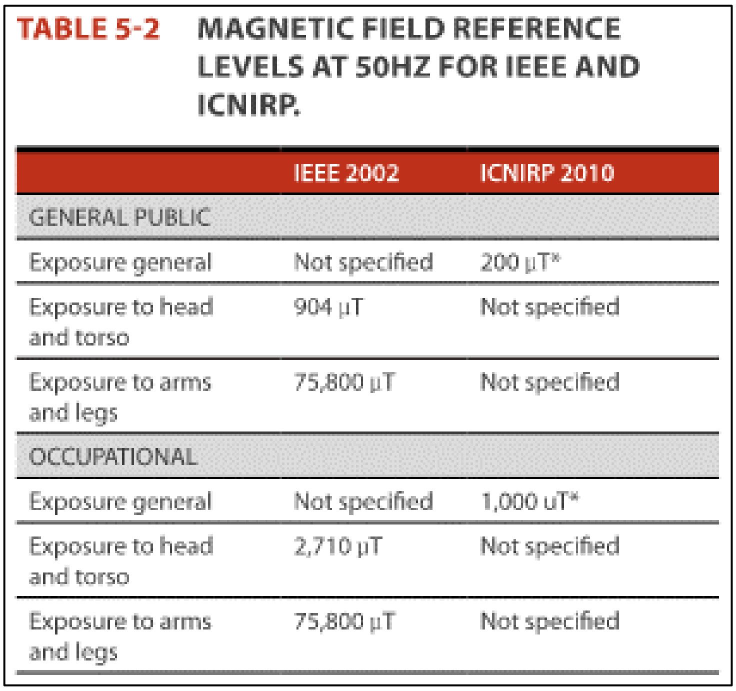


TABLE 5-2 **MAGNETIC FIELD REFERENCE LEVELS AT 50HZ FOR IEEE AND ICNIRP.**

	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

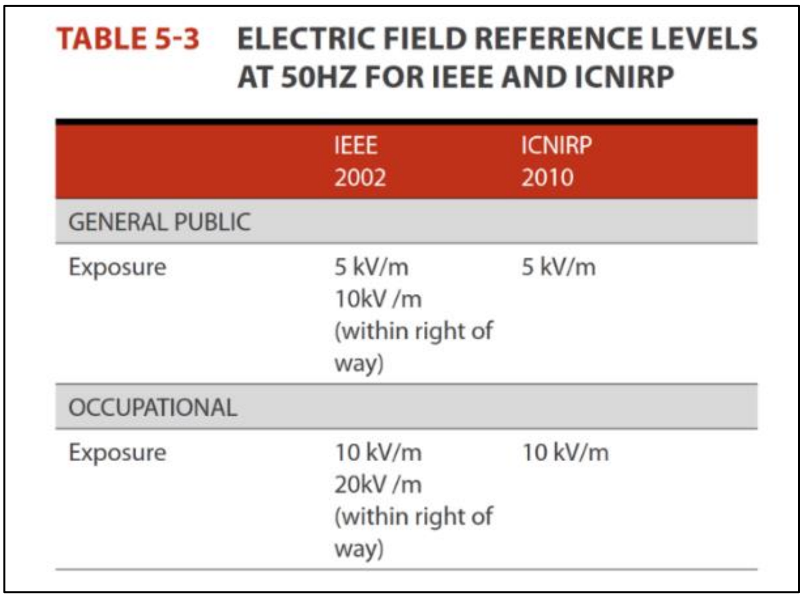


TABLE 5-3 **ELECTRIC FIELD REFERENCE LEVELS AT 50HZ FOR IEEE AND ICNIRP**

	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 ICNIRP reference levels are defined at 1 m above ground, considering the cumulative impact on the head, body, arms, and legs of a person standing on the ground. These levels are evaluated directly beneath the overhead line or directly above the underground cable.

Should the magnetic field and electric field strength calculations at 1 m above ground 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 3: Modelled Scenarios

No.	Conductor Description	Voltage	Maximum WTGs Connected	Current in each conductor
1	3 x 1 Core Underground 33 kV Cable – Double Circuit	33 kV	6	420 A
2	Overhead 33 kV Power Line – Single Circuit	33 kV	6	840 A
3	Overhead 330 kV Transmission Line – Single Circuit	330 kV	59*	826 A
4	Overhead 330 kV Transmission Line – Double Circuit	330 kV	118 59* per circuit	826 A

* This study considers the worst-case scenario only, where a maximum of 59 WTGs is connected per circuit.

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 double-circuit 33 kV cables with less than 6 WTGs connected.
- Single Circuit 330 kV overhead transmission line with less than 59 WTGs connected.
- Double Circuit 330 kV overhead transmission line with less than 59 WTGs connected per circuit.

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 per circuit. These underground cable circuits consist of two parallel circuits of three single-core cables, each conductor having a cross-sectional area of 630 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 Φ200 mm PVC conduit (see Appendix C). The separation between two cable circuits is typically 300 mm, as shown in Figure 4.

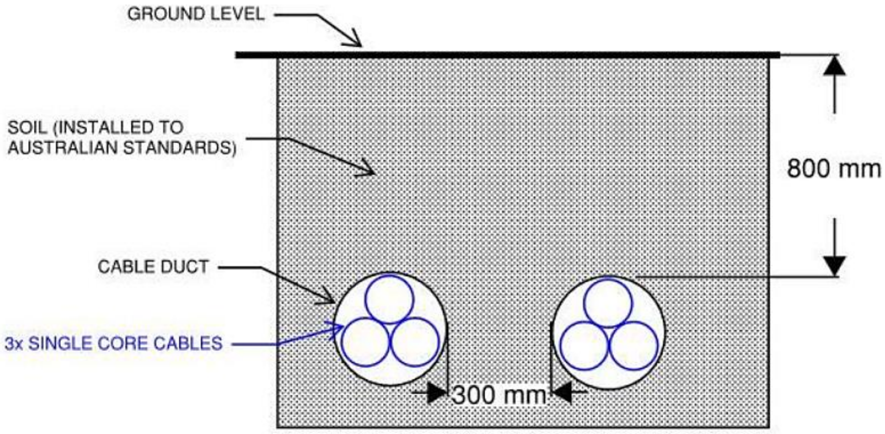


Figure 4: Underground Cable Installation Concept Design

4.5.3 Overhead 33 kV Power Line Concept Design

The proposed overhead 33 kV power line will be supported by line poles with a vertical conductor arrangement, designed to accommodate a maximum of 6 WTGs connected in series. These poles have been modelled per the minimum requirements of AS 7000 [6] which is considered a conservative approach.

In the concept design, each 33 kV line pole will feature three 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.

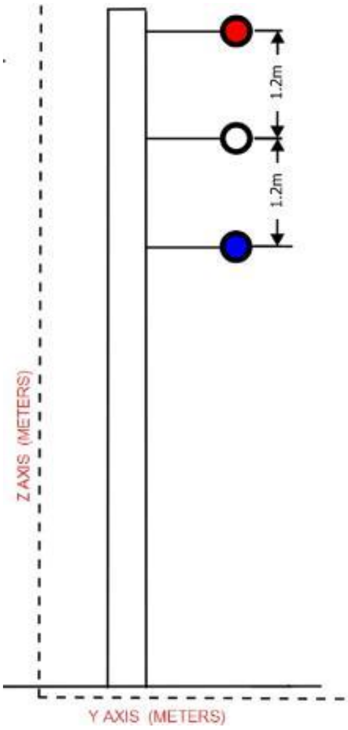


Figure 5: 33 kV Line Pole "Typical" Configuration

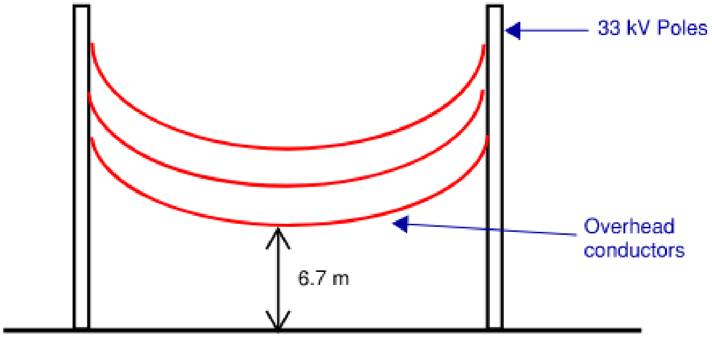


Figure 6: 33 kV Power Lines

4.5.4 Overhead 330 kV Transmission Line Concept Design

The proposed overhead single circuit 330 kV transmission line will be supported by steel towers with a horizontal conductor arrangement comprised of twin ACSR/GZ Mango conductors on suspension insulators, with a bundle spacing of 380 mm, designed to accommodate a maximum of 59 WTGs.

The horizontal separation between each phase conductor would be 10.7 m, and the conductors would be strung such that the lowest sag at the midspan on any sections of the line would be at least 8 m as specified in Table 3.5 of AS/NSZ 7000:2016. Refer to Figure 7(a) and Figure 8(a) below for the assumed 330 kV single circuit overhead line configuration.

The proposed overhead double circuit 330 kV transmission line will be supported by steel towers, vertical conductor arrangement, with each circuit designed to accommodate a maximum of 59 WTGs connected in series. These towers have been modelled in accordance with the minimum requirements of AS 7000 [6] which is considered a conservative approach.

The horizontal separation distance between the circuits is 14 m featuring three vertically spaced conductors. The separation distance between each conductor will be 7 m, and the conductors will be strung such that the lowest sag at the midspan on any sections of the line would be at least 8 m as specified in Table 3.5 of AS/NSZ 7000:2016. Refer to Figure 7(b) and Figure 8(b) below for the assumed 330 kV double circuit overhead line configuration.

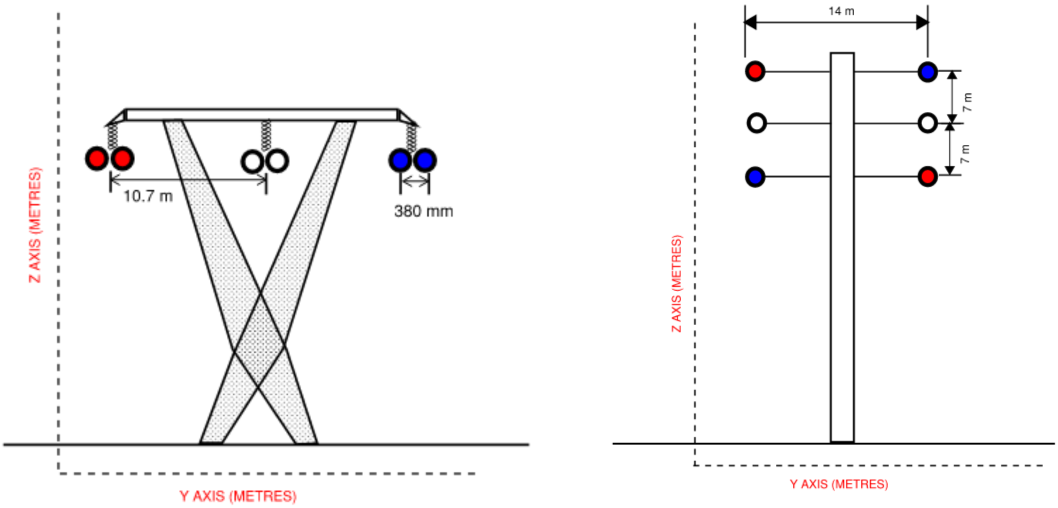


Figure 7: 330 kV (a) Single Circuit Transmission Tower (b) Double Circuit Transmission Tower

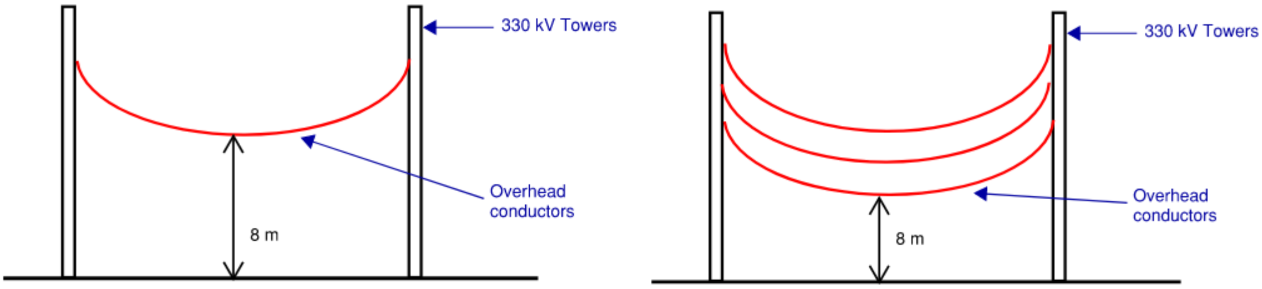


Figure 8: 330 kV (a) Single Circuit Transmission Tower (b) Double Circuit Transmission Tower

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 circuits of 3 x 630 mm^2 cables laid in single conduit each buried at a depth of 800 mm below ground. Each cable is loaded to 420 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 40 μT. Hence, there are no unsafe EMFs 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.

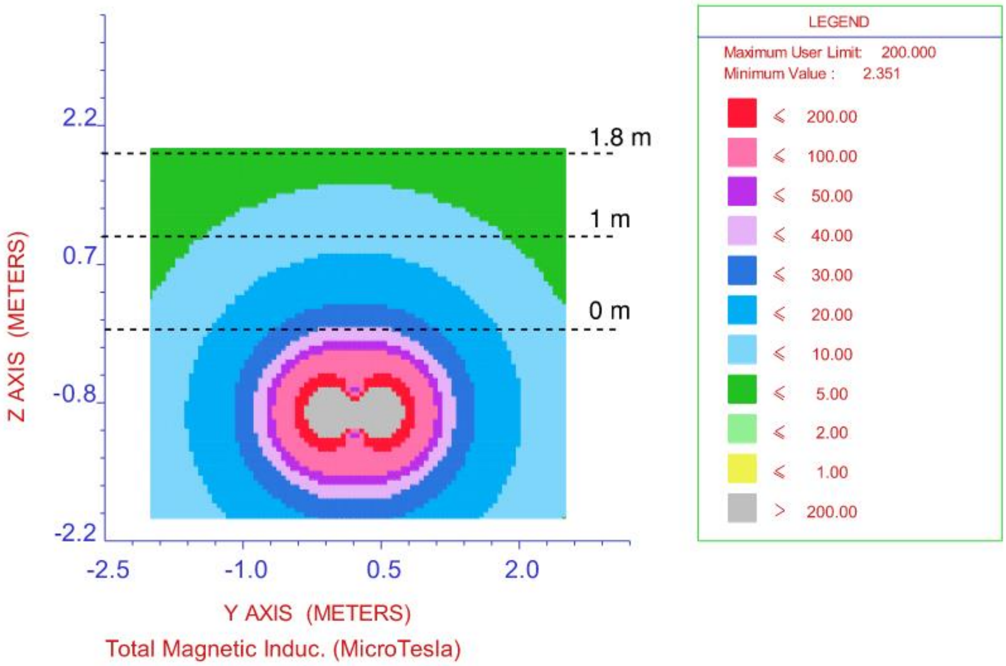


Figure 9 Magnetic Field Strength of 33 kV Underground Cables Carrying 420 A

5.2 33 kV Overhead Power Lines

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 above ground due to the overhead line conductors is within the 200 μT safe exposure limit specified in Section 4.3, Figure 2.

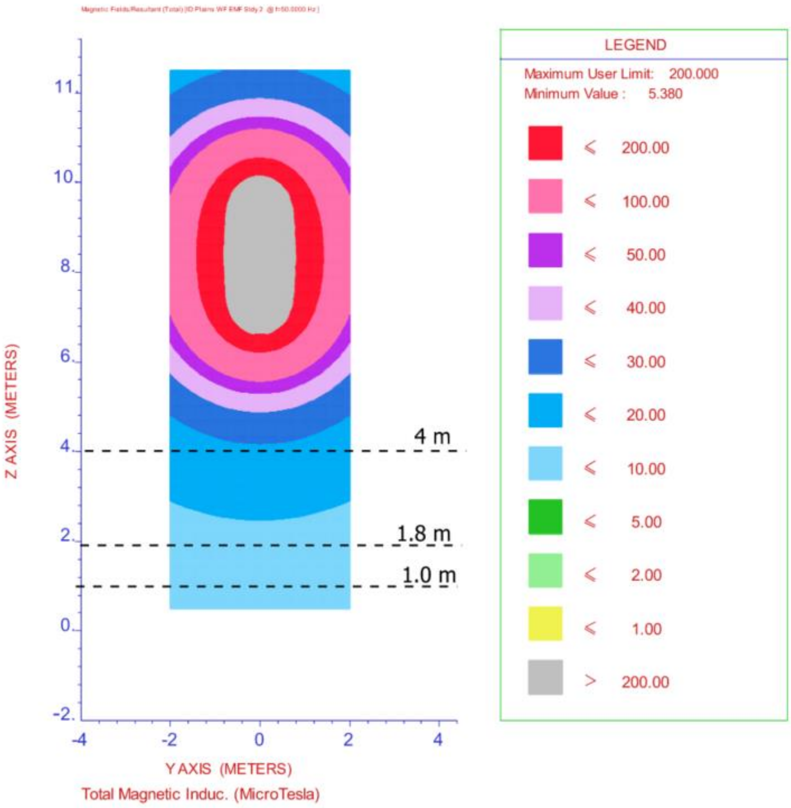


Figure 10 Magnetic Field Strength of 33 kV Overhead Power Lines Carrying 840 A

5.3 330 kV Overhead Transmission Lines

5.3.1 Single Circuit

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 above ground due to the overhead line conductors is 31 μT, within the 200 μT safe exposure limit specified in Section 4.3, Figure 2.

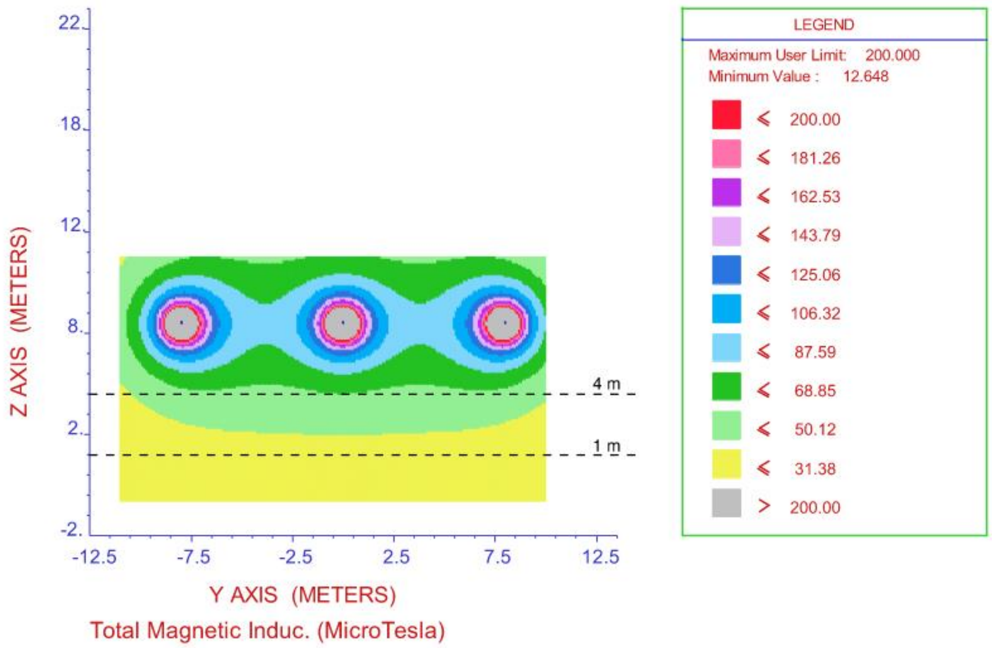


Figure 11: Magnetic Field Strength of 330 kV Overhead Transmission Lines Carrying 826 A

5.3.2 Double Circuit

Figure 12 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 above ground due to the overhead line conductors is 20 µT, within the 200 µT safe exposure limit specified in Section 4.3, Figure 2.

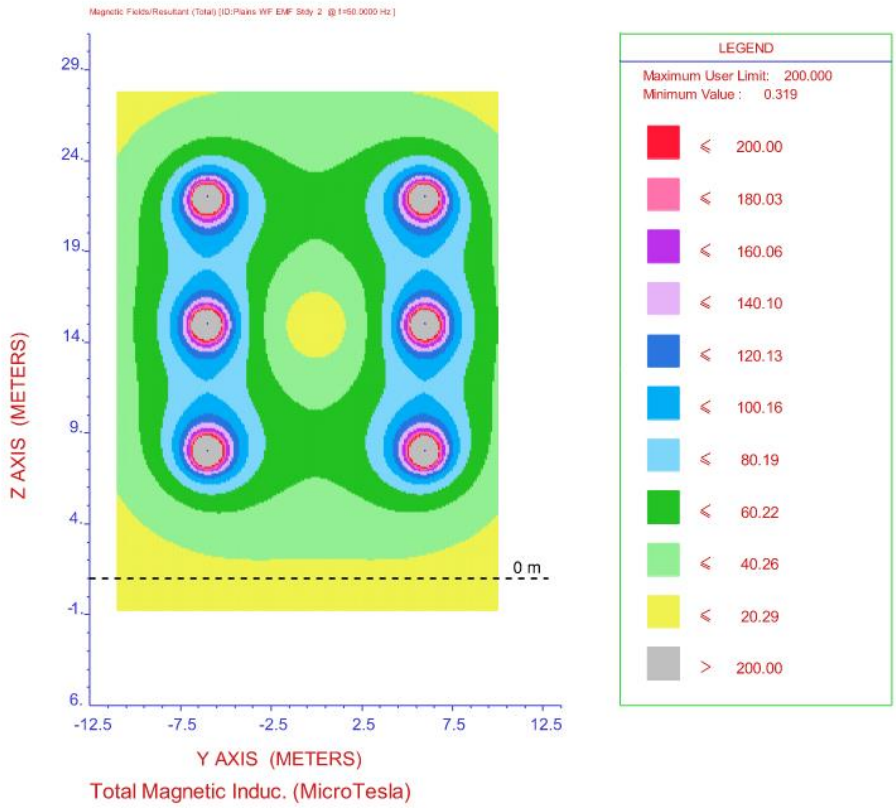


Figure 12: Magnetic Field Strength of 330 kV Overhead Double Transmission Lines Carrying 1652 A

5.4 Electric Field

5.4.1 33 kV Underground Cable

The electric fields in an underground cable are contained within the metallic cable screen and no external fields exists. Hence, a study is not necessary.

5.4.2 33 kV Overhead Power Line

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

5.4.3 330 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 the 330 kV single or double overhead transmission line.

Figure 13 shows the electric field strength of the single circuit at 1 m above ground. The results show that directly below the transmission line, the electric field strength is 7.4 kV/m, above the ICNIRP permissible limit, for public exposure. However, this is within TransGrid's permissible limits.

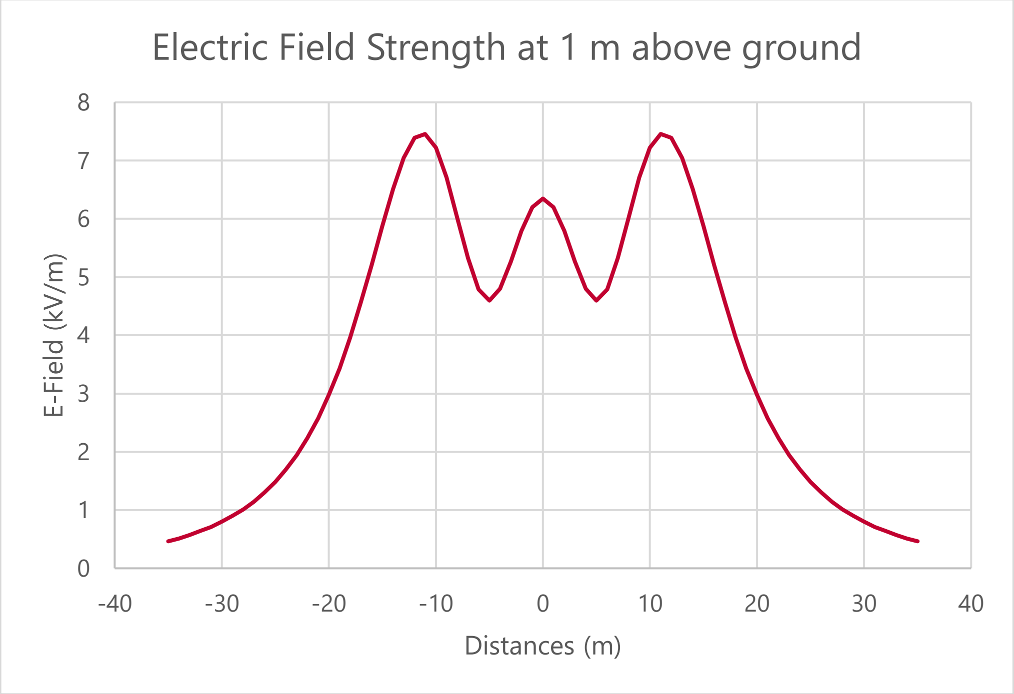


Figure 13: Electric Field Strength of 330 kV Single Circuit Overhead Transmission Line

Figure 14 shows the electric field strength of the double circuit at 1 m above ground. The results show that directly below the transmission line, the electric field strength is 3.9 kV/m, within the 5 kV/m permissible limit. Due to the transposed phasing in the double circuit, the electric fields mutually cancel out. Hence, the results are within the ICNIRP reference levels.

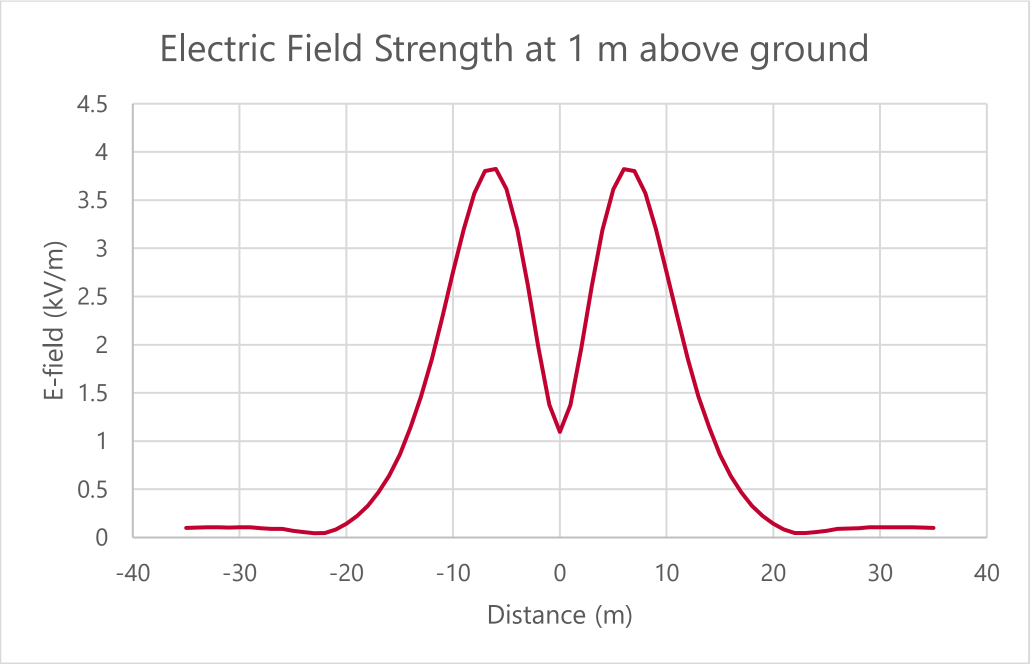


Figure 14: Electric Field Strength of 330 kV Double Circuit Overhead Transmission Line

6 Conclusion

Industry standard EMF modelling software CDEGS was used to predict the electric and magnetic fields associated with the proposed electrical infrastructure required for the project. EMF limits for this study are taken from the *International Commission on Non-Ionising Radiation Protection* (ICNIRP) and TransGrid's electric field limits based on the dosimetric analysis. The limit of electric field strength and magnetic field strength to protect human health as determined by the ICNIRP are 5kV/m and 200 μT respectively and TransGrid's is 9.1 kV/m. This EMF study aligns with the EIS assessment criteria.

6.1.1 Magnetic Field Assessment

The result of CDEGS-HIFREQ modelling indicates that across all scenarios the magnetic field strengths 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 overhead conductors radiate 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 4.

Table 4 Magnetic Field Strength Results Summary

Installation Method	Observation Location	Field Strength Result (μT)	Pass / Fail
Underground 33 kV Cable	1 m above ground	<10	PASS
Overhead 33 kV Power Line – Single Circuit	1 m above ground	<10	PASS
Overhead 330 kV Transmission Line – Single Circuit	1 m above ground	<31	PASS
Overhead 330 kV Transmission Line – Double Circuit (at 8m Height)	1 m above ground	<20	PASS

6.1.2 Electric Field Assessment

The result of CDEGS-HIFREQ modelling indicates that the electric field strengths at 1 m for the 330 kV single circuit are above the 5kV/m exposure limit for public exposure specified in Section 4.3, Figure 3. However, TransGrid considers this an acceptable level, based on their more precise dosimetric analysis method.

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

The 8 m minimum ground clearance must be maintained in order to remain within the safe electric field strength limits under the single circuit and double circuit 330 kV transmission lines. 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 5.

Table 5 Electric Field Strength Results Summary

Installation Method/	Observation Location	Field Strength Result (kV/m)	Pass / Fail[3]
Overhead 330 kV Transmission Line – Single Circuit	1 m above ground	<7.4	PASS*
Overhead 330 kV Transmission Line – Double Circuit	1 m above ground	<3.9	PASS

*Passes TransGrid's limit but not ICNIRP limit for Public Exposure

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 ICNIRP guidelines for general and occupational exposure for the magnetic while the electric field strengths comply with TransGrid's limits derived from dosimetric methods.

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.

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[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.

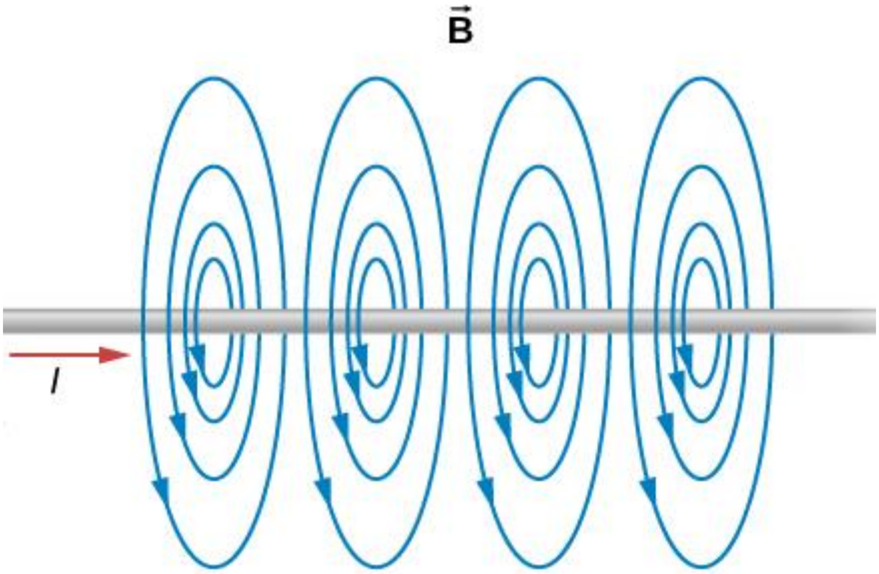


Figure 15 Magnetic Field Around a Conductor

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.

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

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.

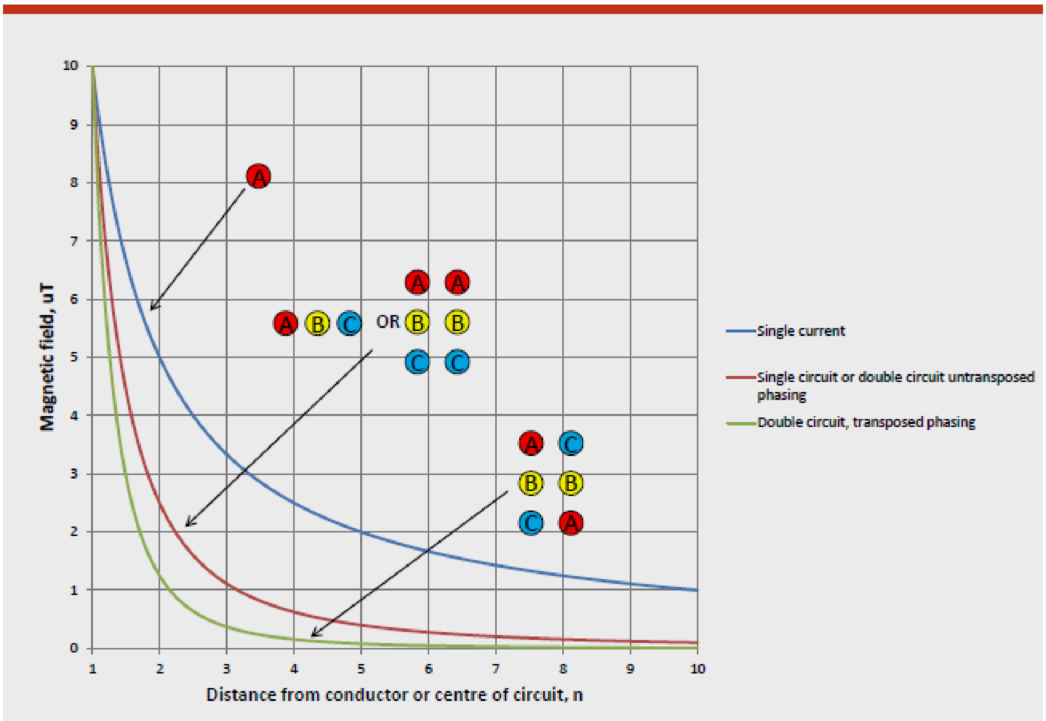
EMF from a three-phase system

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.

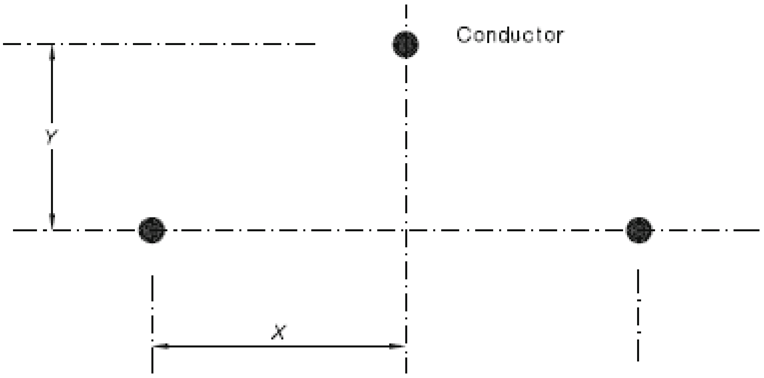


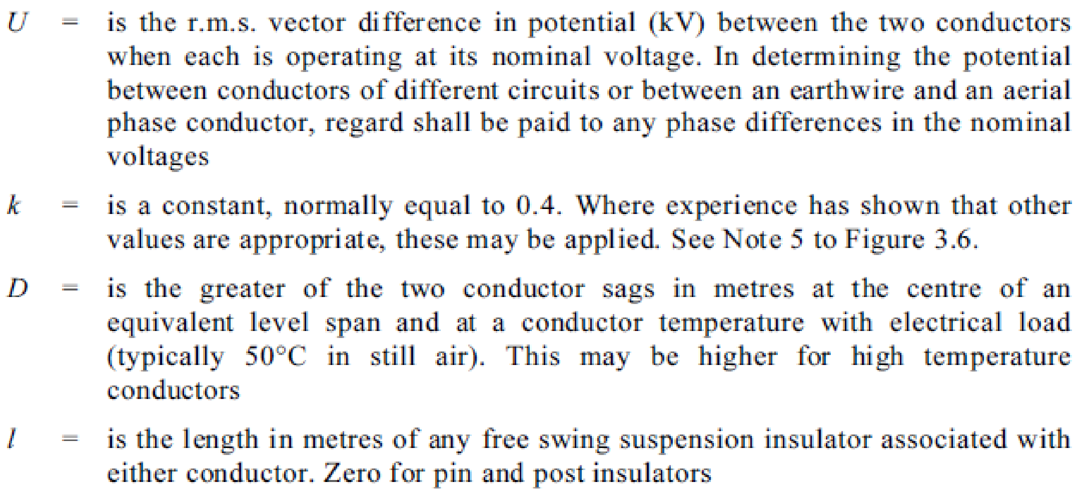
FIGURE 3.5 CONDUCTOR SEPARATION AT MID SPAN (ONE CIRCUIT)

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

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 6 and Table 8 for 33 kV and 330 kV conductors respectively.

Table 6 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 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)	1.3930	m	
Swinging conductor allowance	2	m	Typical industry value

Table 8 330 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

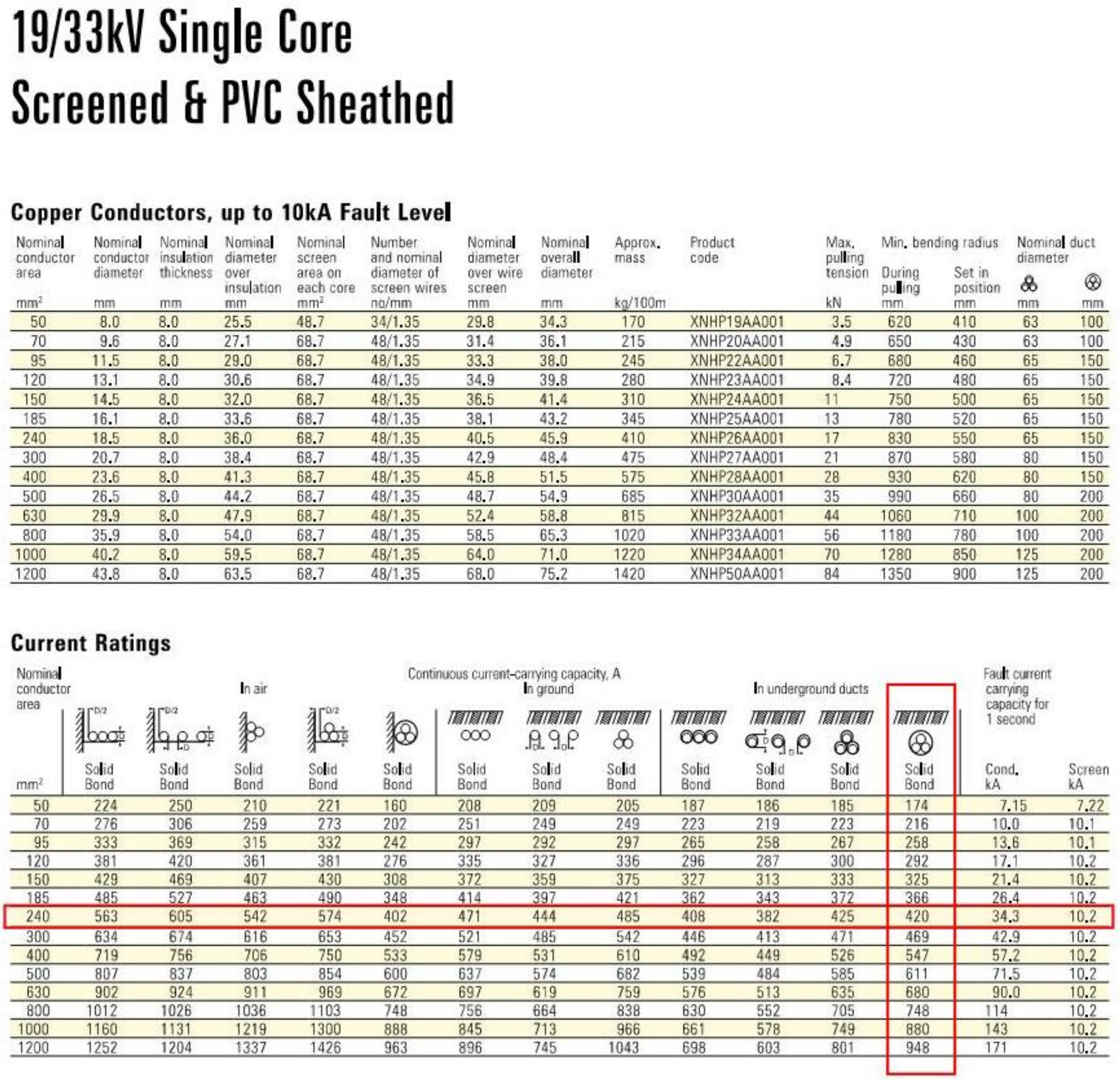
Variable	Value	Unit	Comment
D	4	m	Typical industry value
li	2.4	m	Typical industry value
Results			
Y (Vertical separation)	4.02	m	
Swinging conductor allowance	2	m	Typical industry value

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, 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.



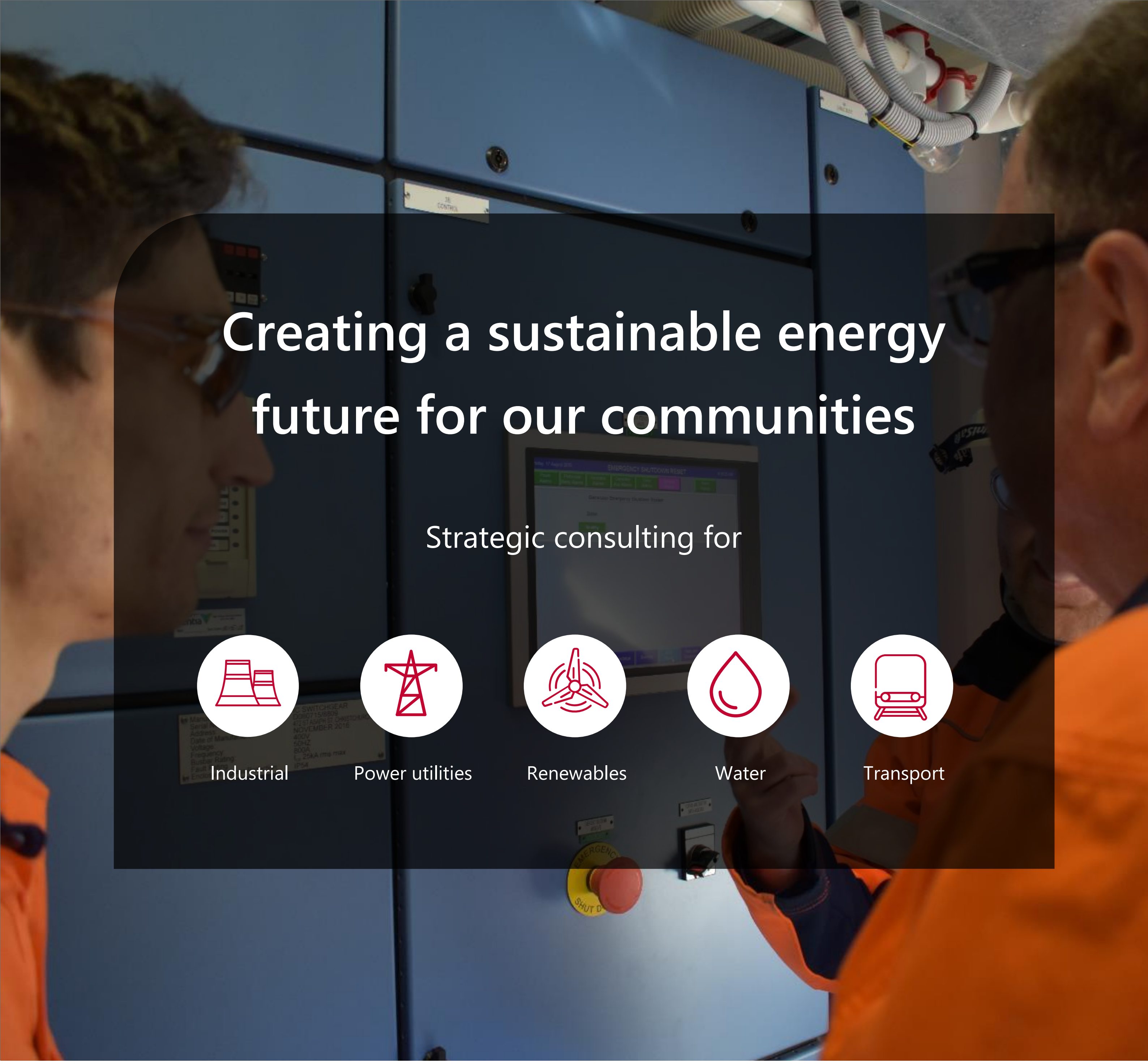
19/33kV Single Core
Screened & PVC Sheathed

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 mm	Nominal duct diameter 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	Continuous current-carrying capacity, A In air					In ground			In underground ducts				Fault current carrying capacity for 1 second	
mm²	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



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