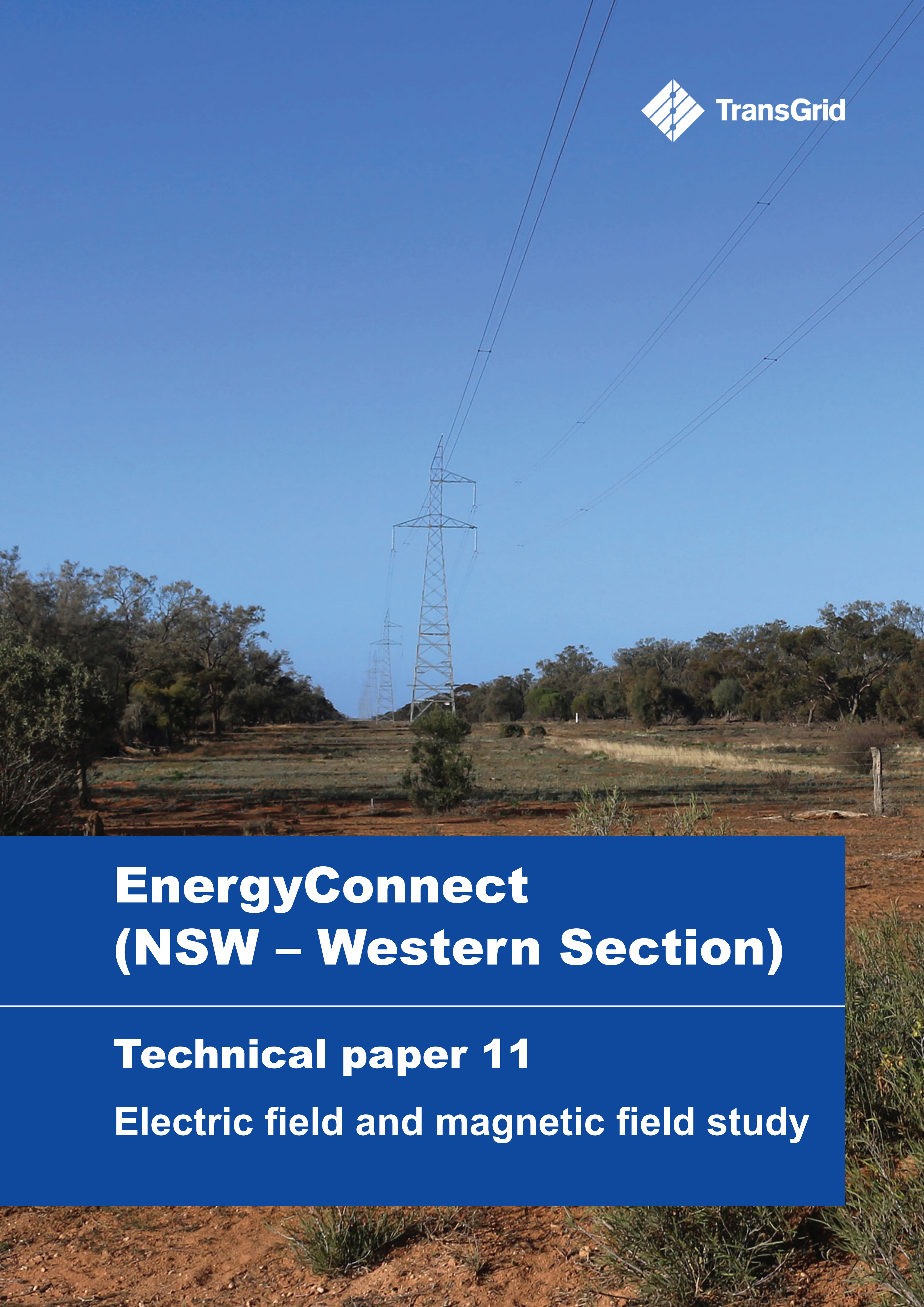

EnergyConnect (NSW – Western Section)

Technical paper 11

Electric field and magnetic field study

Sensitivity: General

Project EnergyConnect Electric and Magnetic Field Study – EIS1

Prepared for TransGrid

Prepared by Beca Pty Ltd

ABN: 85 004 974 341

14 October 2020

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Contents

Appendices

Revision History

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Action	Name	Signed	Date
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Approved by	Mark Jacob		21 October 2020
on behalf of	Beca Pty Limited		

Glossary of Terms

μT	Microtesla
ARPANSA	Australian Radiation Protection and Nuclear Safety Agency
EF	Electric field
EFS	Electric field strength
ELF	Extremely low frequency
EMF	Electric and magnetic fields
MFD	Magnetic field density
IARC	International Agency for Research on Cancer
ICNIRP	International Commission on Non-Ionizing Radiation Protection
IEEE	Institute of Electrical and Electronics Engineers
kV/m	Kilovolts per metre
pu	per unit
WHO	World Health Organisation
V/m	Volts per metre

Executive Summary

TransGrid and ElectraNet Pty Ltd (ElectraNet) are planning a new interconnector between the Robertstown Substation in South Australia (SA) and the Buronga Substation in New South Wales (NSW), which comprises a double circuit 330 kilovolt (kV) transmission line. In addition to the 330kV double circuit transmission line, TransGrid is also planning a double circuit 220kV transmission line between the Buronga Substation and the Red Cliffs Substation in Victoria.

This report is an assessment of the electric and magnetic field (EMF) performance of the latest transmission line designs. The purpose of the assessment is to check the EMF levels beneath the proposed 220kV and 330kV double circuit lines against public exposure guidelines.

The magnetic field levels directly under the proposed lines are well below the International Commission on Non-Ionizing Radiation Protection (ICNIRP) general public exposure reference limit of 2,000 milligauss (mG) in all cases, including during the contingency case of one circuit in service with increased load and the other circuit out of service.

Based on the minimum ground clearance for the proposed lines, the electric field levels directly under the proposed line are within 7.8 kilovolts per metre (kV/m), in all cases. The 7.8kV/m value can be shown to meet the ICNIRP general public basic restriction of 0.02 V/m for the central nerve stimulation tissue of the head, as determined by TransGrid commissioned modelling. The minimum clearance is typically at the middle of the span between towers where the conductor is at its lowest, and the majority of the line is well above this clearance. The minimum ground clearance (maximum sag) also only applies when the line is running at its maximum rating which occurs for the contingency case in hot weather conditions only.

The EMF levels associated with the contingency loads will only occur directly under the line for short periods on rare occasions. Time weighted average figures are provided to give more typical levels during normal operation both under the line and at the edge of the easement.

1 Introduction

TransGrid and ElectraNet Pty Ltd (ElectraNet) are planning a new interconnector between the Robertstown Substation in South Australia and the Buronga Substation in New South Wales. Project EnergyConnect will deliver the proposed new interconnector. TransGrid's Project EnergyConnect scope includes the construction of a double circuit 330kV transmission line between the South Australian border and Buronga Substation, approximately 140 km in length.

In addition to the new 330kV double circuit transmission line, TransGrid is also planning a new 24 km long double circuit 220kV transmission line to replace the existing line between Buronga and Red Cliffs Substation in Victoria.

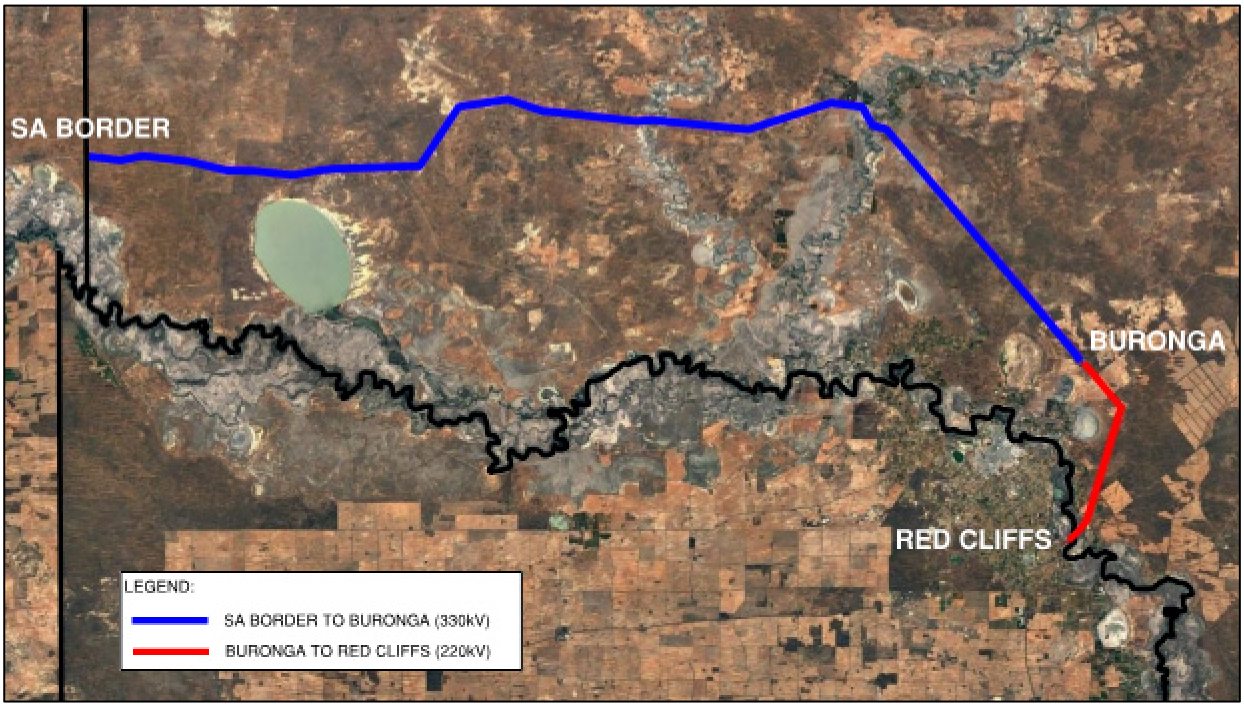

Figure 1-1: Proposed line route for Project EnergyConnect (TransGrid scope)

Beca Pty Ltd (Beca) has previously undertaken conductor and structure selection studies for the 330kV and 220kV double circuit transmission lines for Project EnergyConnect. The transmission line structure geometry has been further developed since the original conductor selection assessment and the transmission line easement width has been increased.

Beca has now been commissioned by TransGrid to undertake an assessment of the electric and magnetic field (EMF) performance of the latest transmission line designs and revised easement width. The purpose of the assessment is to check the EMF levels in the vicinity of the line against recognised public exposure guidelines.

2 Overview of Electric and Magnetic Fields

This section provides an overview of EMF setting out the exposure limits adopted for Project EnergyConnect based on applicable national and international guidelines.

2.1 What are electric and magnetic fields?

Electric and magnetic fields exist wherever electricity is generated, transmitted or distributed in power lines or cables, or used in electrical appliances. Electrical systems used for the transmission of electricity in Australia operate at a frequency of 50 Hertz (Hz) and give rise to extremely low frequency (ELF) EMF in their vicinity.

Electricity has two principal components, an electrical component and a magnetic component. Electric fields are determined by voltage, and the electric field at any given location around a transmission line will be largely constant. The electric field is proportional to the voltage, which remains within a plus/minus 10% level as long as the equipment is energised. The higher the operating voltage of the line, the higher the electric field around the conductor itself. This is partially offset at ground level as the higher voltage lines are run at a greater height above ground.

Magnetic fields on the other hand, will change in strength over time in line with the magnitude of the current. Whenever an electric charge moves, a magnetic field is created that is proportional to the current. Therefore, the higher the current, the higher the magnetic field. Variations in the current follow fairly typical patterns, with morning and evening peaks, and larger loads reflecting seasonal variations.

Magnetic fields are normally quantified in terms of the magnetic flux density which is measured in tesla (T). Measurements are most frequently given in microtesla (μT), which is 1 millionth of a tesla. Another unit commonly used to measure the magnetic field is the gauss (G) or milligauss (mG), where 10 mG is the equivalent of 1 μT. Electric fields are measured in units of volts per metre (V/m) and are normally given as kilovolts per metre (kV/m) where 1kV/m = 1000 V/m.

Electric and magnetic fields reduce rapidly with distance from their source. For transmission lines, electric and magnetic fields are between approximately four to eight times lower for every doubling of distance from a line. Electric fields are shielded by most objects, including trees, buildings and human skin. Unlike electric fields, magnetic fields cannot easily be shielded and pass through most materials.

The current carried by a transmission line directly influences the magnetic field. It also indirectly influences the electric field levels experienced below the line. The current has a heating effect on the conductors so that increasing current increases the conductor sag. Weather conditions such as air temperature, solar radiation, and wind speed also affect line sag. As line sag increases, the electric and magnetic fields experienced below the lines at ground level also increase. This is because the distance between the line (the source of the fields) and the ground decreases.

The table below provides typical field strengths from the measurement of fields from a range of sources. While field strengths will usually be within the ranges of values shown, values outside the range are possible.

Table 2-1: Typical range of magnetic fields and electric fields*

	Source	Typical range of magnetic fields (mG)[1]	Typical range of electric fields (kV/m)[2]
Around the home / office	Background in the home or office	0.5 – 1.5	0.003 - 0.02
	Electric stove	2 - 30	0.07 – 0.10
	Refrigerator	2 - 5	
	Electric kettle	2 - 10	
	Toaster	2 - 10	
	Television	0.2 - 2	
	Electric blanket	5 - 30	0.058 – 0.6
	Hair dryer	10 - 70	0.3 – 0.8
	Pedestal fan	0.2 - 2	
In public streets / neighbourhood	Street powerlines (directly underneath)	2 - 30	0.01 – 0.06
	Street powerlines (10 m away)	0.5 - 10	
	High voltage transmission line (directly underneath)	10 - 200	0.003 – 9[3]

* Note: Levels of magnetic fields may vary from the range of measurements shown.

The electric and magnetic fields around power lines and electrical appliances are not a form of radiation. The word ‘radiation’ is a very broad term, but generally refers to the propagation of energy away from some source. For example, light is a form of radiation, emitted by the sun and light bulbs. ELF fields do not travel away from their source, but are fixed in place around it. They do not propagate energy away from their source. They bear no relationship, in their physical nature or effects on the body, to true forms of radiation such as x-rays or microwaves[4].

[1] Sourced from ARPANSA: https://www.arpansa.gov.au/understanding-radiation/radiation-sources/more-radiation-sources/measuring-magnetic-fields

[2] Sourced from Transpower New Zealand Ltd, EMF Fact Sheet 3: https://www.transpower.co.nz/resources/factsheet-3-electric-and-magnetic-field-strengths

[3] This range covers the lower value of the range for 110kV line through to a 500kV line and hence the large difference in the range.

[4] New Zealand Ministry of Health, *Electric and Magnetic Fields and Your Health, Information on electric and magnetic fields associated with transmission lines, distribution lines and electrical equipment (2013 Edition),* Page 14.

2.2 Health and electric and magnetic fields

Potential effects of electric and magnetic fields

It is well known and understood that ELF electric and magnetic fields induce internal electric fields and currents in the body. If the external fields are strong enough, these induced electric fields can interfere with the body's nervous system causing nerve and muscle stimulation and changes in nerve cell excitability in the central nervous system[5]. The effects on the human body include hair movement, the magneto-phosphene effect and micro-shocks[6]. These effects, described below, occur at field strengths well above field strengths found below a transmission line (i.e. well above the limits set out in Section 2.3):

- Hair movement - Hair can be caused to move by strong electric fields.
- The magneto-phosphene effect - This effect results from currents induced in humans by either electric or magnetic fields. These weak currents can cause a flickering in the peripheral vision. Although the magneto-phosphene effect is mildly distracting it is a temporary effect on vision which has no lasting health effect after field levels reduce.
- Micro-shocks – Micro-shocks may occur in particular circumstances when the body comes into contact with objects such as fence lines that may have a voltage induced in them.

The exposure guidelines set out in Section 2.3 are in place to protect against these biological effects.

Health research

Much of the scientific research examining long-term risks from ELF magnetic field exposure has focused on childhood leukaemia. In 2002, the International Agency for Research on Cancer (IARC), (part of the World Health Organisation (WHO)) published a monograph classifying ELF magnetic fields as "possibly carcinogenic to humans" – Group 2B[7]. This classification is used to denote an agent for which there is limited evidence of carcinogenicity in humans and less than sufficient evidence for carcinogenicity in experimental animals. The Monograph identifies that *"this classification was based on pooled analyses of epidemiological studies demonstrating a consistent pattern of a two-fold increase in childhood leukaemia associated with average exposure to residential power-frequency magnetic field above 3 to 4 mG*". Evidence for all other cancers in children and adults, as well as other types of exposures (i.e. static fields and ELF electric fields) was considered "not classifiable" either due to insufficient or inconsistent scientific information[8].

In June 2007 the WHO reported on the possible health effects of exposure to ELF magnetic fields. The *Extremely Low Frequency Fields Environmental Health Criteria (EHC) Monograph No.238* examined scientific evidence suggesting that everyday, chronic low-intensity (above 3 to 4 mG) power-frequency magnetic field exposure poses a health risk based on epidemiological studies demonstrating a consistent pattern of increased risk for childhood leukaemia. The principle conclusion on health risks were as follows[9]:

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[5] Sourced from World Health Organisation: https://www.who.int/peh-emf/publications/facts/fs322/en/

[6] Energy Networks Australia, EMF Management Handbook, January 2016, pp 12

[7] The agents classified by the IARC Monographs are available at https://monographs.iarc.fr/list-of-classifications

[8] Sourced from World Health Organisation: https://www.who.int/peh-emf/publications/facts/fs322/en/

[9] WHO, Extremely Low Frequency Fields Environmental Health Criteria (EHC) Monograph No.238.

- There are established acute effects of exposure to strong ELF electromagnetic fields, and compliance with existing international guidelines provides adequate protection.
- Epidemiological studies suggest an increased risk of childhood leukaemia for long-term (ie, periods of years) average exposures greater than 3 to 4 mG . Some aspects of the methodology of these studies introduce uncertainties in the hazard assessment. Laboratory evidence and mechanistic studies do not support a causal relationship, but the evidence is sufficiently strong to remain a concern.
- If the relationship is causal, ELF fields could be responsible for 0.2–4.9% of leukaemia cases worldwide. Hence the global impact on public health, if any, is limited and uncertain.
- Scientific data suggesting a link with other diseases (other childhood and adult cancers, depression, suicide, reproductive problems, developmental and immunological disorders, and neurological disease) is much weaker, but in some cases (e.g. cardiovascular disease, breast cancer) is sufficient to rule out a causal relationship.

Based on this review of health effects, the WHO advises that:

> *"Despite the feeling of some people that more research needs to be done, scientific knowledge in this area is now more extensive than for most chemicals. Based on a recent in-depth review of the scientific literature, the WHO concluded that current evidence does not confirm the existence of any health consequences from exposure to low level electromagnetic fields."*[10]

Overall, the picture is largely unchanged since publication of the WHO review in 2007. The possibility that long-term exposures to magnetic fields somehow increases the risk of developing childhood leukaemia remains an open question. The results from epidemiological data (which show an association between ELF magnetic field exposure and an increased risk of childhood leukaemia) are not supported by experimental and mechanistic data[11]. The research on possible links with neurodegenerative diseases has also provided no consistent results[12].

The International Commission on Non-Ionizing Radiation Protection (ICNIRP) states in regard to establishing exposure guidelines based on the WHO Monograph:

> *"It is the view of ICNIRP that the currently existing scientific evidence that prolonged exposure to low frequency magnetic fields is causally related with an increased risk of childhood leukaemia is too weak to form the basis for exposure guidelines. In particular, if the relationship is not causal, then no benefit to health will accrue from reducing exposure."*[13]

[10] Accessed from https://www.who.int/peh-emf/about/WhatisEMF/en/index1.html on 21 July 2020.

[11] WHO, Electromagnetic fields and public health fact sheet, accessed from https://www.who.int/peh-emf/publications/facts/fs322/en/ on 21 July 2020.

[12] Interagency Committee on the Health Effects of Non-ionising Fields, Report to Ministers 2015.

[13] ICNIRP Guidelines for Limiting Exposure to Time-Varying Electric and Magnetic Fields (1 Hz - 100 kHz), 2010.

2.3 Exposure limit guidelines for electric and magnetic fields

The Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) is the Federal Government agency charged with the responsibility for protecting the health and safety of people, and the environment, from EMF. The ARPANSA recommends the use of the exposure guidelines provided by ICNIRP. These exposure guidelines are set out below.

International Commission for Non-Ionizing Radiation Protection Guidelines

The ICNIRP *Guidelines for Limiting Exposure to Time-Varying Electric and Magnetic Fields (1 Hz - 100 kHz)* set fundamental limits on electrical fields induced in the body by EMF. The limits which are expressed in terms of induced electric fields in the body are termed 'basic restrictions'.

Induced electric fields in the body are difficult to measure or calculate, so the guidelines also provide reference levels. Reference levels are in terms of the more easily measured ambient electric and magnetic fields that give rise to the induced internal electric fields. Provided field strengths are below the reference levels, resulting induced electric fields will be within the basic restriction. If exposures exceed the reference level, this does not necessarily mean that the basic restriction is also exceeded, however, a more comprehensive analysis is required in order to verify compliance with the basic restrictions.

The ICNIRP reference levels for exposure of the public are 200μT and 5kV/m for magnetic and electric fields respectively. These limits apply to both children and adults. ICNIRP re-issued their guidelines in 2010, revising the public exposure limit for magnetic field from 100 to 200 μT (micro tesla). The essential biological basis for the guidelines has remained unchanged for more than 20 years. The ICNIRP basic restriction and reference levels are provided in Table 2-2.

Table 2-2: EMF guidelines for the general public (ICNIRP)

		Level
Basic restriction		
Central nervous system tissues of the head		0.02V/m
All tissues of head and body		0.4V/m
Reference level	Electric field	5kV/m
	Magnetic field	200μT

ICNIRP's limiting thresholds for general public exposure are widely accepted as providing complete protection against all known adverse health effects of electric and magnetic fields. ARPANSA's current advice is *"The ICNIRP Extremely Low Frequency (ELF) guidelines are consistent with ARPANSA's understanding of the scientific basis for the protection of the general public (including the foetus) and workers from exposure to ELF EMF".*

TransGrid's approach to the management of electric fields

It is TransGrid policy to comply with the ICNIRP Guidelines at all times and to meet the general public reference levels for electric fields (5kV/m) where possible. However, as transmission lines of 330kV and higher can exceed the reference level in some locations, it is necessary to assess them further to determine compliance with the basic restrictions.

TransGrid's *Transmission Line Design Manual – Major New Build* specifies that electric fields produced by a new transmission line shall be limited to the meet the basic restrictions stated within the ICNIRP guidelines for limiting exposure to time-varying electric and magnetic fields (1 Hz – 100 kHz) 2010. Compliance shall be against the peak maximum voltage at lowest ground clearance for the transmission line (i.e. the worst case).

220kV lines typically comply with the 5kV/m reference level without additional consideration of internal electric fields as provided by the guidelines. The modelling of the 220kV configuration for the lines as set out in Section 3 confirm compliance. TransGrid have previously commissioned modelling of 330kV transmission line design configurations to evaluate compliance with the ICNIRP reference level for electric field. The calculated maximum external electric field at a height of 1 metre above ground was 6.93kV/m for a 330kV transmission line.

The calculated maximum electric field from this line configuration exceeds the ICNIRP reference level and therefore, dosimetric analyses[14] of the internal electric fields is required. This was completed using an anatomically accurate human a body model beneath the 330 kV transmission line at midspan where the conductors are closest to a person and electric-field levels are highest. The analysis used the internal electric fields of 0.02 V/m for the central nerve stimulation tissue of the head, being the most restrictive limit (with 0.04 V/m applying for all tissues of the head and body). The analysis determined to meet the ICNIRP general public basic restriction of 0.02 V/m for the central nerve stimulation tissue of the head, the maximum external electric field shall not exceed 9.1kV/m at 1 m height above the ground. Based on this, TransGrid have designed Project EnergyConnect 330kV line to meet a more conservative figure of 7.8kV/m.

2.4 Exposure limits

The exposure limits used as the basis of this report are based on the TransGrid commissioned modelling and the selection of a limit as listed in Table 2-3.

Table 2-3: EMF exposure limits for the general public

	Level
Electric field	7.8 kV/m
Magnetic field	2,000 mG

2.5 Implantable medical devices

The commonest active medical devices are pacemakers and defibrillators. There is a great deal of variation between different medical implants, including the function of the device, the model and the way it is fitted and programmed. Members of the general public are generally briefed by their physician regarding the management of their medical implant and its susceptibility to interference.

Standards for the designers and manufacture of medical devices require that the devices need to be designed with an immunity up to the general public reference levels as set by ICNIRP[15]. This means that older devices are considered to be immune up to 100µT (1,000mG), being the ICNIRP 1998 level. A very small proportion of cardiac pacemakers has been found to be sensitive to 50Hz electric and magnetic fields close to the ICNIRP limits for public exposure[16]. Where this is the case, it is most likely that they will revert to a fixed pacing mode, which poses no immediate threat to the wearer.

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

[15] For example CENELEC 50527-1 and European Directive 90/385/EEC.

[16] Ministry of Health, Electric and Magnetic Fields and Your Health, 2013 edition.

For persons wearing a hearing aid or cochlear implant, 50Hz magnetic field noise can occur when near transmission lines (heard as a buzzing sound), however, this will not damage the devices or the ear[17].

2.6 Effects on food production and animals

Electric and magnetic fields have the potential to affect farmed mammal species similarly to humans. Therefore, where EMF levels are within the ICNIRP Guidelines, there is unlikely to be any perceptible effect on animals. There is limited published material addressing this matter. One that is widely referenced is the Gibbs Report[18] which concluded that: *'The magnetic fields created by power lines do not affect the health or reproductive capacity of farm animals'*.

For vegetation it noted that: *'The magnetic fields created by power lines do not affect the health or reproductive capacity of farm animals'* ; that *'from a practical point of view, the electric fields created by transmissions lines have no adverse effect on crops, pasture, grasses or native flora, other than trees, growing under or near to the lines'* and that *'No reason exists for concern as to the effect of the fields on animals or plants* . However, the report did note that beehives near power lines can be adversely affected and that the growth of trees under the line can be reduced by the effect of corona.

There is a body of research examining the effects of EMF on the reproductive biology and physiology of birds in the wild and under aviary conditions. Most studies indicate that EMF exposure of birds generally changes, but not always consistently in effect or in direction, their behaviour, reproductive success, growth and development, physiology and endocrinology, and oxidative stress under EMF conditions[19].

2.7 Managing electric and magnetic fields

TransGrid designs new infrastructure to meet EMF exposure guidelines. This is done by modelling transmission lines and other infrastructure to enable the accurate prediction of electric and magnetic field strengths. Predictions of field levels as they relate to typical (and worst case) operation give an indication of likely field levels to members of the public and to consenting authorities. The results of this modelling are provided in Section 3.

Scientific uncertainty around the association between EMF and childhood leukaemia has led to significant debate. From a risk management perspective, prudent avoidance and precautionary approaches have been advocated. In Australia, prudent avoidance was defined by the former Chief Justice of the High Court of Australia, Sir Harry Gibbs, as *"doing whatever can be done at modest cost and without undue inconvenience to avoid the possible risk to health"*[20].

In a June 2007 report on possible EMF health effects the WHO make the following statements: '*In recommending precautionary approaches, an overriding principle is that any actions taken should not compromise the essential health, social and economic benefits of electric power*.' and '*Provided that these benefits are not compromised, implementing precautionary procedures to reduce exposures is reasonable*

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[17] British Cochlear Implant Group: https://www.bcig.org.uk/safety/

[18] Gibbs, Sir Harry (1991). Inquiry into community needs and high voltage transmission line development. Report to the NSW Minister for Minerals and Energy. Sydney, NSW: Department of Minerals and Energy, February 1991.

[19] Kim J. Fernie & S. James Reynolds (2005) *The Effects of Electromagnetic Fields from Power Lines on Avian Reproductive Biology and Physiology: A Review*, Journal of Toxicology and Environmental Health, Part B, 8:2, 127-140, DOI: 10.1080/10937400590909022

[20] Gibbs, Sir Harry (1991)

and warranted.'[21] The WHO stated that these precautionary approaches do not support setting exposure limits below those determined by the analysis of the health effects research. In addition, in relation to the selection of measures, the WHO states that *"given both the weakness of the evidence for a link between exposure to ELF magnetic fields and childhood leukaemia, and the limited impact on public health if there is a link, the benefits of exposure reduction on health are unclear. Thus the costs of precautionary measures should be very low."*[22]

The techniques that are available to reduce EMF exposures associated with transmission relate to the characteristics of electric and magnetic fields and can be summarised as:

- the reduction of field levels with distance from their source; and
- mutual cancellation of the fields from different phases;

The transmission line route has been chosen to minimise impact on landowners and avoid dwellings where possible. The EMF levels fall away rapidly either side of the line. It is not expected that people would spend extended periods of time within the easement.

The transmission line minimum heights above ground have been designed to keep EMF levels within acceptable limits directly under the line. There are other drivers, both cost and aesthetic, to keep the line as low as possible.

Closer phase spacings reduce the EMF levels. The phase spacings have been reduced as far as practical. Minimum spacings are essential for electrical reasons.

2.8 Cumulative effects

In places, the new transmission lines will be close to other transmission lines and smaller distribution lines. There is a cumulative effect arising from multiple transmission lines. Multiple power lines can lead to enhancement or reduction of magnetic fields depending on their configuration Given that the EMF levels fall away rapidly with distance, this effect is only notable when the lines are in very close proximity. For known assets, this cumulative effect can be calculated.

The smaller distribution lines will have much lower EMF levels, will be out of phase with the larger transmission lines and the cumulative effect will be minimal. The largest magnetic field from each source will govern.

[21] WHO, *Extremely Low Frequency Fields Environmental Health Criteria (EHC) Monograph No.238*.

[22] WHO, *Extremely Low Frequency Fields Environmental Health Criteria (EHC) Monograph No.238*, pp 13.

3 Electric and magnetic field simulation results

3.1 Calculations

SES-EnviroPlus, a commercial software package, was used to calculate the EMF at 1 m above the normal standing position of the public. The concept light suspension tower phase and circuit spacings were used for the new lines. The concept strain tower phase and circuit spacings were used for the landing spans. There is negligible difference between the two tower types. The geometries of the towers used for the assessment are provided in Appendix E.

Actual design dimensions may vary from the concept dimensions used. Differences are likely to be small but reconfirmation of the calculated values may be required.

A line voltage equal to the system highest voltage of 10% above normal and the rated line loading outlined in

Table 3-1 was applied for the calculations. The current in each phase was calculated using Equation 1.

$$\mathrm{I} = \frac{\mathrm{S} \times 10^3}{\sqrt{3}.\mathrm{V}_{LL}}\ [A]$$

Where: S = Apparent circuit power [MVA]

V_{LL} = Rated line voltage [kV]

Table 3-1: Transmission line rating

Transmission Line	Maximum contingency loading per circuit		Time weighted average loading per circuit	
	MVA	A	MVA	A
Concept 330 kV	1080	1890	400	700
Concept 220 kV	1100	2887	400	1050
Circuit X5/3 (220 kV)	596	1564	400	1050
Circuit X2 (220 kV)	613	1609	400	1050

Calculations are done for the worst case voltage and current on the lines. The contingency case is with only one line in service with a higher current. The time weighted average gives a typical daily average load and both circuits in service.

The EMF levels associated with the contingency loads will only occur for short periods on rare occasions. The time weighted average figures are provided to give more typical levels during normal operation.

For the contingency case the calculations were done for the minimum ground clearance of the circuit. For the time weighted average case the ground clearance was increased based on the change in conductor sag between the contingency and time weighted average cases. The change in conductor sag was calculated for an average span and the time weighted average case conductor sag considered the mean maximum ambient temperature across summer months (between 1991-2020).

3.2 Concept Transmission Lines

The calculated worst case EMF for the bulk of the line route is based on concept light suspension tower phase and circuit spacings at mid span and edge of the easement are summarised in Table 3-2 and Table 3-3 respectively. The EMF plots are included in Appendix B. The calculated EMF for other tower types resulted in almost the same values as the concept light suspension tower type.

The EMF levels fall rapidly with distance from the line. This is shown in the figures given for the edge of the easement and in the profiles in Appendix B.

Table 3-2: Maximum calculated EMF directly under line mid span

Transmission Line	Maximum contingency circuit loading		Time weighted average circuit loading	
	EFS (kV/m)	MFD (mG)	EFS (kV/m)	MFD (mG)
Concept 330 kV	6.32	272	4.65	99
Concept 220 kV	4.58	430	2.93	139

Table 3-3: Maximum calculated EMF at edge of easement

Transmission Line	Maximum contingency circuit loading		Time weighted average circuit loading	
	EFS (kV/m)	MFD (mG)	EFS (kV/m)	MFD (mG)
Concept 330 kV	0.19	35	0.07	6.50
Concept 220 kV	0.08	97	0.09	17

3.3 Substation Landing Spans

Table 3-4 and Table 3-5 summarise the calculated worst case EMF directly under the line and at edge of easement respectively for a landing span into a substation. The concept strain tower was used for the calculation. Refer to Appendix C for EMF plots.

Table 3-4: Maximum calculated EMF directly under line for landing span

Transmission Line	Maximum contingency circuit loading		Time weighted average circuit loading	
	EFS (kV/m)	MFD (mG)	EFS (kV/m)	MFD (mG)
330 kV concept strain	6.29	272	4.40	116
220 kV concept strain	4.56	430	2.92	139

Table 3-5: Maximum calculated EMF at edge of easement for landing span

Transmission Line	Maximum contingency circuit loading		Time weighted average circuit loading	
	EFS (kV/m)	MFD (mG)	EFS (kV/m)	MFD (mG)
330 kV concept strain	0.21	36	1.75	44
220 kV concept strain	0.09	97	0.07	17

3.4 Parallel Transmission Lines

The EnergyConnect transmission lines run parallel to existing TransGrid 220kV transmission lines in places along the proposed alignments. The phasing of the adjacent circuit is assumed to be the worst for cumulative EMF. The calculated worst case EMF directly under the line and at edge of easement are summarised in Table 3-6 and Table 3-7 respectively in these circumstances. The EMF plots are included in Appendix D.

Table 3-6: Maximum calculated EMF directly under line mid span – parallel lines

Transmission Line	**Maximum contingency circuit loading**		**Time weighted average circuit loading**	
	EFS (kV/m)	**MFD (mG)**	**EFS (kV/m)**	**MFD (mG)**
New 330 kV parallel with Circuit X2	6.35	375	4.68	221
New 220 kV parallel with Circuit X5/3 & future NSW Eastern Section (330 kV)(1)	6.33	440	4.66	217

Table 3-7: Maximum calculated EMF at edge of easement – parallel lines

Transmission Line	Maximum contingency circuit loading		Time weighted average circuit loading	
	EFS (kV/m)	**MFD (mG)**	**EFS (kV/m)**	**MFD (mG)**
New 330 kV parallel with Circuit X2	0.35	40	0.44	31
New 220 kV parallel with Circuit X5/3 & future NSW Eastern Section (330 kV)(1)	0.43	97	0.40	41

[1] The proposed 330kV line that forms part of the future NSW – Eastern Section of EnergyConnect

4 Summary of Results

The magnetic field levels directly under the proposed lines are well below the ICNIRP general public exposure reference limit of 2,000 mG in all cases, including during the contingency case of one circuit in service with increased load and the other circuit out of service.

Based on the minimum ground clearance for the proposed lines, the electric field levels directly under the proposed line are within 7.8kV/m, in all cases. The 7.8kV/m value can be shown to meet the ICNIRP general public basic restriction of 0.02 V/m for the central nerve stimulation tissue of the head, as determined by TransGrid through separate modelling (as detailed in section 2.3). The minimum clearance is typically at the middle of the span between towers where the conductor is at its lowest, and the majority of the line is well above this clearance. The minimum ground clearance (maximum sag) also only applies when the line is running at its maximum rating which occurs for the contingency case in hot weather conditions only.

The EMF levels associated with the contingency loads will only occur directly under the line for short periods on rare occasions. Time weighted average figures are provided to give more typical levels during normal operation. Figures are provided for both directly under the line and at the edge of the easement.

5 References

[1] International Commission on Non-Ionizing Radiation Protection, “Guidelines for limiting exposure to time-varying electric, magnetic and electromagnetic fields (100 KHZ TO 300 GHZ)). Health Physics 99(6):818-836; 2010.

[2] Institute of Electrical and Electronics Engineers, “Standard C95.1-2019 - IEEE Standard for Safety Levels with Respect to Human Exposure to Electric, Magnetic, and Electromagnetic Fields, 0 Hz to 300 GHz”, 2019.

[3] New Zealand Ministry of Health, “Interagency Committee on the Health Effects of Non-ionising Fields: Report to Ministers 2015”, April 2015.

[4] World Health Organisation, “Extremely Low Frequency Fields Environmental Health Criteria Monograph No.238”, June 2007.

[5] World Health Organisation, “Electromagnetic fields and public health fact sheet”, https://www.who.int/peh-emf/publications/facts/fs322/en/

Appendix A – Transmission Line Input Data

Oper.	Circuit	Substations		Rated	Owner	Section	Split	Length	Structures					Phase Conductors		Overhead Earthwires		Phase	Comm.	Design	Mutual Coup.		
kV	No.	From	To	kV	Name	No.	Phase	(km)	From	To	Type	Side	Name	No.	Type	First	Second	Rot'n	Date	Temp.	Section	Split	Circuit
	62	Jindera	Wagga 330		TG	Total		99.600															
				330	TG	1		4.439	271	27	SCST	L	SC	2 x	Mango	SC/GZ 7/.144	OPGW B 24/3.	WBR	May-80	85			
				330	TG	2		3.653	27	16	SCST	L	SC	2 x	Mango	SC/GZ 7/.144	OPGW A 8/3.3	WBR	May-80	85			
				330	TG	3		91.510	16	1	SCST	L	SL	2 x	Mango	SC/GZ 7/.144	OPGW A 8/3.3	WBR	May-80	85			
	63	Darlngt Pt	Wagga 330		TG	Total		151.700															
				330	TG	1		3.669	414a	404	SCST	L	QSA	2 x	Mango	Opal	Opal	WBR	Mar-88	85			
				330	TG	2		139.900	404	26	SCST	L	QSA	2 x	Mango	SC/GZ 7/3.75	SC/GZ 7/3.75	WBR	Mar-88	85			
				330	TG	3		3.653	26	16	SCST	L	SC	2 x	Mango	SC/GZ 7/3.75	SC/GZ 7/3.75	WBR	Mar-88	85			
				330	TG	4		4.439	16	1	SCST	L	SC	2 x	Mango	Opal	Opal	WBR	Mar-88	85			
	64	Lowertumut	Uppertumut		TG	Total		40.600															
				330	TG	1		0.087	Ltss	105	SCST	L	SA		Jarrah	SC/GZ 7/.144	OPGW B 24/3.	WBR	May-57	65			
				330	TG	2		34.830	105	17	SCST	L	SA	2 x	Bison 0.35"	SC/GZ 7/.144	OPGW A 8/3.3	WBR	May-57	65			
				330	TG	3		2.755	17	7	SCST	L	SAH		Jarrah	SC/GZ 7/.144	OPGW A 8/3.3	WBR	May-57	71			
				330	TG	4		1.534	7	6	SCST	L	SAH		Jarrah	SC/GZ19/.128	OPGW A 8/3.3	WBR	May-57	71			
				330	TG	5		1.398	6	Utss	SCST	L	SAH		Jarrah	SC/GZ 7/.144	OPGW B 24/3.	WBR	May-57	85			
220	0X1	Buronga Ss	Red Clf Ts		TG	Total		23.900															
				220	TG	1		22.500	T.60	Bord	SCST	L	NSA	2 x	Lemon		SC/GZ 7/3.25	RBW	Mar-79	85			
				220	TG	2		1.404	Bord	T.1	SCST	L	NSA	2 x	Lemon		SC/GZ 7/3.25	RBW	Mar-79	85			
	X2	Broken Hil	Buronga Ss		TG	Total		259.500															
				220	TG	1		41.150	T711	T608	SCST	L	NSA	2 x	Lemon		SC/GZ 7/3.25	BWR	Mar-79	85			
				220	TG	2		87.920	T608	T388	SCST	L	NSA	2 x	Lemon		SC/GZ 7/3.25	WRB	Mar-79	85			
				220	TG	3		63.490	T388	T229	SCST	L	NSA	2 x	Lemon		SC/GZ 7/3.25	RBW	Mar-79	85			
				220	TG	4		66.910	T229	T.61	SCST	L	NSA	2 x	Lemon		SC/GZ 7/3.25	BWR	Mar-79	85			
	X5/1	Balranald	Darlngt Pt		TG	Total		249.800															
				220	TG	1		123.300	Balr	319	SCST	L	NSA	2 x	Lemon		SC/GZ 7/3.25	RBW	Jun-88	85			
				220	TG	2		63.170	319	162	SCST	L	NSA	2 x	Lemon		SC/GZ 7/3.25	WRB	Jun-88	85			
				220	TG	3		10.120	162	140	SCST	L	NSA	2 x	Lemon		SC/GZ 7/3.25	BWR	Jun-88	85			
				220	TG	4		18.330	140		SCST	L	NSA	2 x	Lemon		SC/GZ 7/3.25	BWR	Jun-88	85			
				220	TG	5		21.740			SCST	L	NSA	2 x	Lemon		SC/GZ 7/3.25	BWR	Jun-88	85			
				220	TG	6		10.220			SCST	L	NSA	2 x	Lemon		SC/GZ 7/3.25	BWR	Jun-88	85			
				220	TG	7		0.884		7	SCST	L	NSA	2 x	Lemon		SC/GZ 7/3.25	BWR	Jun-88	85			
				220	TG	8		2.076	7	1	SCST	L	NSA	2 x	Lemon		SC/GZ 7/3.25	BWR	Jun-88	85			
	X5/3	Balranald	Buronga Ss		TG	Total		148.000															
				220	TG	1		3.340	Balr	637	SCST	L	NSA	2 x	Lemon		SC/GZ 7/3.25	RBW	Jun-88	85			
				220	TG	2		63.280	637	796	SCST	L	NSA	2 x	Lemon		SC/GZ 7/3.25	WRB	Jun-88	85			
				220	TG	3		81.380	796	998	SCST	L	NSA	2 x	Lemon		SC/GZ 7/3.25	BWR	Jun-88	85			
	996/2	Morven Tee	Wagga 330		TG	Total		64.970															
				132	TG	1		60.500	T193	T37	SCWP	L	VP-AA		Panther 0.2"	SC/GZ 7/.128	SC/GZ 7/.128	RWB	May-81	85			
				132	TG	2		4.470	T37	W330	DCST	R	DSL		Panther 0.2"	Wolf 0.15"	Wolf 0.15"		May-81	85	1		994

Oper.	Circuit	Substations		Rated	Owner	Section	Split	Length	Structures					Phase Conductors		Overhead Earthwires		Phase	Comm.	Design	Mutual Coup.		
kV	No.	From	To	kV	Name	No.	Phase	(km)	From	To	Type	Side	Name	No.	Type	First	Second	Rot'n	Date	Temp.	Section	Split	Circuit
	99A	Finley 132	Uranquinty	132	**TG**	1		167.300	Fnly	T9-8	SCWP	L	VP-AA		Panther 0.2"	SC/GZ 7/.128	SC/GZ 7/.128		May-71	85			
	99L	Coleambaly	Deniliq132		**TG**	Total		152.700															
				132	**TG**	1		21.740	1050	1130	SCCP	L	LQH		Lemon	SC/GZ 7/3.25	SC/GZ 7/3.25	RWB	May-89	85			
				132	**TG**	2		18.330	1130	1196	SCCP	L	LQH		Lemon	SC/GZ 7/3.25	SC/GZ 7/3.25	WBR	May-89	85			
				132	**TG**	3		19.440	1196	1261	SCCP	L	LQH		Lemon	SC/GZ 7/3.25	SC/GZ 7/3.25	WBR	May-89	85			
				132	**TG**	4		44.950	1261	1501	SCCP	L	LQH		Lemon	SC/GZ 7/3.25	SC/GZ 7/3.25	BRW	May-89	85			
				132	**TG**	5		47.200	1501	1754	SCCP	L	LRK		Lemon		SC/GZ 7/3.25	RBW	May-89	85			
				132	**TG**	6		1.000	1754	1760	SCCP	L	LRK		Lemon		Cherry	RBW	May-89	85			

Appendix B – Concept Lines EFS and MFD Calculations

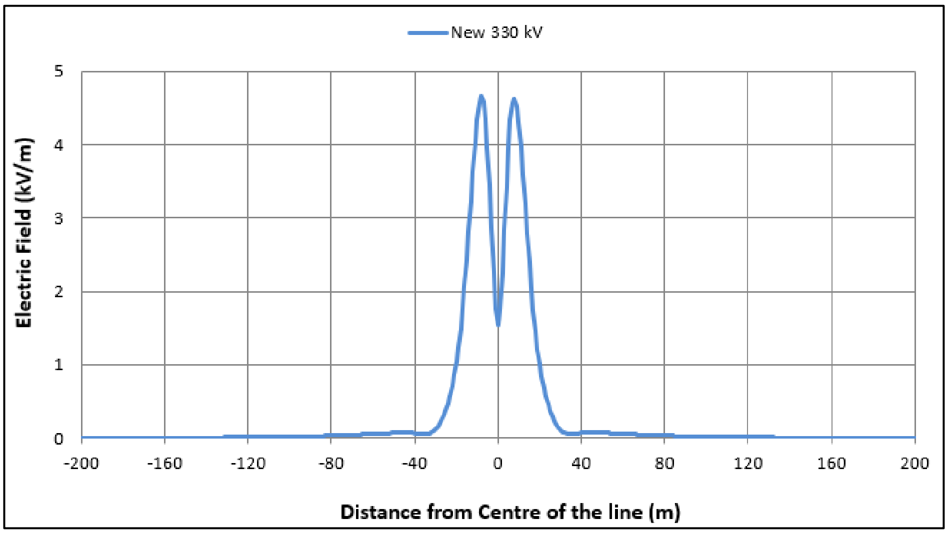


Figure 5-1: Concept 330 kV line electric field strength – time weighted average case

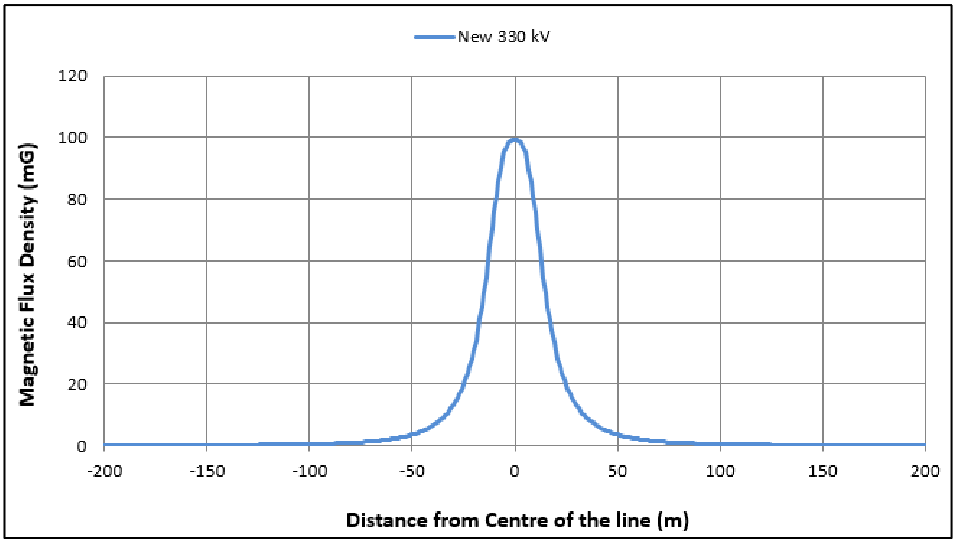


Figure 5-2: Concept 330 kV line magnetic flux density – time weighted average case

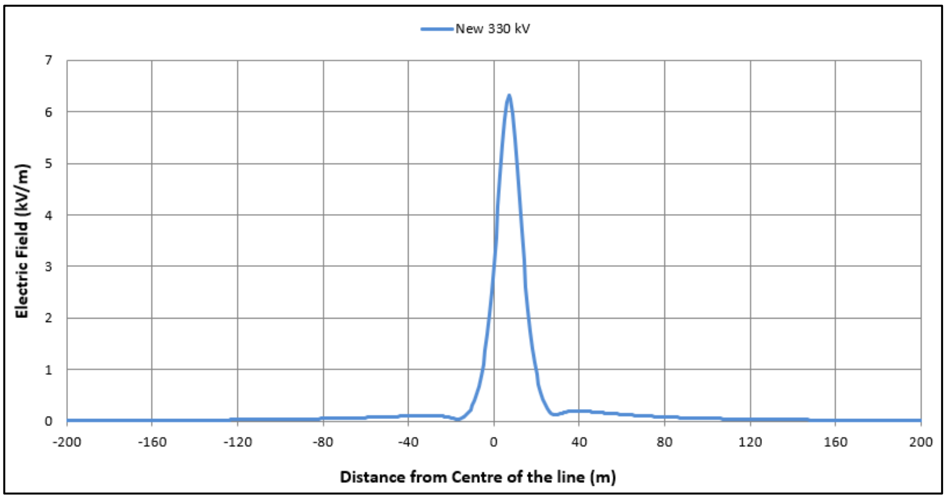


Figure 5-3: Concept 330 kV line electric field strength – maximum contingency case

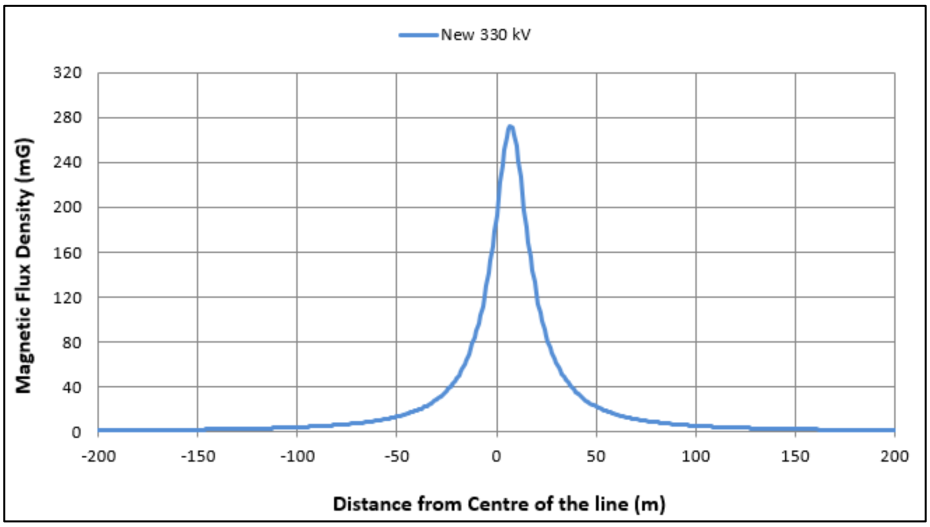


Figure 5-4: Concept 330 kV line magnetic flux density – maximum contingency case

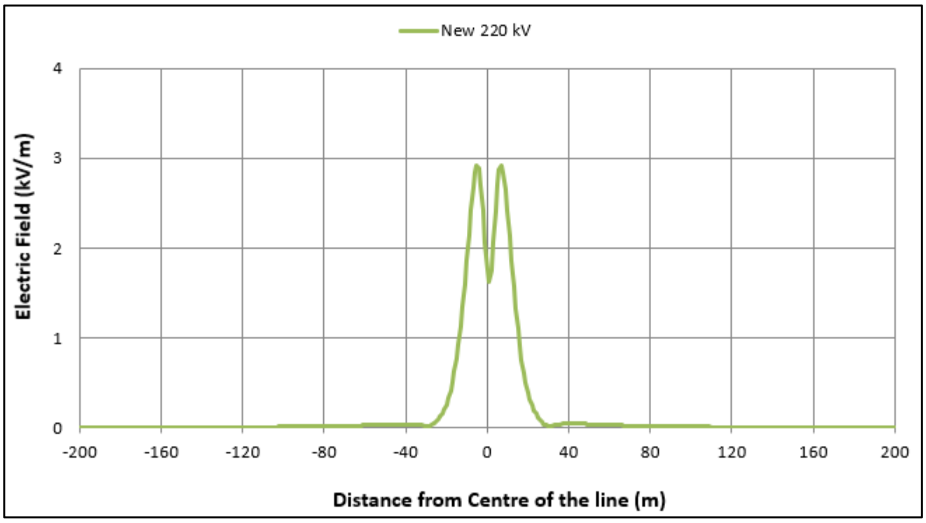


Figure 5-5: Concept 220 kV line electric field strength – time weighted average case

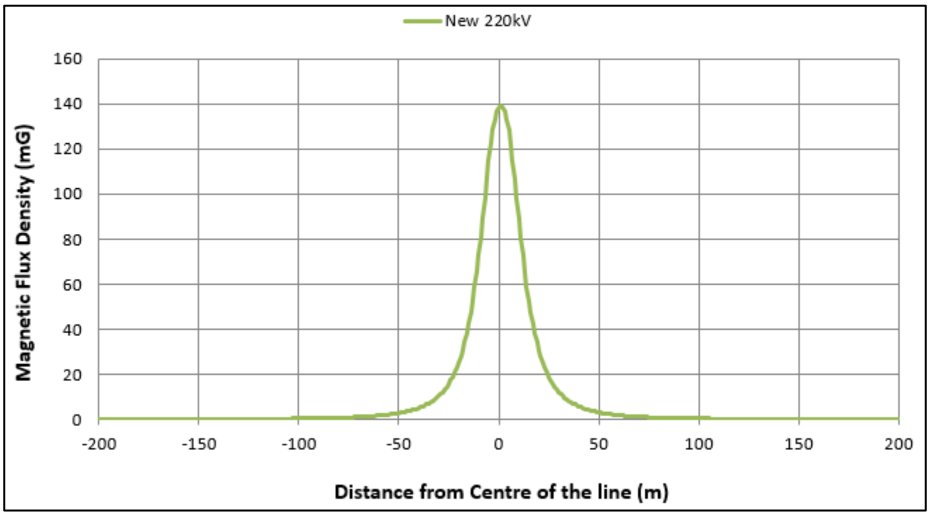


Figure 5-6: Concept 220 kV line magnetic flux density – time weighted average case

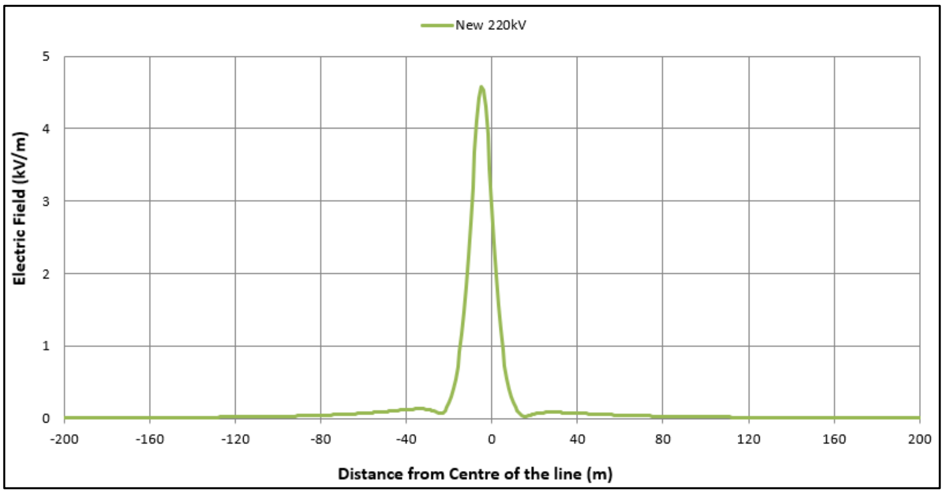


Figure 5-7: Concept 220 kV line electric field strength – maximum contingency case

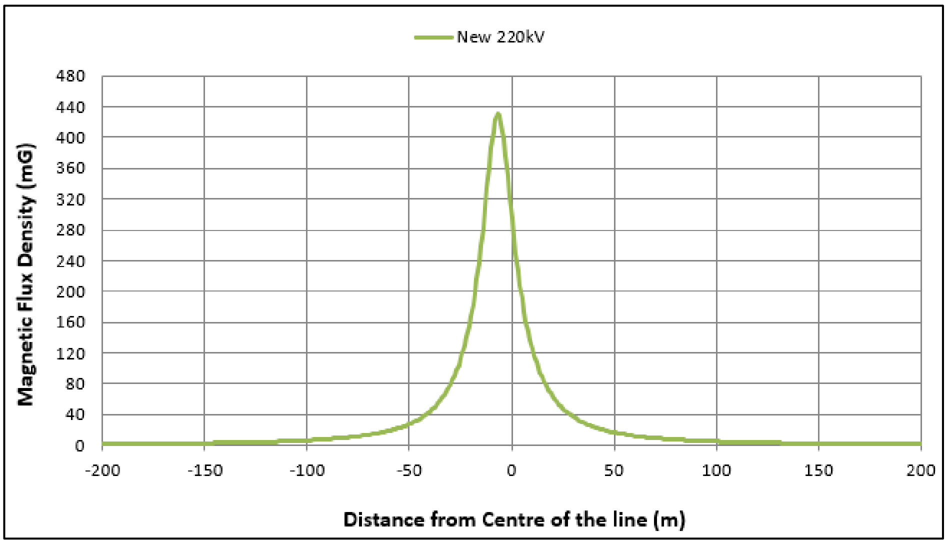


Figure 5-8: Concept 220 kV line magnetic flux density – maximum contingency case

Appendix C – Substation Landing Spans EFS and MFD Calculations

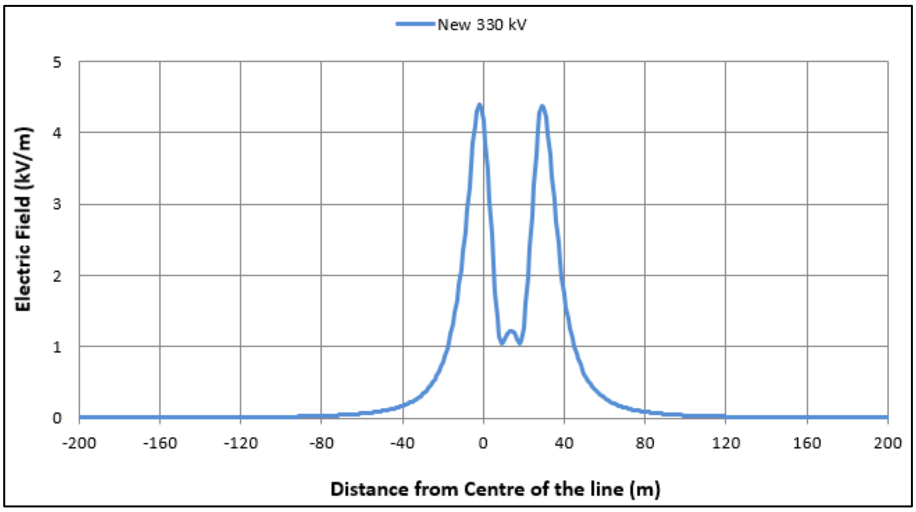


Figure 5-9: Substation Landing Span - Concept 330 kV line electric field strength – time weighted average case

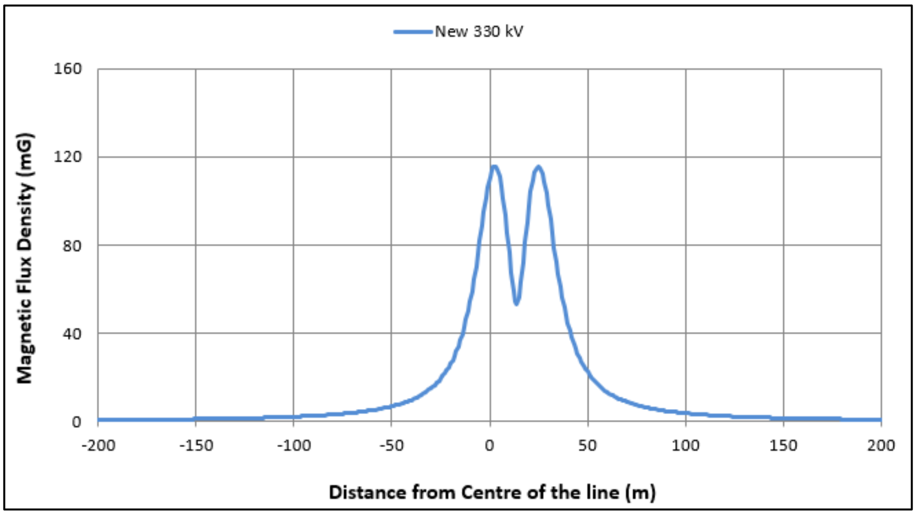


Figure 5-10: Substation Landing Span - Concept 330 kV line magnetic flux density – time weighted average case

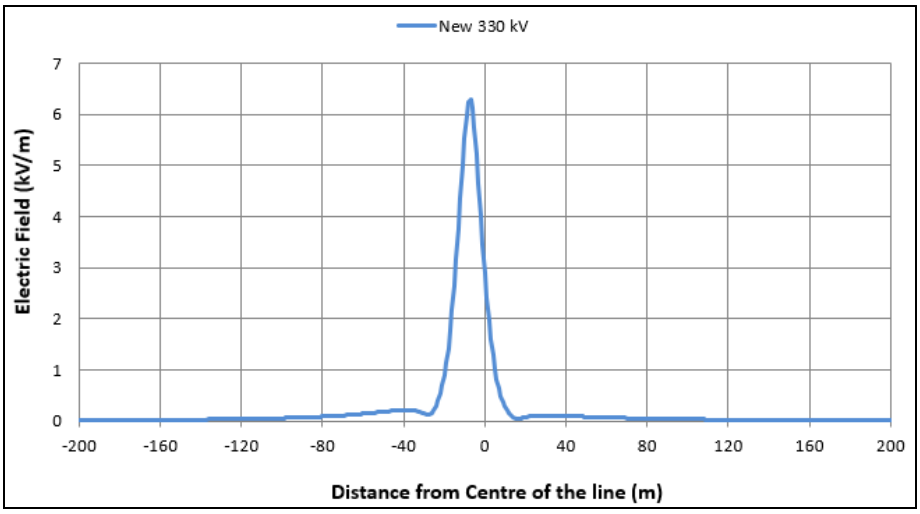


Figure 5-11: Substation Landing Span - Concept 330 kV line electric field strength – maximum contingency case

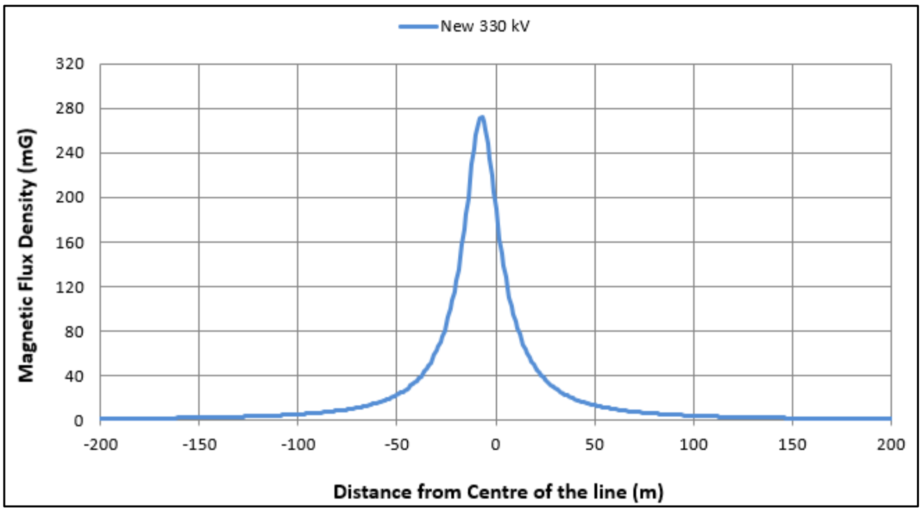


Figure 5-12: Substation Landing Span - Concept 330 kV line magnetic flux density – maximum contingency case

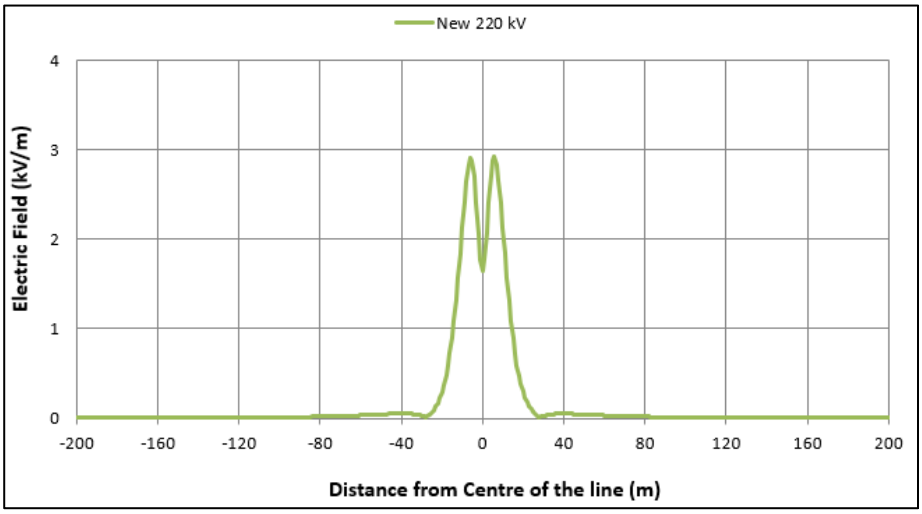


Figure 5-13: Substation Landing Span - Concept 220 kV line electric field strength – time weighted average case

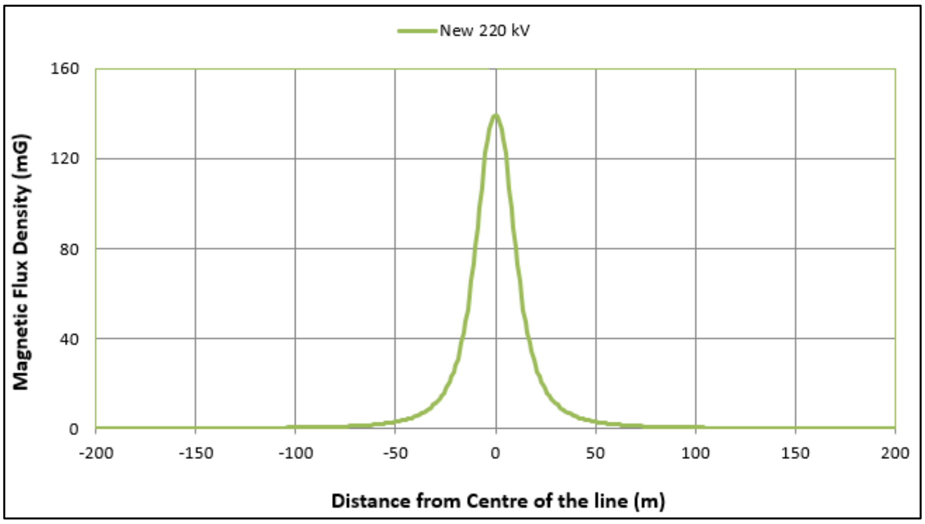


Figure 5-14: Substation Landing Span - Concept 220 kV line magnetic flux density – time weighted average case

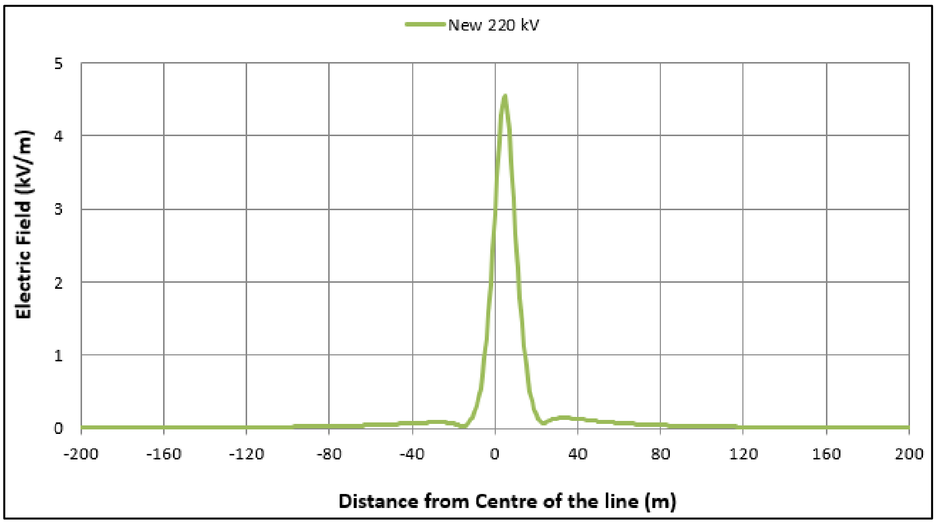


Figure 5-15: Substation Landing Span - Concept 220 kV line electric field strength – maximum contingency case

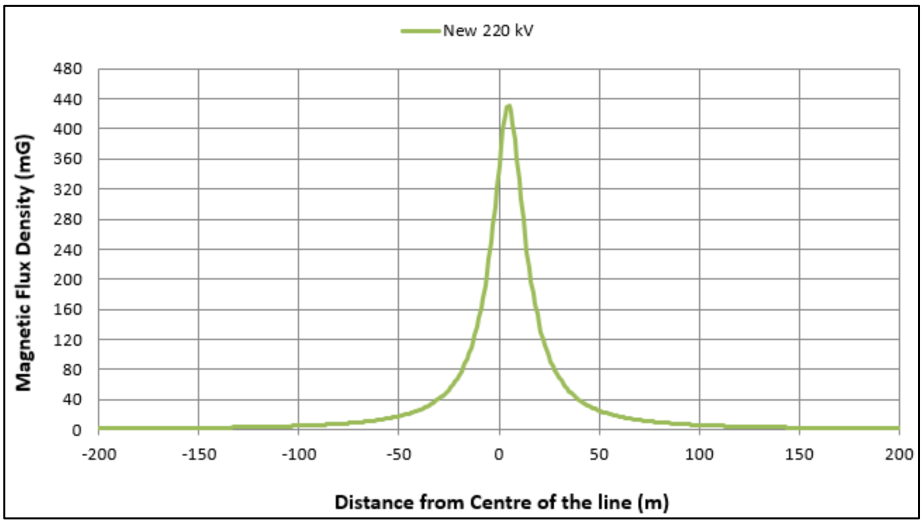
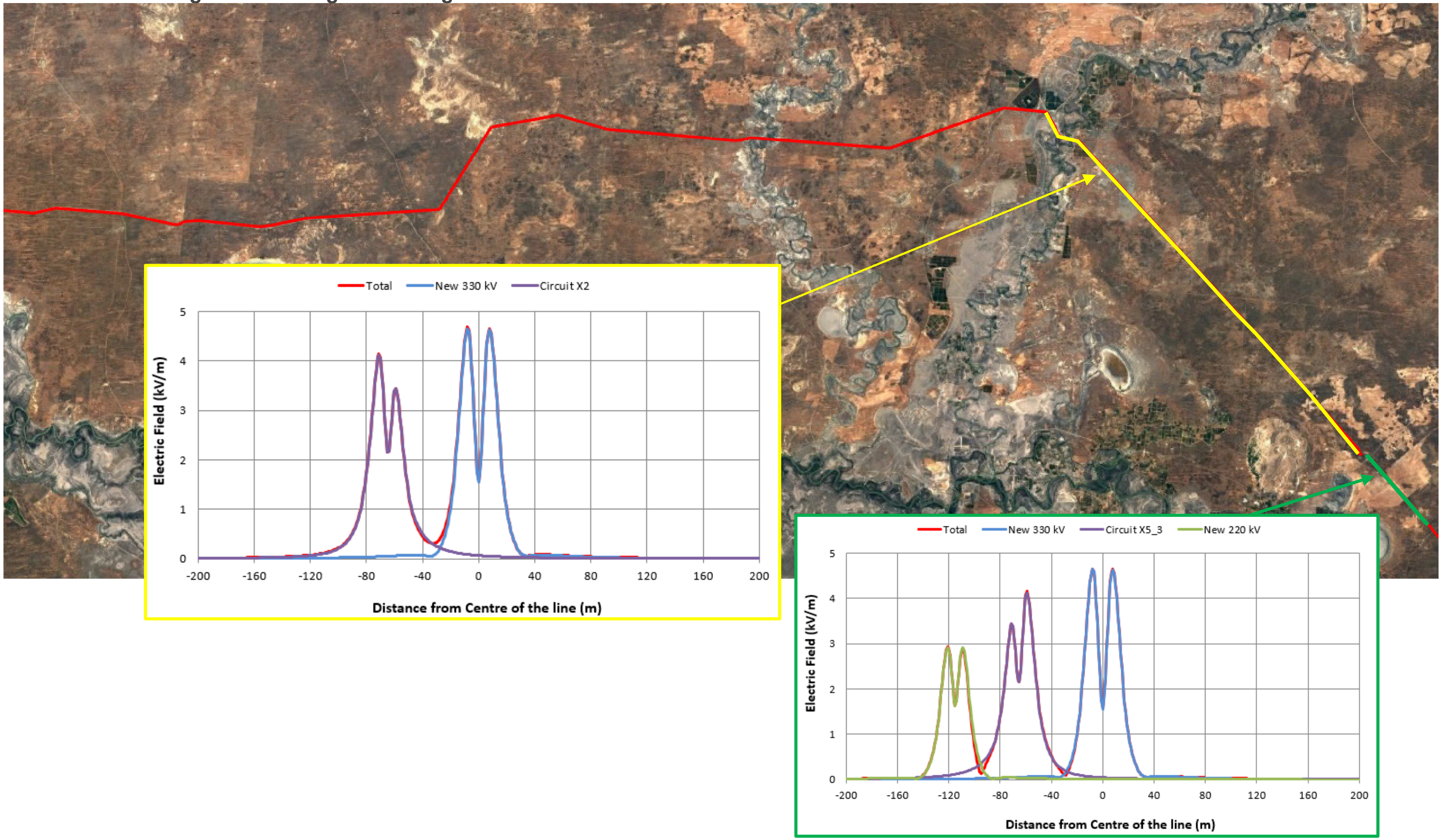


Figure 5-16: Substation Landing Span - Concept 220 kV line magnetic flux density – maximum contingency case

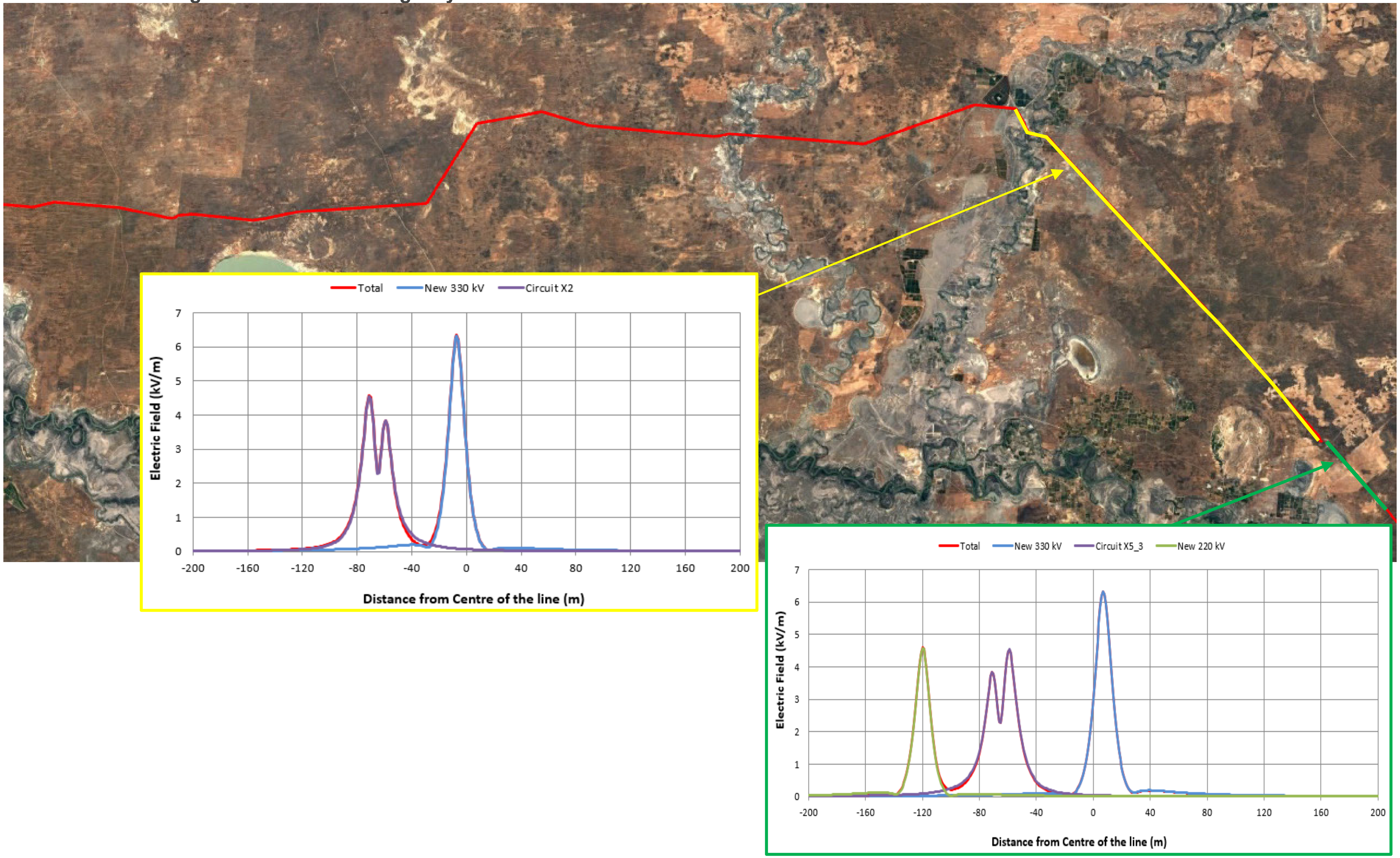
Appendix D – Parallel Lines EFS and MFD Calculations

Buronga – Border (concept 330 kV)

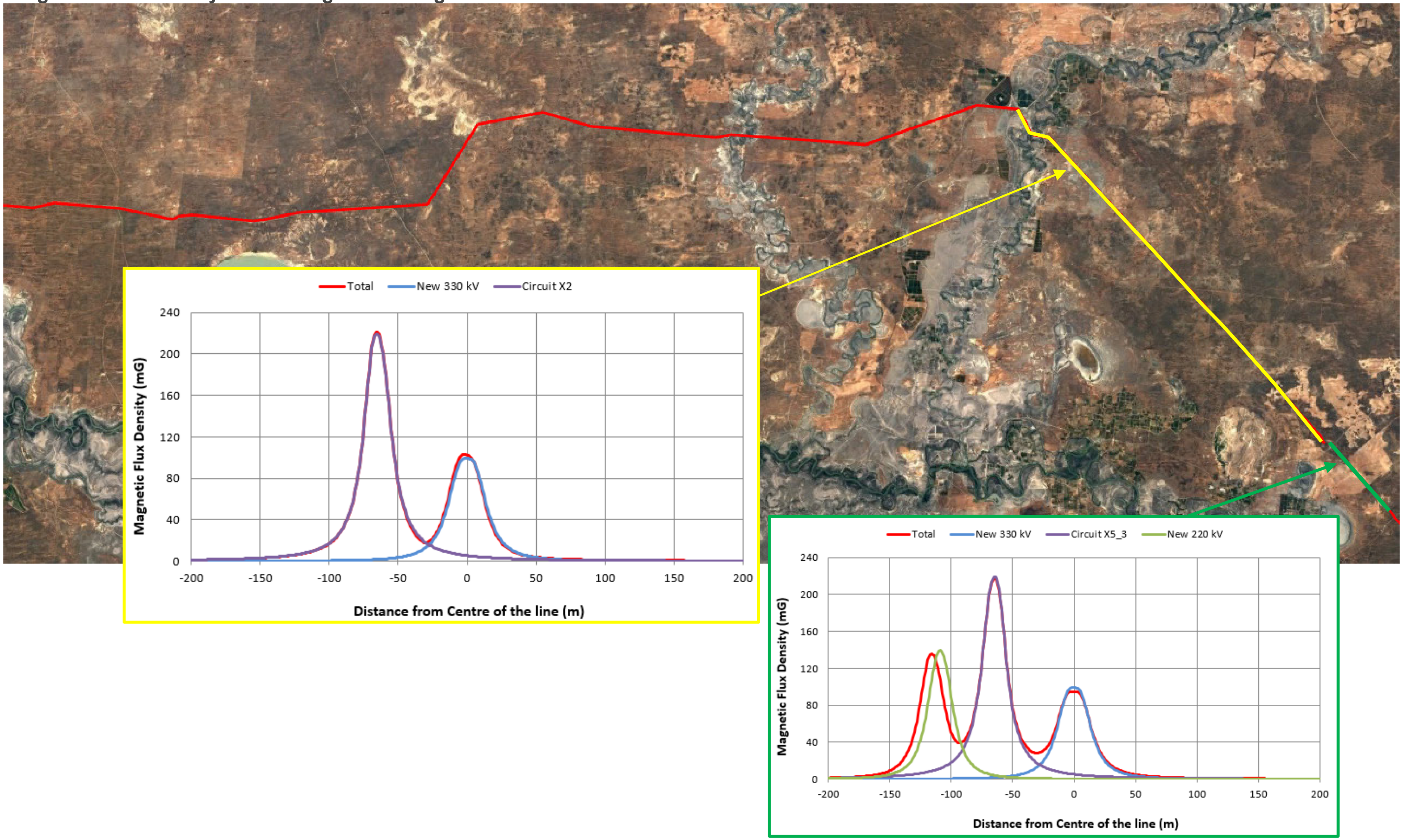
Electric Field Strength - Time weighted average case



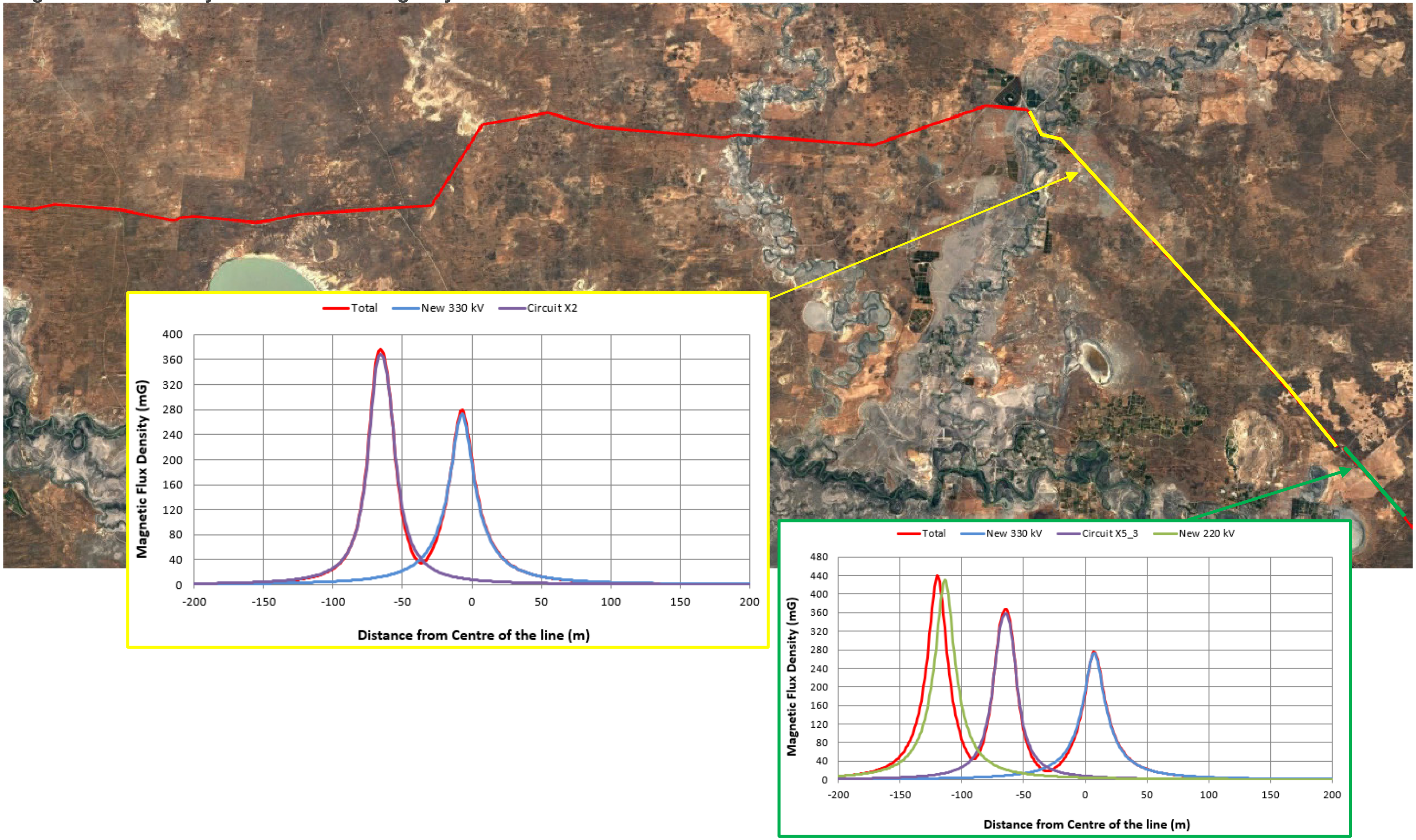
Electric Field Strength – Maximum contingency case



Magnetic Flux Density - Time weighted average case



Magnetic Flux Density – Maximum contingency case



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Appendix E – Tower Geometries

New 330 kV parallel with Circuit X5/3 & New 220 kV (time weighted average case)

COORDINATES OF PHASE CONDUCTORS (EXCLUDING CIRCUIT OFFSET)

BUNDLE NUMBER	COORDINATES-OF-BUNDLE ABSCISSA meter(s)	HEIGHT meter(s)	PHASE NUMBER
1	-7.150	10.200	1
2	-7.150	17.400	2
3	-7.150	24.600	3
4	7.150	24.600	1
5	7.150	17.400	2
6	7.150	10.200	3
7	-69.300	14.200	1
8	-69.800	8.800	2
9	-60.200	8.800	3
10	-119.700	9.600	1
11	-119.700	15.300	2
12	-119.700	21.000	3
13	-110.300	21.000	1
14	-110.300	15.300	2
15	-110.300	9.600	3

New 330 kV

Circuit X5/3

New 220 kV

COORDINATES OF NEUTRAL WIRES (EXCLUDING CIRCUIT OFFSET)

NEUTRAL WIRE NUMBER	<COORDINATES-OF-WIRE> ABSCISSA meter(s)	HEIGHT meter(s)	PHASE NUMBER
16	-7.150	28.600	0
17	7.150	28.600	0
18	-65.700	22.300	0
19	-119.700	23.500	0
20	-110.300	23.500	0

New 330 kV

Circuit X5/3

New 220 kV

New 330 kV parallel with Circuit X5/3 & New 220 kV (Maximum contingency case)

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COORDINATES OF PHASE CONDUCTORS (EXCLUDING CIRCUIT OFFSET)
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BUNDLE NUMBER	COORDINATES-OF-BUNDLE ABSCISSA meter(s)	HEIGHT meter(s)	PHASE NUMBER
1	-7.150	9.000	1
2	-7.150	16.200	2
3	-7.150	23.400	3
4	7.150	23.400	1
5	7.150	16.200	2
6	7.150	9.000	3
7	-69.300	13.700	1
8	-69.800	8.300	2
9	-60.200	8.300	3
10	-119.700	8.300	1
11	-119.700	14.000	2
12	-119.700	19.700	3
13	-110.300	19.700	1
14	-110.300	14.000	2
15	-110.300	8.300	3

New 330 kV (bundles 1–6)

Circuit X5/3 (bundles 7–9)

New 220 kV (bundles 10–15)

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COORDINATES OF NEUTRAL WIRES (EXCLUDING CIRCUIT OFFSET)
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NEUTRAL WIRE NUMBER	<COORDINATES-OF-WIRE> ABSCISSA meter(s)	HEIGHT meter(s)	PHASE NUMBER
16	-7.150	27.400	0
17	7.150	27.400	0
18	-65.700	22.100	0
19	-119.700	22.200	0
20	-110.300	22.200	0

New 330 kV (wires 16–17)

Circuit X5/3 (wire 18)

New 220 kV (wires 19–20)

New 330 kV parallel with Circuit X2 (time weighted average case)

COORDINATES OF PHASE CONDUCTORS (EXCLUDING CIRCUIT OFFSET)

BUNDLE NUMBER	COORDINATES-OF-BUNDLE ABSCISSA meter(s)	HEIGHT meter(s)	PHASE NUMBER
1	-7.150	10.200	1
2	-7.150	17.400	2
3	-7.150	24.600	3
4	7.150	24.600	1
5	7.150	17.400	2
6	7.150	10.200	3
7	-60.700	14.200	1
8	-60.200	8.800	2
9	-69.800	8.800	3

New 330 kV

Circuit X2

COORDINATES OF NEUTRAL WIRES (EXCLUDING CIRCUIT OFFSET)

NEUTRAL WIRE NUMBER	<COORDINATES-OF-WIRE> ABSCISSA meter(s)	HEIGHT meter(s)	PHASE NUMBER
10	-7.150	28.600	0
11	7.150	28.600	0
12	-64.300	22.600	0

New 330 kV

Circuit X2

New 330 kV parallel with Circuit X2 (Maximum contingency case)

COORDINATES OF PHASE CONDUCTORS (EXCLUDING CIRCUIT OFFSET)

BUNDLE NUMBER	COORDINATES-OF-BUNDLE ABSCISSA meter(s)	HEIGHT meter(s)	PHASE NUMBER
1	-7.150	9.000	1
2	-7.150	16.200	2
3	-7.150	23.400	3
4	7.150	23.400	1
5	7.150	16.200	2
6	7.150	9.000	3
7	-60.700	13.700	1
8	-60.200	8.300	2
9	-69.800	8.300	3

New 330 kV

Circuit X2

COORDINATES OF NEUTRAL WIRES (EXCLUDING CIRCUIT OFFSET)

NEUTRAL WIRE NUMBER	<COORDINATES-OF-WIRE> ABSCISSA meter(s)	HEIGHT meter(s)	PHASE NUMBER
10	-7.150	27.400	0
11	7.150	27.400	0
12	-64.300	22.100	0

New 330 kV

Circuit X2