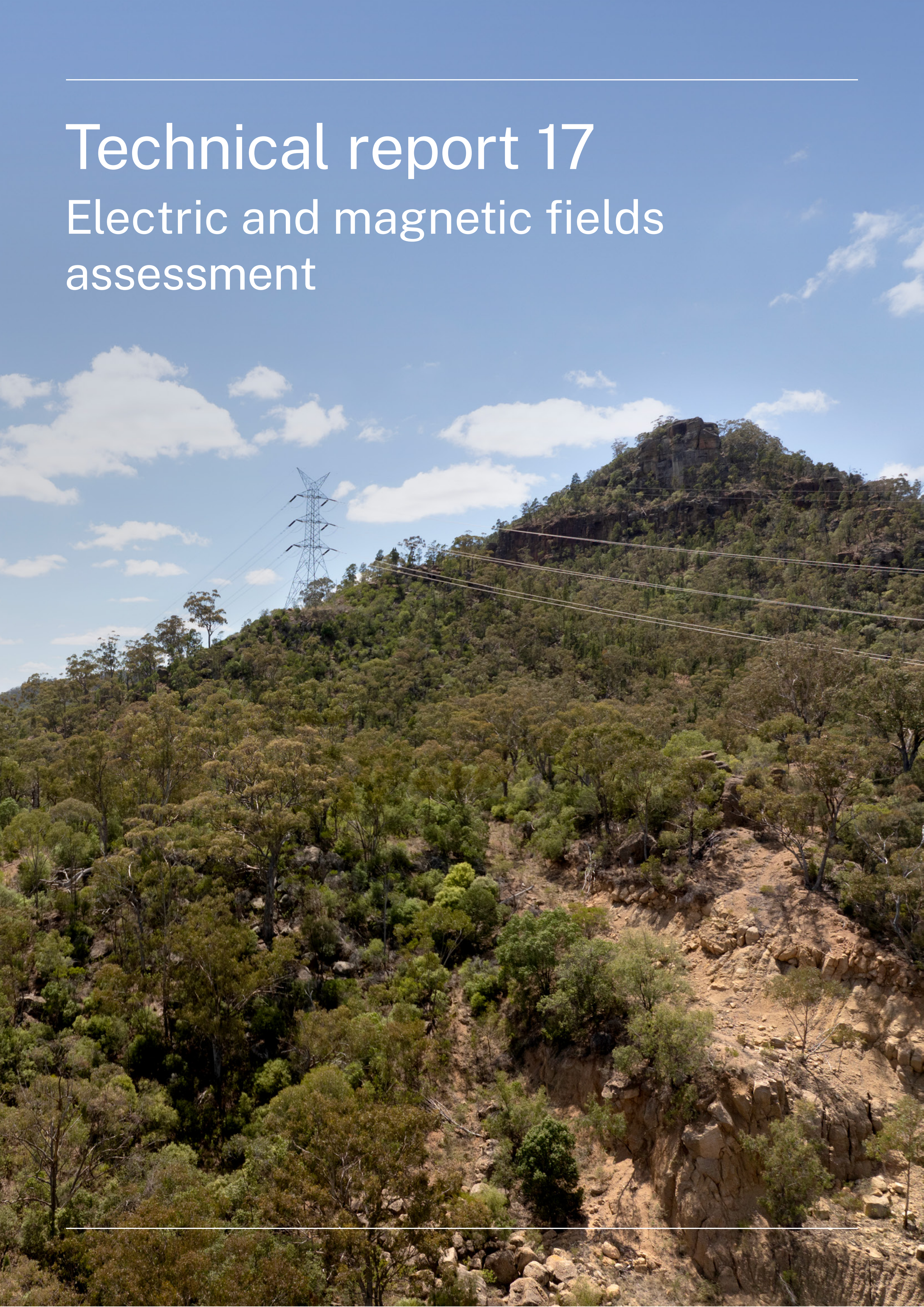
Technical report 17

Electric and magnetic fields assessment



HUNTER TRANSMISSION PROJECT - HTP

Transmission Lines Electric and Magnetic Fields (EMF) Assessment

Prepared for EnergyCo
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Contents

Appendices

Revision History

Revision Nº	Prepared By	Description	Date
0	Arpana Korshapati	Draft Issue	14/03/2025
1	Arpana Korshapati	Gold Review – Draft (not for public release)	03/05/2025
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on behalf of	Beca Pty Ltd		

Glossary of Terms

AVP	Australian Energy Market Operator Victorian Planning
ARPANSA	Australian Radiation Protection and Nuclear Safety Agency
CDEGS	Current Distribution Electromagnetic Interference Grounding and Soil Structure Analysis
EF	Electric Field
EFS	Electric Field Strength
EMF	Electric and Magnetic Fields
ELF	Extremely Low Frequency
EHV	Extra High Voltage
ENA	Energy Networks Association
EPRI	Electric Power Research Institute
HIFREQ	Electromagnetic Fields Analysis Software
IARC	International Agency for Research on Cancer
ICNIRP	International Commission on Non-Ionizing Radiation Protection
IEEE	Institute of Electrical and Electronics Engineers
IRPA/INIRC	International Non-Ionising Radiation Committee of the International Radiation Protection Association
kV	Kilovolts
kV/m	Kilovolts per metre
MFD	Magnetic Flux Density
MGC	Minimum Ground Clearance
mG	Milligauss
OPGW	Optical Ground Wire
p.u	per unit
TWA	Time Weighted Average
SEARs	Secretary's Environmental Assessment Requirements
μT	Microtesla
WHO	World Health Organization

Executive Summary

The Hunter Transmission Project (HTP, the project) involves the construction of a new overhead 500 kilovolt (kV) transmission line of around 110 kilometres connecting the existing 500 kV transmission line at Bayswater to the existing 500 kV transmission line in the Olney State Forest near Eraring in the Hunter region of New South Wales (NSW). EnergyCo has commissioned Beca Pty Ltd (Beca) to evaluate the electrical performance of the new HTP overhead 500 kV double circuit transmission line with respect to electric and magnetic fields (EMF).

The purpose of the assessment is to check the EMF levels beneath the proposed HTP 500 kV double circuit lines against the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) recommended International Commission on Non-Ionizing Radiation Protection (ICNIRP) public exposure guidelines.

Electric and Magnetic Fields (EMF)

The magnetic field levels directly beneath the HTP 500 kV double circuit transmission line are well below the ICNIRP general public exposure reference limit of 2,000 milligauss (mG) for all considered scenarios, including during the contingency case of one circuit in service with increased load and the other circuit out of service.

The magnetic field levels associated with the contingency loads will only occur for short periods on rare occasions. Time weighted average loads associated with normal operation are provided to give more typical levels during normal operation both under the line and at the edge of the easement. The magnetic field levels at the edge of the easement under normal operating conditions for the bulk of the line (away from other transmission line crossings and parallel lines) are similar to those associated with a typical hairdryer.

The electric field levels directly under the proposed transmission line are within 9.1 kilovolts per metre (kV/m), in all cases. The 9.1 kV/m value can be shown to meet the ICNIRP general public basic restriction of 0.02 V/m for the central nervous system tissues of the head, as determined by Transgrid commissioned modelling.

Prudent Avoidance

EnergyCo is guided by leading health authorities (ARPANSA) and the World Health Organisation (WHO) for EMF health effects and have adopted Transgrid's precautionary approach[1] to EMF. In developing the arrangement and preferred alignment of the HTP 500 kV double circuit transmission line, EnergyCo has:

- Adopted a minimum ground clearance height of 13.5 metres providing a margin and reducing fields when compared to the absolute minimum ground clearance of 12.5 metres.
- Adopted tower designs which feature relatively compact phase spacings, which help reduce the resulting EMF.
- Utilised low reactance phase arrangements to allow mutual cancellation of the fields from different phases.
- Advised that the transmission line corridor selection process[2] implemented included the consideration and selection of a corridor which maximises distances to dwellings and inhabited areas wherever possible.

It is recommended that Prudent Avoidance mitigation measures continue to be applied through design and construction where warranted and practicable in accordance with EnergyCo policy for prudent avoidance as outlined in Section 4.5. Within 12 months after energisation, field strength measurements will be undertaken at several locations along the transmission line corridor (i.e. at the edge of the transmission line easement,

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[1] For more information regarding Transgrid's precautionary approach and how EMF are considered in the planning, design and location of HTP West, please see the following fact sheet: https://www.transgrid.com.au/media/1nrfxwtf/emf-fact-sheet.pdf

[2] The route corridor selection and refinement process applied for HTP is documented separately by EnergyCo in the Environmental Impact Statement.

directly under the lines) to confirm the installation is compliant to the relevant EMF design criteria and applicable standards.

1 Introduction

The Hunter Transmission Project (HTP, the project) involves the construction of a new overhead 500 kV transmission line of around 110 kilometres connecting Bayswater south Switching Station to Olney Switching Station near Eraring in the Hunter region of New South Wales (NSW).

Due to its strategic importance, the NSW Minister for Planning and Public Spaces has declared the HTP to be critical State significant infrastructure (CSSI) under the NSW Environmental Planning and Assessment Act 1979 (EP&A Act).

Under this process, the Energy Corporation of NSW (EnergyCo, the proponent) is required to prepare an environmental impact statement (EIS) in accordance with the *NSW Environmental Planning and Assessment Regulation 2021.*

This Electric and Magnetic Fields (EMF) Study accompanies the EIS for the HTP and addresses the Secretary's environmental assessment requirements (SEARs) issued on 13 August 2024 (see Table 1).

Table 1: HTP SEARs - Electric and Magnetic Fields

Reference	Secretary's Environmental Assessment Requirements
General Requirements	An assessment of potential hazards and risks associated with electric and magnetic fields (EMF) having regard to the latest advice of the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA). Planning Secretary's Environmental Assessment Requirements, Section 5.16 of the Environmental Planning and Assessment Act 1979, Part 8 of the Environmental Planning and Assessment Regulation 2021

The HTP scope includes:

- a new overhead 500 kV double circuit transmission line of around 110 kilometres,
- 2 new switching stations (Bayswater South and Olney),
- upgrades to the existing Bayswater and Eraring substations,
- adjustments and upgrades to existing transmission lines,
- property adjustment works to facilitate access to the transmission lines and switching stations,
- utility adjustments required for the construction of the transmission network infrastructure, and
- ancillary works to support construction, including establishment of new access tracks and upgrade of existing access tracks, construction support sites and temporary worker accommodation, and other construction facilities such as laydown areas.

The new transmission line would transport electricity generated in the Central-West Orana and New England Renewable Energy Zones (REZs). It would connect the existing 500 kV transmission line at Bayswater to the existing 500 kV transmission line in the Olney State Forest near Eraring. This would strengthen the State's core electricity grid and supply clean and reliable energy to NSW consumers for generations to come.

The HTP involves development across 5 local government areas (Muswellbrook, Singleton, Cessnock, Central Coast and Lake Macquarie). Most of this development would be concentrated in and around the HTP corridor.

EnergyCo have adopted Transgrid's Transmission Lines Standards & Guidelines that specify the electric fields produced by a new transmission line shall be limited to meet the basic restrictions stated within the Guidelines for limiting exposure to time-varying electric and magnetic fields (1 Hz – 100 kHz) (ICNIRP 2010). This approach is in line with the one taken to develop the HTP reference design for the transmission line, which also follows the requirements set out in Transgrid's standards and guidelines.

2 Scope of Study

Beca Pty Ltd (Beca) has been commissioned by EnergyCo to assess the electrical performance of the new HTP 500 kV double circuit transmission line with respect Electric and Magnetic fields (EMF). The preferred alignment for the new 500 kV transmission line is identified as an **orange** line in Figure 1. This line is representative of the location of the HTP transmission line for the purposes of the EMF assessment, and it is referred to by this study as HTP 500 kV double circuit transmission line.

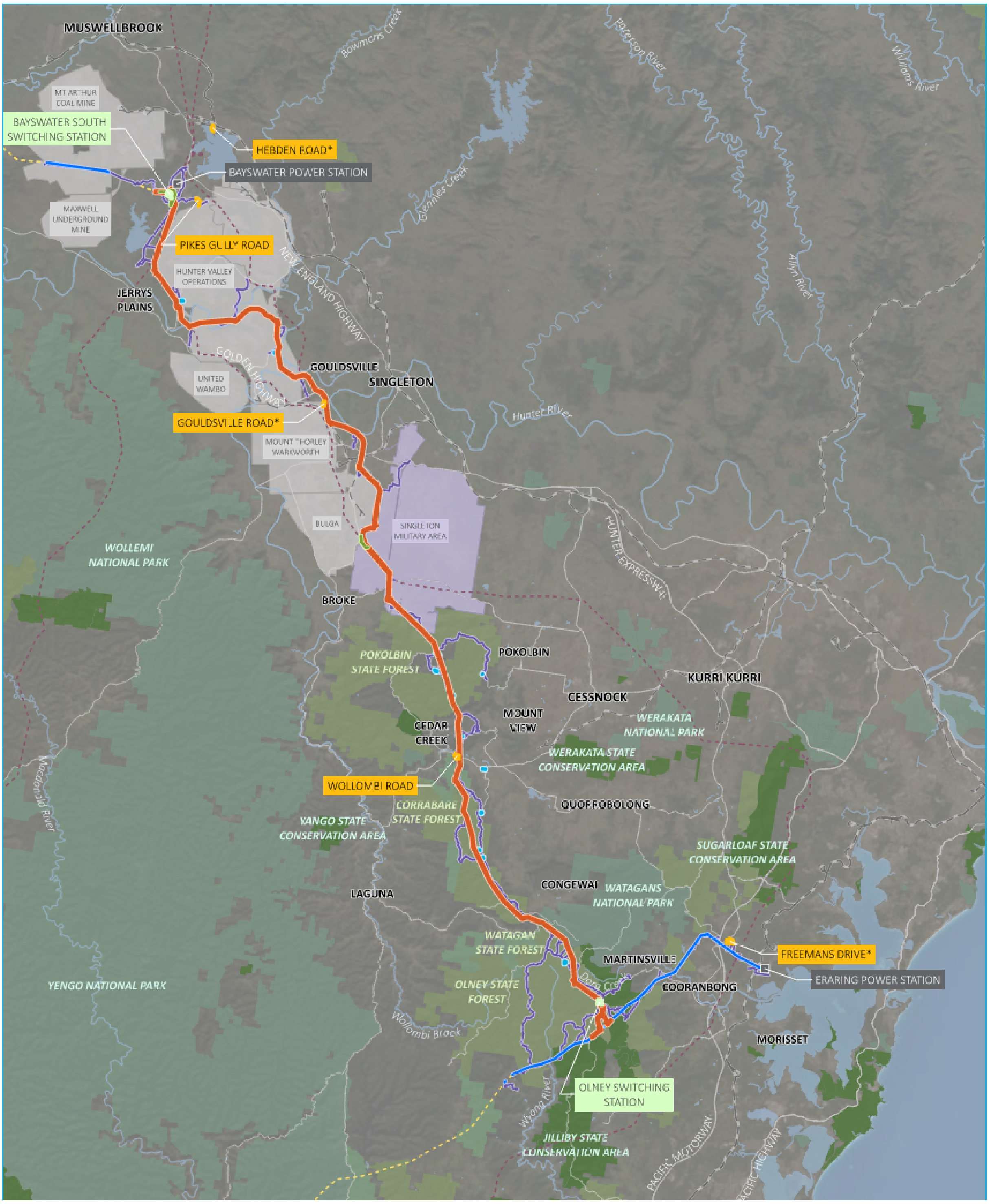

Figure 1: Hunter Transmission Project Overview

The purpose of this study is to identify the absolute limits for the new transmission line's minimum ground clearance, with respect to the applicable limits for EMF, and to protect against chronic (low-level) exposure to EMF with the application of prudent mitigation measures where warranted and practicable.

This EMF study has been carried out in accordance with the requirements of the relevant Transgrid, Australian and international standards, industry guidelines and publications as specified in Table 2.

Table 2: Standards, policies and industry guidelines/publications referenced in the study.

Document	Title	Revision
Transgrid Transmission Line and Substations Design Standards and Guidelines		
-	Transgrid transmission lines standards and guidelines	-
-	Transgrid substations standards and guidelines	
International Standards and Publications		
AS/NZS 7000	Overhead line design	2016
AS/NZS 2067	Substations and High Voltage Installations Exceeding 1kV a.c. - Victoria	2016
ICNIRP	Guidelines for limiting exposure to time-varying electric and magnetic fields (1 Hz to 100 kHz)	2010
Policies and Guidelines, Technical Notes and Publications		
ARPANSA	Measuring magnetic fields *(Source: https://www.arpansa.gov.au/understanding-radiation/radiation-sources/more-radiation-sources/measuring-magnetic-fields)*	-
EPRI	EPRI AC Transmission Line Reference Book – 200 kV and Above	3rd Edition
IEEE Std C95.3.1™-2010	IEEE Recommended Practice for Measurements and Computations of Electric, Magnetic, and Electromagnetic Fields with Respect to Human Exposure to Such Fields, 0 Hz to 100 kHz	2010
IEEE Std 644-2019	IEEE Standard Procedures for Measurement of Power Frequency Electric and Magnetic Fields from AC Power Lines. New York	2019
Journal of Toxicology and Environmental Health Part B, 8:2, 127-140, DOI: 10.1080/10937400590909022	The Effects of Electromagnetic Fields from Power Lines on Avian Reproductive Biology and Physiology: A Review, Kim J. Fernie & S. James Reynolds	2005
Ministry of Health	Interagency Committee on the Health Effects of Non-ionising Fields, Report to Ministers	2018
Ministry of Health	Electric and Magnetic Fields and Your Health, 2013 edition.	
National Radiological Protection Board	ELF Electromagnetic Fields and the Risk of Cancer, Report of an Advisory Group on Non-Ionising Radiation Chairman, Sir Richard Doll, NRPB Vol. 12 No. 1	2001
Report to the NSW Minister for Minerals and Energy. Sydney, NSW: Department of Minerals and Energy	Inquiry into community needs and high voltage transmission line development, Gibbs, S. H.	1991

Document	Title	Revision
Transgrid Electric and Magnetic Fields Fact Sheet	Source: https://www.transgrid.com.au/media/siqnalb1/09-transgrid_a4_factsheet_humelink-_-emf_01-04-2022.pdf	-
UKNPS EN-5	United Kingdom National Policy Statement for Electricity Networks Infrastructure	2023
Bovine Practice 1980: Vol 1 (15): 51-62	A study of Farm Animals Near 765 kV Transmission Lines, HE Amstutz and DB Miller	1980
Preventive Veterinary Medicine Vol 5: 21-36	Effects of Long-Term Exposure to a 400 kV 50 Hz Transmission Line on Estrous and Fertility in Cowers, B Algers and J Hultgren	1987
Journal of Dairy Science Vol 62	An investigation of Dairy Farm Operations in Association with 765 kV Transmission in Ohio, JH Williams and EJ Beiler	1979
Transmission and Distribution, Vol 32: 28 - 30	Pigs Fare Well Under 345 kV Line, AA Mahmoud and D Zimmerman	1982

Qualifications, Assumptions & Exclusions

- The content and outcomes of this report are based on system definition information (refer to document references listed in Section 3), applicable to; system parameters and loading profiles (current and voltage levels). This information has been supplied and confirmed by EnergyCo under this project for use in this assessment.
- A climbing corridor EMF assessment or elevated work platform EMF assessment for tower maintenance is to be assessed during detailed design, and hence not assessed in this report.
- At each transposition location the towers and spans are to be designed such that the EMF falls within safe limits both directly under the line and at the edge of the identified easement. The design and evaluation of the transposed towers and spans is outside of this report. Detailed design of transposed towers is to be completed (by others) during detailed design phase.
- Any significant changes to the information presented in Section 3 will require a revision of this document.
- Transmission and distribution lines parallel to and undercrossing the HTP line achieve the minimum ground clearances as required by AS/NZS 7000.
- Possible effects on telecommunications systems and radio communication services are not assessed as part of this report. Refer to the Hunter Transmission Project, Audible Noise and Radio Frequency Interference Study (Doc. No. 2583080-RPT-100-UE-001 prepared by Beca) for this assessment.

3 Study Inputs

The study of EMF associated with transmission lines heavily depends on factors related to the system definition, including phase conductor/earth wire information, system operating conditions (feeder loading), and tower/line configurations for conductor heights relative to an observation point. Any significant changes to this information will necessitate a revision of this document.

3.1 Reference Documents

The information listed in Table 3 and Table 4 includes drawings and information which have been referred to in this assessment.

Table 3: Reference documents used for EMF study.

Reference	Title	Rev
2583080-RPT-100-JB-001	Hunter Transmission Project – Basis of Design	4.0
-	Hunter Transmission Project - Preferred Route[3] (.Kmz)	-
-	Line 81 (.Kmz)	-
-	Line 82 (.Kmz)	-
-	66 kV Ausgrid Line (.Kmz)	-
-	132 kV Ausgrid Line (.Kmz)	-
-	66 kV HVO Lines (Ausgrid) (.Kmz)	-
-	33 kV AGL Line (Ausgrid) (.Kmz)	-
-	Line 31 and Line 32 (.Kmz)	-
2583080-RPT-100-UE-001	Hunter Transmission Project- HTP- Audible Noise and Radio Frequency Interference Study	-

Table 4: Reference tower drawings used for EMF study.

Reference	Title	Rev
SKE-2583080-TL-001	Hunter TP 500 kV TL- Suspension tower type VSE/VSEH	-
SKE-2583080-TL-002	Hunter TP 500 kV TL- Light strain tower type VTU	-
SKE-2583080-TL-003	Hunter TP 500 kV TL- Medium strain tower type VTV	-
SKE-2583080-TL-004	Hunter TP 500 kV TL- Heavy strain tower type VTW	-
2583080-DRG-400-TL-0011_1	Transgrid line crossings HTP1 Span 92-93, 330 kV Line 81 (Deviation)	1
2583080-DRG-400-TL-0011_4	Transgrid line crossings HTP1 Span 176-177, 330 kV Line 81 (Deviation)	1

[3] Project brochure available online: https://majorprojects.planningportal.nsw.gov.au/prweb/PRRestService/mp/01/getContent?AttachRef=SSI-70610456%2120240509T042827.867%20GMT

4 Overview of Electric and Magnetic Fields

This section provides an overview of electric and magnetic fields (EMF), setting out the exposure limits adopted for HTP based on applicable national and international guidelines. This section does not constitute an expert assessment of the health effects related to EMF. However, it provides a summary of identified studies and guidelines.

4.1 What are Electric and Magnetic fields?

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

Electric fields are determined by voltage, and the electric field strength is measured in kV/m. At any given location around a transmission line, electric fields will be largely constant if the equipment is energised. The higher the operating voltage of the line, the higher the electric field around the conductor itself. Electric fields are reduced significantly as the distance from the conductor increases. Hence, electric fields at ground level under a transmission line can be reduced by increasing its height. Electric fields are shielded by most objects, including trees, buildings, and human skin.

Magnetic fields on the other hand, will change in strength over time in line with the magnitude of the current (Amps). 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 flux density (MFD), the physical quantity of measurement of magnetic fields (measured in milliGauss). Variations in the current follow typical patterns, with morning and evening peaks, and larger loads reflecting seasonal variations. 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 due to the lines sagging closer to the ground level and the distance between the line (the source of the fields) and the ground decreases.

EMF reduce rapidly with distance from their source. For transmission lines, EMF are up to approximately four times lower for every doubling of distance from a line. A similar principle applies to substations: electric and magnetic fields (EMF) decrease rapidly with increasing distance from the source equipment (such as busbars, transformers, and switchgear). While the exact rate of reduction depends on the configuration and type of equipment, the general trend is that EMF levels drop off significantly as you move away from the source.

Figure 2 provides typical magnetic field strengths, while field strengths will usually be within the ranges of values shown, values outside the range are possible.

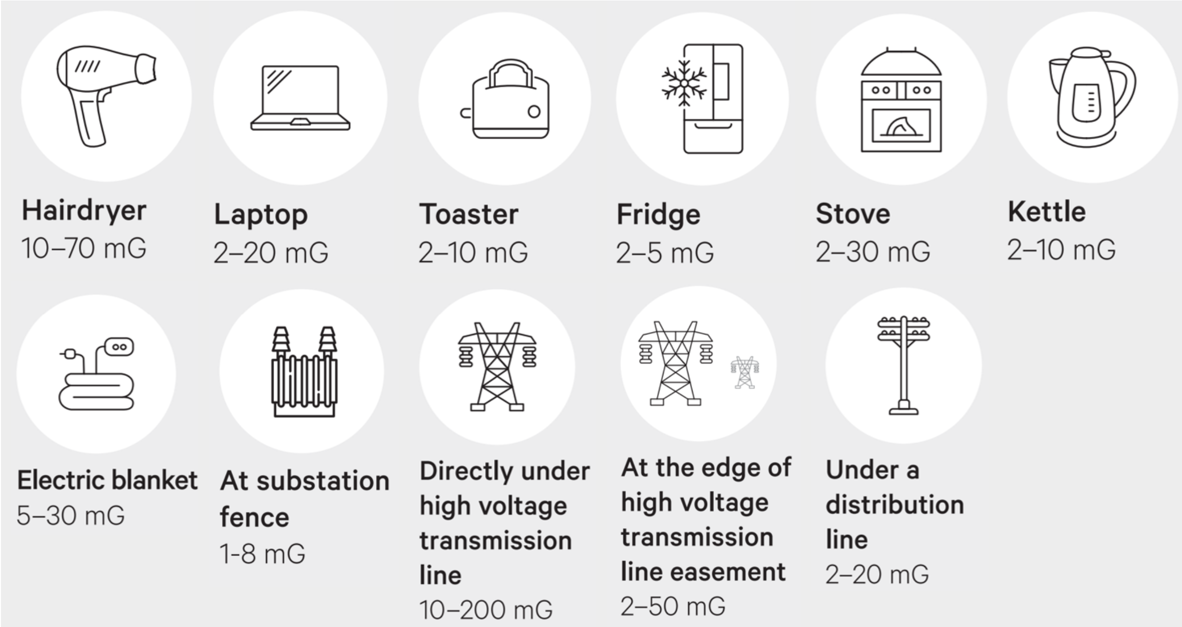

Figure 2: Typical range of magnetic fields[4]

4.2 Health and Electric and Magnetic fields

4.2.1 Potential Effects of Electric and Magnetic Fields

The impact of ELF EMF exposure has been researched worldwide over decades. In Australia, **ARPANSA** maintains continual oversight of emerging research in this field, to maintain and provide accurate and current advice. ARPANSA conclude that "*the scientific evidence does not establish that exposure to ELF EMF [found near powerlines and other electrical sources] is a hazard to human health*"[5].

It is well known and understood that ELF EMF induces internal electric fields and currents in the body. Should the external fields be above the reference levels set out in Table 5, the induced electric fields could interfere with the body's nervous system causing nerve and muscle stimulation and changes in nerve cell excitability in the central nervous system[6]. Such effects on the human body may include hair movement, the magneto-phosphene effect and micro-shocks, as described further below:

- Hair movement can be caused to move by strong electric fields.
- The magneto-phosphene 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 may occur in circumstances when the body comes into contact with objects such as fence lines that may have a voltage induced in them[7].

The exposure guidelines set out in Section 4.2.3 is in place to protect against these biological effects.

[4] Information and diagrams sourced from Transgrid Electric and Magnetic Fields Fact Sheet https://www.transgrid.com.au/media/siqnalb1/09-transgrid_a4_factsheet_humelink-_-emf_01-04-2022.pdf

[5] Sourced from ARPANSA website: https://www.arpansa.gov.au/understanding-radiation/radiation-sources/more-radiation-sources/electricity

[6] Sourced from World Health Organisation: https://www.who.int/publications/m/item/2007-who-research-agenda-for-extremely-low-frequency-fields

[7] Sourced from World Health Organisation: https://www.who.int/publications/m/item/2007-who-research-agenda-for-extremely-low-frequency-fields

4.2.2 Health Research

A large number of studies have been conducted over many years to investigate the possibility of adverse health consequences from ELF EMF. These studies have addressed a wide range of end points including childhood leukaemia, other childhood cancers, cancers in adults, depression, suicide, cardiovascular disorders, reproductive dysfunction, developmental disorders, immunological modifications, neurobehavioral effects, and neurodegenerative disease. In general, the results have been reassuring but, in the case of childhood leukaemia, several studies have reported a statistical association between childhood leukaemia and prolonged exposure to higher-than-normal magnetic fields. This led the **International Agency for Research on Cancer (IARC),** (part of the **World Health Organisation (WHO))** in 2002 to classify ELF magnetic fields as "possibly carcinogenic to humans" – Group 2B[8]. 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 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."* [9]

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[10] No.238 reviewed studies which were conducted after the IARC classified was published. Their principal conclusions on health risks were reported as follows[11]:

- *"The IARC classification was heavily influenced by the association observed in epidemiological studies on childhood leukaemia. The classification of this evidence as limited does not change with the addition of two childhood leukaemia studies published after 2002. Since the publication of the IARC monograph the evidence for other childhood cancers remains inadequate." - WHO 2007*
- 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.

Overall, the picture is largely unchanged since publication of the WHO review in 2007. The fact that, despite over 30 years of laboratory research, no mechanism for an effect has been established, lends weight to the possibility that the observed statistical associations reflect some factor other than a causal relationship. This point was driven by the late Sir Richard Doll, an eminent epidemiologist and chair of the UK National Radiological Protection Board's (NRPB) Advisory Group:

> *"in the absence of clear evidence of a carcinogenic effect in adults, or of a plausible explanation from experiments on animals or isolated cells, the evidence is currently not strong enough to justify a firm conclusion that such fields cause leukaemia in children."*[12]

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

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

[10] The EHC monographs are usually revised if new data becomes available that would change the evaluation

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

[12] National Radiological Protection Board, (UK), ELF Electromagnetic Fields and the Risk of Cancer, Report of an Advisory Group on Non-Ionising Radiation, Chairman, Sir Richard Doll, NRPB Vol. 12 No. 1, Page 164 – 2001.

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[13]. The research on possible links with neurodegenerative diseases has also provided no consistent results[14].

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."*[15]

A recent review, published in March 2015 by the **European Commission and the Scientific Committee on Emerging Newly Identified Health Risks (SCENIHR)** finalised its opinion on the potential health effects of exposure to EMF. Similarly, they concluded that overall:

"..existing studies do not provide convincing evidence for a causal relationship between magnetic field exposure and self-reported symptoms." and,

"..recent results show no evidence of ELF fields on the reproductive function in humans."

In June 2015, WHO released the latest progress report of the International EMF project[16] - the progress report makes specific mention of the SCENIHR publication, and reports that although *"close communication is maintained with the European Commission"* and WHO are "*kept abreast with their work,* no updates to the existing publications are pending.

Basic Restrictions and Reference Levels as specified in the ICNIRP guidelines for General public exposure are based on established health effects as outlined in Section 4.2.3, Table 5.

4.2.3 Exposure Guidelines and Management of EMF

The Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) is the Federal Government agency responsible for advising on exposure limits to Electric and Magnetic Fields (EMF). ARPANSA has adopted the International Commission on Non-Radiation Protection (ICNIRP) guidelines for limiting EMF exposure. These guidelines are one of two international standards recognised by the World Health Organisation (WHO) and are considered international best practice.

The ICNIRP guidelines define **Basic Restrictions** and **Reference Levels** for EMF exposure, with separate specifications for "Occupational" and "**General public**" groups. The more stringent General public levels as specified in the ICNIRP guidelines are considered by this assessment.

General public exposure refers to EMF exposure experienced by individuals who are often unaware of their exposure to electric and magnetic fields. Members of the general public may be continuously exposed and are not reasonably expected to take precautions to minimise or avoid such exposure.

Occupational exposure refers to exposure to EMF experienced by individuals as a result of performing their regular or assigned job activities.

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[13] WHO, Electromagnetic fields and public health fact sheet, accessed from https://www.who.int/publications/m/item/2007-who-research-agenda-for-extremely-low-frequency-fields on 2007

[14] Interagency Committee on the Health Effects of Non-ionising Fields, Report to Ministers 2018.

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

[16] WHO launched the International EMF Project in May 1996, to assess the health and environment effects of EMF exposure, in response to growing public concern in several Member States over possible health effects and diversity of EMF sources. Since commencement, the EMF Project involves over 50 national authorities with interest and responsibility regarding EMF protection, with oversight provided by the International Advisory Committee (IAC).

Basic Restrictions limit EMF exposure based on established biological factors that could lead to adverse health outcomes. These restrictions are expressed as internal electric fields induced within the body that do not result in harmful effects. As Basic Restriction values apply within body tissue, direct measurement is challenging and impractical.

Reference Levels have been calculated as a simpler means of assessing compliance with Basic Restrictions. Reference Levels are easier to measure and serve as an accessible tool for evaluating EMF exposure.

Basic Restrictions and Reference Levels as specified in the ICNIRP guidelines for General public exposure are summarised in Table 5.

Table 5 : EMF guidelines for the general public (ICNIRP)

ICNIRP EMF Guidelines		Levels
Basic Restriction		
Central nervous system tissues of the head		0.02 V/m
Full body tissues		0.4 V/m
Reference Levels	Electric Field	5 kV/m
	Magnetic Field	200 μT (2000 mG)

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"*[17].

However, as transmission lines of this nature (i.e. EHV) can typically exceed the reference level in some locations, it is necessary to assess them in more detail to determine compliance with the basic restrictions.

To further investigate these scenarios where EHV transmission lines may exceed the reference level, Transgrid has previously commissioned Exponent, Inc to undertake dosimetric analyses[18] of the internal electric fields to evaluate compliance with the ICNIRP general public basic restrictions for electric fields. This was completed using an anatomically accurate human body model beneath 330 kV and 500 kV transmission lines at midspan, where the conductors are closest to a person and electric-field levels are highest. The analysis determined that to meet the ICNIRP general public basic restriction of 0.02 V/m, the maximum electric field strength (EFS) value shall not exceed 9.1 kV/m at 1 metre height above the ground level.

Under normal operating conditions, a more stringent electric fields limits of 7.8 kV/m as an additional control measure to reduce spark discharges has been adopted.

Based on the findings of the dosimetric analyses (electric field strength requirement for EHV to comply with ICNIRP general public restriction), the electric field limits applied to this EMF assessment are based on the Transgrid commissioned modelling, while the magnetic field limits are based on the ICNIRP reference levels listed in Table 5.

The exposure limits used for this assessment are summarised in Table 6.

[17] Sourced from ARPANSA website *"Controlling exposure to ELC electric and magnetic fields":* https://www.arpansa.gov.au/understanding-radiation/what-is-radiation/non-ionising-radiation/low-frequency-electric-magnetic-fields#:~:text=The%20ICNIRP%20ELF%20guidelines%20are,available%20at%20International%20Best%20Practice

[18] 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 6: EMF limits

Field		Level
Electric field	Normal Operation[19]	7.8 kV/m
	Maximum Contingency[20]	9.1 kV/m
Magnetic field		2,000 mG

The 'worst-case' magnetic field is typically when only one circuit is in operation (ie. contingency scenario) and carrying the maximum possible load. This is because, with both circuits operating and carrying balanced loads (especially if phases are transposed), the magnetic fields can partially cancel each other out, resulting in a lower net field. When only one circuit is operating at high load and there is no cancellation effect, the magnetic field at ground level can be higher.

EnergyCo have adopted Transgrid's transmission lines standards & guidelines that specify the electric fields produced by a new transmission line shall be limited to 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). Wherever possible, EnergyCo's policy to comply with the ICNIRP Guidelines at all times and to meet the general public reference levels for electric fields (5 kV/m) will be applied.

4.3 Active Implantable Medical Devices

Common active implantable medical devices include pacemakers and defibrillators. There is considerable variation among different medical implants, including the functioning of the device, model, and how they are fitted and programmed. Physicians typically brief members of the public on managing their medical implants and their susceptibility to interference.

European Directive (90/385/EEC) requires devices be designed and manufactured in such a way as to remove or minimise *"risks connected with reasonably foreseeable environmental conditions such as magnetic fields, external electrical influences, electrostatic discharge, pressure or variations in pressure and acceleration"*.

The European Standard (CENELEC 50527-1) interprets this to mean immunity up to the general public reference levels as set by ICNIRP. However, considering the historic ICNIRP 1998 level, older devices are considered to be immune up to 100 μT (1,000 mG), not the current 2,000 mG.

The magnetic fields generated by 500 kV transmission lines, including under contingency conditions, are unlikely to exceed 1,000 mG. Active implantable medical devices that comply with relevant standards should therefore be immune to interference from these transmission lines. However, individuals with such devices who have concerns are advised to consult their treating physician for further information or guidance[21].

4.4 Effects on Food Production, Plants, and Animals

Animals and Food Production

Electric and magnetic fields have the potential to affect farmed mammal species similarly to humans. Where EMF levels are within the ICNIRP Guidelines, there is unlikely to be any perceptible adverse health effect on animals.

[19] The 7.8 kV/m EMF limit is an additional limit implemented by Transgrid as an additional control measure to reduce spark discharges.

[20] The contingency case is defined as an operational state where one circuit is in service with increased load, and the other circuit is out of service.

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

The Gibbs Report[22] is one of the most frequently referenced sources with several studies conducted to investigate the impacts of electric and magnetic fields on farm animals.

The Gibbs Report notes:

"*A number of experiments have been conducted in the field with a view to discovering whether exposure to the electric fields or the magnetic fields created by transmission lines affects the health, behaviour or reproductive performance of livestock. During the period 1977 – 1979 Amstutz and Miller[23] made a study of eleven livestock farms traversed by a 765 kV transmission line, to determine if the fields created by the line had any detectable effect on farm animals. Various types of livestock were kept on the farms, viz., beef cattle, dairy cattle, sheep, hogs and horses. The report found that neither the health, the behaviour nor the performance of any of these livestock was affected by the electric or magnetic fields created by the line."*

Regarding reproductive capacity, the Gibbs Report references studies conducted in Sweden and states:

"*The effect of electromagnetic fields on the fertility of cattle has been extensively studied in Sweden. A study by Algers and Hultgren[24] of cows exposed for 120 days to 400 kV lines with an average electric field of 4 kV and an average magnetic field of 20 mG found that the exposure did not influence the number of inseminations per pregnancy, the overall conception rate or foetal viability. This confirmed the result of an earlier study which showed, contrary to the concern expressed by some farmers who attributed detrimental effects on animal reproduction to the presence of the lines, that the exposure did not cause decreased fertility."*

Additionally, milk production and cattle health were examined in a long-term study involving dairy farms in Ohio. The Gibbs Report summarises this as follows:

"*A study conducted by Williams and Bieler[25] over six years of 55 dairy farms located near 765 kV lines in Ohio found that the lines had no apparent effect on milk production or on the health of cattle."*

Furthermore, research was carried out in Iowa to evaluate the performance, behaviour, and carcass quality of pigs exposed to electric fields from transmission lines. The Gibbs Report summarises this study as follows:

"*An experiment in Iowa by Mahmoud and Zimmerman[26] in which pigs were grown in pens housed under a 345 kV line showed that the fields from the line had no negative effects on the performance, behaviour or carcass quality of the pigs."*

When referring to potential adverse health effect on insects or bugs, the Gibbs Report did note that beehives located near power lines (i.e. within easement, or directly under lines) could be adversely impacted, such as bee's natural pollination behaviours, leading to negative effects on nearby plant communities (plant richness and abundance). Where observed, this can be mitigated with earthed shielding above the beehives if necessary.

'Bees in hives under or near transmission lines are adversely affected by shocks created by currents induced by the lines but the effect can be mitigated by shielding'

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[22] 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

[23] HE Amstutz and DB Miller (1980), A study of Farm Animals Near 765 kV Transmission Lines

[24] B Algers and J Hultgren (1987), Effects of Long-Term Exposure to a 400 kV 50 Hz Transmission Line on Estrous and Fertility in Cowers, Prev, Vet. Med 5:21-36)

[25] JH Williams and EJ Beiler (1979), An investigation of Dairy Farm Operations in Association with 765 kV Transmission in Ohio

[26] AA Mahmoud and D Zimmerman (1982), Pigs Fare Well Under 345 kV Line

'The Magnetic Fields created by power lines do not affect the health or reproductive capacity of farm animals or present a danger to native fauna.'

Similarly, the United Kingdom National Policy Statement for Electricity Networks Infrastructure[27] found that:

"There is little evidence that exposure of crops, farm animals or natural ecosystems to transmission line EMF has any agriculturally significant consequences"

World Health Organisation (WHO), Environmental Health Criteria 238[28], Extremely Low Frequency Fields reports that:

"In animals, the possibility that exposure to ELF fields may affect neurobehavioural functions has been explored from a number of perspectives using a range of exposure conditions. Few robust effects have been established."

Seasonal breeding animals, such as sheep, goats, deer, and others, may inhabit the area surrounding the transmission line. Therefore, the potential adverse effects of EMF on reproduction are a relevant consideration. The WHO, Environmental Health Criteria 238 identifies that *"The impact of melatonin on reproduction is particularly pronounced in seasonally breeding animals, where the effect varies depending on the length of gestation in order to ensure that the offspring are born in late spring when food is plentiful."*

Of relevance is the set of studies of EMF effects on *"seasonal breeders concerned Suffolk sheep; these have a long gestational period and become reproductively active in the autumn, as day length shortens. In two replicate studies (Lee et al., 1993; 1995), Suffolk lambs were exposed outdoors to the magnetic fields generated by overhead transmission lines for about 10 months. The authors reported no effect of exposure on serum melatonin levels or on the onset of puberty."*

When referring to avian species, extensive research and ongoing debate surround the question of whether exposure to EMF impacts the cellular, endocrine, immune, and reproductive systems of vertebrates, due to the limited number of studies and infancy in terms of research.

Kim J. Fernie & S. James Reynolds (2005) The Effects of Electromagnetic Fields from Power Lines on Avian Reproductive Biology and Physiology: A Review[29], reports that:

"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. Some of this work has involved birds under aviary conditions, while other research has focused on free-ranging birds exposed to EMF."

Plants and Vegetation

The Gibbs Report[30] notes that for vegetation, from a practical standpoint, the electric fields generated by transmission lines do not adversely affect crops, pasture, grasses, or native flora, other than trees – whose growth beneath or near the lines (i.e. within easement, or directly under lines) may be reduced by the effect of

[27] United Kingdom National Policy Statement for Electricity Networks Infrastructure (EN-5), paragraph 2.9.58, 17 January 2024

[28] World Health Organisation, Environmental Health Criteria 238, Pages 161 and 171, 13 March 2007

[29] 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

[30] 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

corona[31]. The concern for trees is later dismissed in the report, since tree heights (and vegetation) near power lines needs to be managed anyway for maintaining safety clearance and avoiding interference.

“The growth of trees which are close to a transmission line may be reduced by the effect of corona. In any case, the height of trees on a transmission line easement will be restricted when this is necessary in the interest of safety.”

“From a practical point of view, the Electric Fields created by transmission lines have no adverse effects on crops, pasture grasses or native flora, other than trees growing under or near to the line.”

The Electric Power Research Institute (EPRI) AC Transmission Line Reference Book—200 kV and Above, Third Edition (2005) reports that with regards to dead tree burning *“Experience indicates that burning occurs only at space potentials[32] greater than 100 kV (EPRI 1982)”* and *“the portion of dead trees that intrude inside the space delimited by the 100 kV contour line may experience burning.”*

When referring to tree tip damage, EPRI reports that *“Live trees near a high-voltage line may continue to grow until a flashover occurs.”, “These phenomena were also observed with small plants but at very high electric fields (McKee et al. 1978). Corona damage is mainly caused by positive corona, whose inception occurs at space potentials greater than 30 to 40 kV.”*

Figure 3 shows the space potential contour lines for a typical span on the HTP 500 kV double circuit transmission line. This figure shows that the high-intensity electric field contours which could result in the burning of dead trees or damage to tree tips are limited to the area immediately surrounding the phase conductors.

The vegetation clearing requirements for the HTP 500 kV line specify that sufficient clearance be maintained between phase conductors and any vegetation. When transmission lines are designed, operated, and maintained in accordance with these requirements, there should be no impact on the tips of trees located directly below or near the phase conductors.

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[31] The *corona effect* is a phenomenon of partial electrical discharge caused by the ionisation of the air surrounding a charged conductor. The source of corona discharges on transmission line is the high electric field strength near the surface of each conductor, which is referred to as the conductor Surface Voltage Gradient (SVG).

[32] Space potential – The space potential point in an electric field is a phasor representing the voltage difference between that point and ground. The unit of space potential is volt.

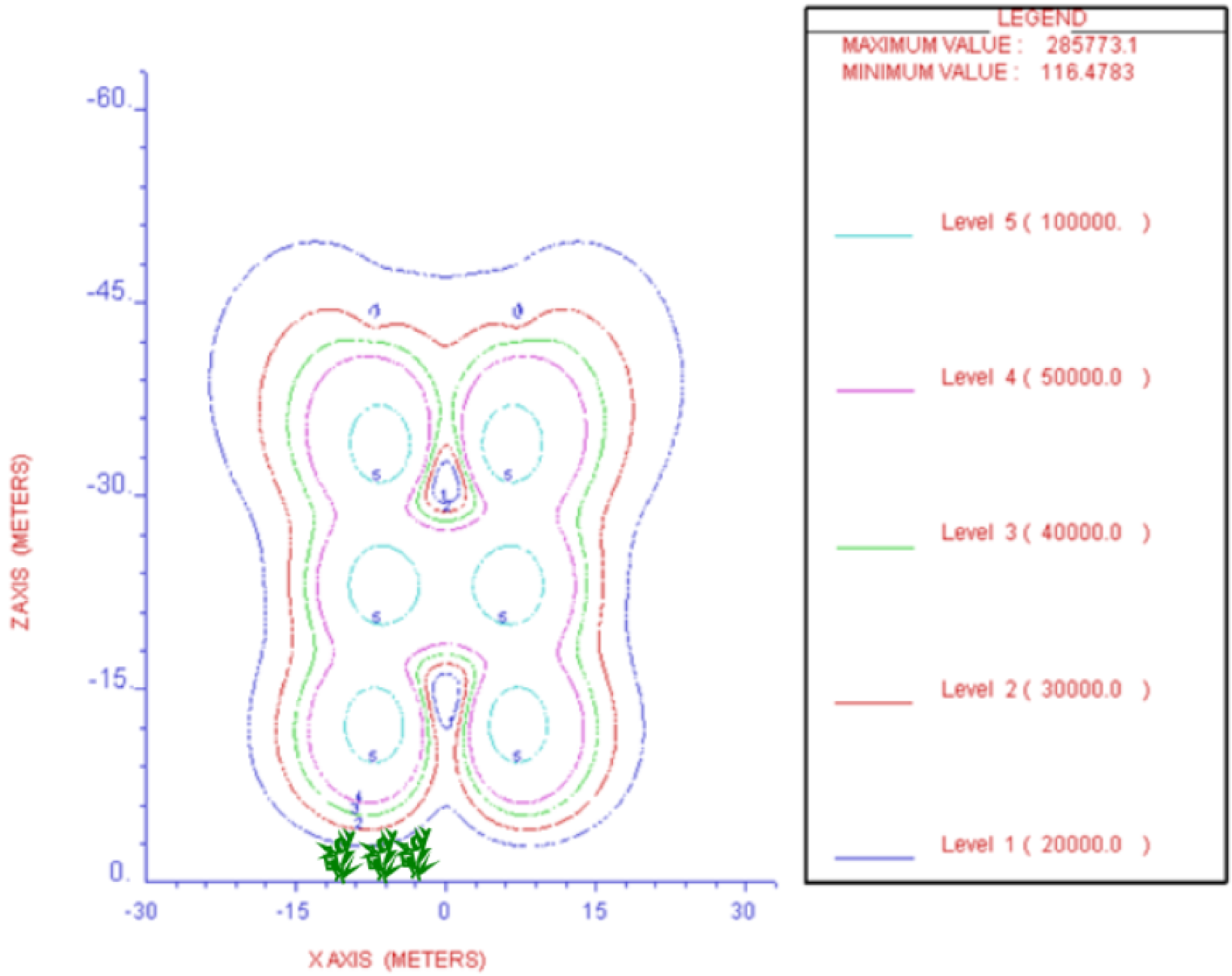

Figure 3: Space potential lines for a 500 kV double circuit transmission line at midspan.

4.5 Prudent Avoidance Policy

From a risk management perspective, EnergyCo have adopted a design philosophy of "prudent avoidance" in line with Energy Networks Association (ENA) EMF Management Handbook (2016). 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*".

In June 2007, WHO reported[33] on possible EMF health effects and made the following statements regarding management of EMF:

- When recommending precautionary steps, "any actions taken should not compromise the essential health, social and economic benefits".
- "It is reasonable and warranted to implement precautionary steps to reduce exposure."
- "The costs of precautionary measures should be very low" given "limited evidence" for links between ELF magnetic-field exposure and childhood leukaemia.

The WHO stated that these precautionary approaches do not support setting limits below the recommended levels set by the exposure guidelines. EnergyCo's position on EMF exposure, which is one of *Prudent Avoidance*, has been adopted in light of (and consistent with) the above findings.

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

The techniques that are available to reduce EMF exposures associated with transmission lines 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.

Typical application of these techniques in transmission line design include:

- Increased ground clearance.
- Compact phase spacings, which help reduce the resulting electric and magnetic fields.
- Low reactance phase arrangements to allow mutual cancellation of the fields from different phases.
- Selection of a transmission line corridor to maximises distances to dwellings and inhabited areas wherever possible.

4.6 Cumulative Effects

Along some sections of the HTP transmission line, the transmission lines will be close to other existing transmission lines. There is a cumulative effect arising from multiple transmission lines, where multiple lines can lead to enhancement or reduction of magnetic fields depending on their configuration. With the EMF levels falling away rapidly with distance, this effect is only notable when the lines are in very close proximity. For known assets (existing and future approved assets), this cumulative effect can be calculated, where the largest magnetic field from each source will govern. The cumulative effects of lines have been considered in this assessment (Section 6.4). For parallel line sections the phasing is nominated to reduce the cumulative of electric fields.

5 System Definition

5.1 HTP Transmission line – System Definition

The baseline parameters used for the assessment in this report are taken from the Basis of Design report for the HTP transmission line project, as summarised below in Table 7.

Table 7: HTP transmission lines – Study parameters

Parameters	Requirements
Hunter Transmission Project 500 kV Double Circuit Transmission Line	
Phase Conductors	Orange ACSR/GZ
Phase Sub-Conductors / Bundle Spacing	4 / 460 mm
Earth Wires[34]	SC/AC 7/4.24
Minimum Ground Clearance	13.5 metres
Phase to Phase (V)	550 kV, 1.1 p.u
Phase to Neutral (V)	317.54 kV, 1.1 p.u
Current Rating	5000 A (Maximum – Summer daytime) 3000 A Time-weighted average (TWA)[35]
Transmission Line Easement	70 metres wide easement (35 metres from centreline)
System Frequency	50 Hz
Phasing Arrangement	Circuit 1 (Right) – RWB and Circuit 2 (Left) – BWR[36]
Preferred Line Route	As per GIS information provided by EnergyCo

5.1.1 HTP Double Circuit Transmission Line Geometry

There are four tower types proposed along the length of HTP 500 kV double circuit transmission line:

- VTU – Light Tension Tower.
- VTV – Medium Tension Tower.
- VTW – Heavy Tension Tower.
- VSE – Suspension Tower / VSEH – Heavy Suspension Tower.

The tower outline drawings referenced in Table 4 define the phase/bundle conductor arrangements considered in the assessment. 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 if designs vary significantly.

For all modelled cases, the relative position of the phase conductors between the two circuits of the HTP 500 kV double circuit transmission line has been modelled considering the transposition[37] requirements on the

[34] SC/AC 7/4.24 earth wires (2 off) have been considered for all models in this assessment.

[35] The time weighted average gives a typical daily average load and both circuits in service. The considered TWA rating of 3000 A for MFD levels assessment is to be confirmed by EnergyCo.

[36] Low reactance phasing is considered for this vertical double circuit line, identified phasing is top to bottom.

[37] Phase conductors are transposed on long transmission lines to balance the mutual impedances and minimise system imbalances. Phase transpositions require the periodic swapping of the relative physical positions of the phase conductors of a transmission line.

line. The phases are to be transposed along the length of the feeder (to minimise EMF and voltage imbalances) and the relative positions of the phases to one another are consistent along the line (at one-thirds and two-thirds length). The results presented in the report are applicable for the three transposed sections.

Table 8: HTP 500 kV Double circuit transmission Line tower geometry

Tower Type	Phase/Earthwire	Horizontal distance from tower centre (metres)	Average Height (at midspan) (metres)
VTU Light Strain Tower	A (Left)	-6.98	43.7
	B (Left)	-7.40	32.9
	C (Left)	-7.83	22.1
	A (Right)	7.83	22.1
	B (Right)	7.40	32.9
	C (Right)	6.98	43.7
	Earthwire (Left)	-8.10	53.06
	OPGW (Right)	8.10	53.06
VTV Medium Strain Tower	A (Left)	-7.15	43.7
	B (Left)	-7.61	32.9
	C (Left)	-8.06	22.1
	A (Right)	8.06	22.1
	B (Right)	7.61	32.9
	C (Right)	7.15	43.7
	Earthwire (Left)	-8.35	53.06
	OPGW (Right)	8.35	53.06
VTW Heavy strain Tower	A (Left)	-8.19	43.7
	B (Left)	-8.63	32.9
	C (Left)	-9.07	22.1
	A (Right)	9.07	22.1
	B (Right)	8.63	32.9
	C (Right)	8.19	43.7
	Earthwire (Left)	-9.35	53.06
	OPGW (Right)	9.35	53.06
VSE/VSEH Light Suspension Tower/Heavy Suspension Tower	A (Left)	-6.26	43.2
	B (Left)	-6.60	32.6
	C (Left)	-6.93	22.1
	A (Right)	6.93	22.1
	B (Right)	6.60	32.6
	C (Right)	6.26	43.2
	Earthwire (Left)	-7.2	53.7
	OPGW (Right)	7.2	53.7

5.2 Nearby Services (Line Crossings, Parallel Lines) – System Definition

With regards to EMF, there is a cumulative effect arising from multiple transmission lines, where multiple lines can lead to enhancement or reduction of magnetic fields depending on their configuration. For identified assets, this cumulative effect can be calculated.

The preferred HTP 500 kV double circuit transmission line runs parallel to, and cross other lines. Identified line crossings are listed in Table 9 and parallel sections are listed in Table 10. These cases include both single and combinations of multiple transmission lines that are crossing/parallel HTP 500 kV double circuit transmission line. The cases resulting in the worst case electric or magnetic fields have been highlighted. These are typically the spans with the lowest ground clearance, and widest phase spacings for each voltage level. Assessments for the highlighted cases are included in Section 6.

It should be noted that many of the lines under crossing the HTP proposed line are in progress of getting upgrade or re-built. The assessment is based on the assumed inputs based on the available designs and standards (Section 3). Any change to the line's parameters, will require re-assessment to determine the minimum ground clearance for the HTP line.

Table 9: Identified crossing nearby services transmission lines

Case	Start structure	End structure	Transmission Line
1	92	93	Transgrid, 1 x 330 kV circuits (Line 81)
2	93	94	Transgrid, 1 x 330 kV circuits (Line 82) **As per case 1**
3	137	138	Transgrid, 1 x 330 kV circuits (Line 82) Ausgrid, 1 x 132 kV circuit (ID: 24413)
4	176	177	Transgrid, 1 x 330 kV circuits (Line 81) **As per case 1**
5	201	202	Transgrid, 1 x 330 kV circuits (Line 31) **As per case 1**
6	202	203	Transgrid, 1 x 330 kV circuits (Line 32) **As per case 1**
7	113	114	Ausgrid, 1 x 66 kV circuit (ID: 2584988) Ausgrid, 1 x 132 kV circuit (ID: 639862)
8	137	138	Transgrid, 1 x 330 kV circuits (Line 82) Ausgrid, 1 x 132 kV circuit (ID: 24413) **As per case 3**
9	162	163	Ausgrid, 1 x 132 kV circuit (Future Line) **As per case 11**
10	171	172	Ausgrid, 1 x 132 kV circuit (Future Line) **As per case 11**
11	186	187	Ausgrid, 1 x 132 kV circuit (ID: 669871)
12	110	111	Ausgrid, 1 x 66 kV circuit (ID: 18513)
13	113	114	Ausgrid, 1 x 66 kV circuit Ausgrid, 1 x 132 kV circuit **As per case 7**
14	130	131	Ausgrid, 2 x 66 kV circuit (ID: 19297)
15	130	131	Ausgrid, 2 x 66 kV circuit (ID: 19297)

Case	Start structure	End structure	Transmission Line
			As per case 14
16	145	146	Ausgrid, 1 x 66 kV circuit (ID: 3057339) **As per case 12**
17	147	148	Ausgrid, 1 x 66 kV circuit (ID: 3057339) **As per case 12**
18	151	152	Ausgrid, 1 x 66 kV circuit (HVO) **As per case 12**
19	153	154	Ausgrid, 1 x 66 kV circuit (HVO) **As per case 12**
20	168	169	Ausgrid, 1 x 66 kV circuit (HVO) **As per case 12**
21	169	170	Ausgrid, 1 x 66 kV circuit (HVO) **As per case 12**

Table 10: Identified parallel nearby services transmission lines

Case	Start structure	End structure	Transmission Line
22	86	96	Transgrid, 2 x 330 kV circuits (Line 81 & 82)
23	94	114	Ausgrid 1x 66 kV circuit (ID: 18513)
24	124	126	Transgrid, 2 x 330 kV circuits (Line 81 & 82) Ausgrid 2 x 66 kV circuit (ID: 19297 & ID: 44795) Ausgrid 1 x 132 kV circuit (ID: 24413)
25	128	130	Ausgrid 2 x 66 kV circuit (ID: 19297 & ID: 44795)
26	132	136	Transgrid, 1 x 330 kV circuits (Line 82) Ausgrid 2 x 66 kV circuit ((ID: 19297 & ID: 44795) Ausgrid 1 x 132 kV circuit (ID: 24413)
27	146	157	Ausgrid 1 x 66 kV circuit (ID: 19297) **As per Case 23**
28	157	158	Ausgrid 1 x 66 kV circuit (ID: 19297) Ausgrid 1x 132 kV circuit proposed (assume as per ID:24413)
29	163	170	Ausgrid 1x 132 kV circuit proposed
30	172	176	Transgrid, 1 x 330 kV circuits (Line 82)
31	177	186	Ausgrid 1x 132 kV circuit proposed Ausgrid 1 x 66kV HVO Transgrid 1 x 330 kV circuit (Line 81)

5.2.1 Nearby Transmission Line Study Parameters

The baseline parameters used for the modelling of nearby 330 kV, 132 kV and 66 kV transmission lines, as provided by EnergyCo (unless otherwise noted) are summarised below in Table 11.

Table 11: Identified nearby services transmission lines parameters

Parameters	Description
330 kV Single Circuit Transmission Line[38]	
Phase Conductors	Olive ACSR/GZ
Phase Sub-Conductors / Bundle Spacing	2 / 380 mm
Earth wires[39]	SC/AC 7/1.44
Minimum Ground Clearance	9 metres
Phase to Phase (V)	363 kV,1.1 p.u
Phase to Neutral (V)	209.58 kV,1.1 p.u
Observation Zone	1 metre (Maximum height of child, or seated adult), 2 metres (Maximum standing height of adult)
Transmission Line Easement	60 metres wide easement (30 metres from centreline)
System Frequency	50 Hz
Phasing Arrangement	Circuit 1 (Left) - RWB and Circuit 2 (Right) - BWR
Preferred Line Route	As per GIS information provided by EnergyCo
Assumed Line Loading	2500 A
132 kV Single Circuit Transmission Line[40]	
Phase Conductors	Olive ACSR/GZ
Phase Sub-Conductors	1
Earth wires	SC/AC 7/1.44
Minimum Ground Clearance	6.7 metres
Phase to Phase (V)	146 kV,1.1 p.u
Phase to Neutral (V)	83.83 kV,1.1 p.u
Observation Zone	1 metre (Maximum height of child, or seated adult),
Transmission Line Easement	45 metres wide easement (22.5 metres from centreline)
System Frequency	50 Hz
Phasing Arrangement	Circuit 1 - RWB
Preferred Line Route	As per GIS information provided by EnergyCo
Assumed Line Loading	1300 A
66 kV Single Circuit Transmission Line[41]	
Phase Conductors	AAC Pluto
Phase Sub-Conductors	1
Earth wires	SC/AC 7/1.44

[38] The parameters considered for this transmission line are obtained from files provided or assumed based on standards, any changes to the parameter requires re-assessment.

[39] SC/AC 7/1.44 earth wires (2 off) have been considered for all models in this assessment.

[40] The parameters considered for this transmission line are obtained from files provided or assumed based on standards, any changes to the parameter requires re-assessment.

[41] The parameters considered for this transmission line are obtained from files provided or assumed based on standards, any changes to the parameter requires re-assessment.

Parameters	Description
Minimum Ground Clearance	6.7 metres
Phase to Phase (V)	72.6 kV,1.1 p.u
Phase to Neutral (V)	41.92 kV,1.1 p.u
Observation Zone	1 metre (Maximum height of child, or seated adult),
Transmission Line Easement	30 metres wide easement (15 metres from centreline)
System Frequency	50 Hz
Phasing Arrangement	Circuit 1 - RWB
Preferred Line Route	As per GIS information provided by EnergyCo
Assumed Line Loading	800 A

5.2.2 Nearby Transmission Line Tower Geometry

The tower geometries considered in this assessment are based on the provided information and standard requirements. The proposed circuits or circuit deviations are derived from preliminary designs, and actual tower dimensions may vary. Although differences are likely to be minor, recalculating the values may be necessary if any dimensional changes occur. The tower geometries evaluated in this assessment are detailed in Table 12.

Table 12: Nearby Services Tower Geometry

Transmission Line	Phase/Earthwire	Horizontal distance from tower centre (metres)	Minimum Ground Clearance (at midspan) (metres)
Line 81 [42] 330 kV	A	12	9 [11][43]
	B	0	
	C	-12	
	Earthwire	12	14.2
	Earthwire	-12	
	OPGW	-9.65	
Line 82[44] 330 kV	A	10.9	9.6 [11]
	B	0	
	C	-10.9	
	Earthwire	8.1	19.5
	OPGW	-8.1	
	OPGW	-7.75	
132 kV	A	5	6.7
	B	0	
	C	-5	
	Earthwire	2	9.4

[42] Case number 1, refer to Table 9.

[43] This assessment identifies that at the proposed undercrossing locations of the HTP 500 kV double circuit line, 330 kV lines must achieve a minimum ground clearance of 11 m, this is greater than the minimum ground clearance required by AS/NZ 7000 and Transgrid.

[44] Case number 3, refer Table 9.

Transmission Line	Phase/Earthwire	Horizontal distance from tower centre (metres)	Minimum Ground Clearance (at midspan) (metres)
	OPGW	-2	
66 kV	A	-3	6.7
	B	0	
	C	-3	
	Earthwire	3	8.7
	OPGW	-3	

5.3 Case Studies – Parallel Line Operations

To assess the cumulative effects arising specifically due to parallel lines – it is necessary to study multiple operational cases. This will allow the enhancement or reduction of magnetic fields to be observed based on the operational state of each line.

For the HTP 500 kV double-circuit line considered in this study, four different binary operational cases have been applied, as shown in Table 13.

For analysis of magnetic field, TWA loading and average conductor heights have been applied where both circuits on the same line are energised, and minimum height and maximum current rating (summer day rating) have been applied where one of two circuits are energised.

For electric field assessment, the minimum heights specified in Table 12 have been applied to all scenarios.

Table 13: Operational states for parallel line assessments – Binary operation (1 = Energised, 0 = De-energised)

Scenario Number / Description	Parallel Lines – Easement Cross Section			
	Line 3 Existing Line	Line 2 Existing Line	Line 1 Preferred Line (HTP 500 kV)	
	Circuit 3	Circuit 2	Inner Circuit	Outer Circuit
State 1 / All circuits energized	1	1	1	1
State 2 / HTP outer circuit de-energised	1	1	1	0
State 3 / HTP inner circuit de-energised	1	1	0	1
State 4 / Existing circuit close to HTP line is de-energised	1	0	1	1

5.4 Minimum Ground Clearance

An iterative process has been applied to the minimum ground clearance defined in the basis of design for HTP (i.e. 13.5 metres), to understand the absolute limits where exceedances are observed and where EMF exposure is minimised.

6 EMF Assessment Results

This section includes all the calculated results of Electric Field Strength (EFS) and Magnetic Flux Density (MFD) of the HTP 500 kV double circuit transmission line EMF limits. The EMF performance of the transmission line is evaluated for all proposed tower types using SESEnviro[45] Ver 19.0.

For all operating states and load cases, the baseline parameters outlined in Section 5 have been considered for all calculated EMF values and then assessed (at the edge of the transmission line easement, and mid-span) for the worst-case voltage and current on the lines. The contingency operation case is defined as an operational state where one circuit is in service with increased load and the other circuit is out of service.

The external fields are assessed at 1 metre above the ground[46], for normal standing position of a person. An iterative process has been applied to the minimum ground clearance defined in the basis of design (i.e. 13.5 metres), to identify the minimum ground clearance required to achieve the limits as discussed in Section 5 based on Transgrid commissioned modelling and the ICNIRP reference levels. Cell values in this section highlighted green or red, are noted to be compliant or non-compliant (respectively) with regards to the applicable corresponding limit found in the tables.

Based on the outcomes of this investigation, EnergyCo and their Contractors/Network Operator will commit to design, construct and operate the line to achieve the absolute minimum ground clearance and to reduce the intensity of the EMF ~~fields~~ generated in frequented areas (where prolonged exposure is possible).

6.1 Electric Field Strength

To determine the absolute minimum ground clearance for the HTP 500 kV double circuit transmission line, each tower type was assessed at various clearance heights ranging from 13.5 metres to 11.0 metres. These heights represent the vertical distance from the ground to the lowest point of conductor sag between towers. The minimum clearance varies due to several factors, including the specific tower type/geometry. For the purposes of this report, ground clearances within the 13.5 m to 11.0 m range were evaluated to identify the lowest clearance at which the magnetic field limit is not exceeded. This assessment informs the minimum clearance thresholds required for the proposed line design.

The resulting electric fields directly under lines and at the edge of line easement has been compared to the applicable electric field limits. For all calculations the line has been energised at the maximum operating voltage (1.1 per unit). This study considers both normal operation (two circuit energised) and contingency operation (one circuit energised) for each tower type.

The results of this study are summarised below in Table 14. Refer to Appendix A – Transmission Line Electric Field Plots for detailed plots.

[45] The SESEnviroPlus software package (part of the CDEGS suite) is an electromagnetic environmental impact assessment analysis (EEIA) tool. For a technical description of the software and its functionality, see: https://www.sestech.com/en/Product/Package/SESEnviroPlus

[46] This is an industry adopted guideline for assessing the spatially averaged EMF exposure for the normal standing position of an average human. This is supported by standards such as IEEE Std C95.3.1™-2010 and IEEE 644-2019.

Table 14: Maximum calculated electric field strength (kV/m)

Tower Type	Operating State	Position	Calculated EFS (kV/m) @ 1 metres above ground Minimum Ground Clearance (metres) 13.5	12.5	12.0	11.0	Limit (kV/m) (see Section 4.2.3)
VTU	Single circuit energized	Edge of easement	0.3	0.2	0.2	0.2	9.1
		Directly under lines	7.4	8.3	8.8	10.0	9.1
	Double circuit energized	Edge of easement	0.4	0.3	0.3	0.3	7.8
		Directly under lines	6.2	7.2	7.7	8.9	7.8
VTV	Single circuit energized	Edge of easement	0.3	0.2	0.2	0.2	9.1
		Directly under lines	7.4	8.3	8.8	10.0	9.1
	Double circuit energized	Edge of easement	0.4	0.3	0.3	0.3	7.8
		Directly under lines	6.3	7.2	7.3	8.9	7.8
VTW	Single circuit energized	Edge of easement	0.3	0.3	0.2	0.2	9.1
		Directly under lines	7.4	8.3	8.8	10.0	9.1
	Double circuit energized	Edge of easement	0.4	0.4	0.4	0.3	7.8
		Directly under lines	6.5	7.4	8.0	9.2	7.8
VSE/V SEH	Single circuit energized	Edge of easement	0.2	0.2	0.2	0.2	9.1
		Directly under lines	7.3	8.2	8.7	9.9	9.1
	Double circuit energized	Edge of easement	0.3	0.3	0.2	0.2	7.8
		Directly under lines	6.0	6.9	7.4	8.6	7.8

For the absolute minimum ground clearance of 12.5 metres the maximum calculated EFS is 8.3 kV/m (91.2 % of the 9.1 kV/m limit) with a single circuit energised, and 7.4 kV/m (94.9 % of the 7.8 kV/m limit) with both circuits energised. While for the proposed minimum ground clearance of 13.5 metres the maximum calculated EFS is 7.4 kV/m (81.3 % of the 9.1 kV/m limit) with a single circuit energised, and 6.5 kV/m (83.3 % of the 7.8 kV/m limit) with both circuits energised.

6.2 Magnetic Flux Density

To determine the absolute minimum ground clearance for the HTP 500 kV double circuit transmission line, each tower type was assessed at various clearance heights ranging from 13.5 metres to 11.0 metres. These heights represent the vertical distance from the ground to the lowest point of conductor sag between towers. The minimum clearance varies due to several factors, including the specific tower type and geometry. For the purposes of this report, ground clearances within the 13.5 m to 11.0 m range were evaluated to identify the lowest clearance at which the magnetic field limit is not exceeded. This assessment informs the minimum clearance thresholds required for the proposed line design.

The resulting magnetic flux density under the lines and at the edge of the line easement has been compared to the applicable magnetic field limits.

The HTP 500 kV double circuit transmission line circuits have been energised considering:

- The maximum current (5000 A) – summer day rating for contingency operation (single circuit energised) assessed at the minimum ground clearance.
- Time weighted average exposure (TWA) for normal operation (both circuits energised) assessed at an average conductor height. Both circuits are energised, each at 3000 A.

The results relating to contingency operation are summarised in Table 15, while the results relating to normal operation are summarised in Table 16. Refer to Appendix B – Transmission Line Magnetic Field Plots for detailed plots and for additional studies results plots for various TWA ratings.

Table 15: Maximum calculated magnetic flux density - summer day rating

Tower Type	Operating State	Position	Calculated MFD (mG) @ 1 metre above ground				Limit (mG)
			Minimum Ground Clearance (metres)				
			13.5	12.5	12.0	11.0	
VTU	Single circuit energized	Edge of easement	144	149	151	155	2000
		Directly under lines	455	510	543	618	2000
VTV	Single circuit energized	Edge of easement	145	150	152	157	2000
		Directly under lines	455	510	543	619	2000
VTW	Single circuit energized	Edge of easement	152	156	160	165	2000
		Directly under lines	455	510	543	618	2000
VSE/VSEH	Single circuit energized	Edge of easement	137	141	143	148	2000
		Directly under lines	451	507	540	614	2000

For the absolute minimum ground clearance of 12.5 meters and during contingency operating conditions[47] the maximum calculated MFD (Summer Day) is 510 mG which is 25.5 % of the allowable limit of 2000 mG. While for the proposed minimum ground clearance of 13.5 metres the maximum calculated MFD (Summer Day) reduces to 455 mG which is 22.8 % of the allowable limit of 2000 mG.

Table 16: Maximum calculated magnetic flux density – TWA considering averaged conductor heights[48]

Tower type	Operating State	Position	Calculated MFD (mG) @ 1 metre above ground	Limit (mG)
VTU	Double circuit energized	Edge of easement	39	2000
		Directly under lines	148	2000
VTV	Double circuit energized	Edge of easement	40	2000
		Directly under lines	150	2000
VTW	Double circuit energized	Edge of easement	44	2000
		Directly under lines	159	2000
VSE/VSEH	Double circuit energized	Edge of easement	35	2000
		Directly under lines	137	2000

For the specified average conductor height and during normal operating conditions it is observed that:

- The maximum calculated $MFD_{(TWA)}$ is 159 mG which is 8.0 % of the allowable limit of 2000 mG.
- The maximum calculated $MFD_{(TWA)}$ at the edge of the easement is 44 mG which is similar to that associated with a typical hairdryer.

6.3 Crossing Transmission Lines

The HTP 500 kV double circuit transmission line alignment crosses an existing and proposed transmission lines as identified in Section 5. The HIFREQ[49] module was used to calculate the EMF under these crossings at 1 metre above the normal standing position of a person. For all operating states and load cases, the baseline parameters outlined in Section 5.1 have been considered for all calculated EMF values and then assessed (at the edge of line easement, and mid-span)The calculated EMF levels and minimum ground clearances of the HTP 500 kV double circuit transmission line are summarised below in Table 17 and

Table 18. Refer to Appendix C – Electric and Magnetic Field Plots at Transmission Line Crossings for detailed plots.

The assessment considered the HTP 500 kV double circuit transmission line circuits being energised under the following specifications:

- The maximum current (5000 A) – summer day rating for contingency operation (single circuit energised) assessed at the minimum ground clearance.

[47] The contingency case is defined as an operational state where one circuit is in service with increased load, and the other circuit is out of service.

[48] Assessment considered a lowest conductor height of 21.3 metres to verify the magnetic field levels, as this represents the lowest line height considered in the study for this line. The magnetic field at heights above this will comply with the reference MFD limits.

[49] Electromagnetic Fields Analysis Software module of Current Distribution Electromagnetic Interference Grounding and Soil Structure Analysis (CDEGS)

- Time weighted average exposure (TWA) for normal operation (both circuits energised) assessed at an average conductor height. Both circuits are energised, each at 3000 A.

Other lines have been energised considering the currents reported in Table 11.

The assessment has considered the relative line heights based on minimum clearance requirements outlined AS 7000, which specifies undercrossing clearances of 5.2 metres for 500 kV lines or the minimum height to achieve EMF compliance, whichever is greater. The minimum ground clearance of HTP 500 kV double circuit transmission line near crossing has been summarised in Table 17 for the assessed cases.

Table 17: Calculated maximum electric field – crossings

Transmission Line Case[50]	Operating State	HTP Minimum Ground Clearance (m)	Electric Field (kV/m)		Limits (kV/m)
			Under the lines	Edge of the easement	
1	Single circuit	26.0	7.1	1.4	9.1
	Double circuit		7.3	1.5	7.8
3	Single circuit	25.1	7.5	1.5	9.1
	Double circuit		7.5	1.5	7.8
7	Single circuit	14.6	7.8	1.6	9.1
	Double circuit		7.6	1.5	7.8
11	Single circuit	14.6	8.0	1.6	9.1
	Double circuit		7.5	1.7	7.8
12	Single circuit	14.6	7.4	1.5	9.1
	Double circuit		6.5	1.3	7.8
14	Single circuit	13.9	8.0	1.6	9.1
	Double circuit		6.6	1.3	7.8

Table 18: Calculated maximum MFD – crossings

Transmission Line Case	Operating State	Magnetic Field (mG)		Limits (mG)
		Under the lines	Edge of the easement	
1	Single circuit	610	137	2000
	Double circuit	558	121	2000
3	Single circuit	663	144	2000
	Double circuit	614	130	2000
7	Single circuit	691	145	2000
	Double circuit	465	92	2000
11	Single circuit	710	212	2000
	Double circuit	465	115	2000

[50] Case number, refer to Table 9

Transmission Line Case	Operating State	Magnetic Field (mG)		Limits (mG)
		Under the lines	Edge of the easement	
12	Single circuit	512	138	2000
	Double circuit	309	85	2000
14	Single circuit	560	156	2000
	Double circuit	300	65	2000

For the specified minimum ground clearances for all the under-crossing cases studied, the maximum calculated EFS is 8.0 kV/m which is 87.9 % of allowable limit of 9.1 kV/m for under crossing cases. Similarly,

the maximum calculated MFD is 710 mG and $MFD_{(TWA)}$ is 614 mG, which is 35.5 % and 30.7 % of the allowable limit of 2000 mG.

6.4 Parallel Transmission Lines

The HTP 500 kV double circuit transmission line alignment parallels existing and proposed transmissions line as identified in Section 5. The SESEnviro Ver 19.0 module was used to calculate the EMF under these crossings at 1 metre above the normal standing position of a person. For all operating states and load cases, the baseline parameters outlined in Section 5.1 have been considered for all calculated EMF values and then assessed (at the edge of the transmission line easement, and mid-span). The calculated EMF levels are summarised below in Table 19 and Table 20.

Cell values in this section highlighted green or red, are noted to be compliant or non-compliant (respectively) with regards to the applicable corresponding limit found in Table 19 and Table 20.

Lines have been energised considering:

- The maximum current (5000 A) – summer day rating for contingency operation (single circuit energised) assessed at the minimum ground clearance.
- Time weighted average exposure (TWA) for normal operation (both circuits energised) assessed at an average conductor height. Both circuits are energised, each at 3000 A.
- Other lines have been energised considering the currents reported in Table 11.
- HTP 500 kV line double line parallel with 330 kV transmission line assessment considers parallel easements to share a boundary line, without encroaching – for a centre – centre distance of 65 metres[51].
- HTP 500 kV line double line parallel 132 kV transmission line assessment considers parallel easements to share a boundary line, without encroaching – for a centre – centre distance of 57.5 metres[52].
- HTP 500 kV line double line parallel 66 kV transmission line assessment considers parallel easements to share a boundary line, without encroaching – for a centre – centre distance of 50 metres[53].

[51] Only a single tower/line configuration has been modelled parallel assessment, as this tower's phase configuration inherently produce higher results at mid-span and would be the worst case when considering cumulative effects.

[52] Only a single tower/line configuration has been modelled parallel assessment, as this tower's phase configuration inherently produce higher results at mid-span and would be the worst case when considering cumulative effects.

[53] Only a single tower/line configuration has been modelled parallel assessment, as this tower's phase configuration inherently produce higher results at mid-span and would be the worst case when considering cumulative effects.

The assessment has considered the system definition for parallel systems as per Section 5 of this report and the absolute minimum ground clearance considered for the HTP 500 kV double circuit transmission line of 12.5 metres as determined by Section 6.1. It is noted that increasing the minimum ground clearance to 13.5 m (the proposed minimum ground clearance for the HTP 500 kV line) will reduce the resulting electric and magnetic fields both under the line and at the edge of the easement.

For the definition of the various operating states, refer Table 13

Table 19: Calculated maximum electric field - parallel

Transmission Line Case[54]	Operating State[55]	Electric Field (kV/m)		Limits (mG)
		Under the lines	Edge of the easement	
22	State 1	7.0	1.3	7.8
	State 2	8.2	1.2	9.1
	State 3	8.3	1.2	9.1
	State 4	6.9	0.3	7.8
23	State 1	6.9	0.4	7.8
	State 2	8.2	0.3	9.1
	State 3	8.2	0.3	9.1
	State 4	6.9	0.3	7.8
24	State 1	6.9	0.3	7.8
	State 2	8.2	0.1	9.1
	State 3	8.2	0.2	9.1
	State 4	6.9	0.3	7.8
25	State 1	6.9	0.3	7.8
	State 2	8.2	0.1	9.1
	State 3	8.2	0.2	9.1
	State 4	6.9	0.3	7.8
26	State 1	6.9	0.4	7.8
	State 2	8.2	0.3	9.1
	State 3	8.2	0.3	9.1
	State 4	6.9	0.4	7.8
28	State 1	6.9	0.9	7.8
	State 2	8.2	0.8	9.1
	State 3	8.2	0.8	9.1
	State 4	6.9	0.8	7.8
29	State 1	6.9	0.8	7.8
	State 2	8.2	0.9	9.1

[54] Case number, refer to Table 10

[55] For parallel operating states, please refer to Table 13.

Transmission Line Case[54]	Operating State[55]	Electric Field (kV/m)		Limits (mG)
		Under the lines	Edge of the easement	
	State 3	8.2	1.0	9.1
	State 4	6.9	0.3	7.8
30	State 1	6.9	1.5	7.8
	State 2	8.1	1.5	9.1
	State 3	8.2	1.7	9.1
	State 4	6.9	0.3	7.8
31	State 1	6.9	0.4	7.8
	State 2	8.2	0.3	9.1
	State 3	8.2	0.3	9.1
	State 4	6.9	0.3	7.8

Table 20: Calculated maximum magnetic field - parallel

Transmission Line Case[56]	Operating State	Magnetic Field (mG)		Limits (mG)
		Under the lines	Edge of the easement	
22	State 1	747	128	2000
	State 2	630	217	2000
	State 3	664	92	2000
	State 4	615	31	2000
23	State 1	225	42	2000
	State 2	506	140	2000
	State 3	508	112	2000
	State 4	125	34	2000
24	State 1	551	78	2000
	State 2	551	200	2000
	State 3	553	148	2000
	State 4	552	47	2000
25	State 1	273	66	2000
	State 2	505	188	2000
	State 3	508	144	2000
	State 4	284	37	2000
26	State 1	572	145	2000
	State 2	565	199	2000

[56] Case number, refer to Table 10

Transmission Line Case[56]	Operating State	Magnetic Field (mG)		Limits (mG)
		Under the lines	Edge of the easement	
	State 3	574	103	2000
	State 4	569	79	2000
28	State 1	395	183	2000
	State 2	510	196	2000
	State 3	510	173	2000
	State 4	364	136	2000
29	State 1	395	85	2000
	State 2	510	206	2000
	State 3	515	149	2000
	State 4	364	33	2000
30	State 1	244	114	2000
	State 2	489	223	2000
	State 3	518	150	2000
	State 4	125	34	2000
31	State 1	413	59	2000
	State 2	511	86	2000
	State 3	509	141	2000
	State 4	420	30	2000

Considering an absolute minimum ground clearance of 12.5 metres for HTP 500 kV double circuit transmission line parallel section, the maximum calculated EFS is 8.3 kV/m which is 91.2 % of the allowable limit of 9.1 kV/m. Similarly, the maximum calculated MFD is 664 mG and 747 mG (TWA) which is 33.2 % and 37.05 % of the allowable limit of 2000 mG. Increasing the minimum ground clearance to 13.5 m (the proposed minimum ground clearance for the HTP 500 kV line) will reduce the resulting electric and magnetic fields both under the line and at the edge of the easement.

6.5 General EMF Assessment at the Proposed Switching Stations

The substation works which are proposed to be undertaken as part of the Hunter Transmission Project are summarised below:

- Change of two 500kV connections at the existing Bayswater 500 kV/330 kV substation within the existing footprint and existing high voltage equipment within the substation
- Augmentation and modifications at the existing Eraring 500 kV/330 kV substation, including installation of two new transformers
- New Bayswater South 500 kV switching station
- New Olney 500 kV switching station

6.5.1 Bayswater 500 kV / 330 kV Substation

The existing Bayswater substation would be reconnected as part of the Hunter Transmission Project to accommodate the double circuit 500 kV connection of the proposed Bayswater South switching station. The proposed brownfield substation works does not modify the existing Bayswater high plant.

There are no modifications proposed to the existing Bayswater substation as part of the Hunter Transmission Project and no change to the existing EMF impacts associated with the existing operation of this substation.

6.5.2 Eraring 500 kV / 330 kV Substation

The existing Eraring substation would be augmented as part of the Hunter Transmission Project to accommodate the double circuit 500 kV connection of the proposed Olney switching station. The proposed brownfield substation works include:

- Two, three-phase sets of single-phase 500 kV/330 kV transformers,
- New, modified, and relocated 500 kV and 330 kV overhead connections
- Modified 500kV and 330kV switch bays and bench extension.
- 500 kV equipment such as circuit breakers, current transformers, voltage transformers, disconnectors, earth switches, surge arresters and interconnections
- 500 kV busbar modifications and associated interconnections

The modifications proposed to the existing Eraring substation as part of the Hunter Transmission Project are not expected to worsen the overall EMF impacts associated with the existing operation of this substation.

6.5.3 Proposed Bayswater South 500 kV Switching Station

The new 500 kV Bayswater South 500kV switching station is located southwest of the existing Bayswater Power Station and Bayswater Substation as shown in Figure 4. The proposed switching station allows for up to six, breaker-and-a-half diameters. Each diameter would typically include:

- Three-phase 500 kV reactors
- 500 kV equipment such as circuit breakers, current transformers, voltage transformers, disconnectors, earth switches, surge arresters and interconnections
- 500 kV busbars and associated power voltage transformers, surge arresters, and interconnections

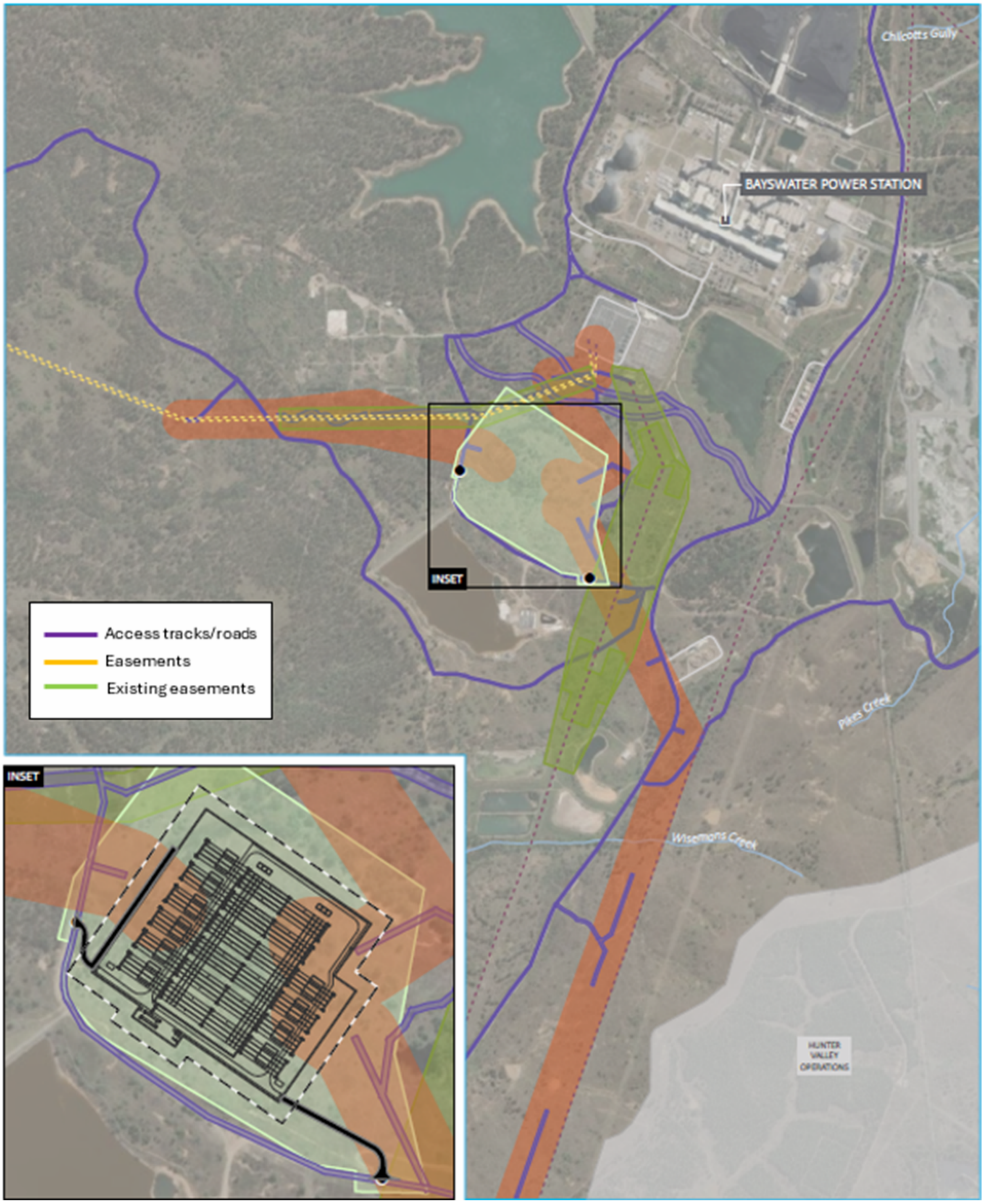

Figure 4: Bayswater South Switching Station Location.

The proposed switching station will be enclosed by security fencing, with access strictly limited to authorised personnel.

The surrounding land is used for power generation and resource extraction; the nearest identified public access area is the New England Highway which is more than 2 km from the proposed switching station, identified residential dwellings and other sensitive locations are further away.

The Bayswater South switching station is approximately 200 m from the existing Bayswater substation, at this distance it is not expected that the EMFs from each source will significantly influence each other. This shall be confirmed during detailed design phase.

6.5.4 Proposed Olney 500 kV Switching Station

The new 500 kV Olney switching station is in Olney State Forest as shown in Figure 5. The proposed switching station allows for up to four, breaker-and-a-half diameters.

Each diameter would typically include:

- 500 kV equipment such as circuit breakers, current transformers, voltage transformers, disconnectors, earth switches, surge arresters and interconnections
- 500 kV busbars and associated power voltage transformers, surge arresters, and interconnections
- Provision is made for possible future three-phase 500 kV reactors should these be required.

The proposed switching station will be enclosed by security fencing, with access strictly limited to authorised personnel. The surrounding land is used for forestry and recreation. No dwellings, dedicated recreation areas, facilities or other sensitive locations have been identified in the vicinity of the switching station.

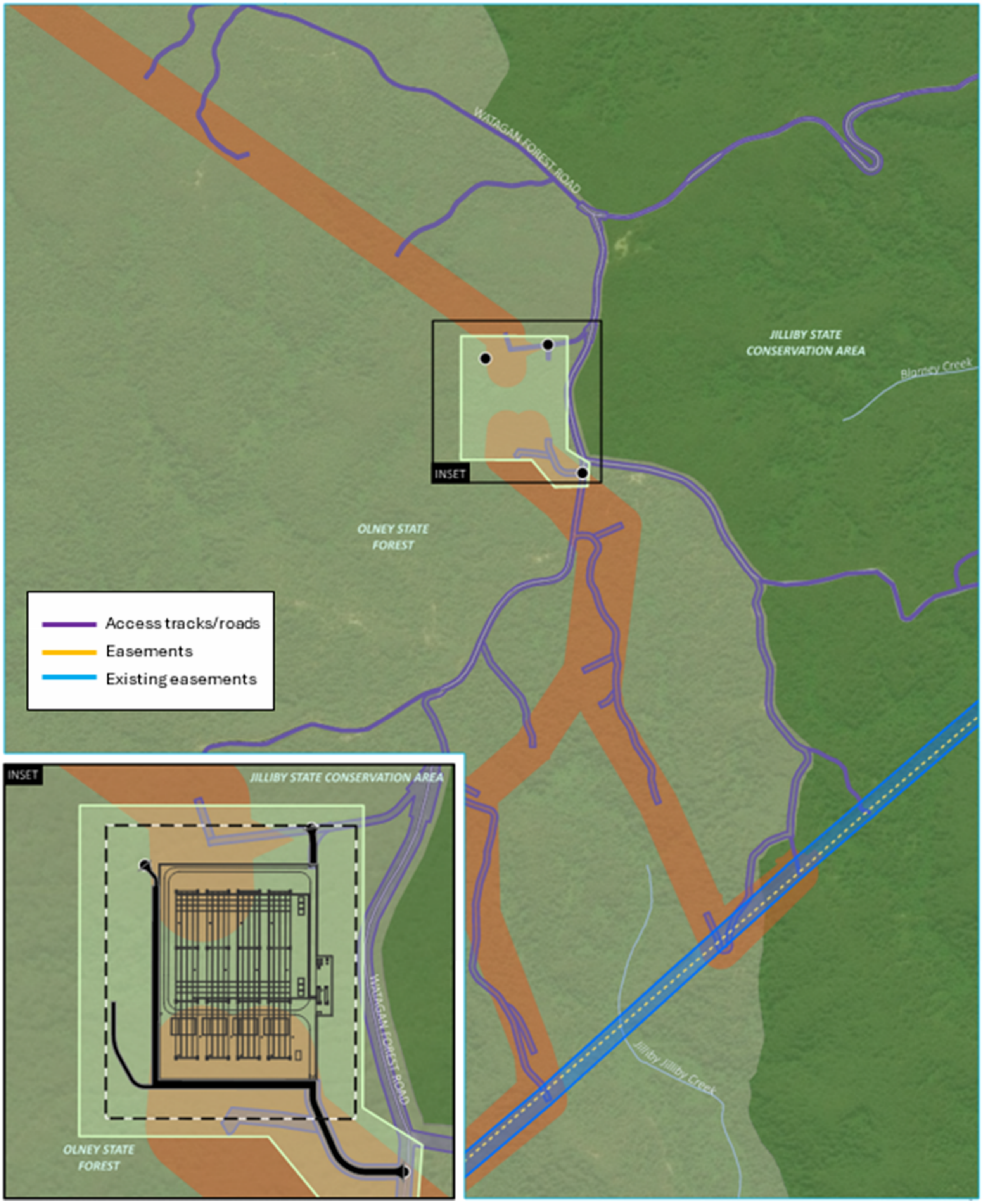

Figure 5: Olney Switching Station Location.

6.5.5 Public Exposure

Publicly accessible areas around each of the proposed 500kV switching stations and existing 500/330kV substations are assessed against the electric and magnetic field Public Exposure Reference Levels outlined in the ICNIRP guidelines (and Section 4.2.3 of this document).

The design and construction of the existing and proposed switching stations associated with the HTP transmission line shall meet the ICNIRP public exposure guidelines such that:

- The calculated electric field strength (EFS) 1 metre above ground, at the boundary of the switching station (where access is un-restricted), will be designed to be within the ICNIRP EF reference level of 5 kV/m.
- The calculated magnetic flux density (MFD) 1 metre above ground, at the boundary of the switching station (where access is un-restricted), will be designed to be within the ICNIRP MF reference level of 2,000 mG.
- In line with the prudent avoidance policy, design methods may include implementing further controls to restrict public access to affected areas.

6.5.6 Occupational Exposure

The ICNIRP guidelines set lower (more conservative) limits for the general public to account for continuous, long-term exposure and the presence of sensitive individuals. Occupational limits are higher, reflecting the assumption that workers are healthy adults, trained, and exposed for shorter periods in controlled environments.

The design of the switching stations and modifications to existing substations will be such that EMF levels in all accessible areas comply with the ICNIRP Occupational Guideline Levels as outlined in Table 21.

Table 21: EMF guidelines for the Restricted Areas (ICNIRP)

ICNIRP EMF Guidelines		Levels
Basic Restriction		
Central nervous system tissues of the head		0.1 V/m
Full body tissues		0.8 V/m
Reference Levels	Electric Field	10 kV/m
	Magnetic Field	1,000 μT (10,000 mG)

6.5.7 EMF Assessment

The proposed switching stations and existing substations are enclosed by security fencing, with access strictly limited to authorised personnel.

The new switching stations, and substation modifications will utilise standard 500 kV and 330kV equipment configurations and be designed to comply with the required electrical and boundary clearances, equipment heights, and phasing arrangements as outlined in the relevant Transgrid Standard Design Manuals, Australian standards, and international standards. Under this scenario it is expected that EMF levels at accessible locations will remain within the applicable exposure limits.

This is based on industry experience and the conservative nature of established design standards, which are intended to enable compliance with EMF guidelines under typical operating conditions.

The policies and precautionary methods of Prudent Avoidance (see Section 4.5) shall be applied throughout the design and construction of the proposed switching stations.

Within 12 months after energisation, field strength measurements shall be undertaken at each switching station to produce an EMF compliance report, to verify the respective switching station is compliant to the relevant EMF design criteria.

7 Results and Recommendations

This section outlines the results and subsequent recommendations following the Electric and Magnetic Field (EMF) study for the HTP 500 kV double circuit transmission line.

The EMF performance of the HTP 500 kV double circuit transmission line has been assessed (at 1 metre above ground) under both normal and contingency operating conditions. It can be seen from the results presented in Section 6 that EMF levels directly underneath and at the edge of the line easements are within the safe limits in accordance with the ARPANSA recommended ICNIRP public exposure guidelines when the following minimum ground clearances are achieved by the HTP 500 kV double circuit transmission line:

- 13.5 metres for the bulk of the line
- 26 metres at 330 kV line crossings
- 14.6 metres at 66 and 132 kV line crossings.

Magnetic Fields

The maximum magnetic fields have been evaluated against the applicable limits (see Section 6) for the line included in the scope of the study, tower configurations, operating states, load conditions and positions near the line (i.e. edge of easement, or directly under lines).

For all results calculated at or above the minimum ground clearances determined in this study, the maximum calculated electric fields fall within the applicable limits of 2000 mG. The maximum calculated results for considering the minimum ground clearance for each unique configuration are presented below in Table 22.

The magnetic field levels associated with the contingency loads will only occur for short periods on rare occasions. Time weighted average loads associated with normal operation are provided in Table 22 to give more typical levels during normal operation both under the line and at the edge of the easement.

Table 22: Calculated maximum magnetic fields under contingency conditions

Transmission Line Configuration	Maximum Magnetic Fields		Limit (mG)
	Directly under the lines (mG)	Edge of easement (mG)	
Normal System Operation (Both circuits in service)			
HTP 500 kV double circuit transmission line	455	150	2000
HTP 500 kV double circuit transmission line at under crossings	710	216	2000
HTP 500 kV double circuit transmission line parallel cases	747	183	2000
Contingency[57] Operation (Single circuit in service)			
HTP 500 kV double circuit transmission line	159	44	2000
HTP 500 kV double circuit transmission line at under crossings	614	130	2000
HTP 500 kV double circuit transmission line parallel cases	747	183	2000

Electric Fields

[57] The contingency case is defined as an operational state where one circuit is in service with increased load, and the other circuit is out of service.

The maximum electric field strength has been evaluated against the applicable limits (see Section 6) for all lines included in the scope of the study, and consider cumulative effects (i.e. line crossing, parallel lines), tower configurations, operating states, load conditions and positions near the line (i.e. edge of easement, or directly under lines).

For all results calculated at or above the minimum ground clearances determined in this study, the maximum calculated electric fields fall within the applicable limits for HTP 500 kV double circuit transmission line and for parallel sections. The maximum calculated results as presented below in Table 23 assume the recommendations outlined in the following section are applied.

Table 23: Calculated maximum electric fields (kV/m)

Transmission lines Configuration	Maximum Electric Fields		Limit (kV/m)
	Directly Under Lines (kV/m)	Edge of Easement (kV/m)	
Normal System Operation (Both circuits in service)			
HTP 500 kV double circuit transmission line	6.5	0.4	7.8
HTP 500 kV double circuit transmission line under crossing	7.6	1.6	7.8
HTP 500 kV double circuit transmission line parallel	7.0	1.5	7.8
Contingency[58] Operation (Single circuit in service)			
HTP 500 kV double circuit transmission line	7.4	0.3	9.1
HTP 500 kV double circuit transmission line under crossing	8.0	1.6	9.1
HTP 500 kV double circuit transmission line parallel	8.2	1.7	9.1

Recommendations

EnergyCo is guided by leading health authorities (ARPANSA and WHO) for EMF health effects and takes a precautionary approach[59] to EMF. In compliance with the relevant Australian exposure guidelines (ARPANSA) and being consistent with the concept of Prudent Avoidance, the following recommendations are in-line with the guidance provided by WHO as it pertains to reducing exposure through actions of Prudent Avoidance, which are reasonable and warranted. The recommendations are as follows:

- Prudent mitigation measures be applied through design and construction where warranted and practicable in accordance with EnergyCo policy for prudent avoidance as outlined in Section 4.5.
- The proposed minimum ground clearance height of 13.5 metres (HTP 500 kV double circuit transmission line) to be retained.
- Where undercrossing HTP, 330 kV lines should achieve a minimum ground clearance of 11 metres, which is greater than the minimum ground clearance required by AS7000 and Transgrid. Identified line deviations

[58] The contingency case is defined as an operational state where one circuit is in service with increased load, and the other circuit is out of service.

[59] For more information regarding EnergyCo precautionary approach and how EMF are considered in the planning, design and location of HTP, please see the following fact sheet: https://www.transgrid.com.au/media/1nrfxwtf/emf-fact-sheet.pdf

requiring this increased ground clearance are listed below, Transgrid's 330 kV design modifications will address these three locations such that no EMF issues will occur.

  - Transgrid 330 kV Line 81, Case 1
  - Transgrid 330 kV Line 31, Case 5
  - Transgrid 330 kV Line 32, Case 6

- Within 12 months after energisation, field strength measurements will be undertaken at several appropriately identified locations along the transmission line (i.e. at the edge of the line easement, directly under the lines) to produce an EMF compliance report, to confirm the installation is compliant to the relevant EMF design criteria.

A

Appendix A – Transmission Line Electric Field Plots

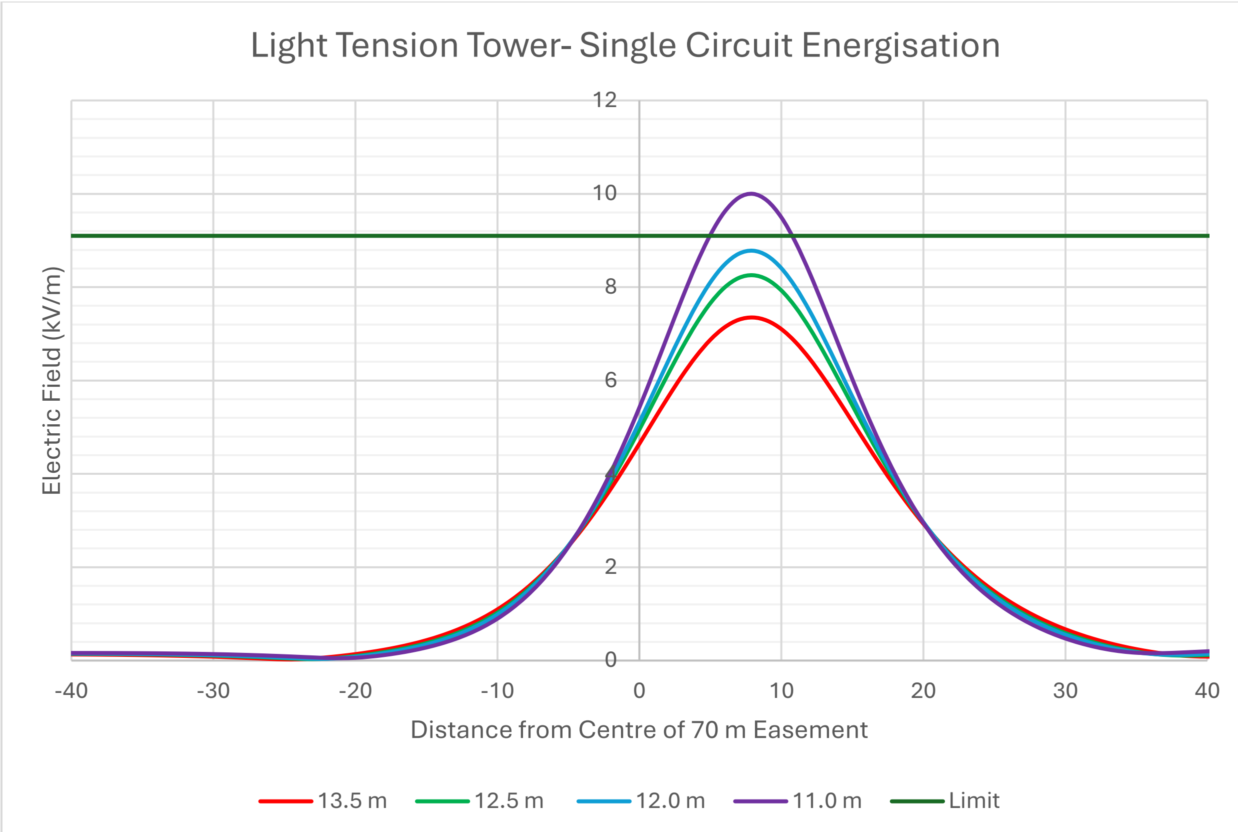

Figure A1: VTU-Light Tension Tower, Single Circuit Energised

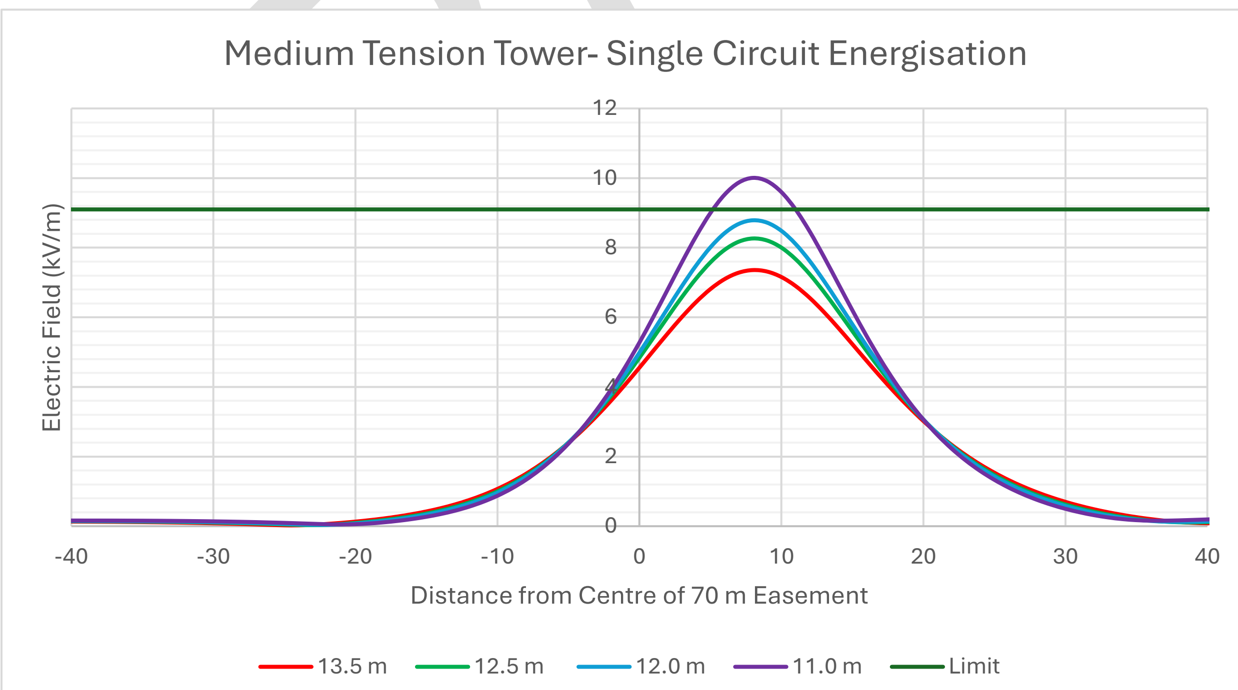

Figure A2: VTV- Medium Tension Tower, Single Circuit Energised

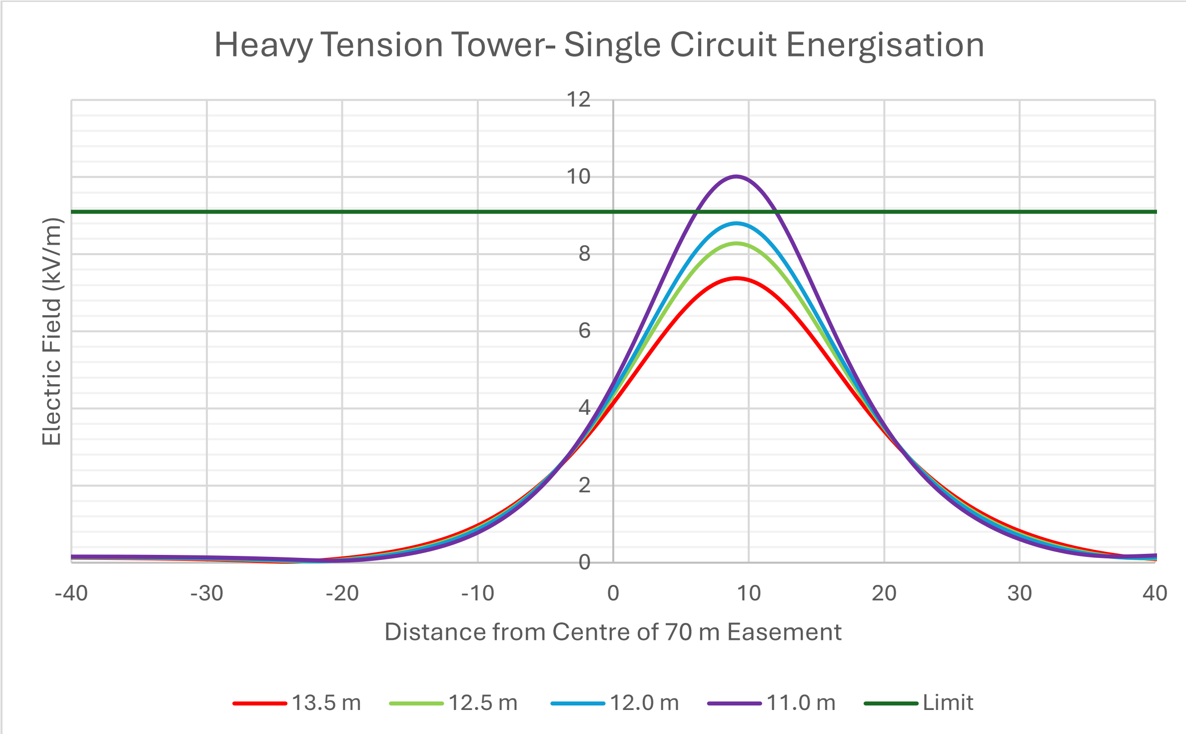

Figure A3: VTW- Heavy Tension Tower, Single Circuit Energised

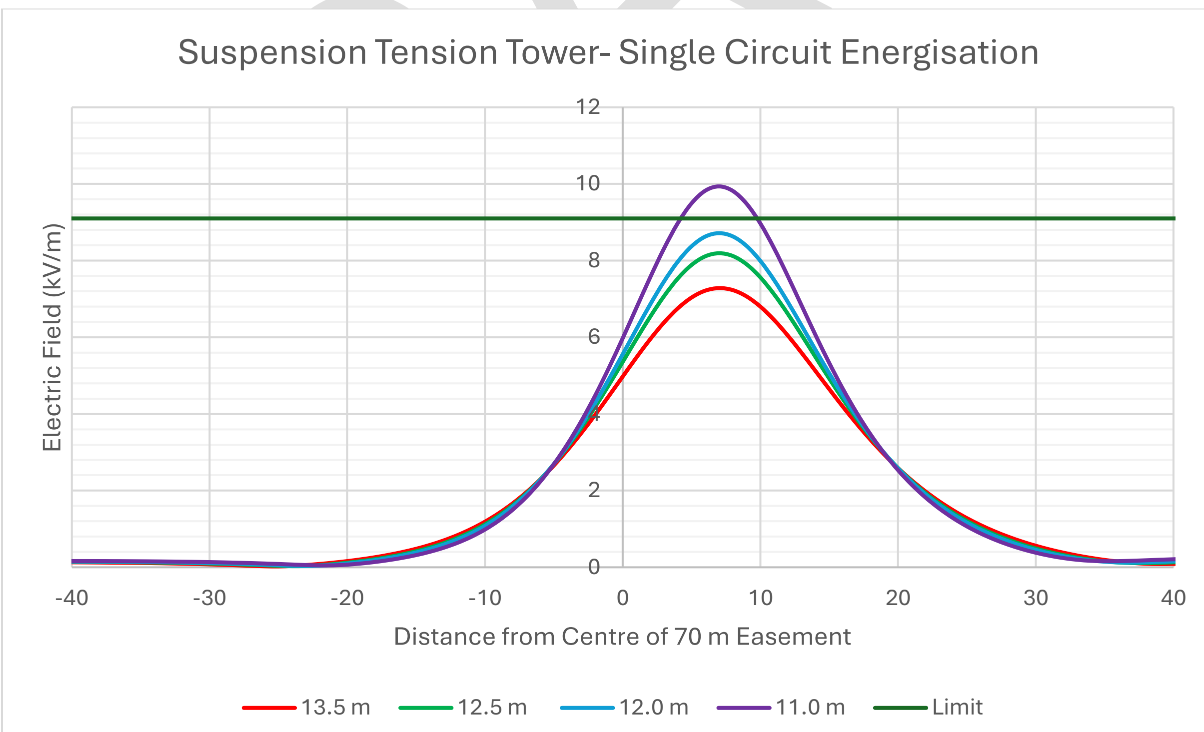

Figure A4: VSE-Suspension Tower, Single Circuit Energised

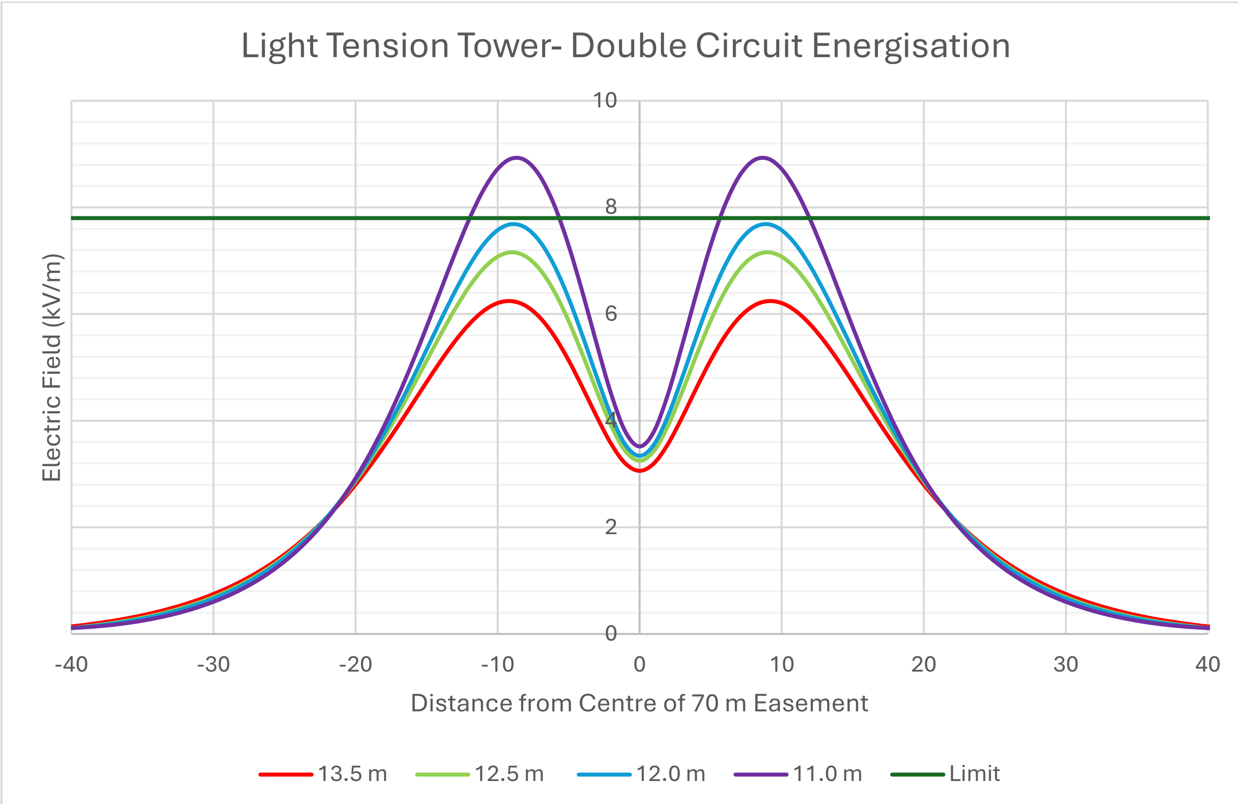

Figure A5: VTU-Light Tension Tower, Both Circuits Energised

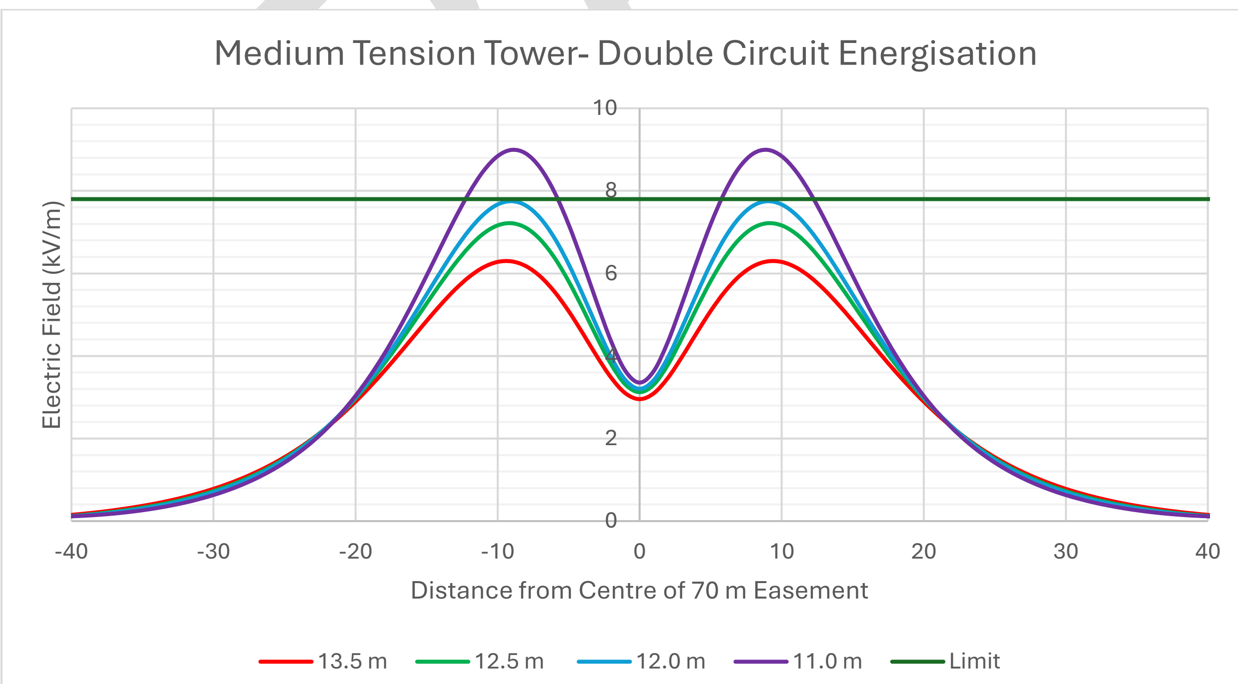

Figure A6: VTV-Medium Tension Tower, Both Circuits Energised

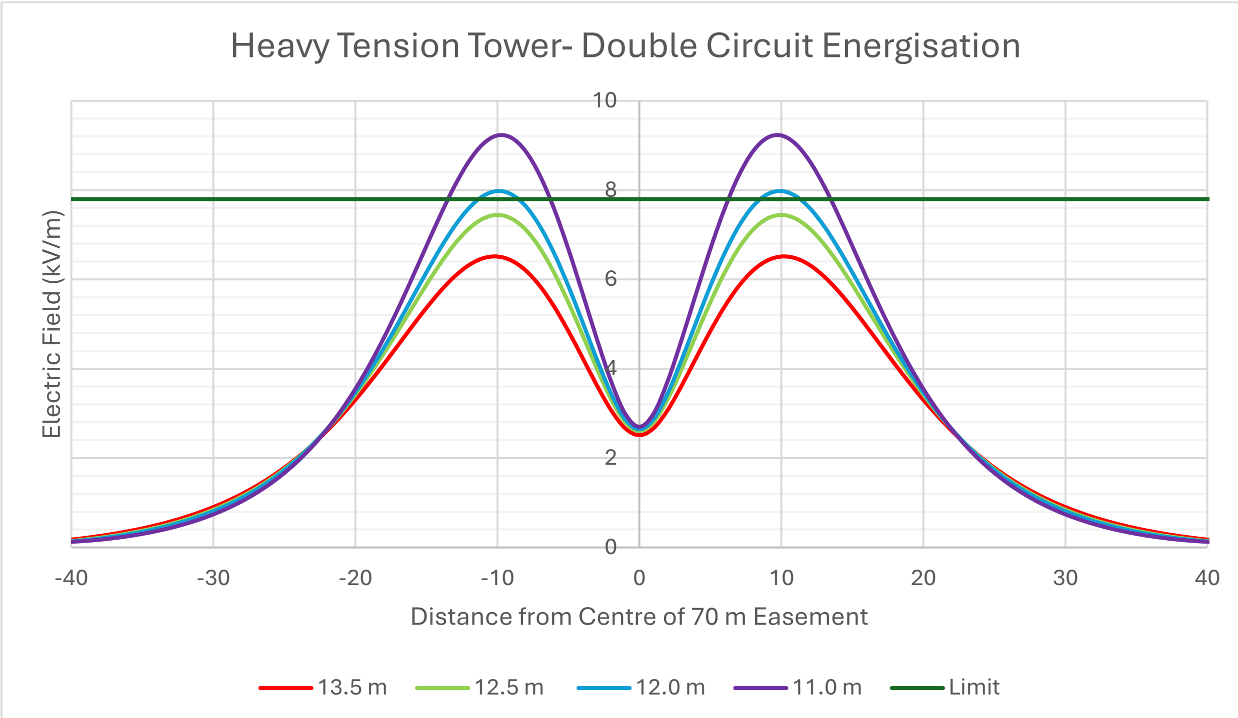

Figure A7: VTW-Heavy Tension Tower, Both Circuits Energised

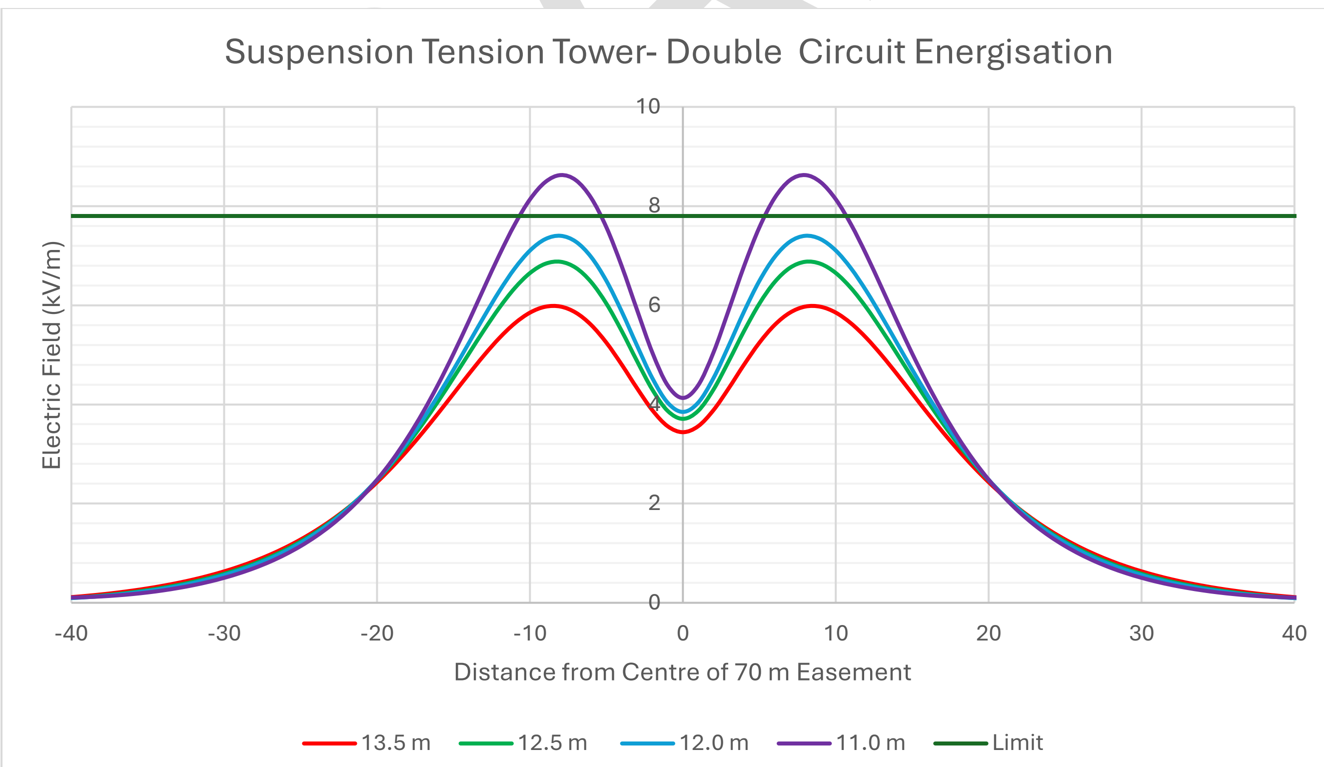

Figure A8: VSE-Suspension Tower, Both Circuits Energised

B

Appendix B – Transmission Line Magnetic Field Plots

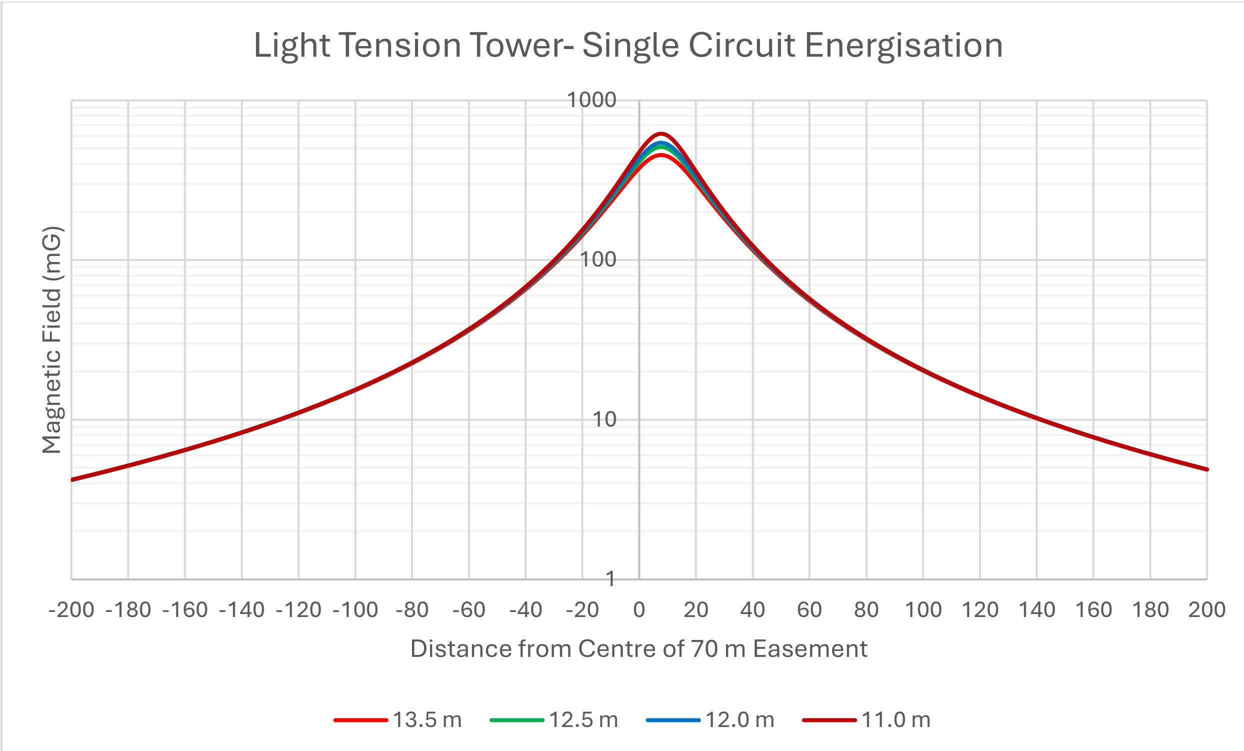

Figure B1: VTU-Light Tension Tower, Single Circuit Energised

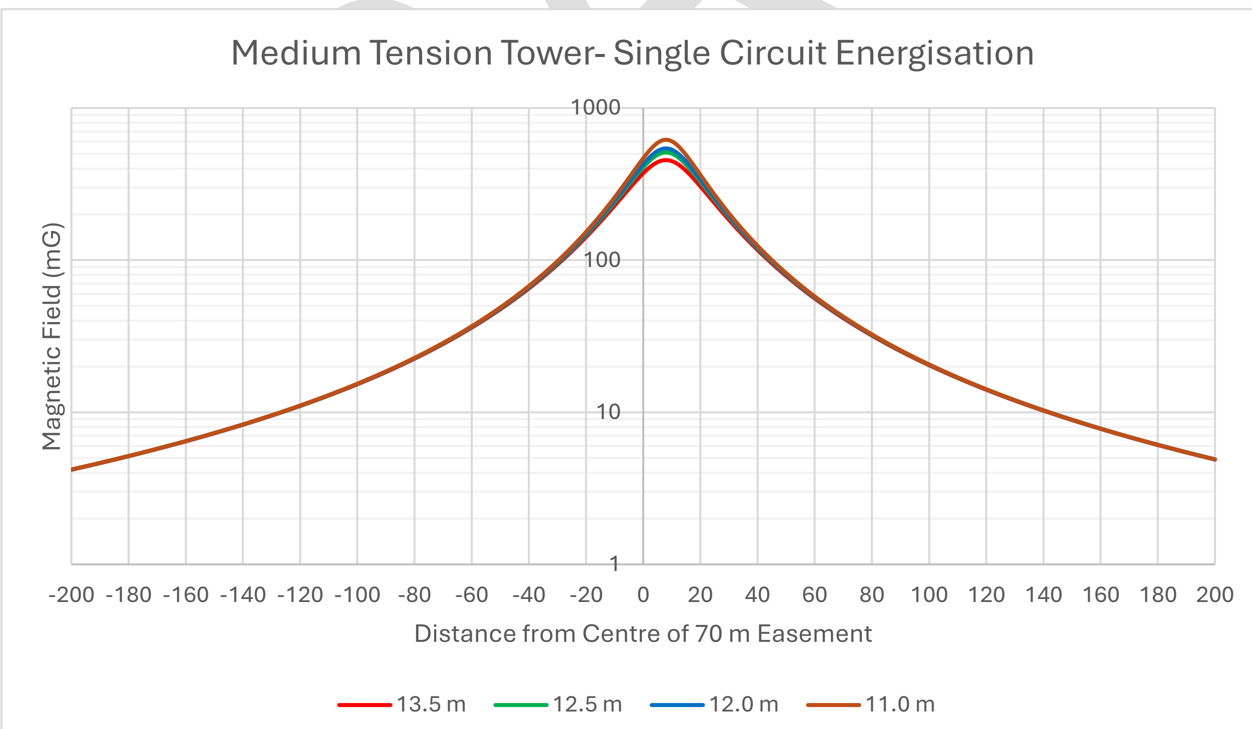

Figure B2: VTV- Medium Tension Tower, Single Circuit Energised

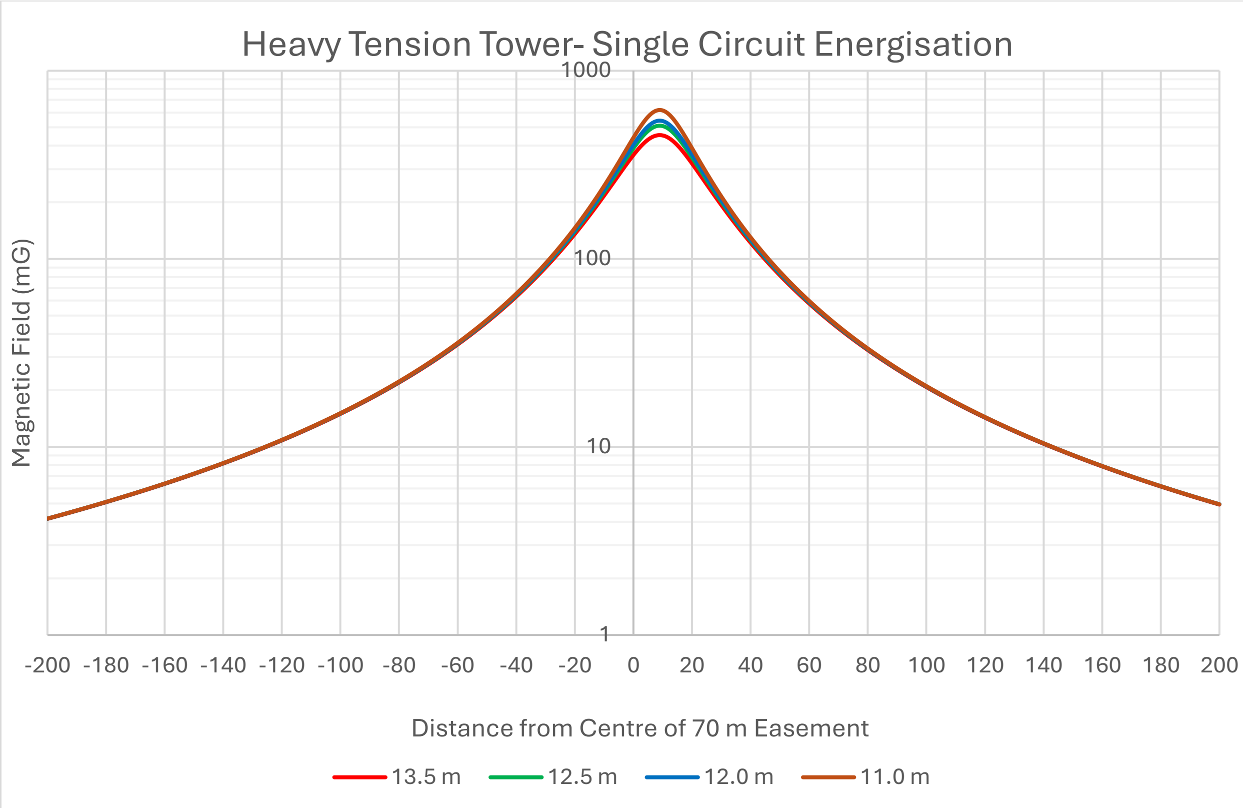

Figure B3: VTW- Heavy Tension Tower, Single Circuit Energised

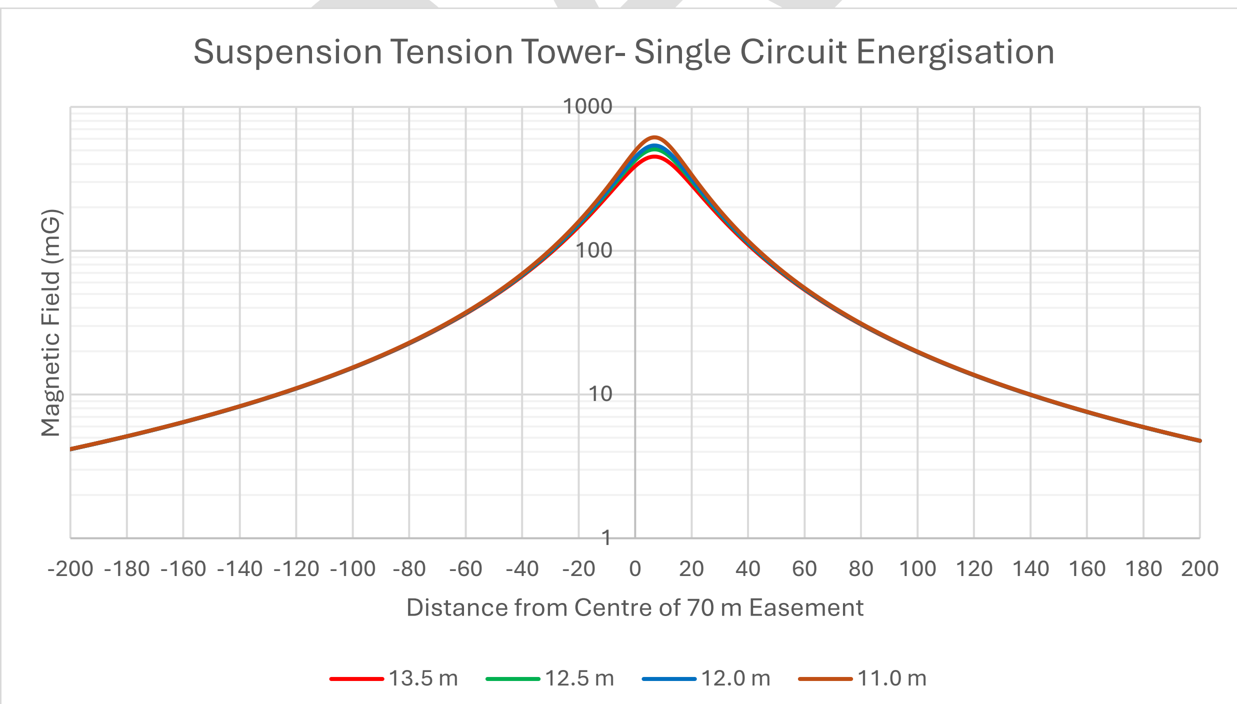

Figure B4: VSE-Suspension Tower, Single Circuit Energised

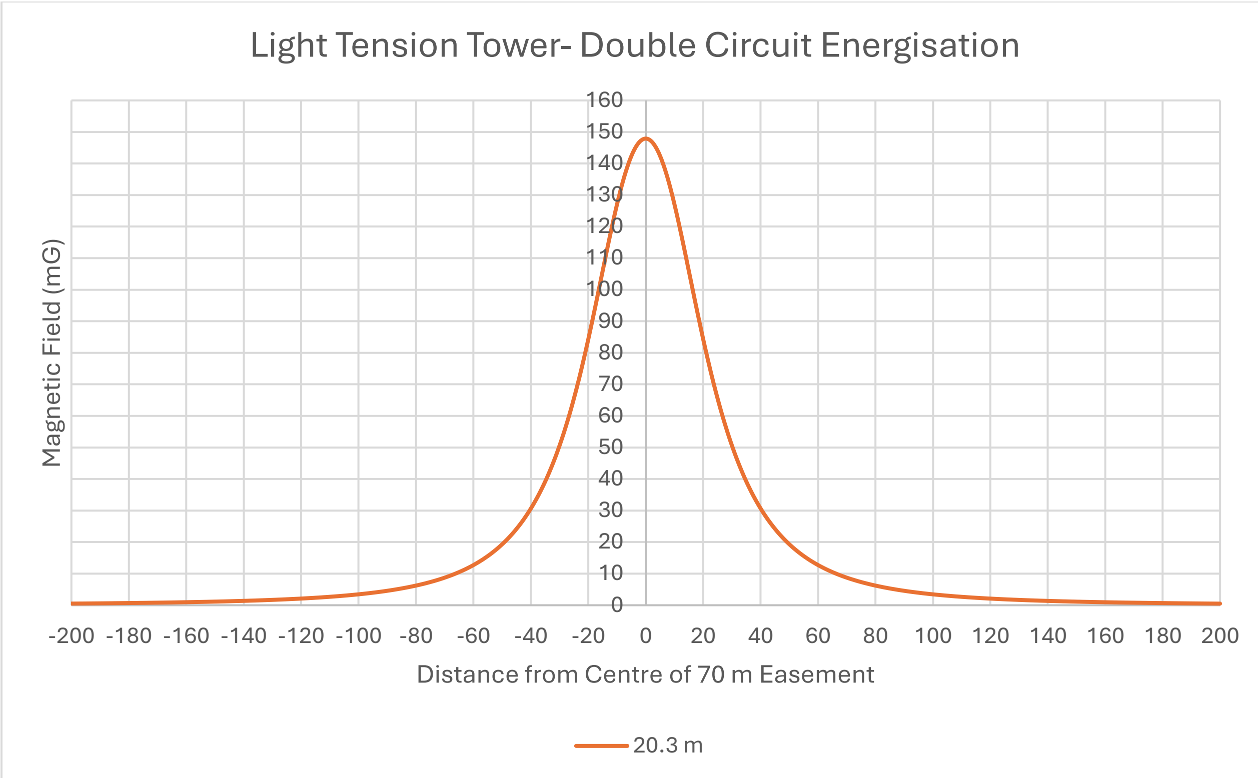

Figure B5: VTU-Light Tension Tower, Both Circuit Energised

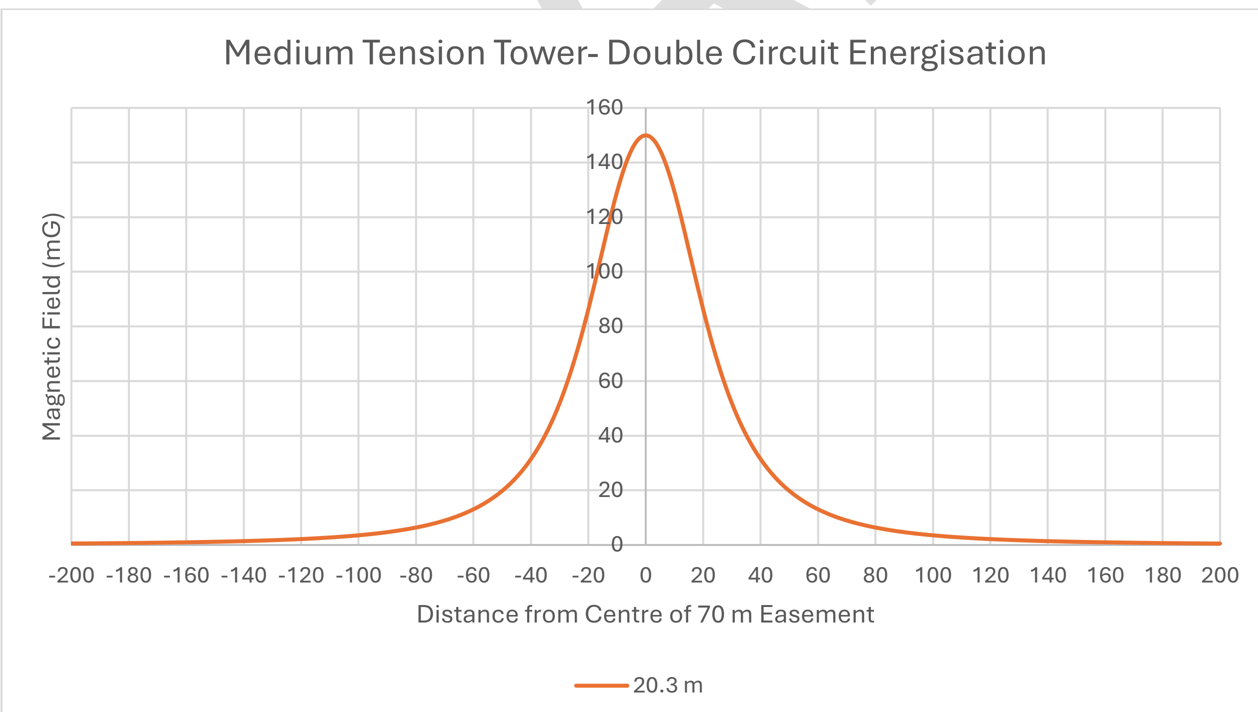

Figure B6: VTV-Medium Tension Tower, Both Circuit Energised

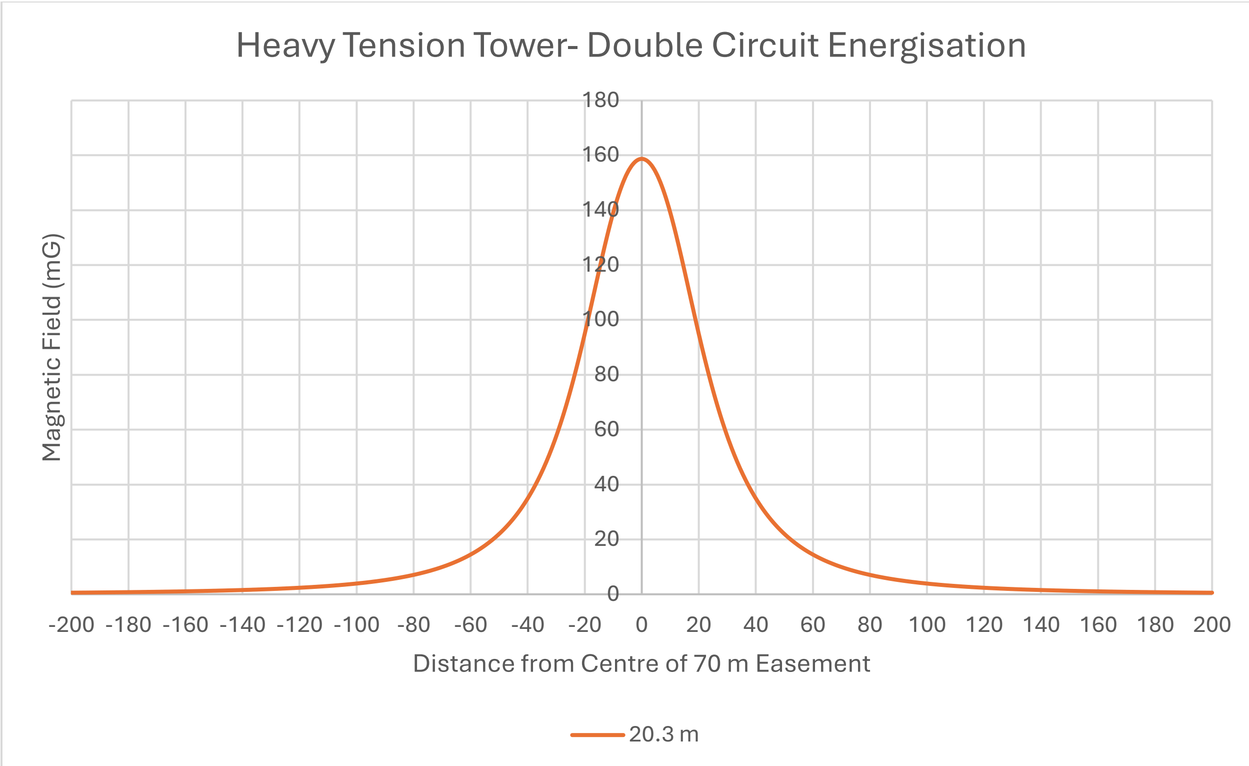

Figure B7: VTW-Heavy Tension Tower, Both Circuit Energised

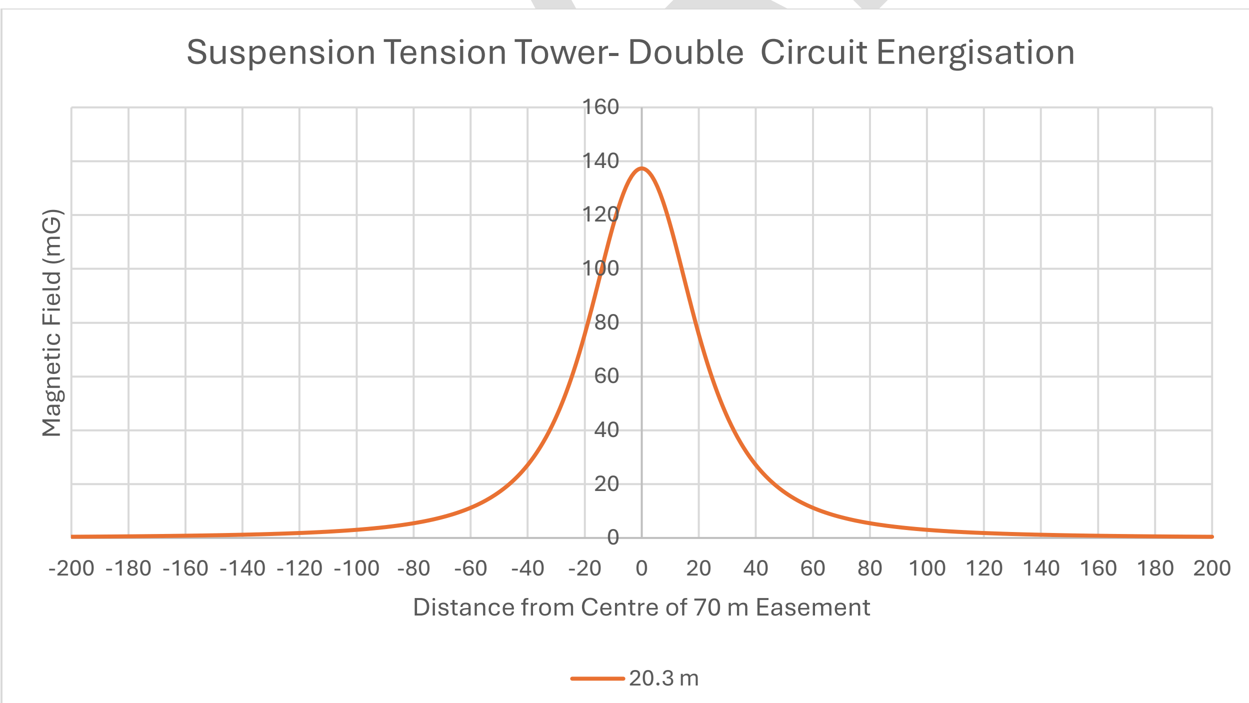

Figure B8: VSE-Suspension Tower, Both Circuit Energised

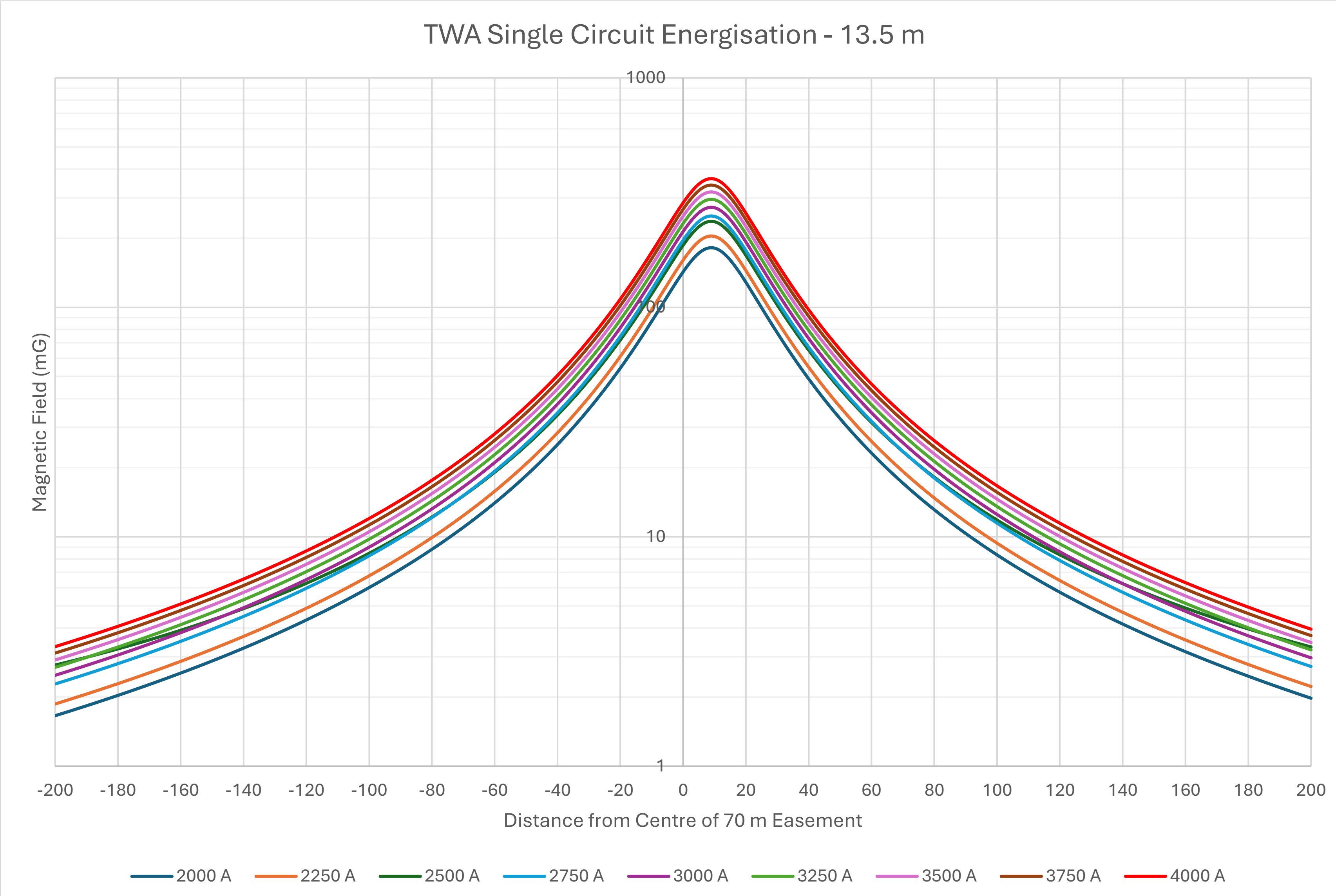

Figure B9: Magnetic Field Density for varying loads, VTW-Heavy Tension Tower at 13.5 m, Single Circuit Energised

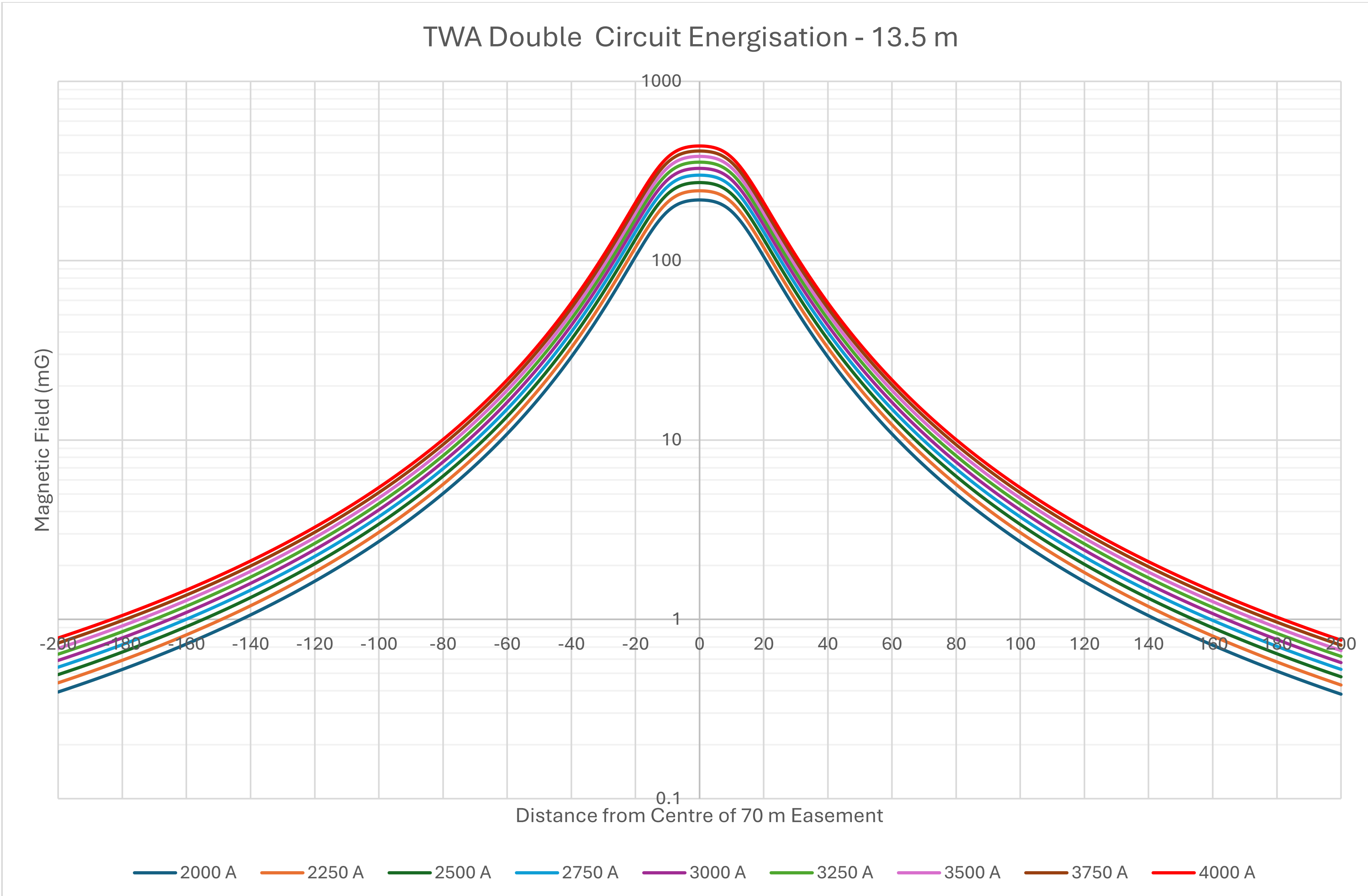

Figure B10: Magnetic Field Density for varying loads, VTW- Heavy Tension Tower at 13.5 m, Both Circuits Energised

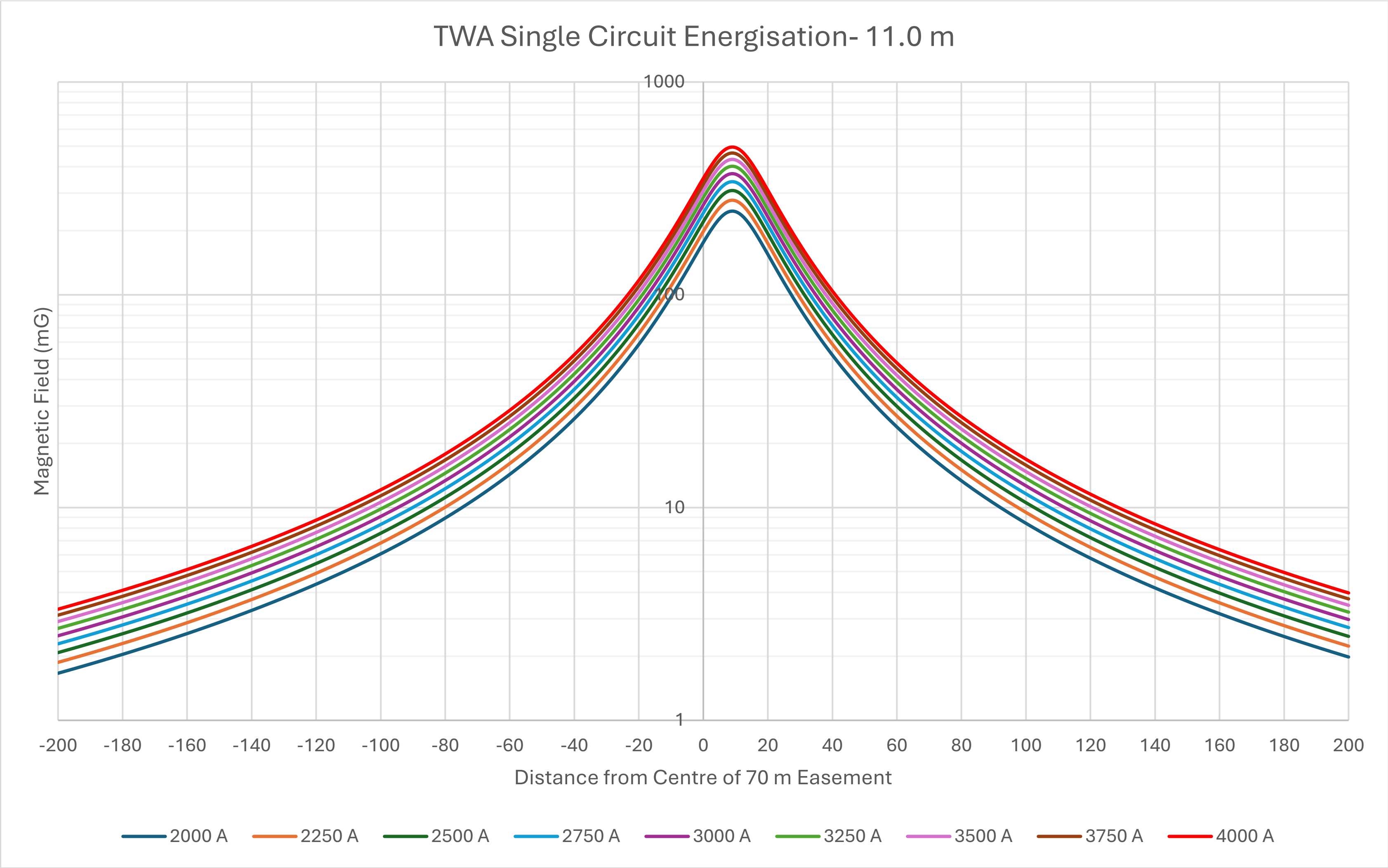

Figure B11: Magnetic Field Density for varying loads, VTW- Heavy Tension Tower at 11 m, Single Circuit Energised

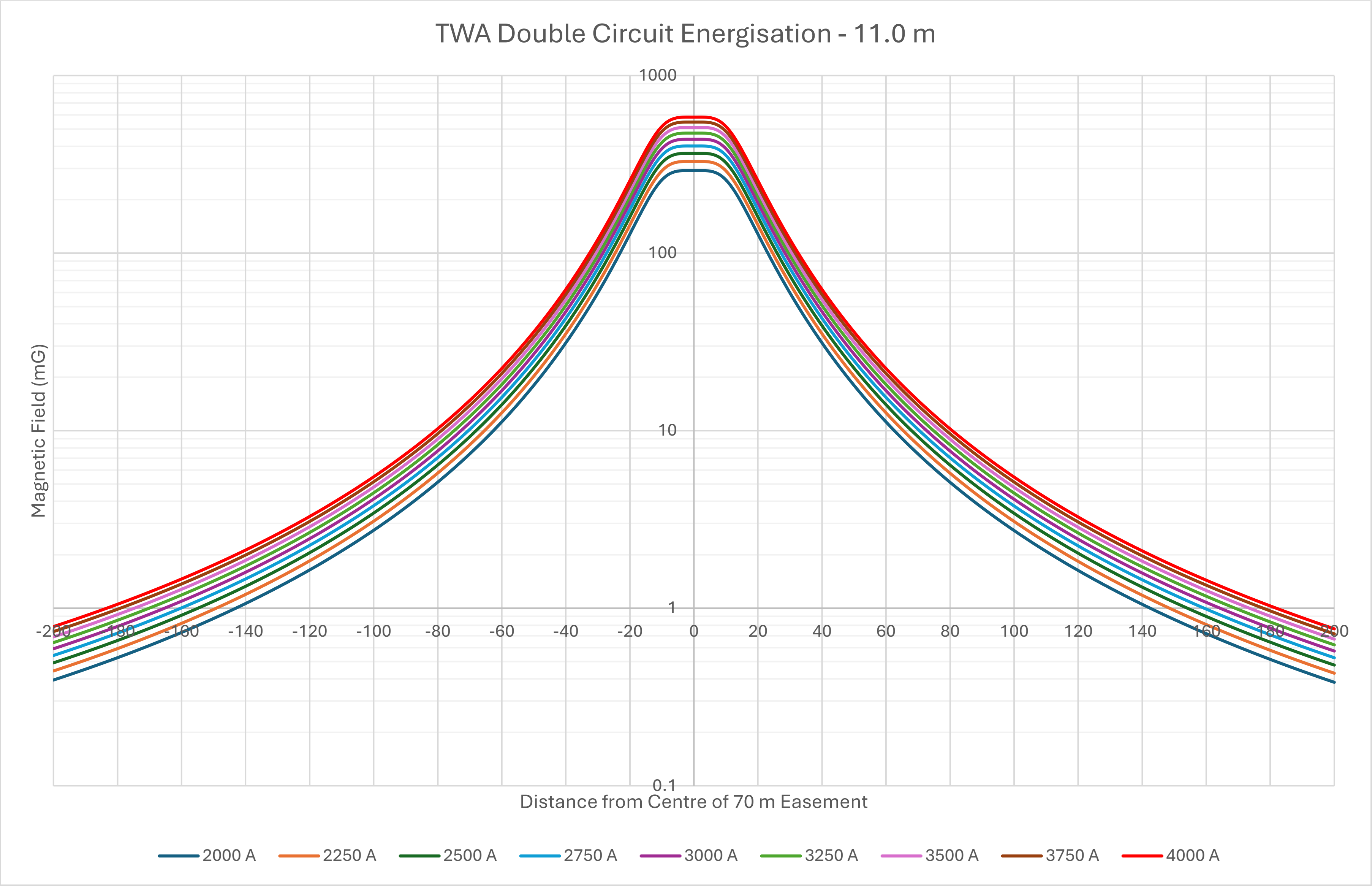

Figure B12: Magnetic Field Density for varying loads, VTW- Heavy Tension Tower at 11 m, Both Circuits Energised

C

Appendix C – Electric and Magnetic Field Plots at Transmission Line Crossings

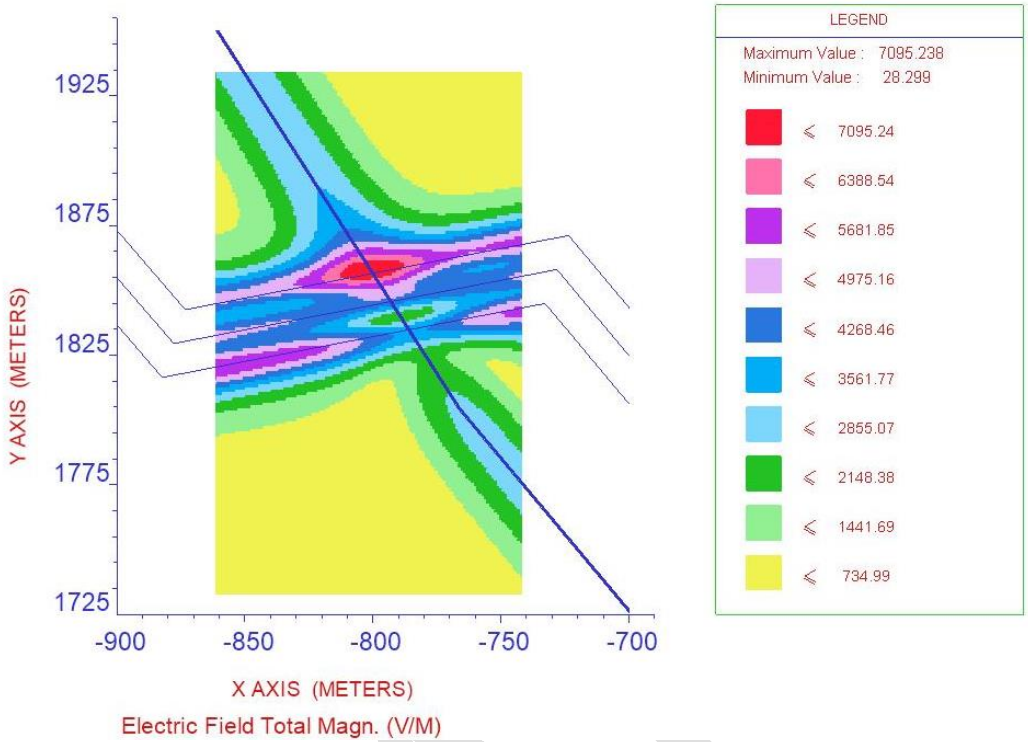

Figure C1: Under Crossing: Case 1, 1 x 330 kV circuits (Transgrid line 81), Single Circuit Energised – Electric Fields

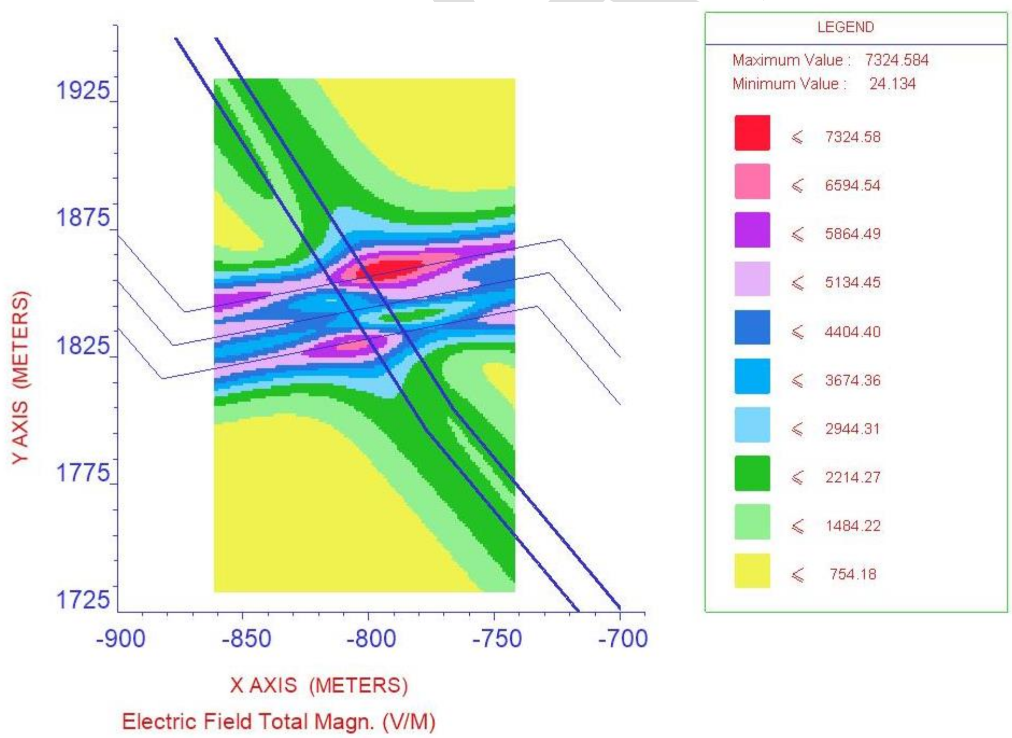

Figure C2: Under Crossing: Case 1, 1 x 330 kV circuits (Transgrid line 81), Both Circuits Energised – Electric Fields

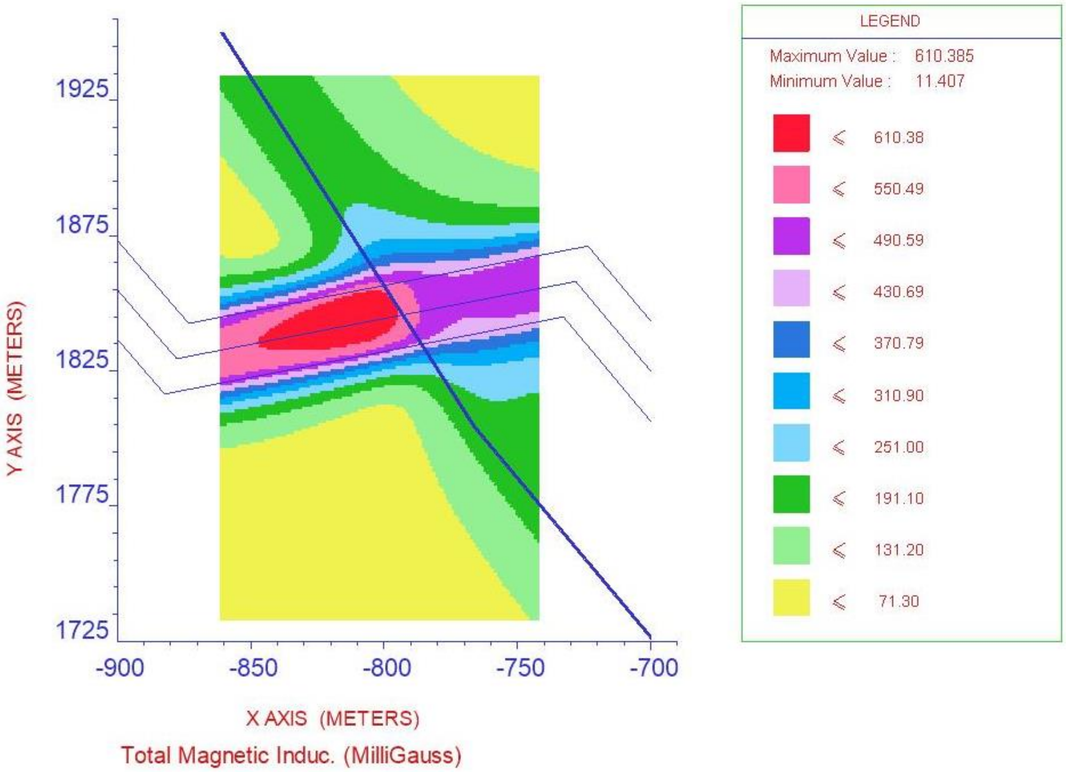

Figure C3: Under Crossing: Case 1, 1 x 330 kV circuits (Transgrid line 81), Single Circuit Energised - Magnetic Fields

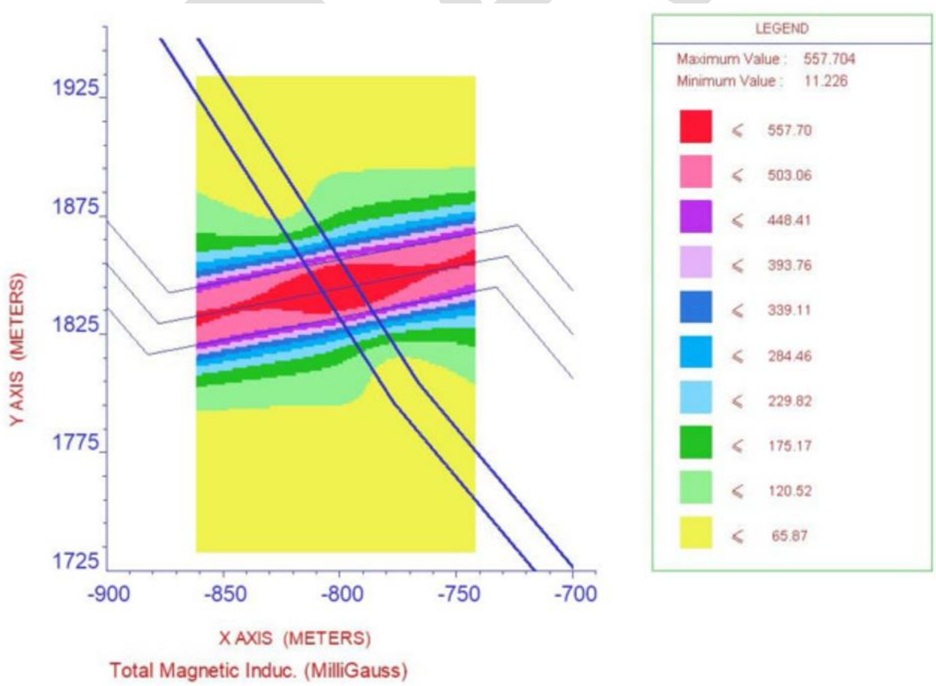

Figure C4: Under Crossing: Case 1, 1 x 330 kV circuits (Transgrid line 81), Both Circuits Energised – Magnetic Fields

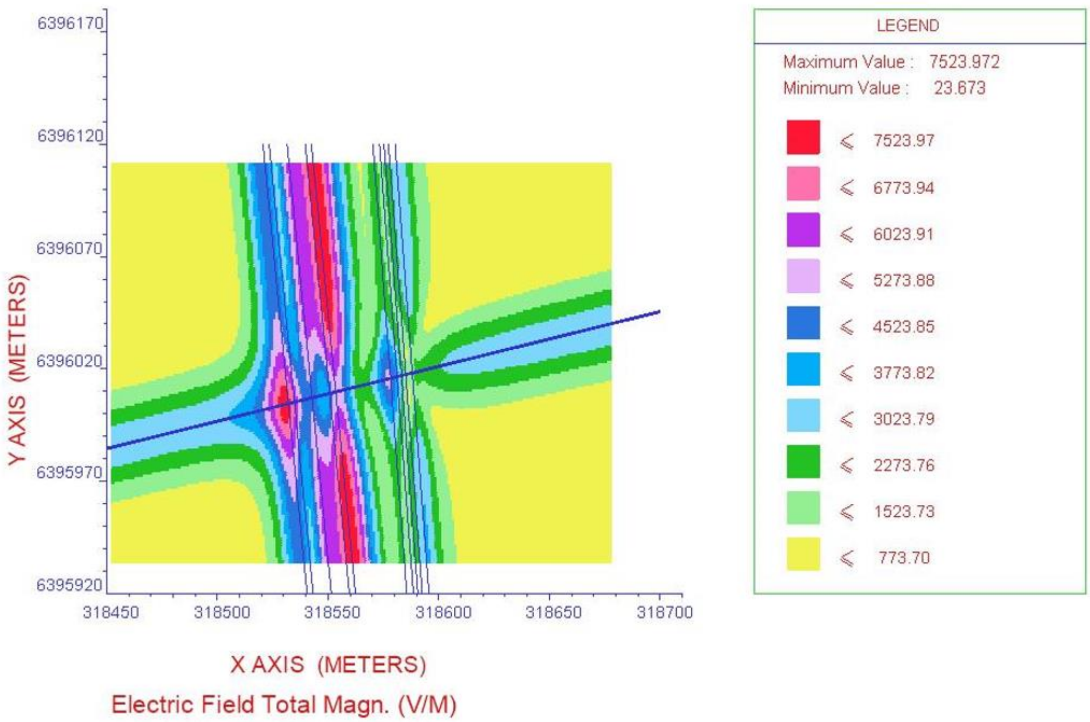

Figure C5: Under Crossing: Case 3, 1 x 330 kV Circuit and 1 x 132 kV Circuit, Single Circuit Energised – Electric Fields

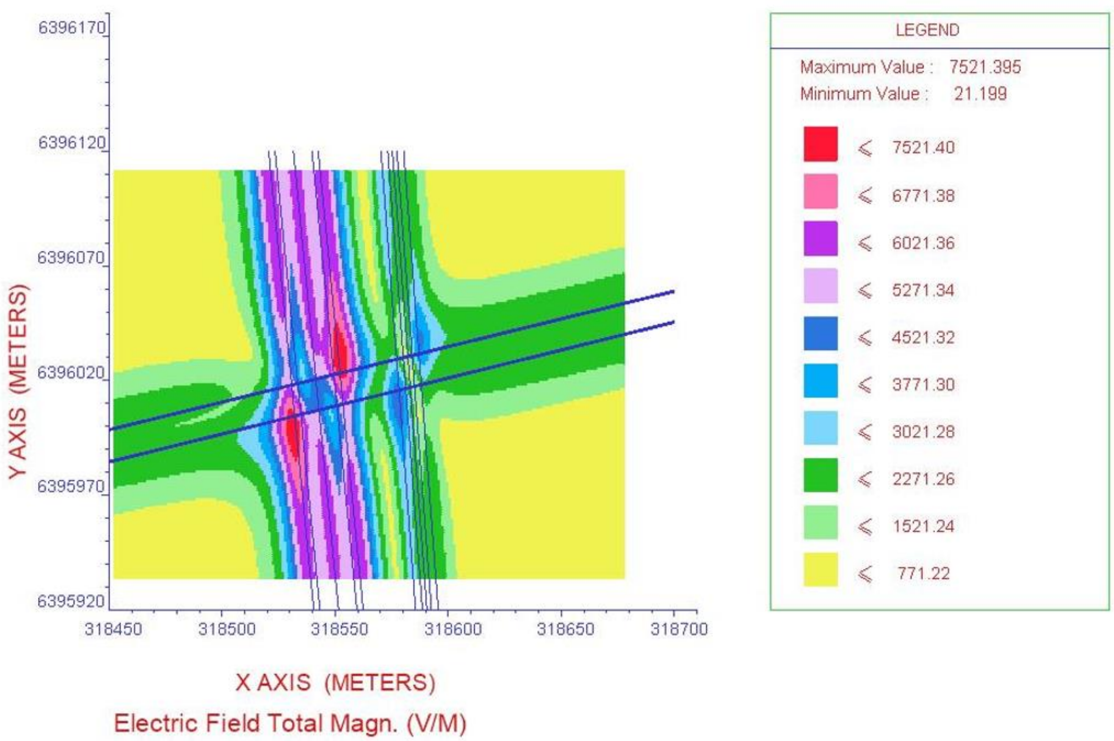

Figure C6: Under Crossing: Case 3, 1 x 330 kV Circuit and 1 x 132 kV Circuit, Both Circuits Energised – Electric Fields

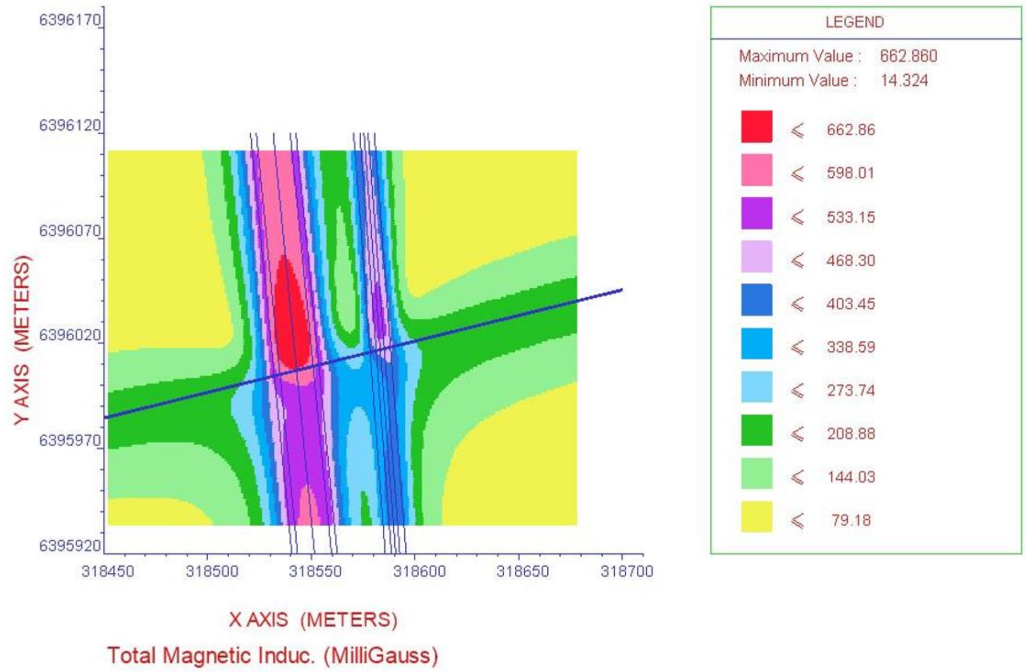

Figure C7: Under Crossing: Case 3, 1 x 330 kV Circuit and 1 x 132 kV Circuit, Single Circuit Energised – Magnetic Fields

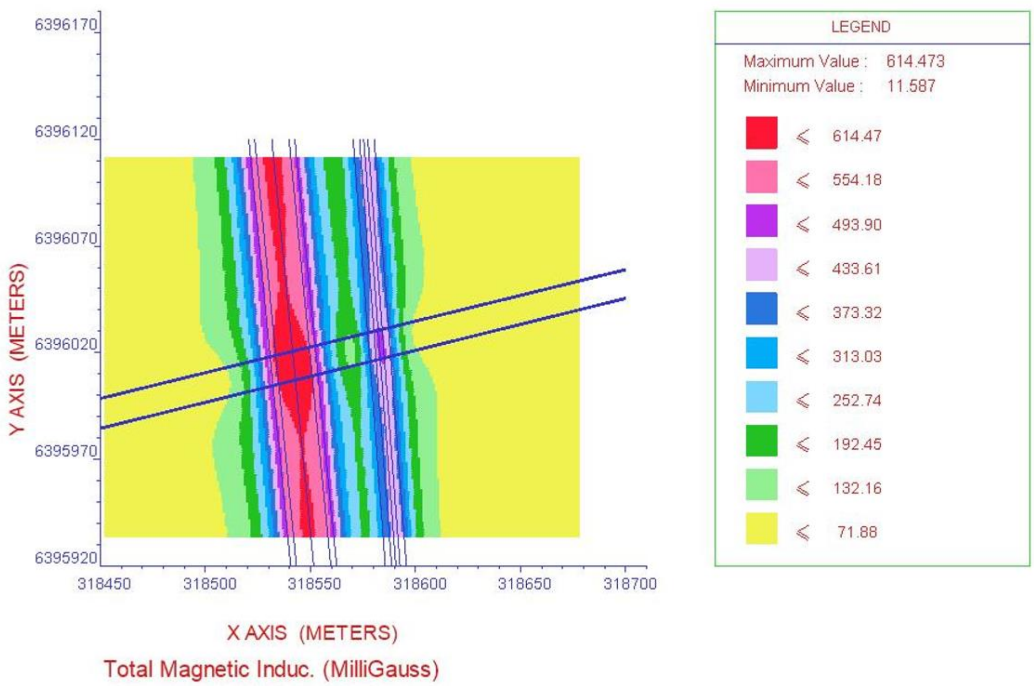

Figure C8: Under Crossing: Case 3, 1 x 330 kV Circuit and 1 x 132 kV Circuit, Both Circuits Energised – Magnetic Fields

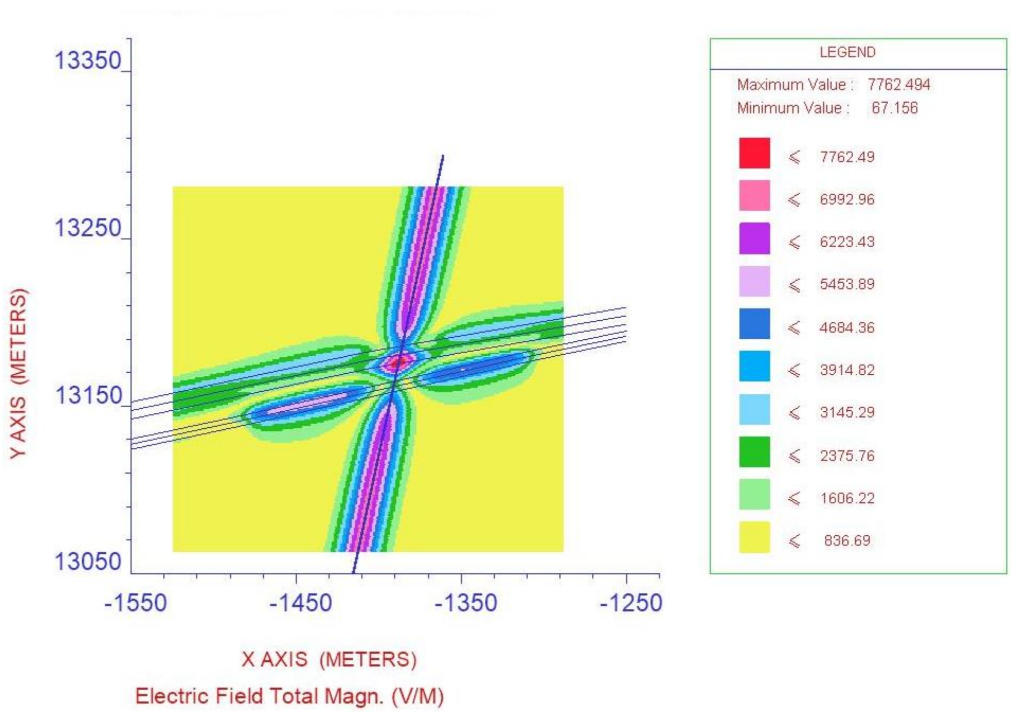

Figure C9: Under Crossing: Case 7, 1 x 132 kV Circuit and 1 x 66 kV Circuit, Single Circuit Energised – Electric Fields

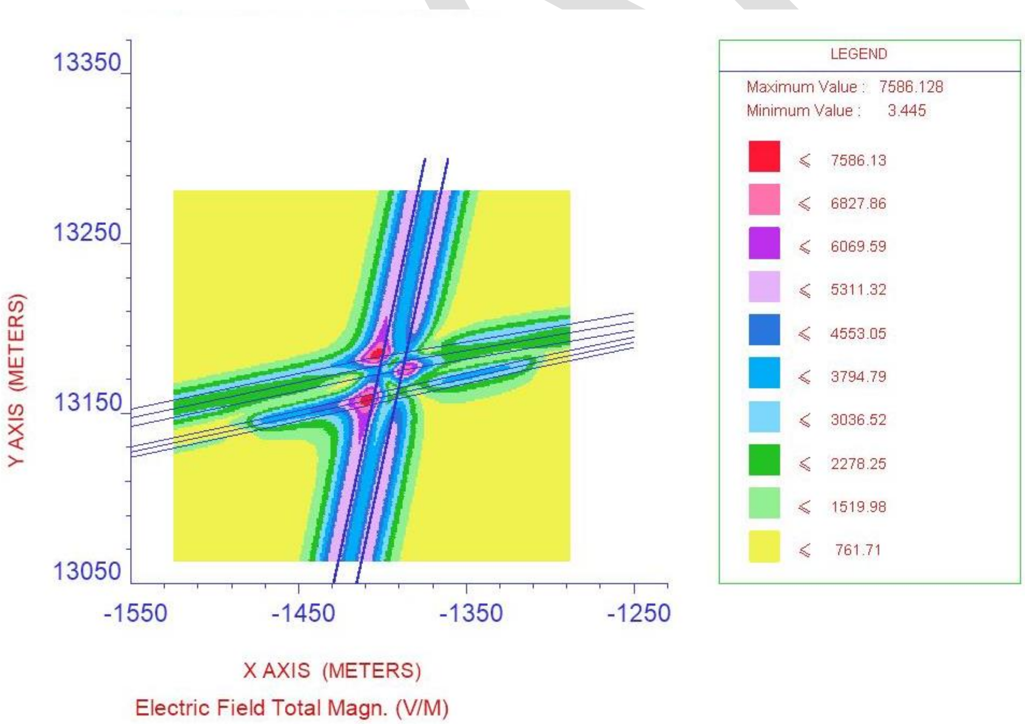

Figure C10: Under Crossing: Case 7, 1 x 132 kV Circuit and 1 x 66 kV Circuit, Both Circuits Energised – Electric Fields

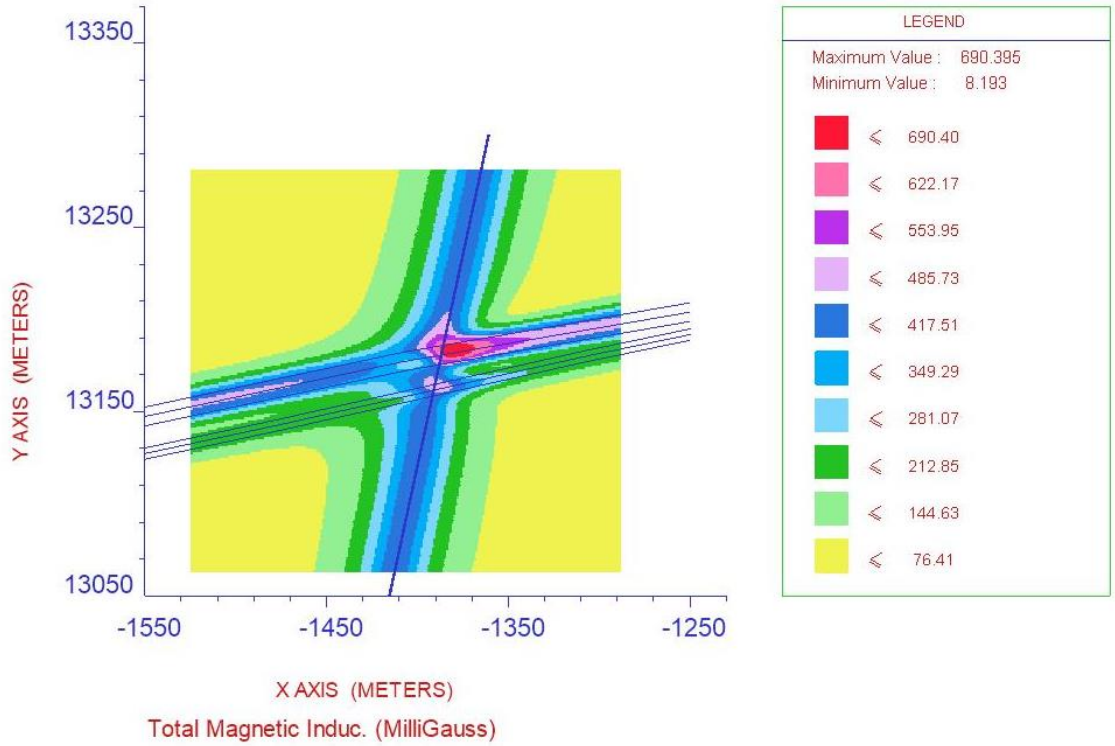

Figure C11: Under Crossing: Case 7, 1 x 132 kV Circuit and 1 x 66 kV Circuit, Single Circuit Energised – Magnetic Fields

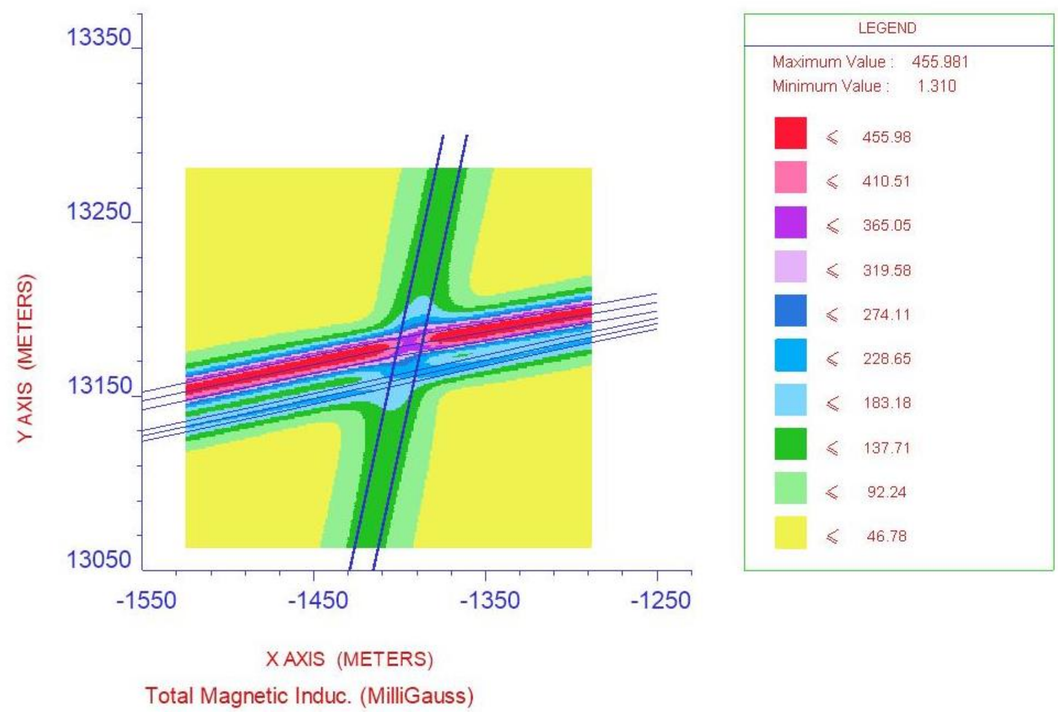

Figure C12: Under Crossing: Case 7, 1 x 132 kV Circuit and 1 x 66 kV Circuit, Both Circuits Energised – Magnetic Fields

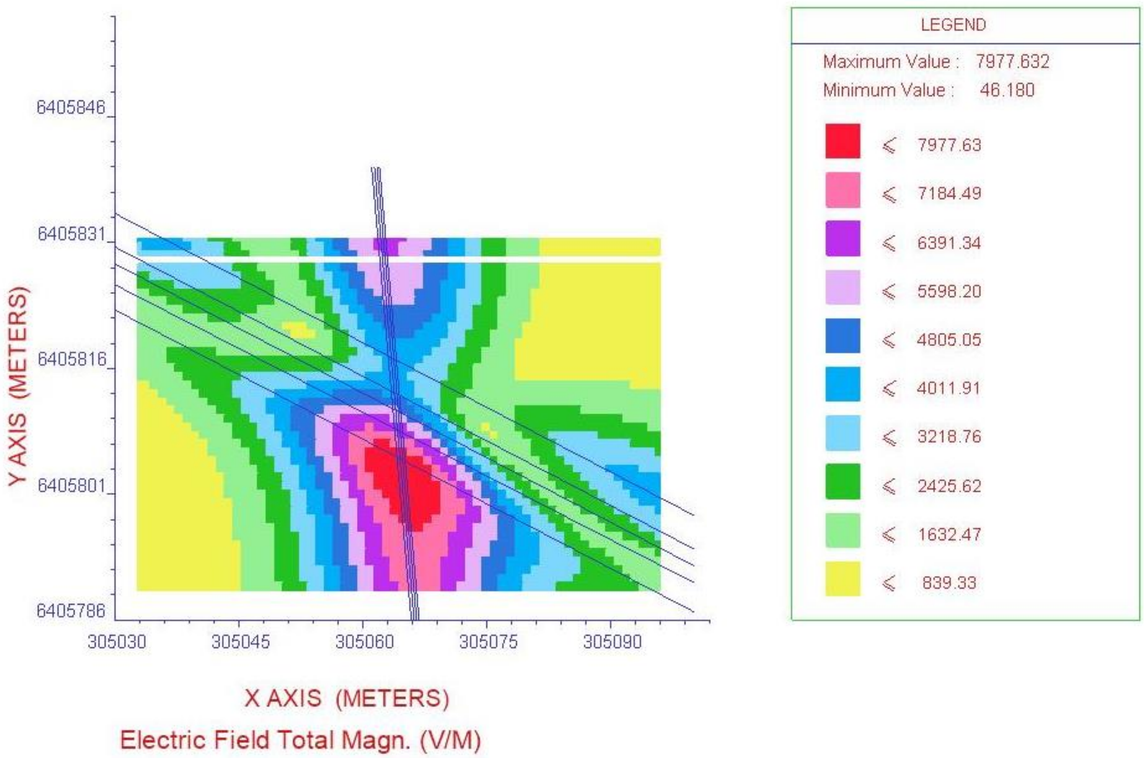

Figure C13: Under Crossing: Case 11, 1 x 132 kV Circuit, Single Circuit Energised – Electric Fields

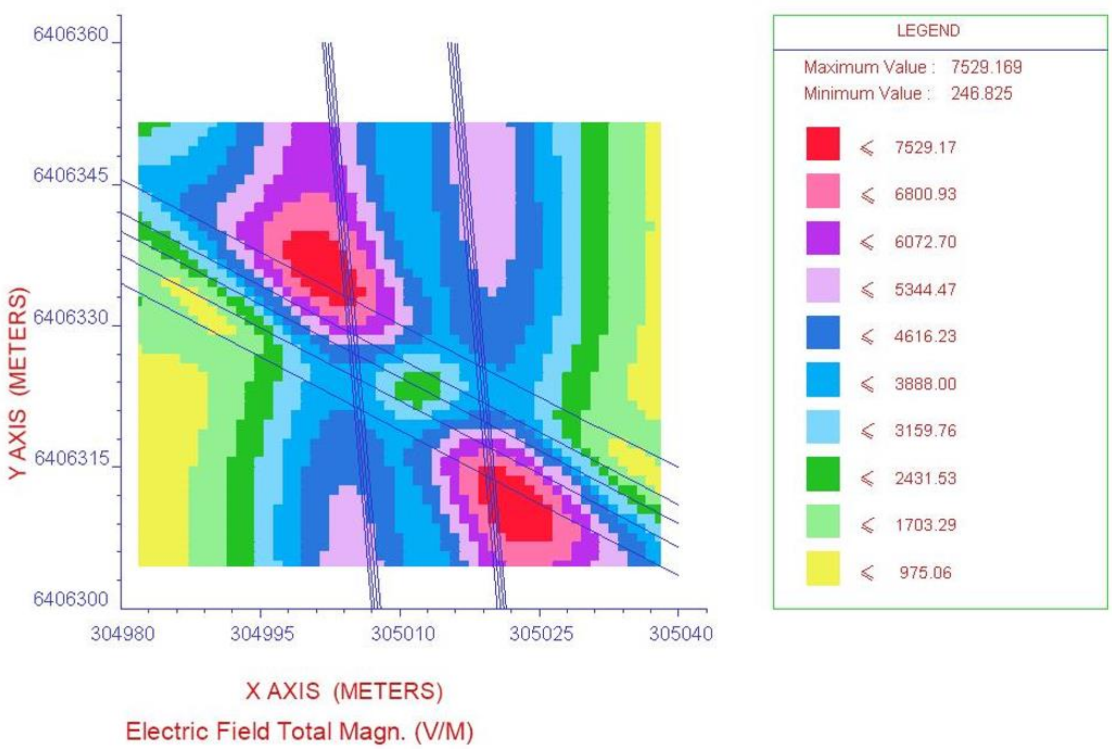

Figure C14: Under Crossing: Case 11, 1 x 132 kV Circuit, Both Circuits Energised – Electric Fields

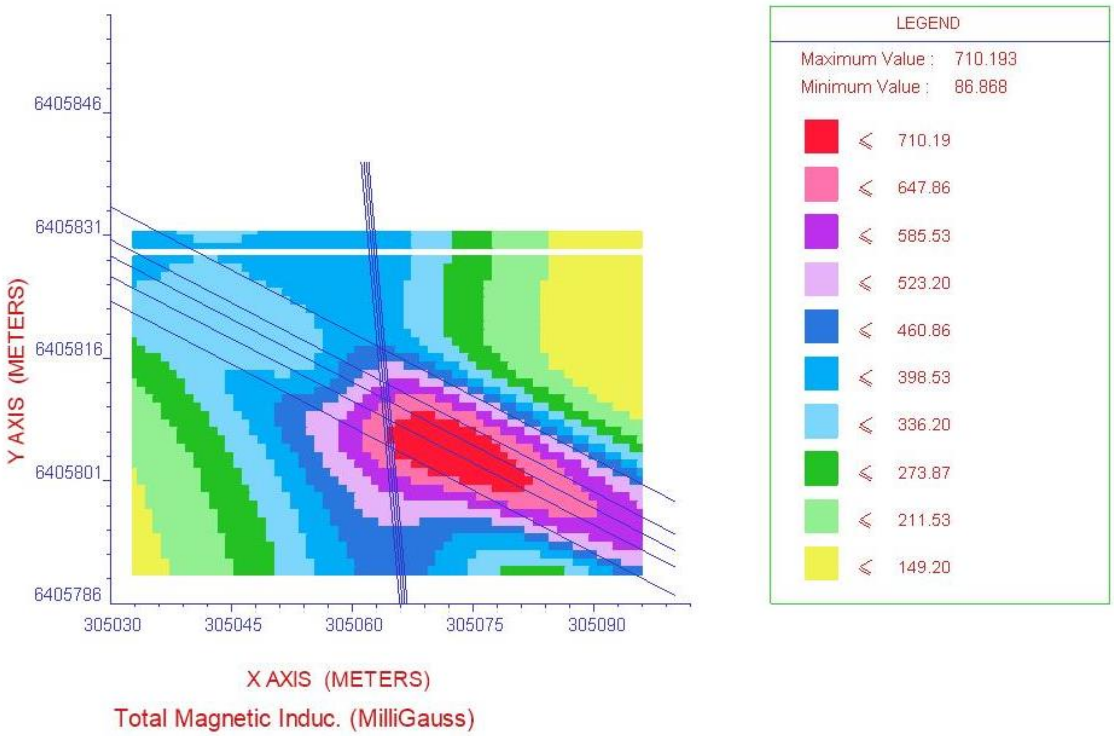

Figure C15: Under Crossing: Case 11, 1 x 132 kV Circuit, Single Circuit Energised – Magnetic Fields

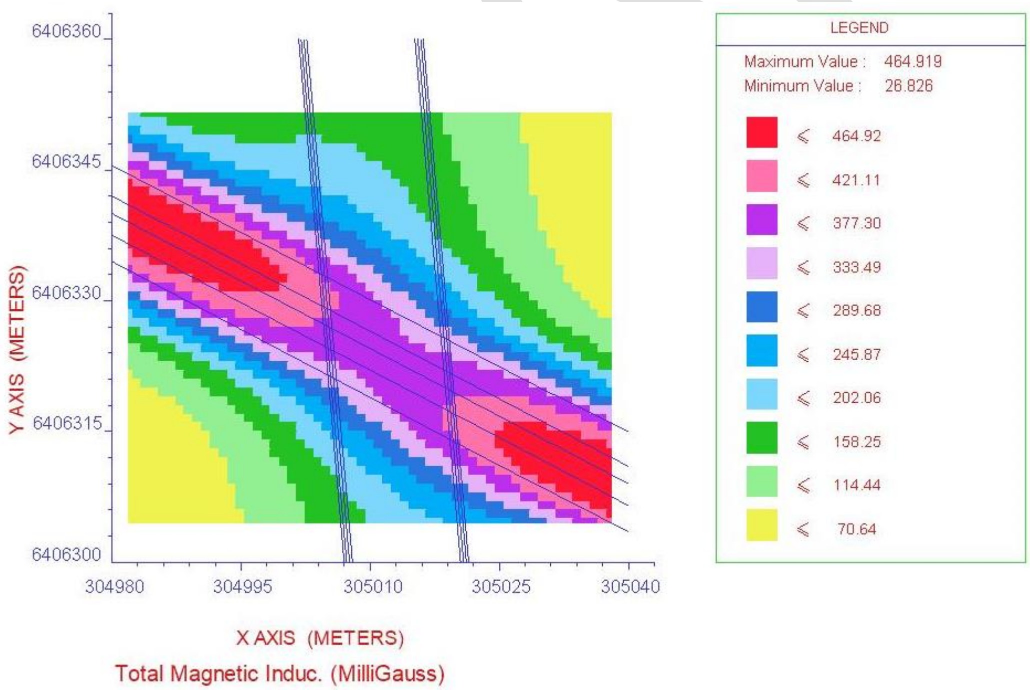

Figure C16: Under Crossing: Case 11, 1 x 132 kV Circuit, Both Circuits Energised – Magnetic Fields

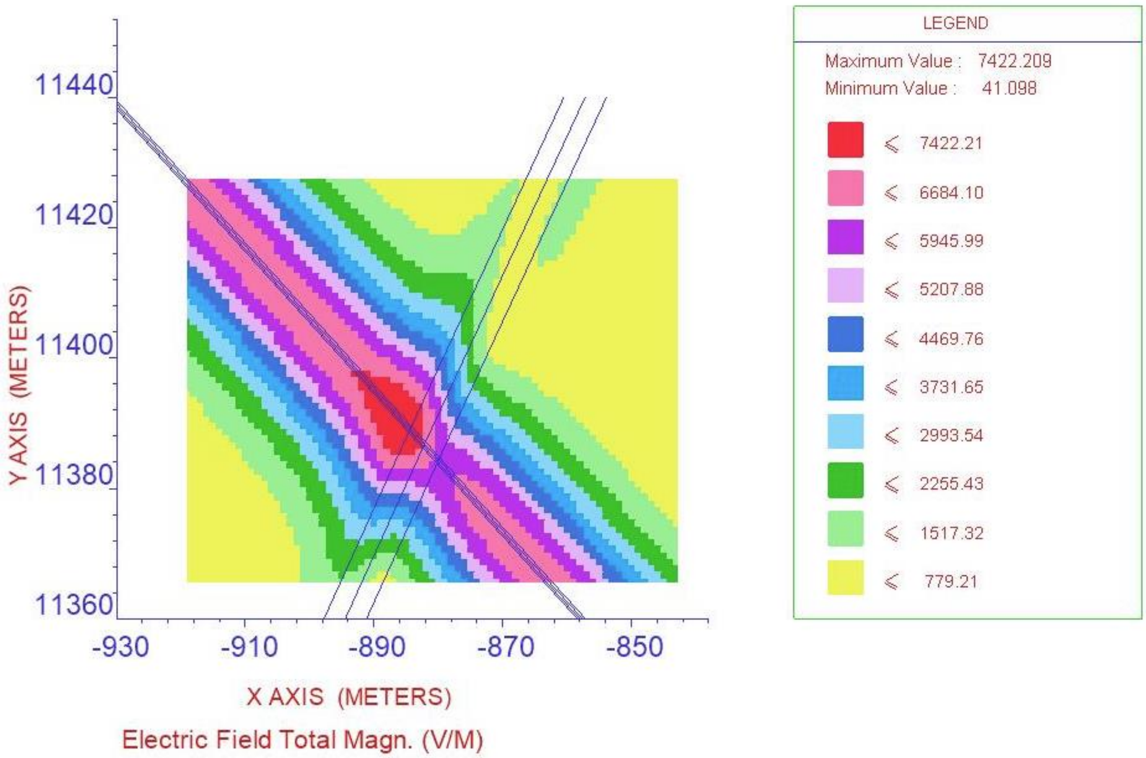

Figure C17: Under Crossing: Case 12, 1 x 66 kV Circuit, Single Circuit Energised – Electric Fields

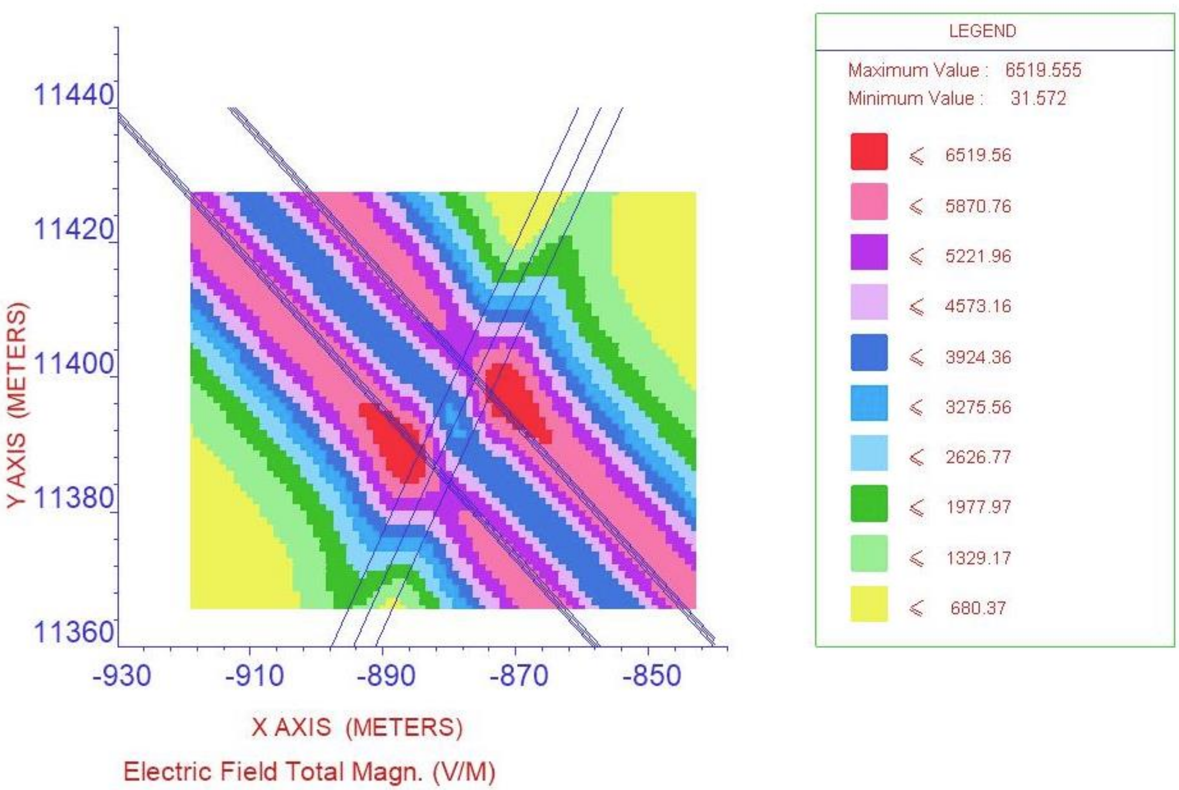

Figure C18: Under Crossing: Case 12, 1 x 66 kV Circuit, Both Circuits Energised – Electric Fields

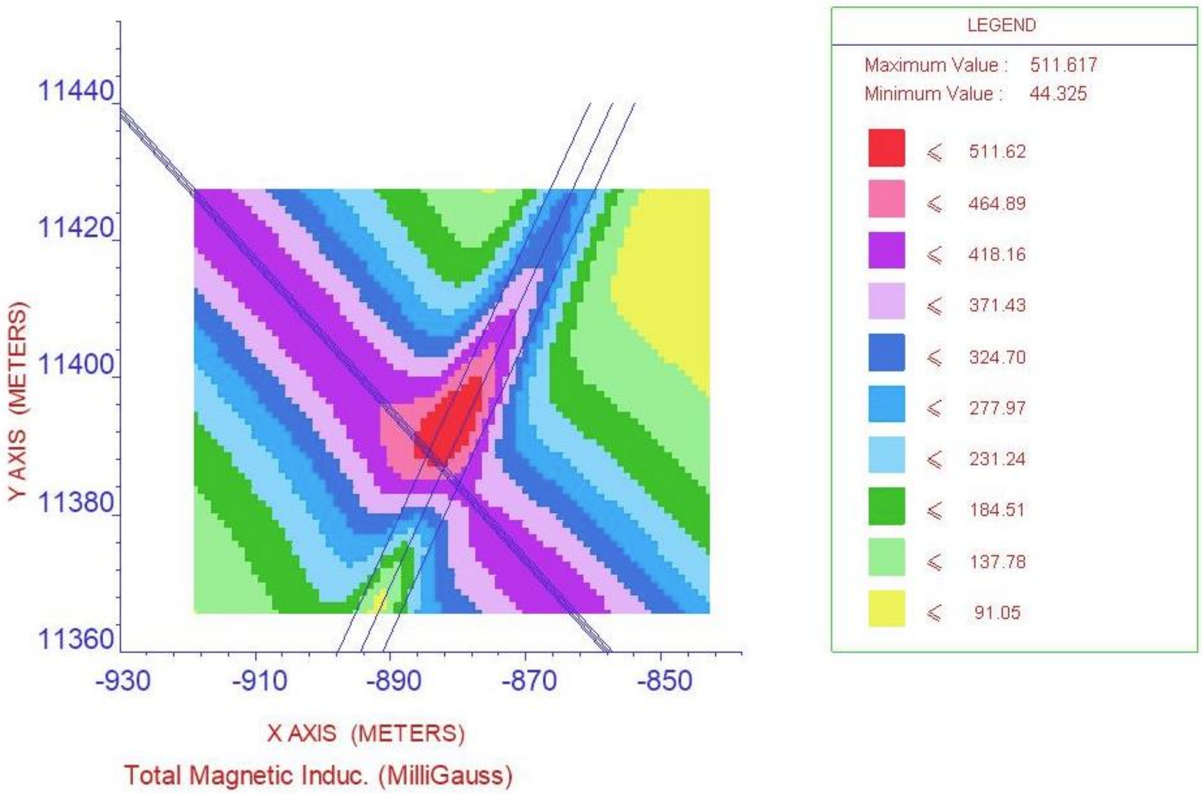

Figure C19: Under Crossing: Case 12, 1 x 66 kV Circuit, Single Circuit Energised – Magnetic Fields

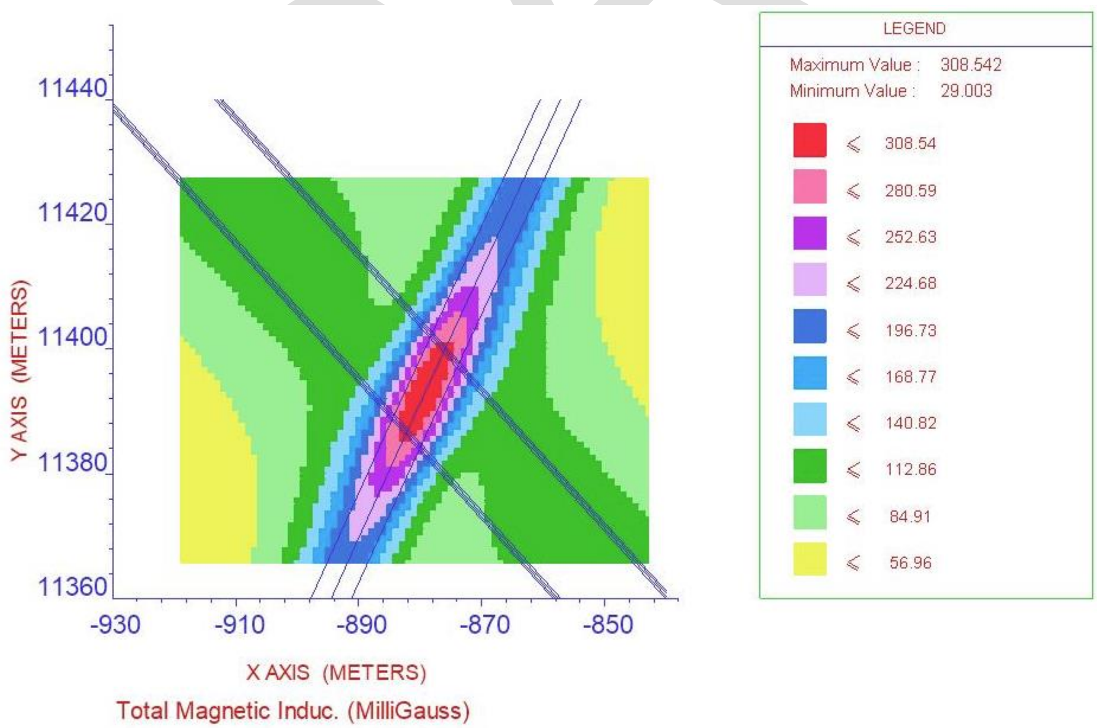

Figure C20: Under Crossing: Case 12, 1 x 66 kV Circuit, Both Circuits Energised – Magnetic Fields

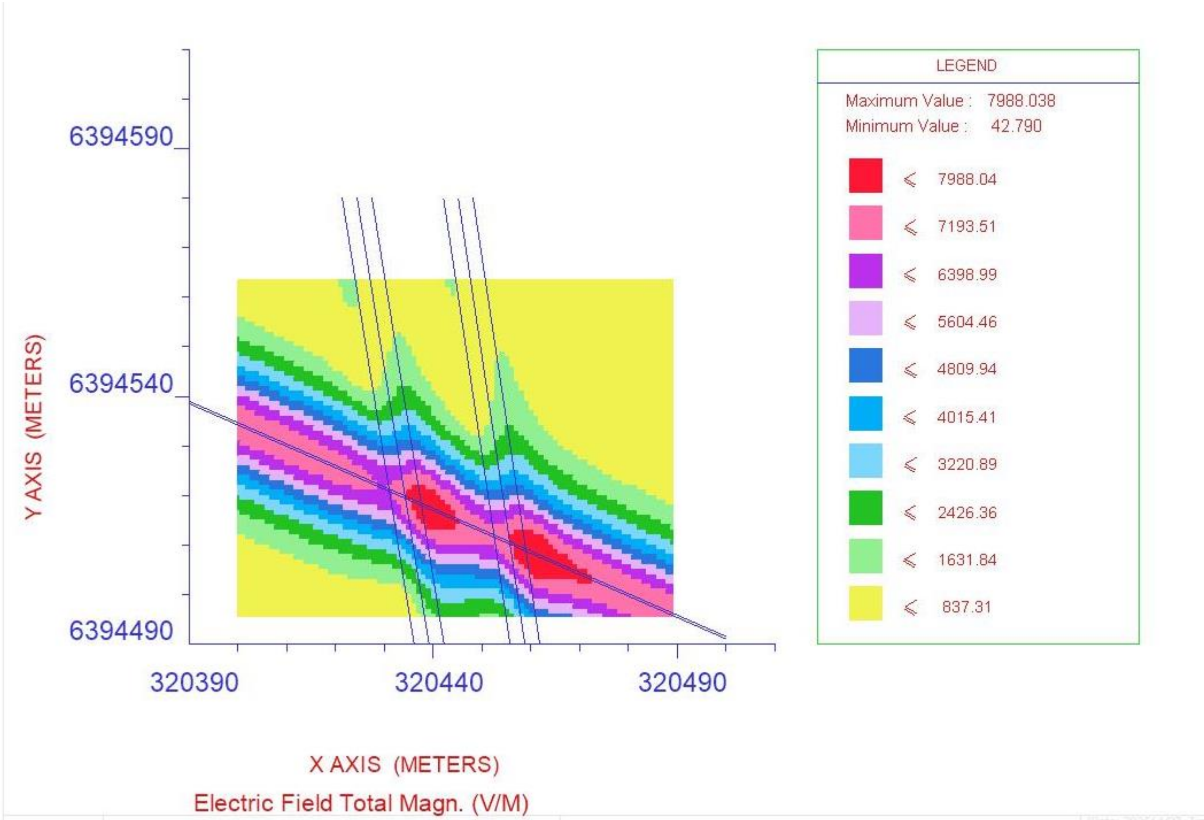

Figure C21: Under Crossing: Case 12, 2 x 66 kV Circuit, Single Circuit Energised – Electric Fields

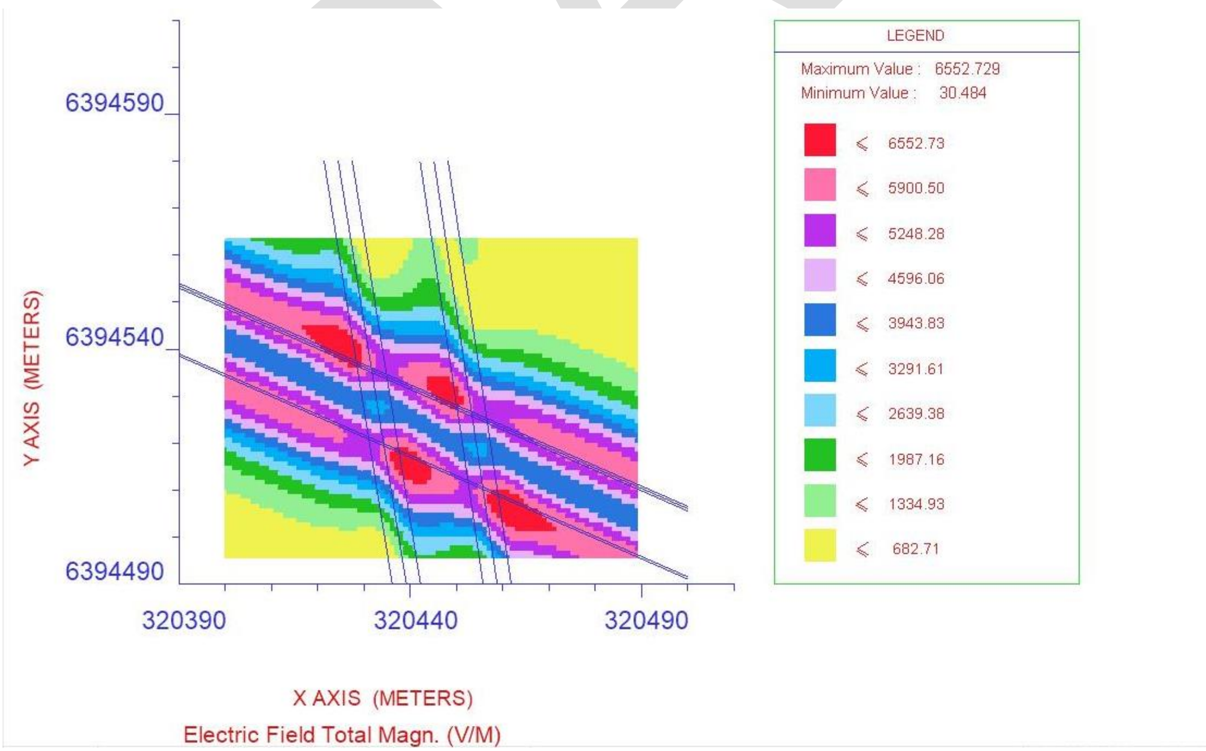

Figure C22: Under Crossing: Case 12, 2 x 66 kV Circuit, Both Circuits Energised – Electric Fields

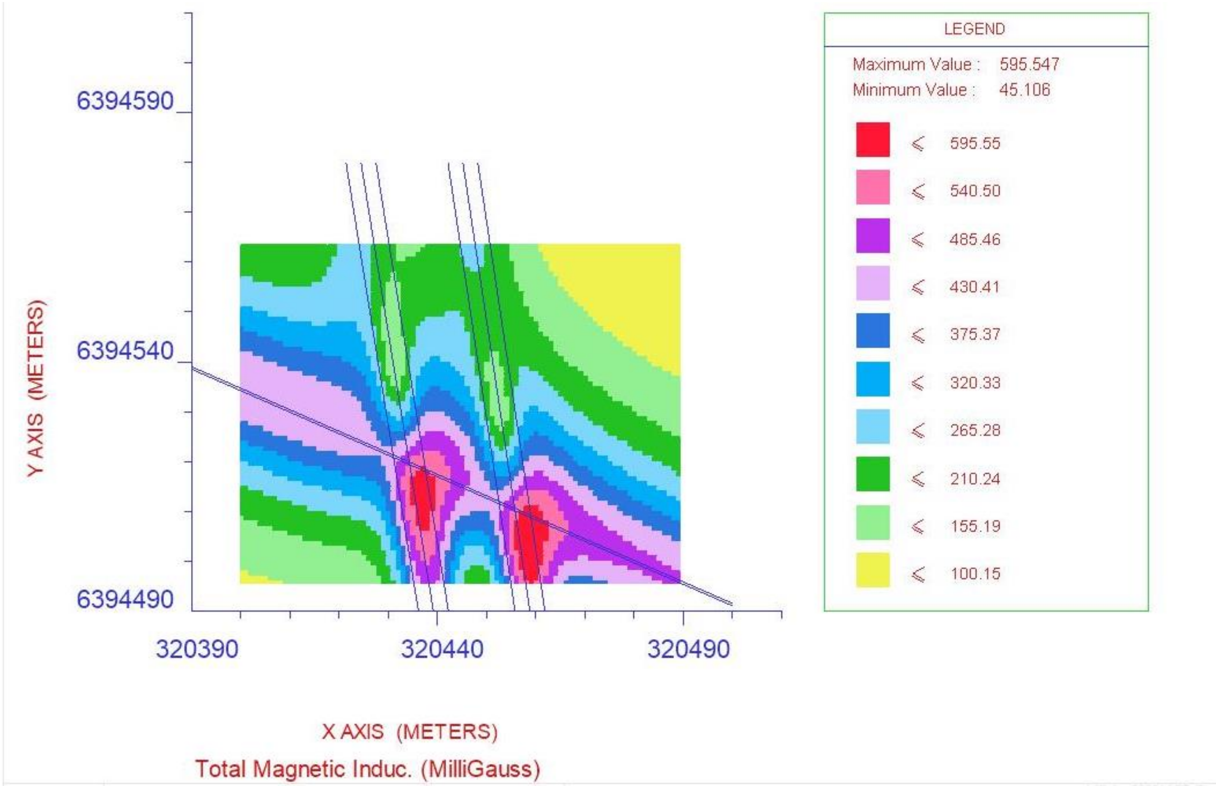

Figure C23: Under Crossing: Case 12, 2 x 66 kV Circuit, Single Circuit Energised – Magnetic Fields

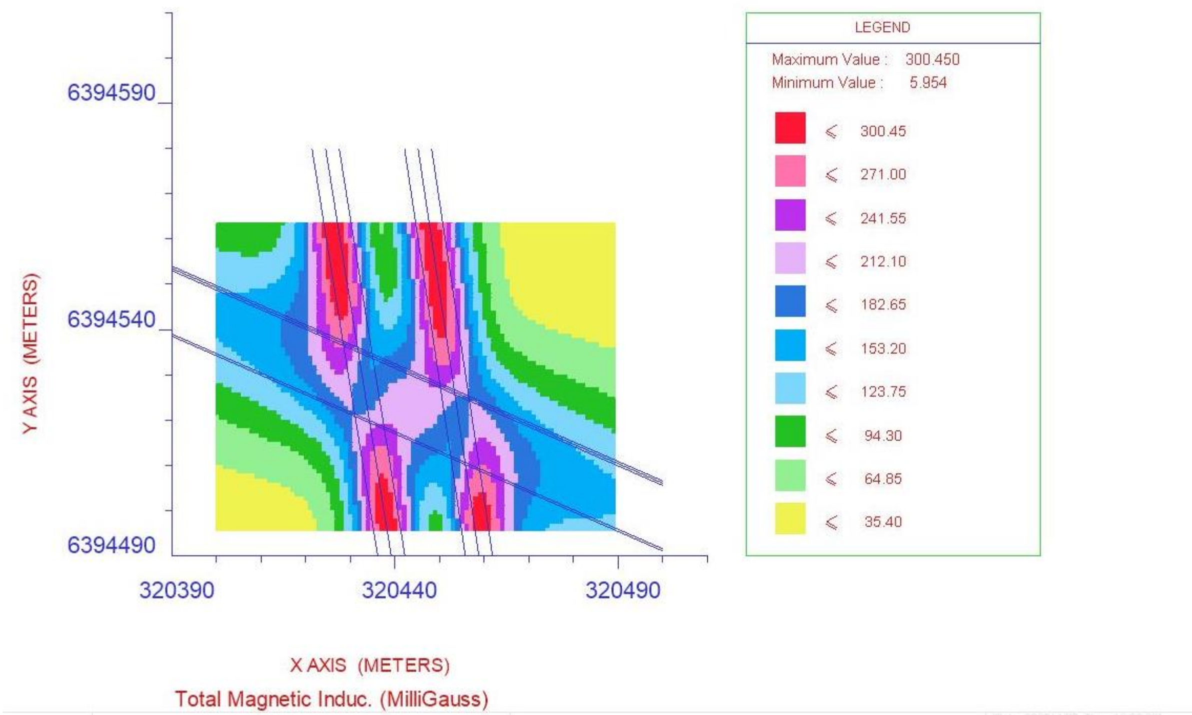

Figure C24: Under Crossing: Case 12, 2 x 66 kV Circuit, Both Circuits Energised – Magnetic Fields

D

Appendix D – Electric and Magnetic Field Plots of Parallel Circuits

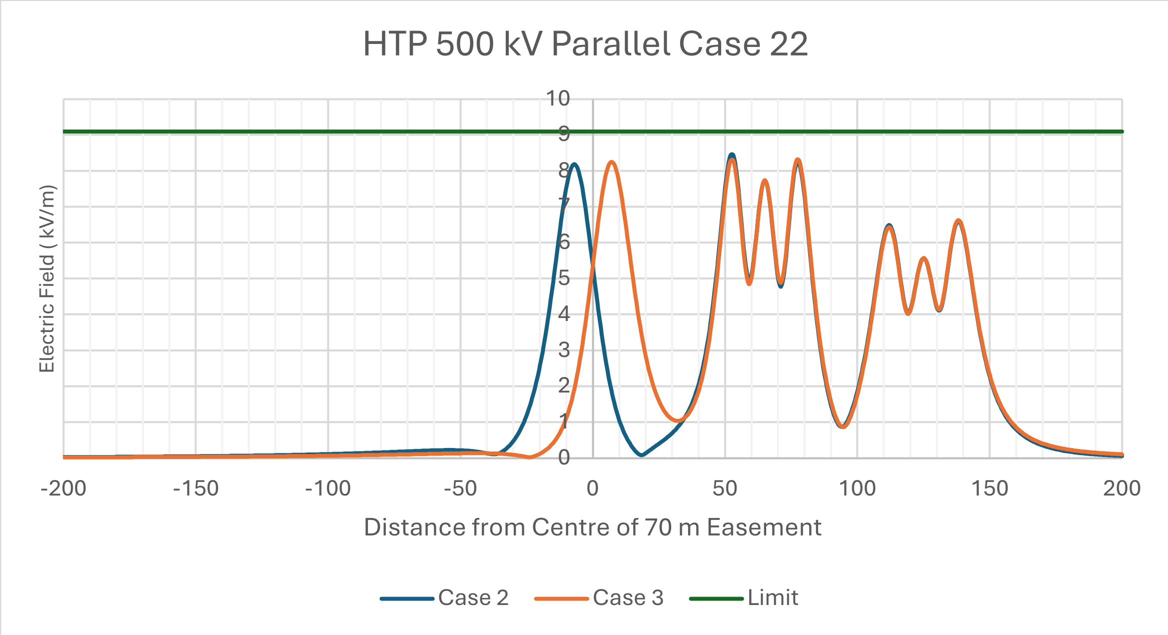

Figure D1: Parallel Circuits: Case 22, 2 x 330 kV circuits (Transgrid lines 81[1] and 82), Various Energisations[2] – Electric Fields

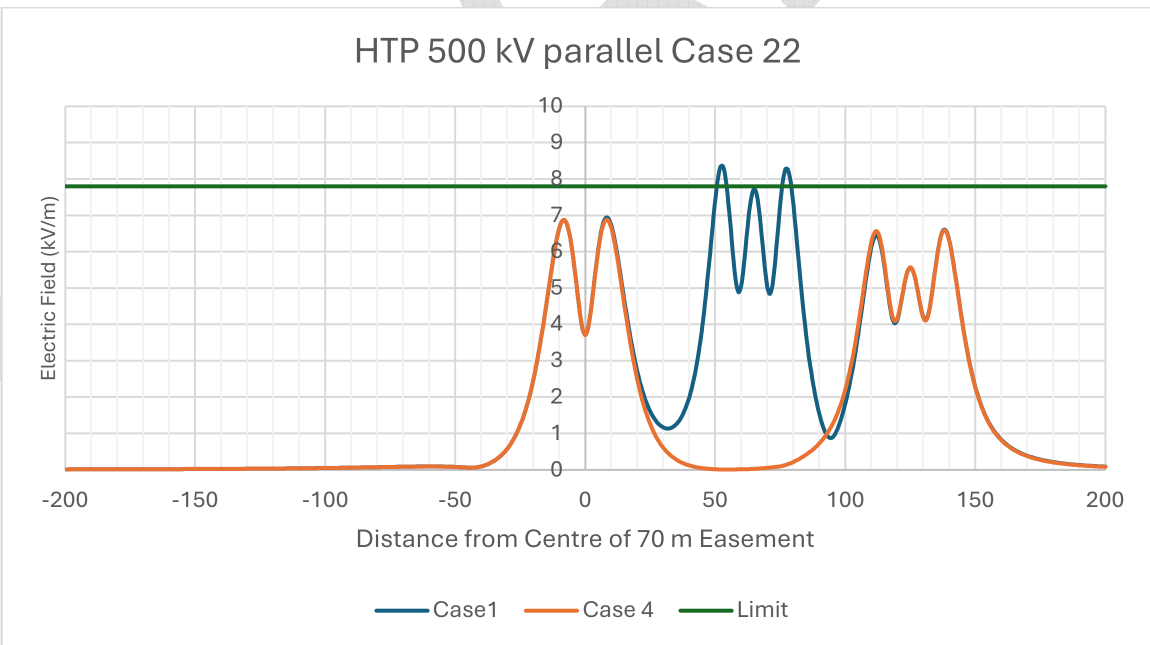

Figure D2: Parallel Circuits: Case 22, 2 x 330 kV circuits (Transgrid lines 81 and 82), Various Energisations – Electric Fields

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[1] Proposed line deviation modelled at 9 m, increased height to be considered by line deviation designer

[2] Case 1) All circuits energized, Case 2) HTP outer circuit de-energised, Case 3) HTP inner circuit de-energised, Case 4) existing circuit close to HTP line is de-energised

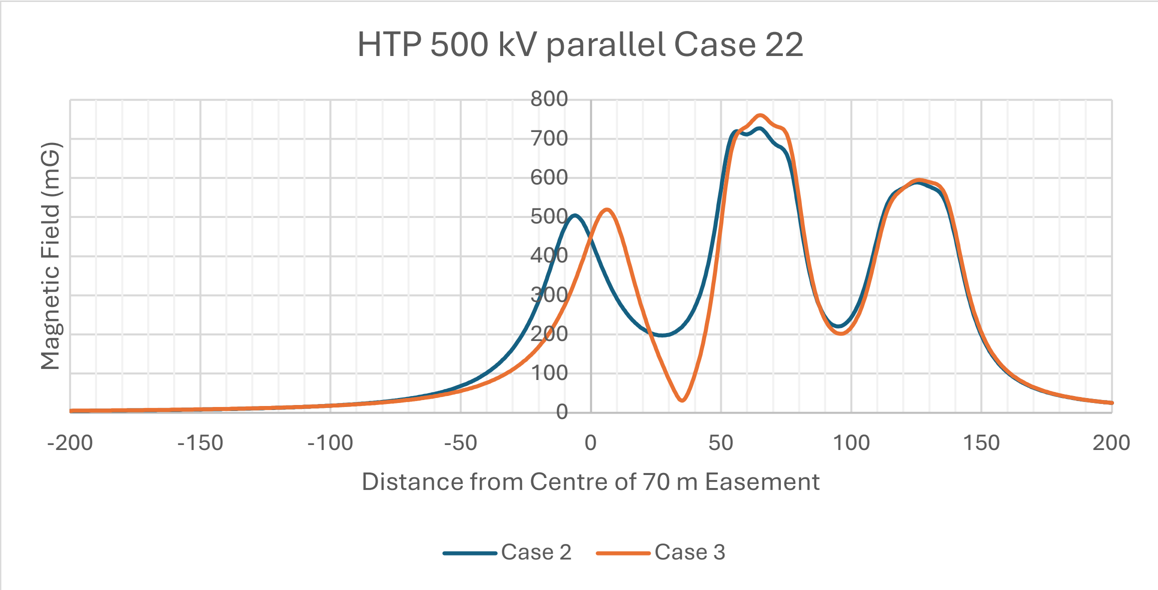

Figure D3: Parallel Circuits: Case 22, 2 x 330 kV circuits (Transgrid lines 81 and 82), Various Energisations[3] – Magnetic Fields

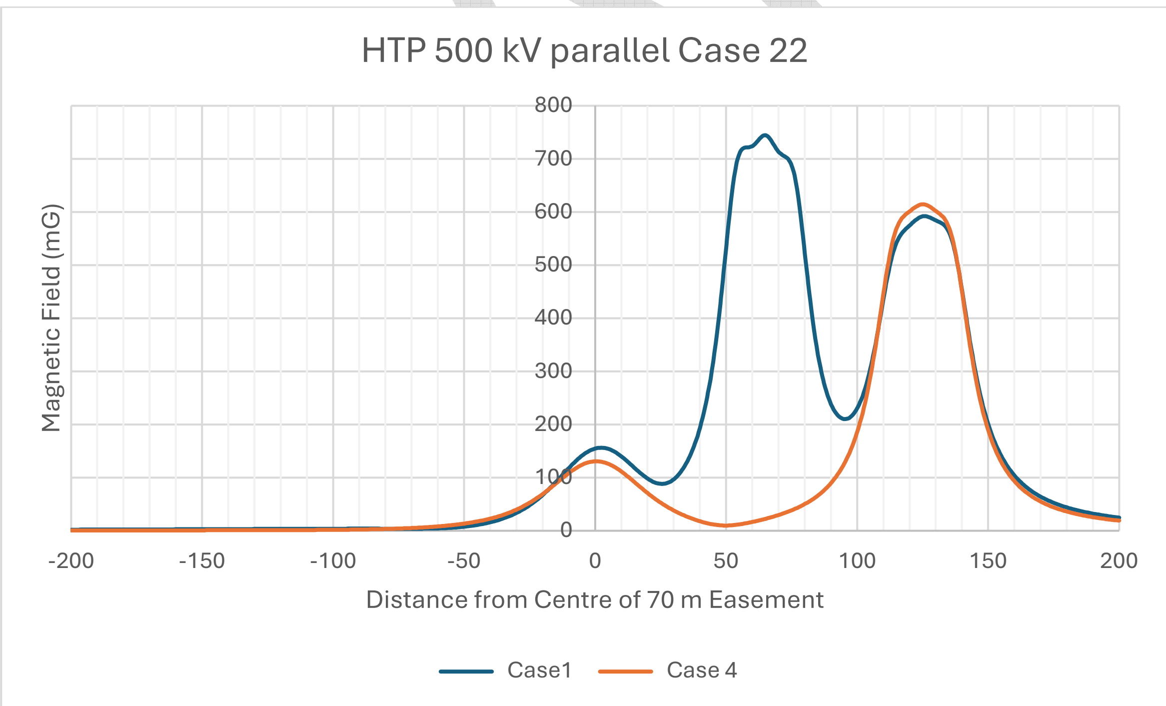

Figure D4: Parallel Circuits: Case 22, 2 x 330 kV Circuits (Transgrid lines 81 and 82), Various Energisations – Magnetic Fields

[3] Case 1) All circuits energized, Case 2) HTP outer circuit de-energised, Case 3) HTP inner circuit de-energised, Case 4) existing circuit close to HTP line is de-energised

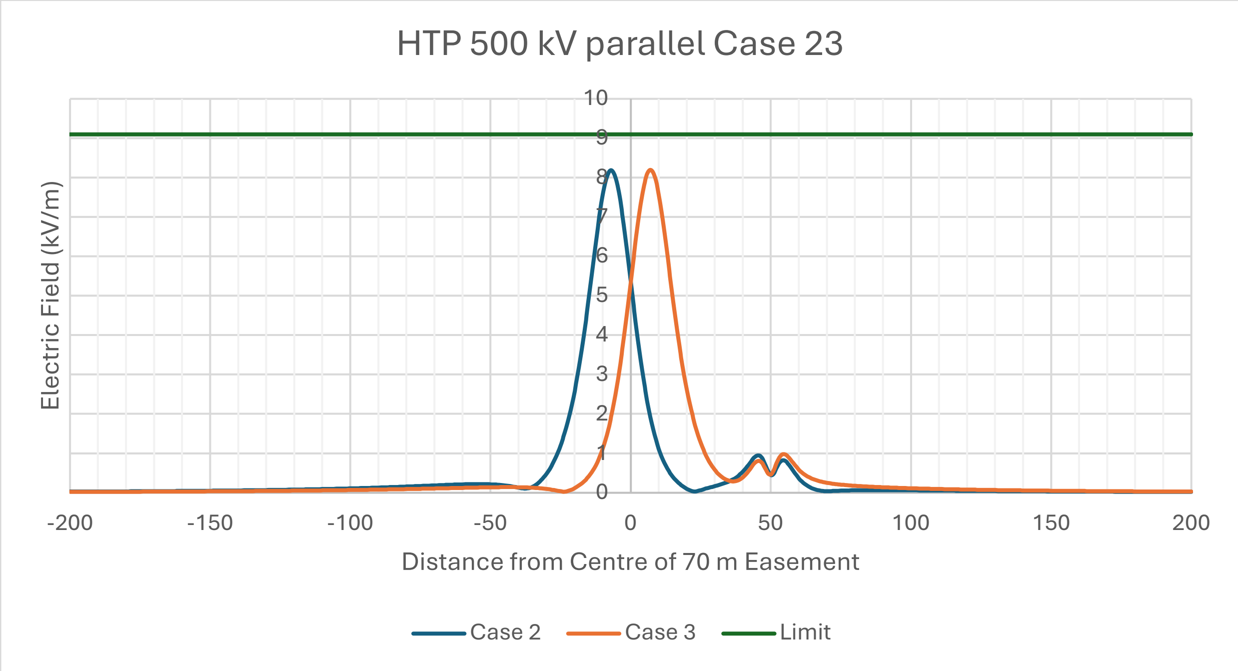

Figure D5: Parallel Circuits: Case 23, 1 x 66 kV Circuit, Various Energisations[4] – Electric Fields

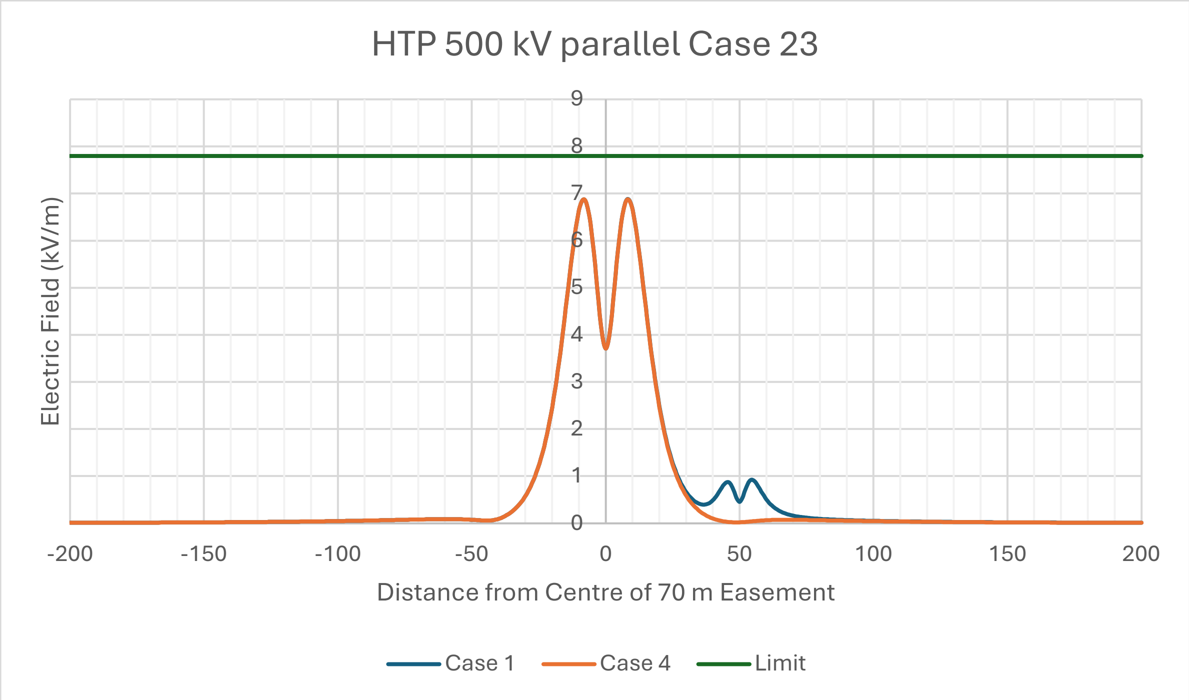

Figure D6: Parallel Circuits: Case 23, 1 x 66 kV Circuit, Various Energisations – Electric Fields

[4] Case 1) All circuits energized, Case 2) HTP outer circuit de-energised, Case 3) HTP inner circuit de-energised, Case 4) existing circuit close to HTP line is de-energised

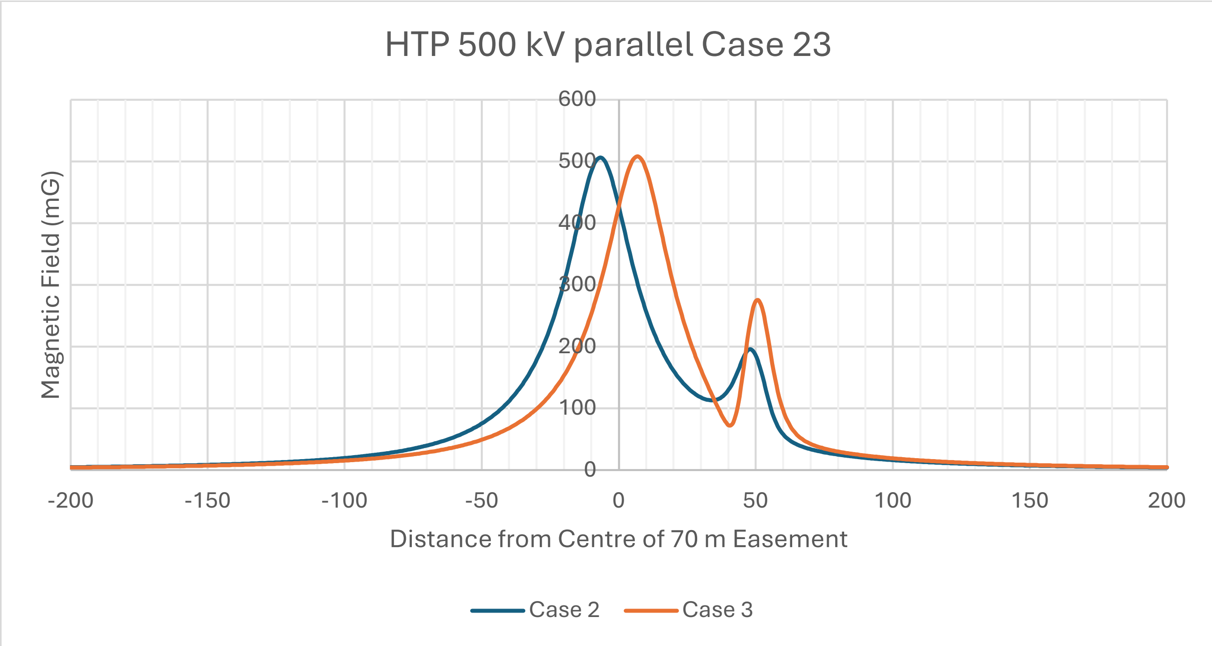

Figure D7: Parallel Circuits: Case 23, 1 x 66 kV Circuit, Various Energisations[5] – Magnetic Fields

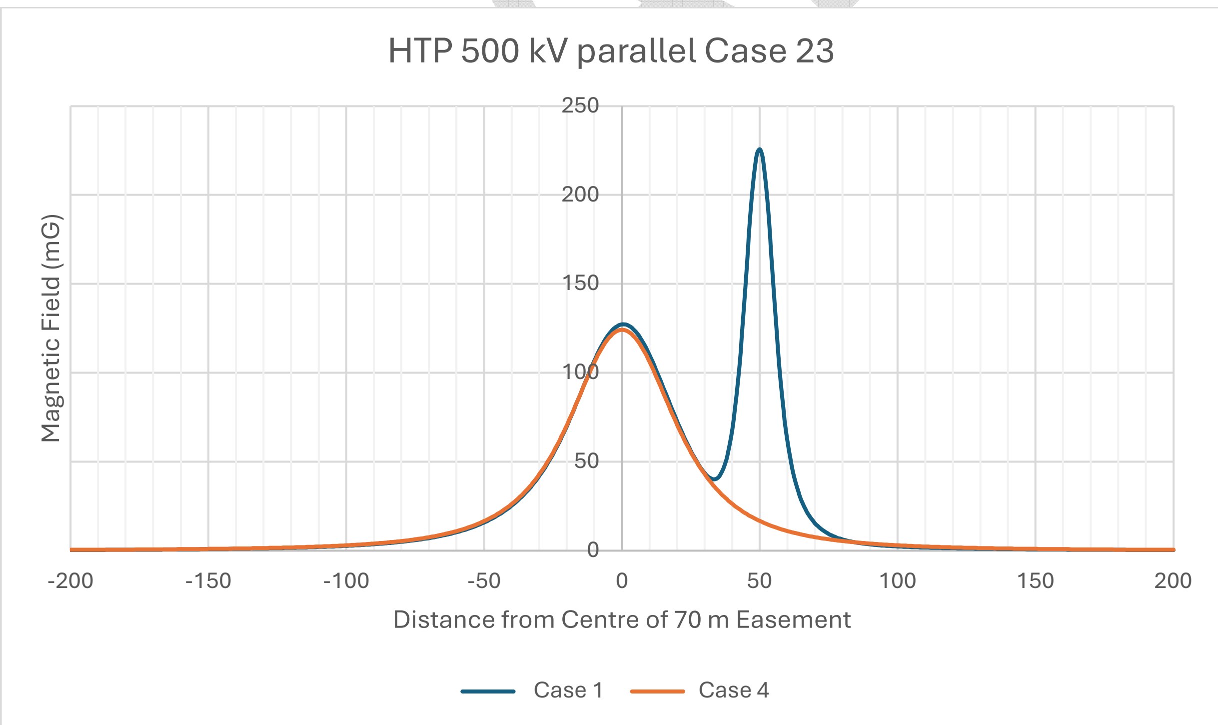

Figure D8: Parallel Circuits: Case 23, 1 x 66 kV Circuit, Various Energisations – Magnetic Fields

[5] Case 1) All circuits energized, Case 2) HTP outer circuit de-energised, Case 3) HTP inner circuit de-energised, Case 4) existing circuit close to HTP line is de-energised

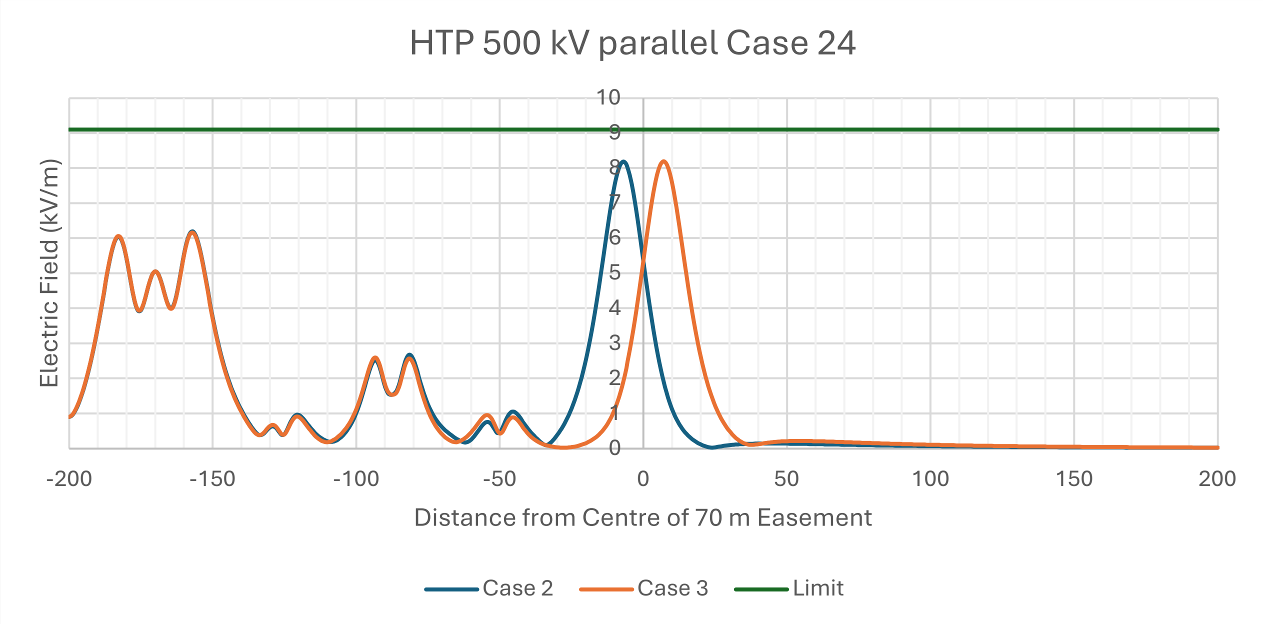

Figure D9: Parallel Circuits: Case 24, 2 x 330 kV Circuits, (lines 81 & 82), 2 x 66 kV Circuits, 1 x 132 kV Circuit, Various Energisations[6] – Electric Fields

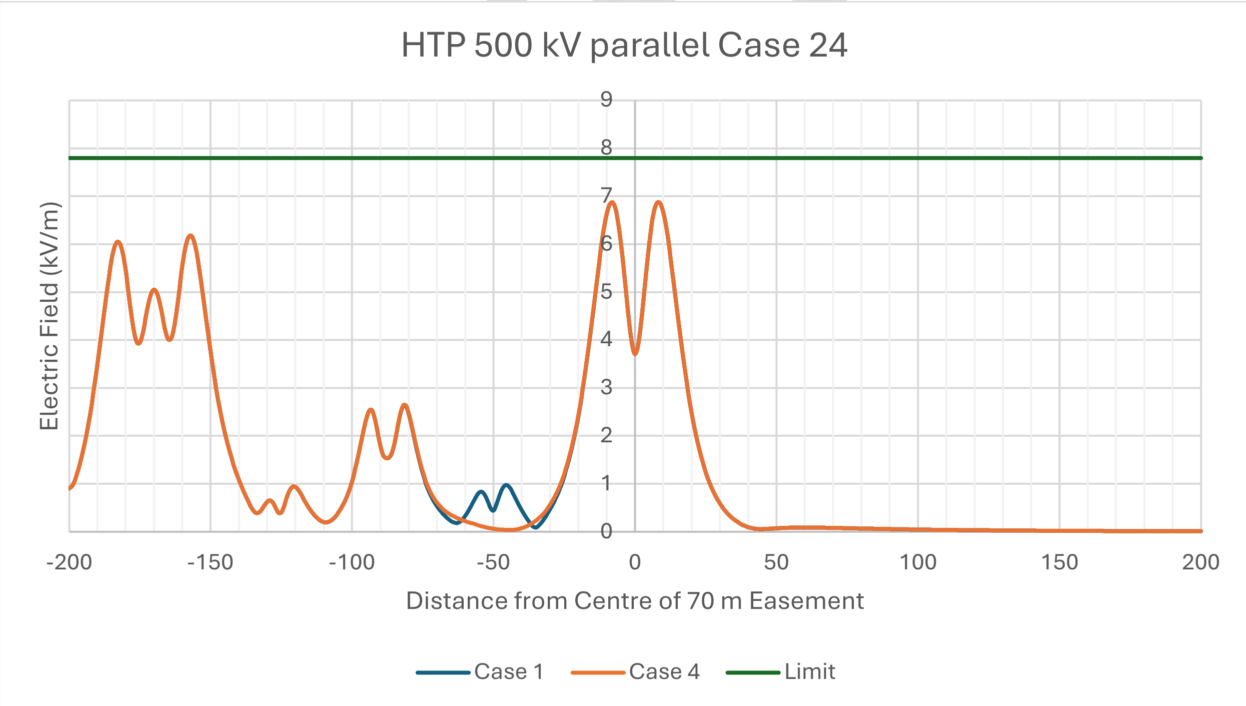

Figure D10: Parallel Circuits: Case 24, 2 x 330 kV Circuits, (lines 81 & 82), 2 x 66 kV Circuits, 1 x 132 kV Circuit, Various Energisations – Electric Fields

[6] Case 1) All circuits energized, Case 2) HTP outer circuit de-energised, Case 3) HTP inner circuit de-energised, Case 4) existing circuit close to HTP line is de-energised

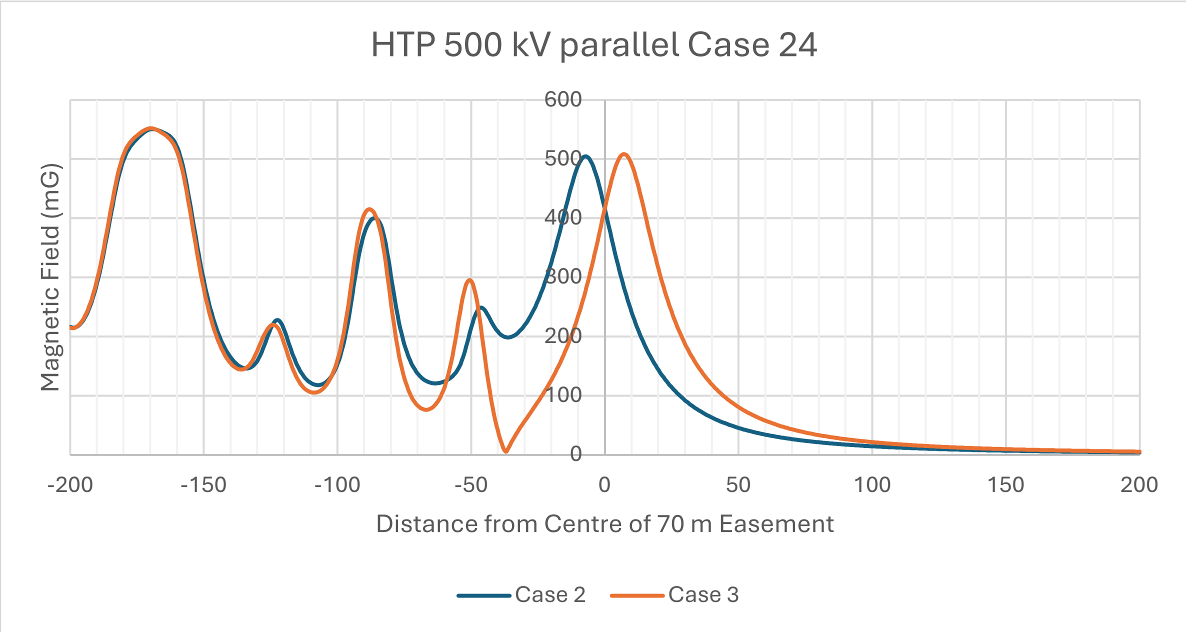

Figure D11: Parallel Circuits: Case 24, 2 x 330 kV Circuits, (lines 81 & 82), 2 x 66 kV Circuits, 1 x 132 kV Circuit, Various Energisations[7] – Magnetic Fields

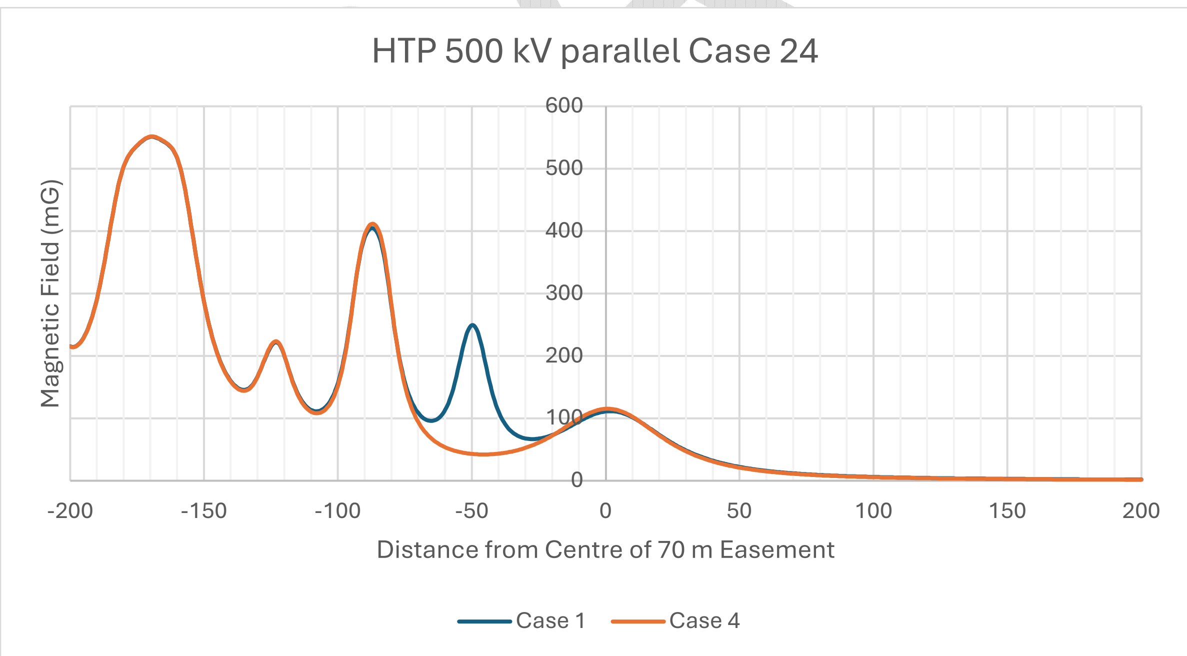

Figure D12: Parallel Circuits: Case 24, 2 x 330 kV Circuits, (lines 81 & 82), 2 x 66 kV Circuits, 1 x 132 kV Circuit, Various Energisations – Magnetic Fields

[7] Case 1) All circuits energized, Case 2) HTP outer circuit de-energised, Case 3) HTP inner circuit de-energised, Case 4) existing circuit close to HTP line is de-energised

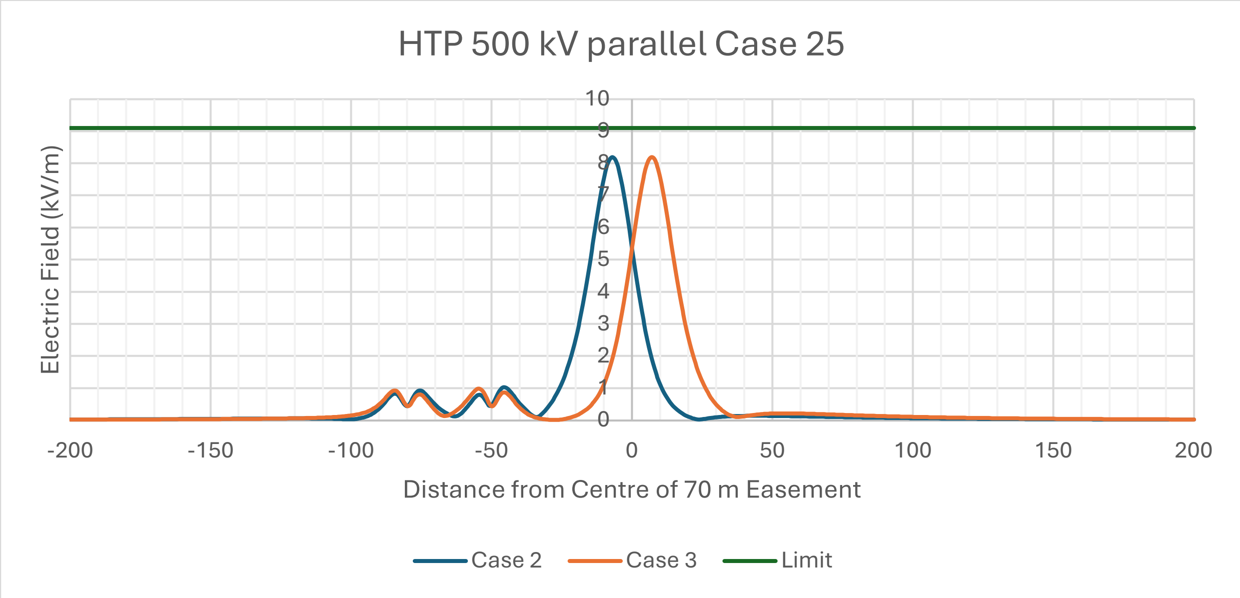

Figure D13: Parallel Circuits: Case 25, 2 x 66 kV Circuits, Various Energisations[8] – Electric Fields

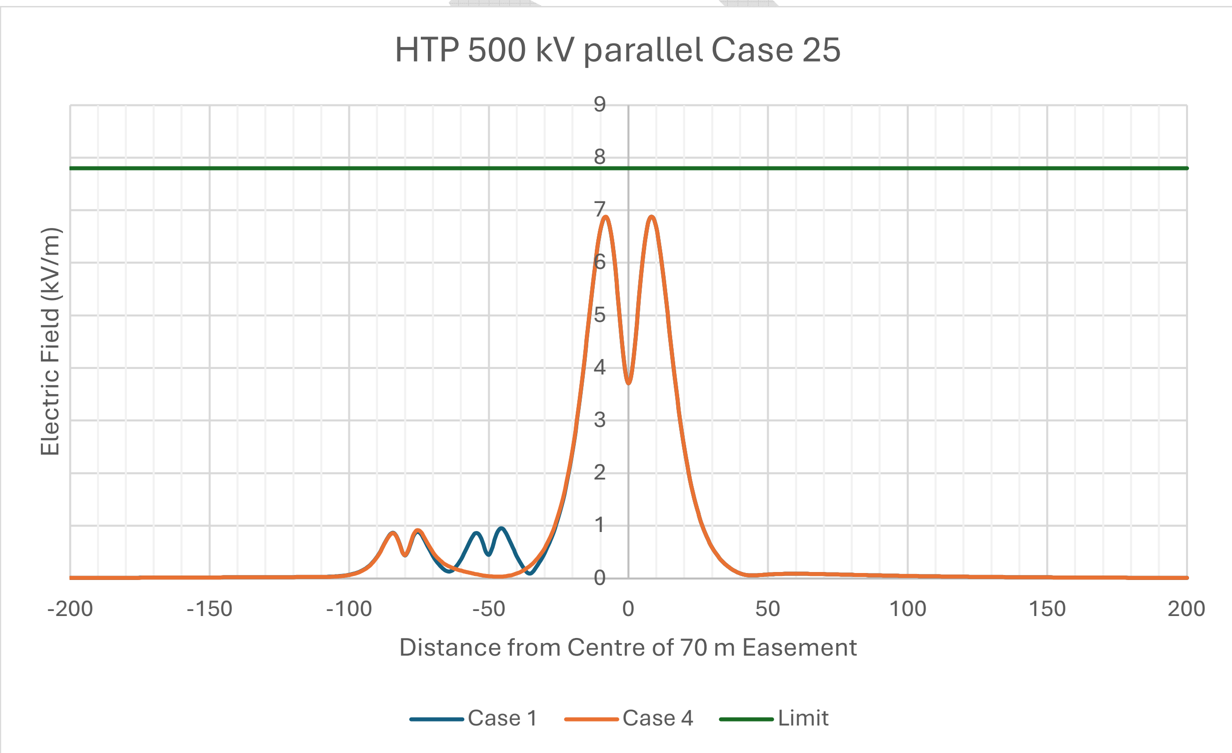

Figure D14: Parallel Circuits: Case 25, 2 x 66 kV Circuits, Various Energisations – Electric Fields

[8] Case 1) All circuits energized, Case 2) HTP outer circuit de-energised, Case 3) HTP inner circuit de-energised, Case 4) existing circuit close to HTP line is de-energised

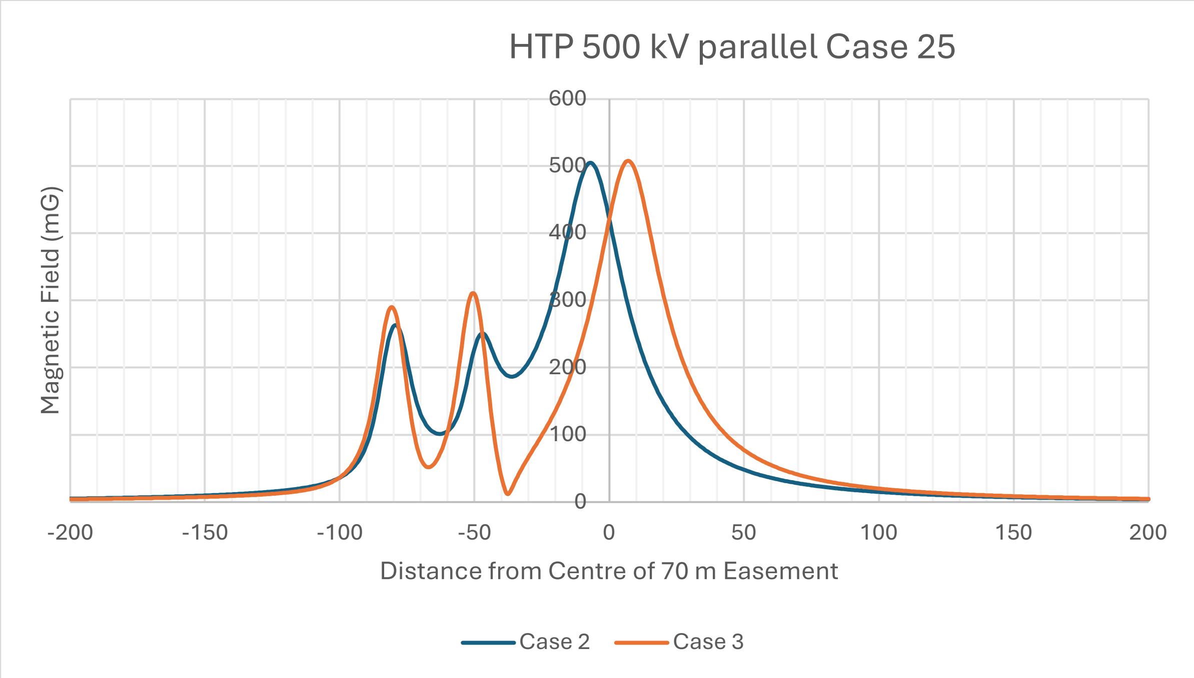

Figure D15: Parallel Circuits: Case 25, 2 x 66 kV Circuits, Various Energisations[9] – Magnetic Fields

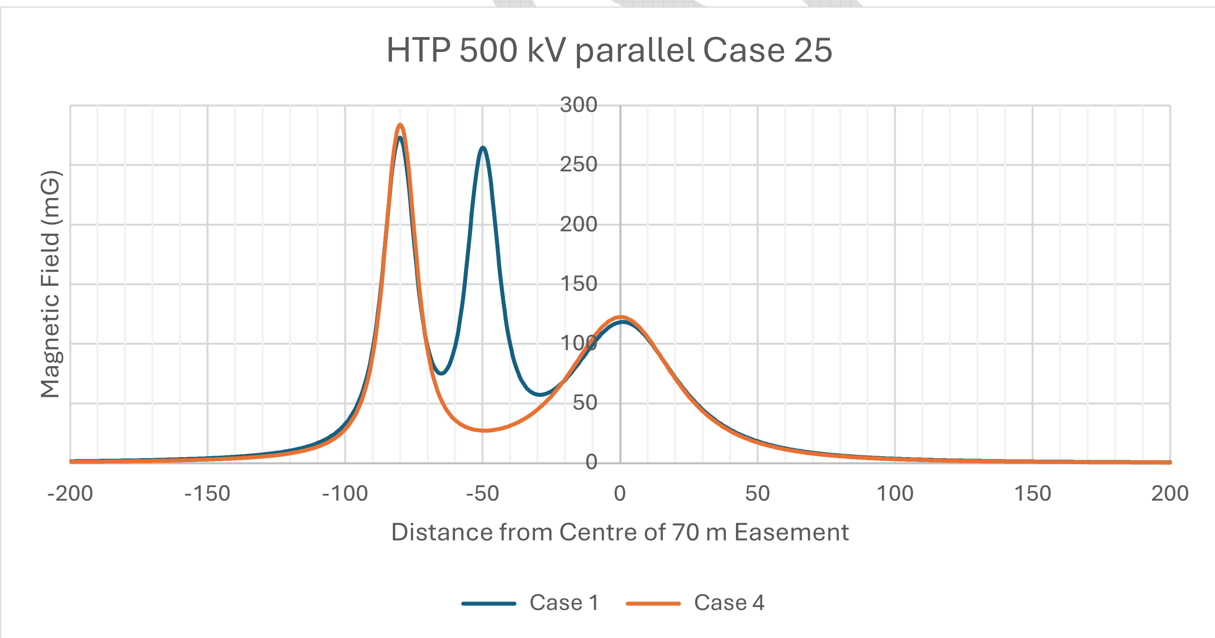

Figure D16: Parallel Circuits: Case 25, 2 x 66 kV Circuits, Various Energisations – Magnetic Fields

[9] Case 1) All circuits energized, Case 2) HTP outer circuit de-energised, Case 3) HTP inner circuit de-energised, Case 4) existing circuit close to HTP line is de-energised

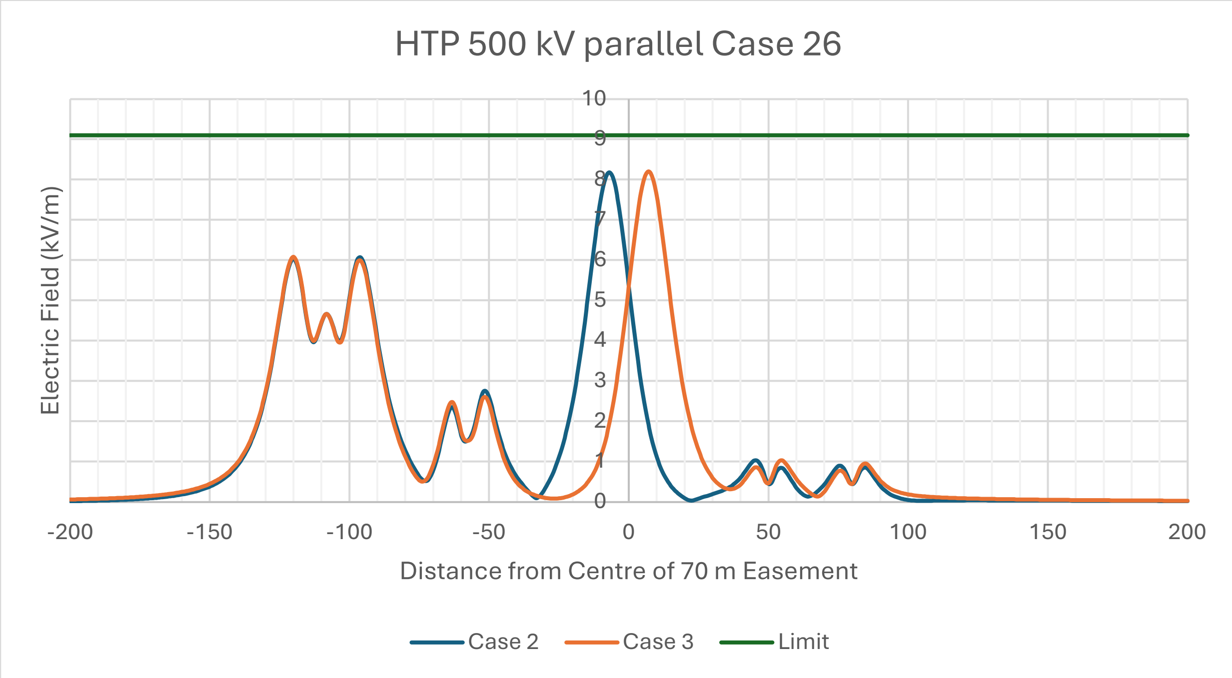

Figure D17: Parallel Circuits: Case 26, 1 x 330 kV Circuit, 2 x 66 kV Circuits, 1 x 132 kV Circuit, Various Energisations[10] – Electric Fields

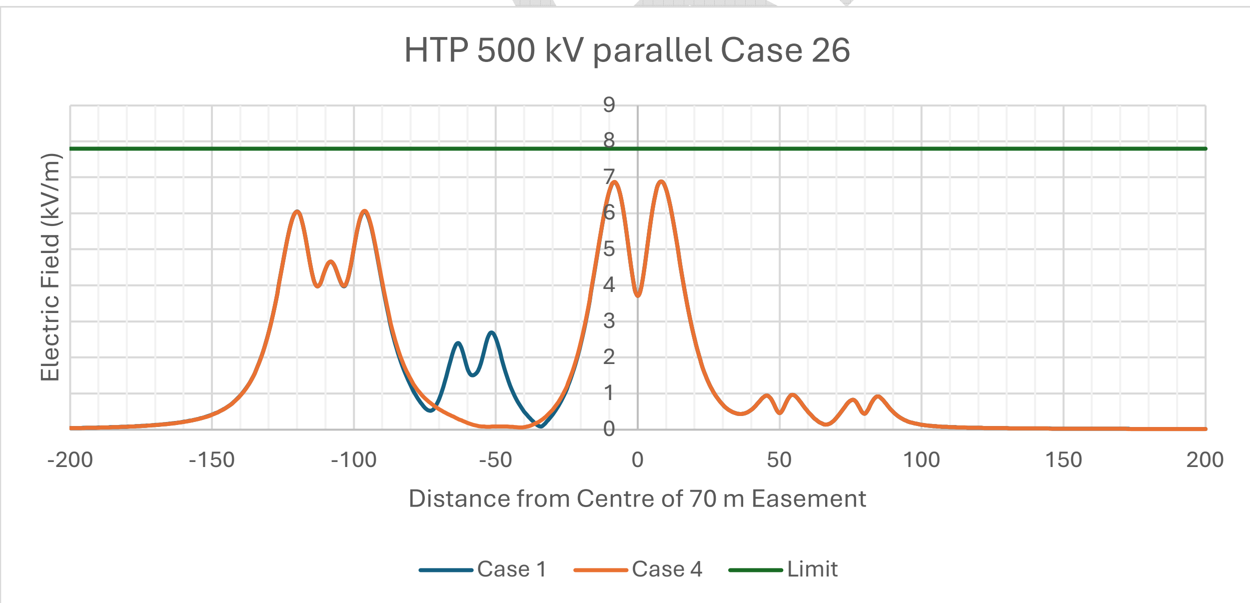

Figure D18: Parallel Circuits: Case 26, 1 x 330 kV Circuit, 2 x 66 kV Circuits, 1 x 132 kV Circuit, Various Energisations – Electric Fields

[10] Case 1) All circuits energized, Case 2) HTP outer circuit de-energised, Case 3) HTP inner circuit de-energised, Case 4) existing circuit close to HTP line is de-energised

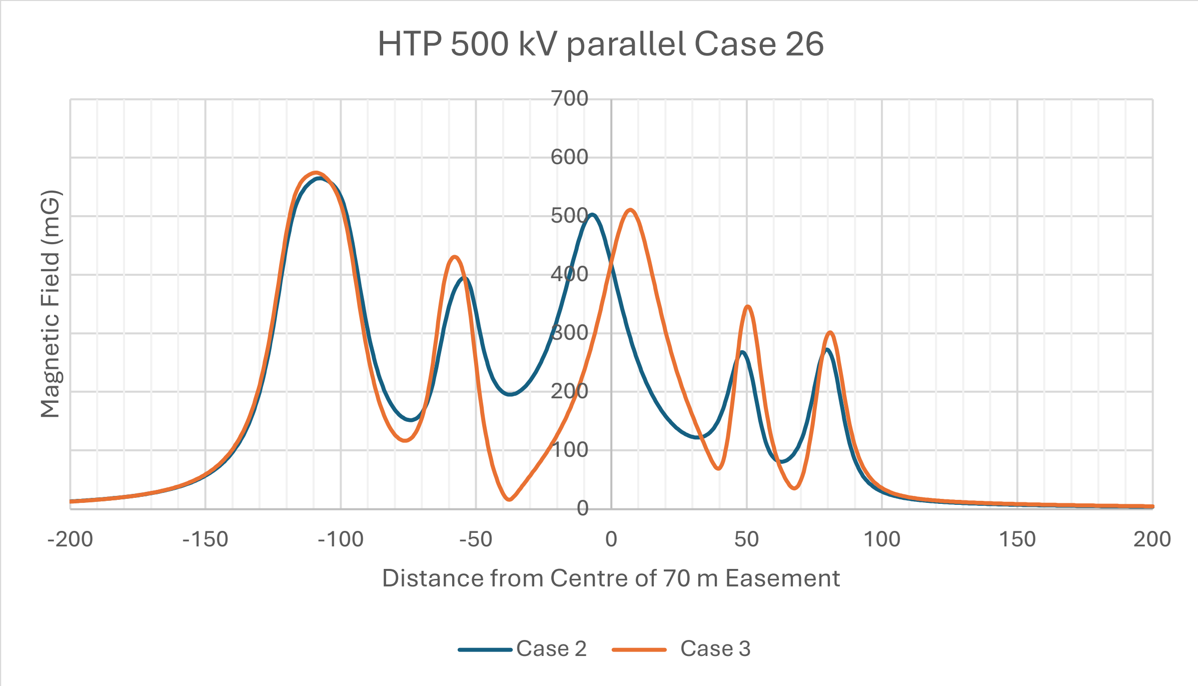

Figure D19: Parallel Circuits: Case 26, 1 x 330 kV Circuit, 2 x 66 kV Circuits, 1 x 132 kV Circuit, Various Energisations[11] – Magnetic Fields

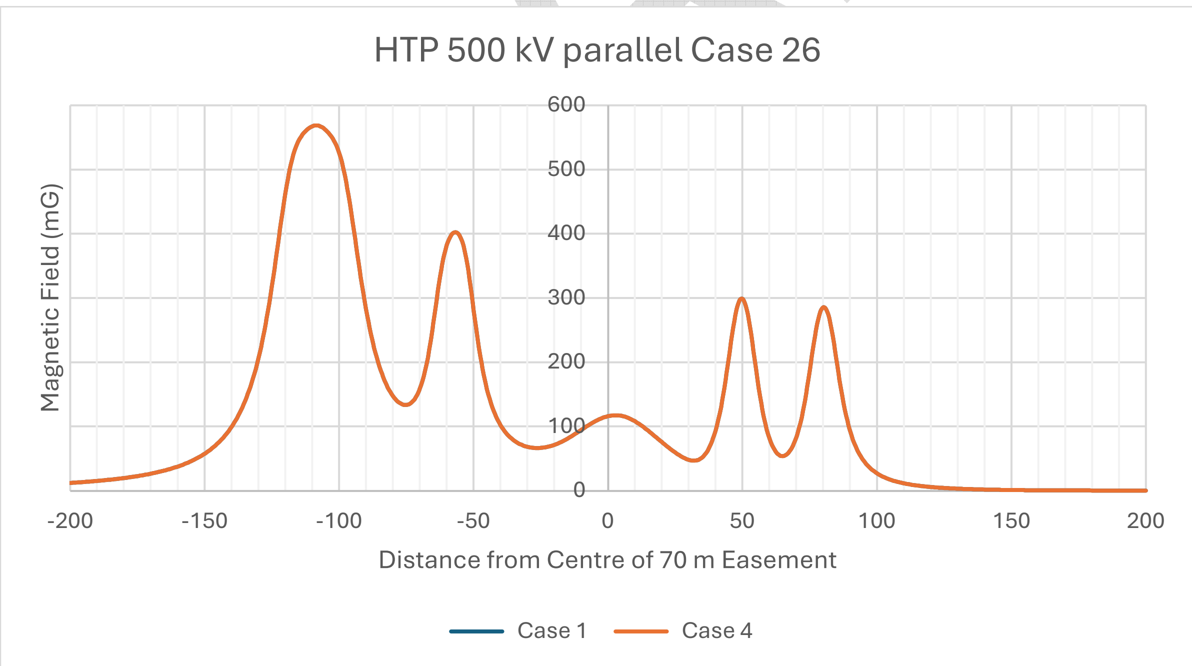

Figure D20: Parallel Circuits: Case 26, 1 x 330 kV Circuit, 2 x 66 kV Circuits, 1 x 132 kV Circuit, Various Energisations – Magnetic Fields

[11] Case 1) All circuits energized, Case 2) HTP outer circuit de-energised, Case 3) HTP inner circuit de-energised, Case 4) existing circuit close to HTP line is de-energised

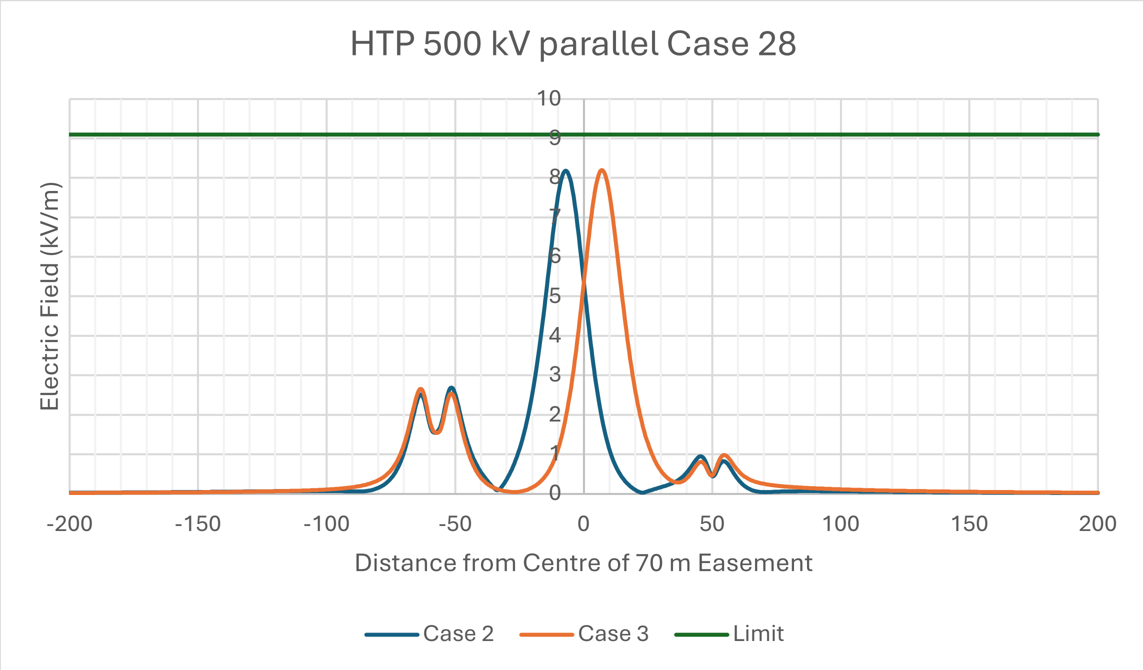

Figure D21: Parallel Circuits: Case 28, 1 x 66 kV Circuits, 1 x 132 kV Circuit, Various Energisations[12] – Electric Fields

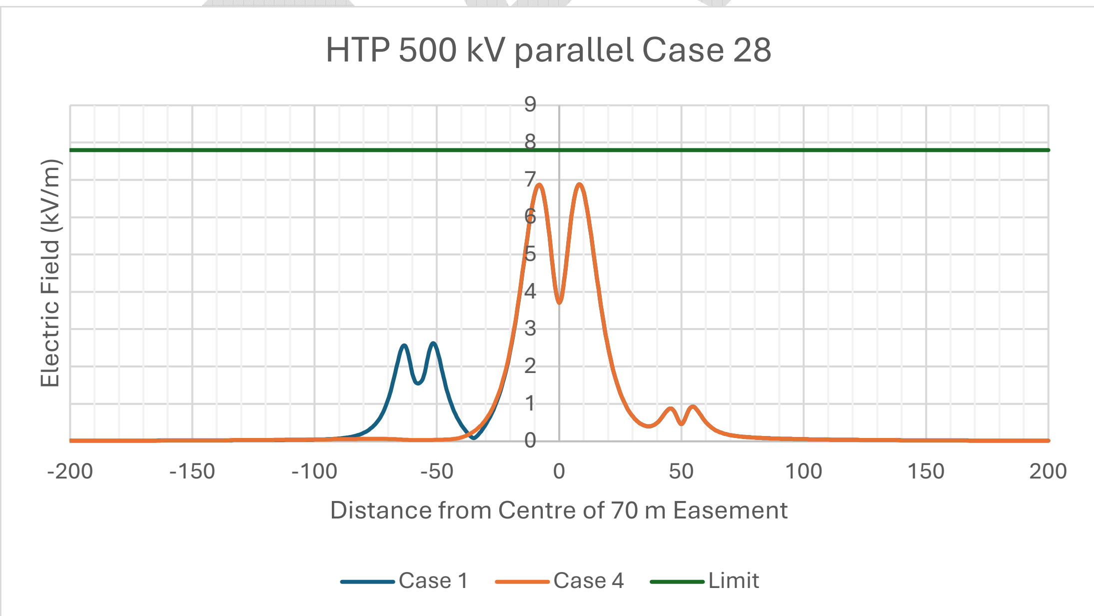

Figure D22: Parallel Circuits: Case 28, 1 x 66 kV Circuits, 1 x 132 kV Circuit, Various Energisations – Electric Fields

[12] Case 1) All circuits energized, Case 2) HTP outer circuit de-energised, Case 3) HTP inner circuit de-energised, Case 4) existing circuit close to HTP line is de-energised

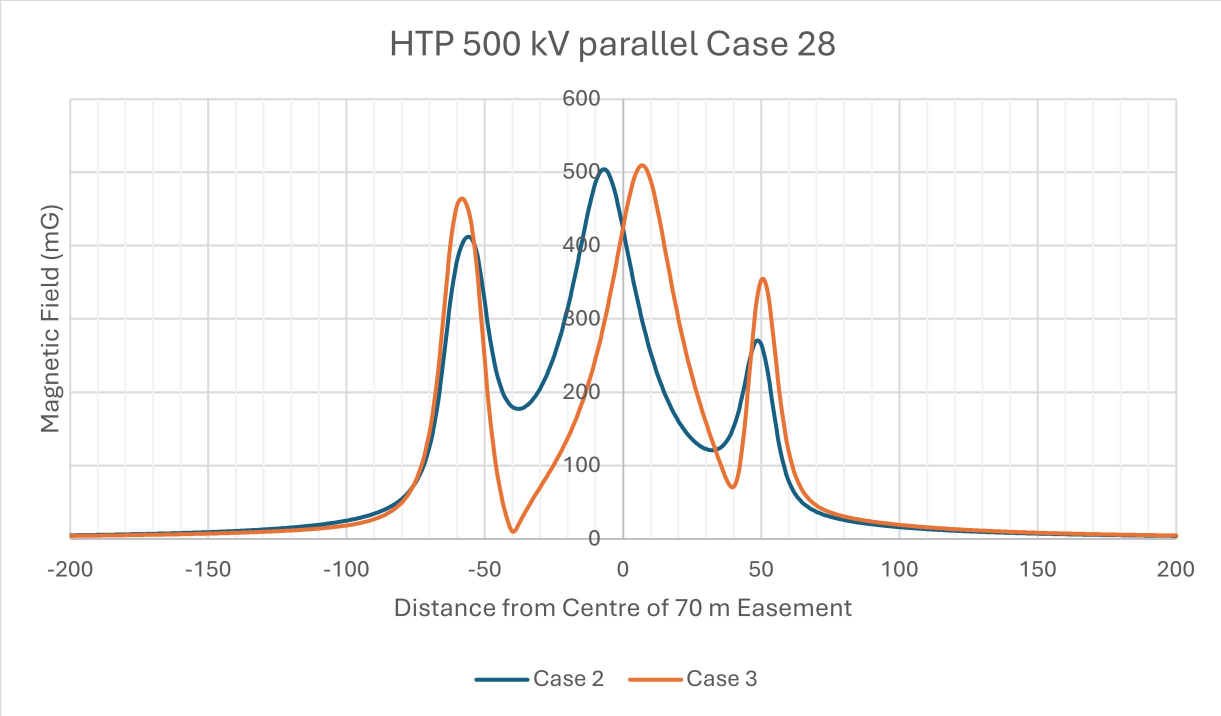

Figure D23: Parallel Circuits: Case 28, 1 x 66 kV Circuits, 1 x 132 kV Circuit, Various Energisations[13] – Magnetic Fields

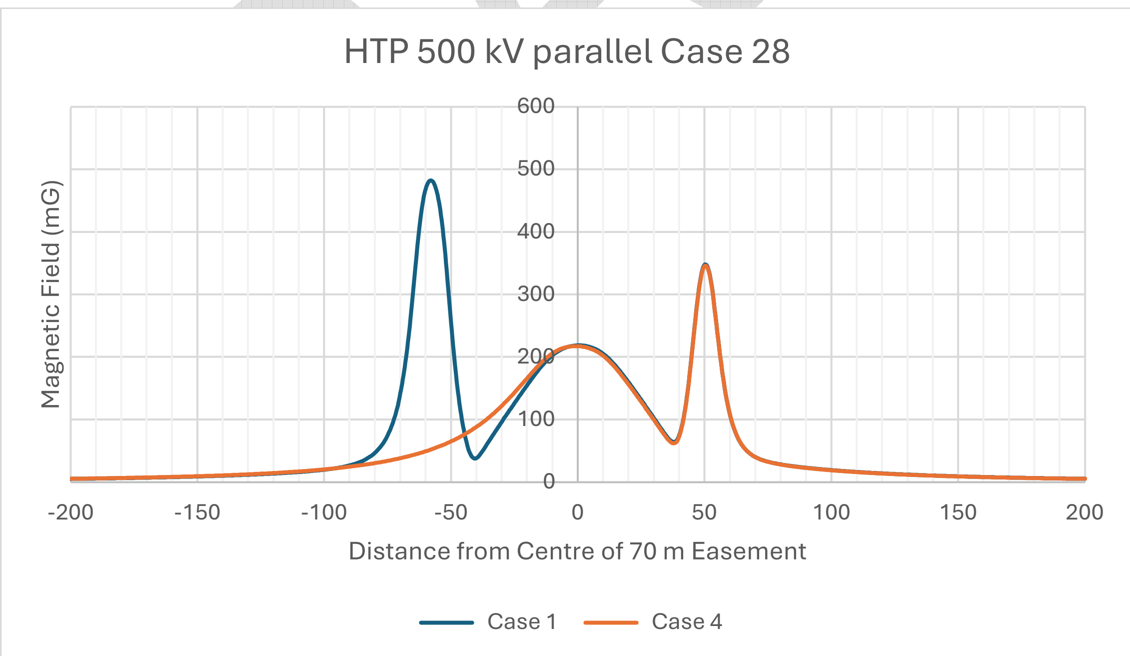

Figure D24: Parallel Circuits: Case 28, 1 x 66 kV Circuits, 1 x 132 kV Circuit, Various Energisations – Magnetic Fields

[13] Case 1) All circuits energized, Case 2) HTP outer circuit de-energised, Case 3) HTP inner circuit de-energised, Case 4) existing circuit close to HTP line is de-energised

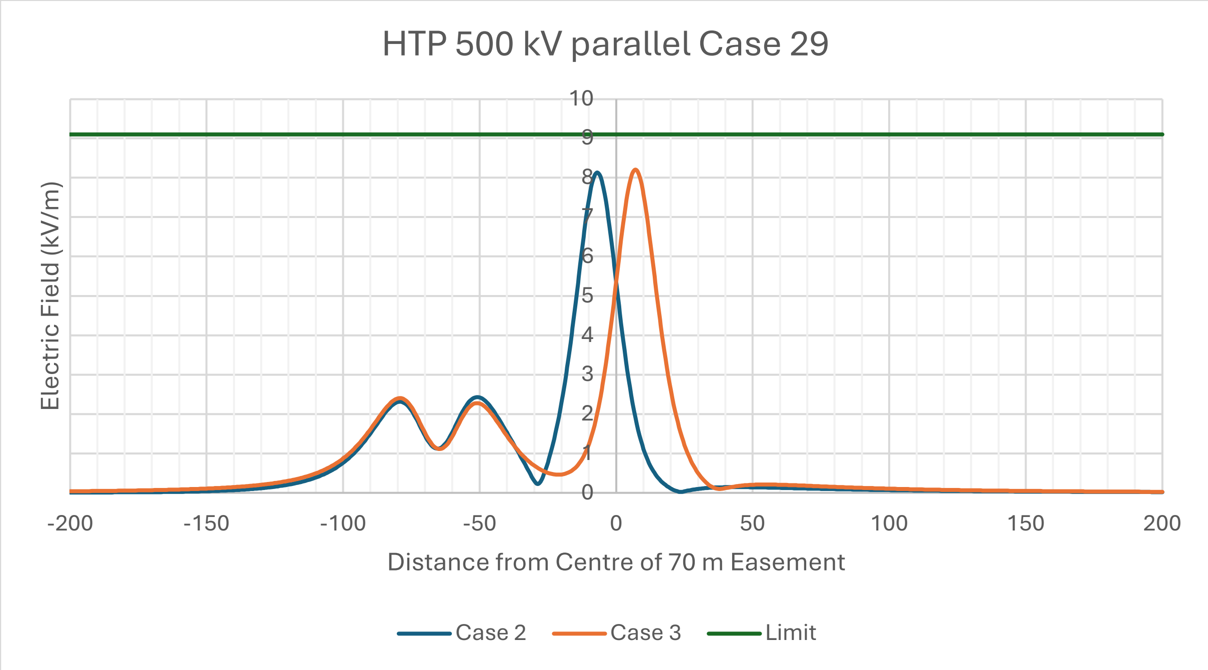

Figure D25: Parallel Circuits: Case 29, 1 x 132 kV Circuit, Various Energisations[14] – Electric Fields

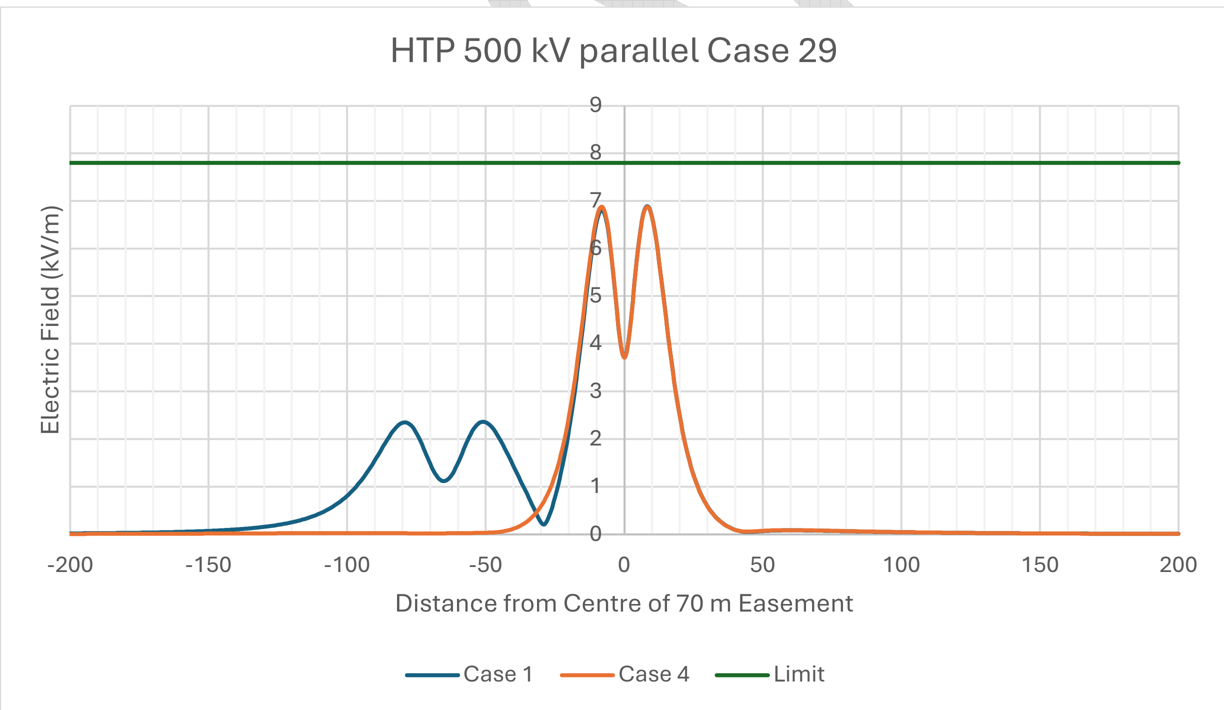

Figure D26: Parallel Circuits: Case 29, 1 x 132 kV Circuit, Various Energisations – Electric Fields

[14] Case 1) All circuits energized, Case 2) HTP outer circuit de-energised, Case 3) HTP inner circuit de-energised, Case 4) existing circuit close to HTP line is de-energised

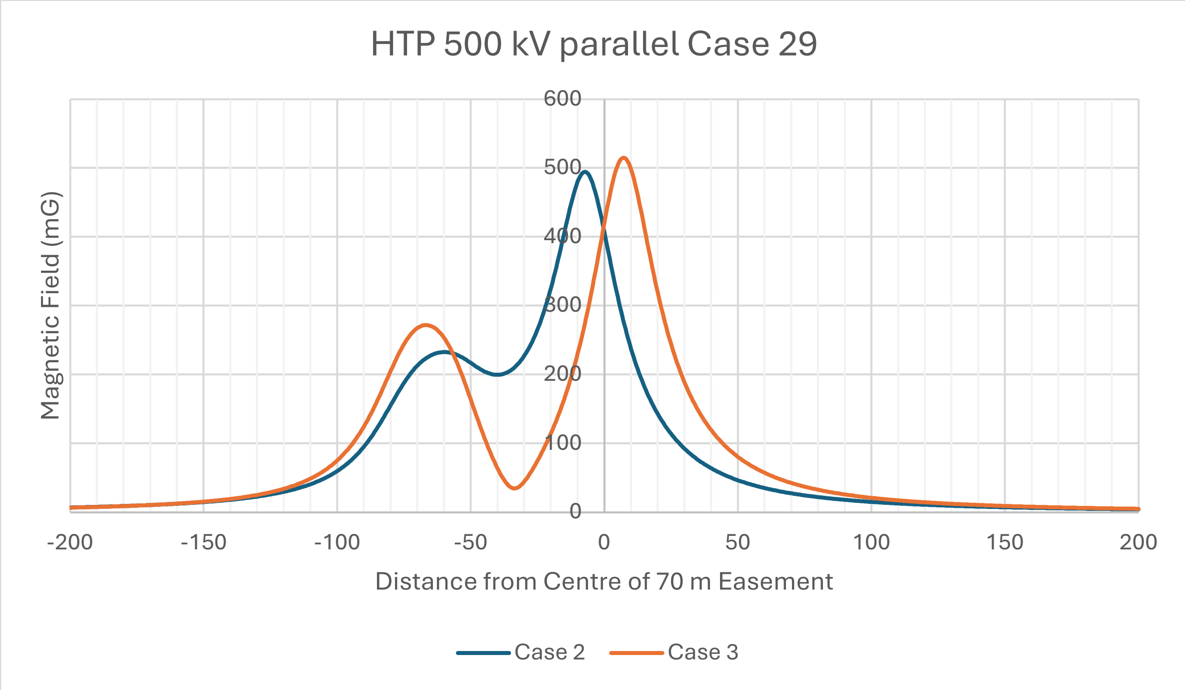

Figure D27: Parallel Circuits: Case 29, 1 x 132 kV Circuit, Various Energisations[15] – Magnetic Fields

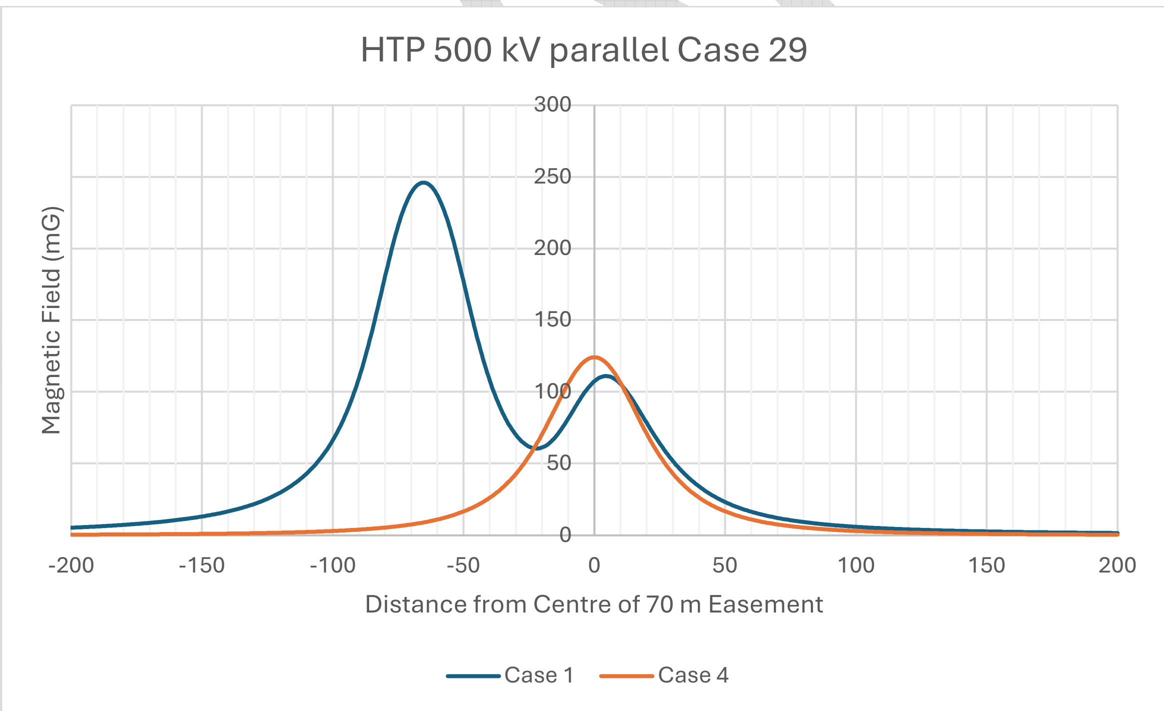

Figure D28: Parallel Circuits: Case 29, 1 x 132 kV Circuit, Various Energisations – Magnetic Fields

[15] Case 1) All circuits energized, Case 2) HTP outer circuit de-energised, Case 3) HTP inner circuit de-energised, Case 4) existing circuit close to HTP line is de-energised

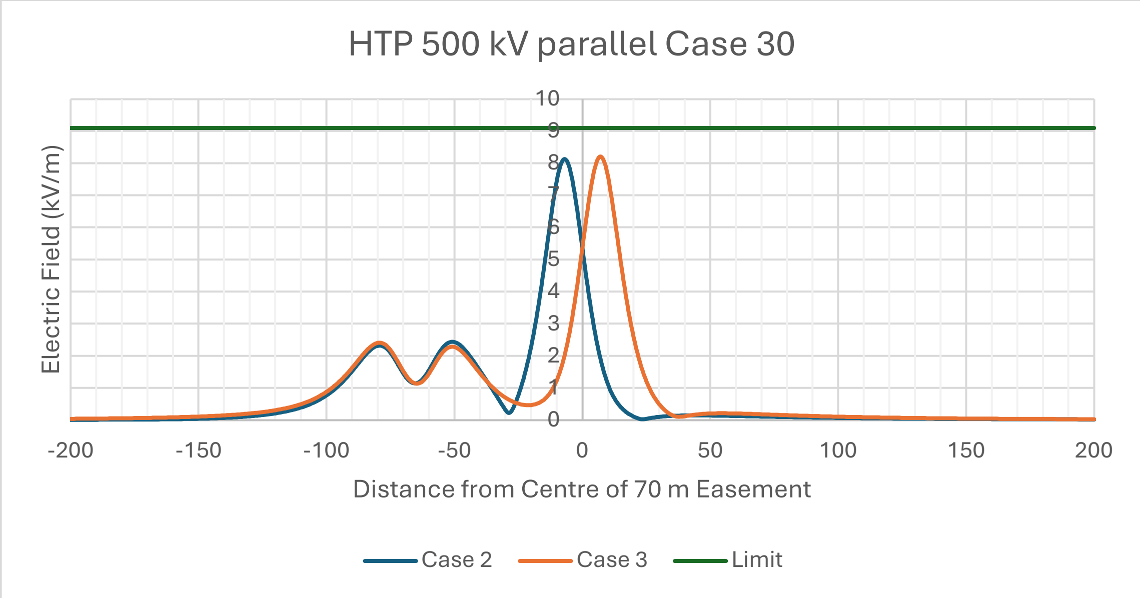

Figure D29: Parallel Circuits: Case 30, 1 x 330 kV Circuit[16], Various Energisations[17] – Electric Fields

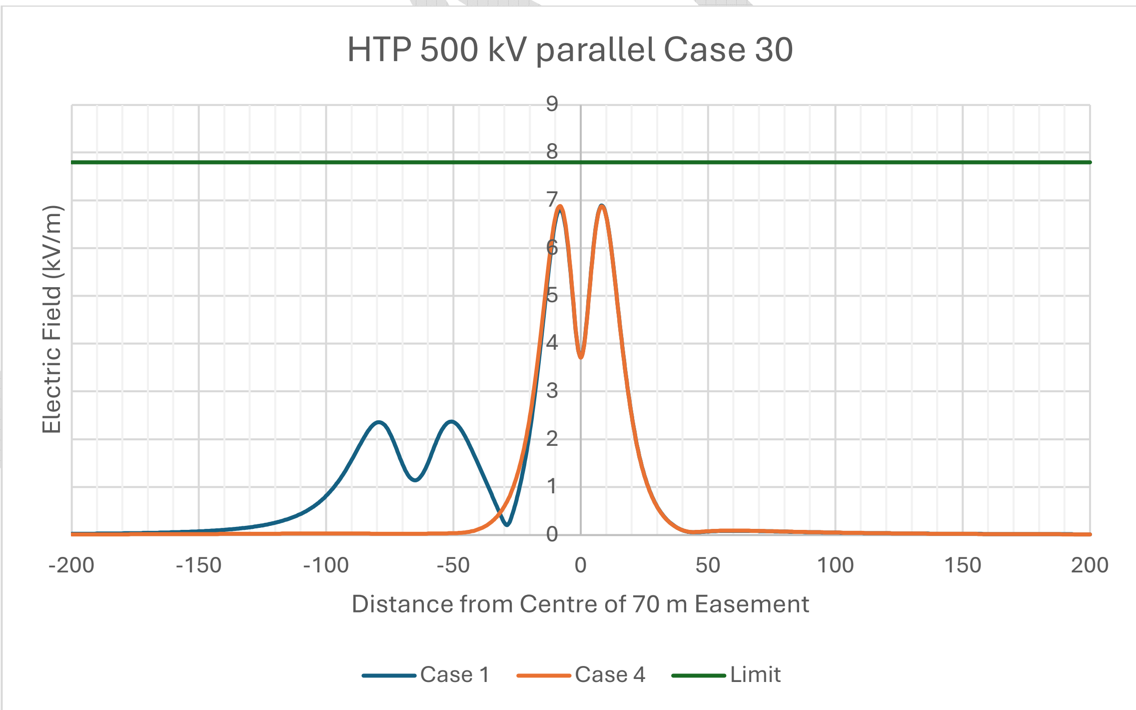

Figure D30: Parallel Circuits: Case 30, 1 x 330 kV Circuit, Various Energisations – Electric Fields

[16] Increased circuit minimum ground clearance of 17.7 m in this location results in reduced electric fields under the 330 kV line in this location.

[17] Case 1) All circuits energized, Case 2) HTP outer circuit de-energised, Case 3) HTP inner circuit de-energised, Case 4) existing circuit close to HTP line is de-energised

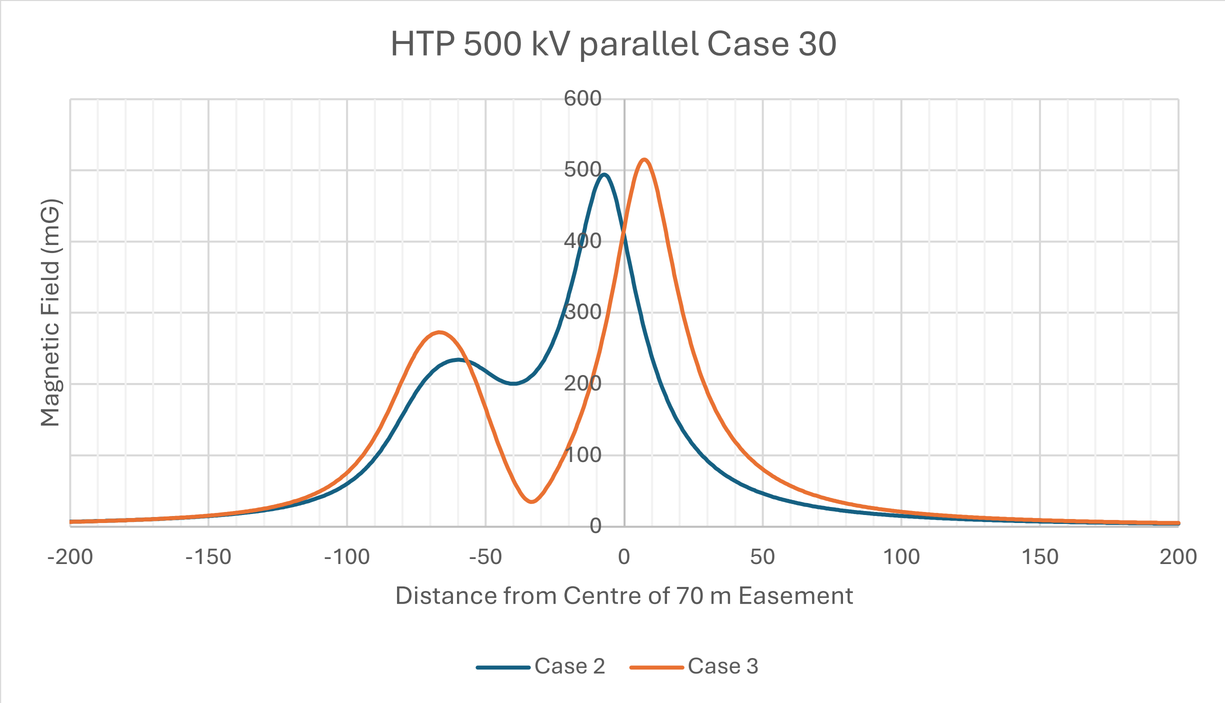

Figure D31: Parallel Circuits: Case 30, 1 x 330 kV Circuit, Various Energisations[18] – Magnetic Fields

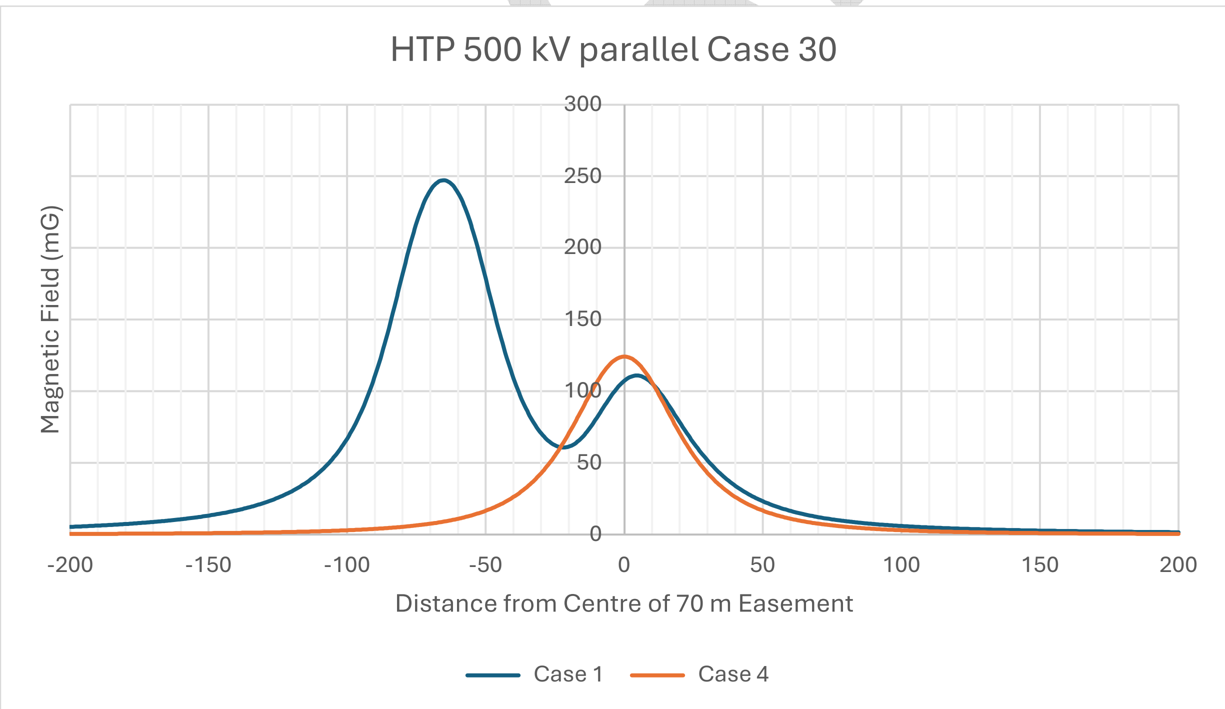

Figure D32: Parallel Circuits: Case 30, 1 x 330 kV Circuit, Various Energisations – Magnetic Fields

[18] Case 1) All circuits energized, Case 2) HTP outer circuit de-energised, Case 3) HTP inner circuit de-energised, Case 4) existing circuit close to HTP line is de-energised

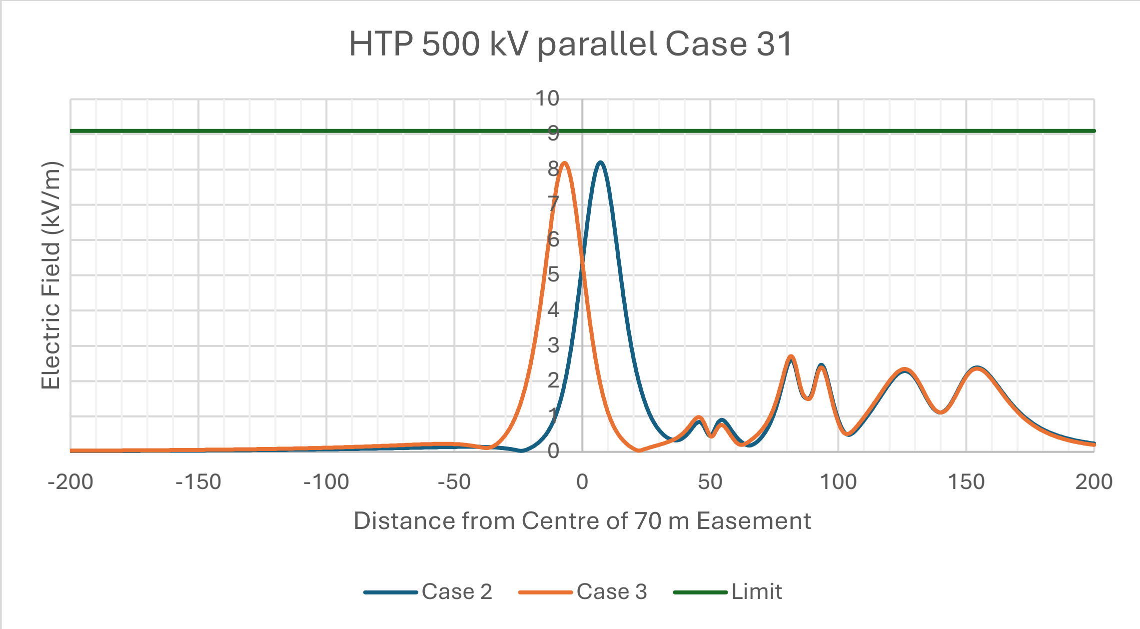

Figure D33: Parallel Circuits: Case 31, 1 x 330 kV Circuit[19], 1x 132 kV Circuit, and 1 x 66 kV Circuit, Various Energisations[20] – Electric Fields

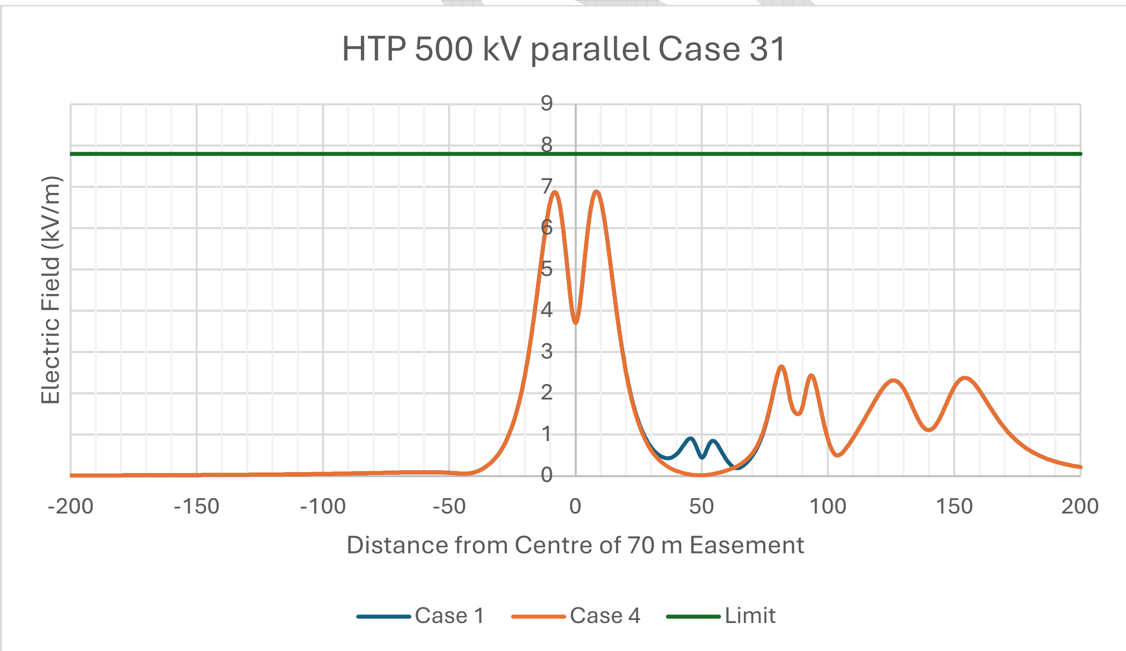

Figure D34: Parallel Circuits: Case 31, 1 x 330 kV Circuit, 1x 132 kV Circuit, and 1 x 66 kV Circuit, Various Energisations – Electric Fields

[19] Increased circuit minimum ground clearance of 17.7 m in this location results in reduced electric fields under the 330 kV line in this location.

[20] Case 1) All circuits energized, Case 2) HTP outer circuit de-energised, Case 3) HTP inner circuit de-energised, Case 4) existing circuit close to HTP line is de-energised

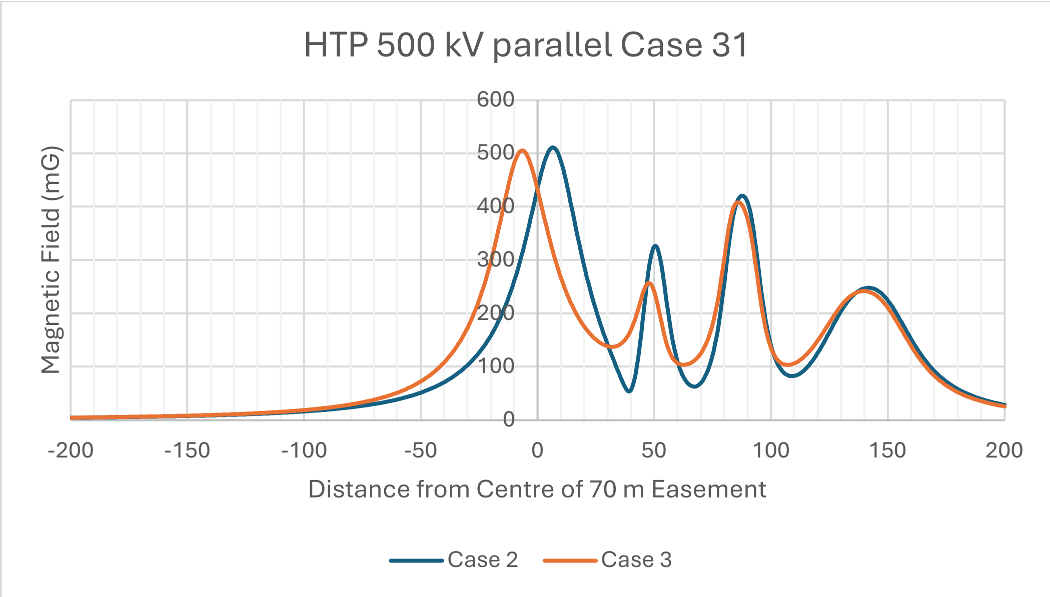

Figure D35: Parallel Circuits: Case 31, 1 x 330 kV Circuit, 1x 132 kV Circuit, and 1 x 66 kV Circuit, Various Energisations[21] – Magnetic Fields

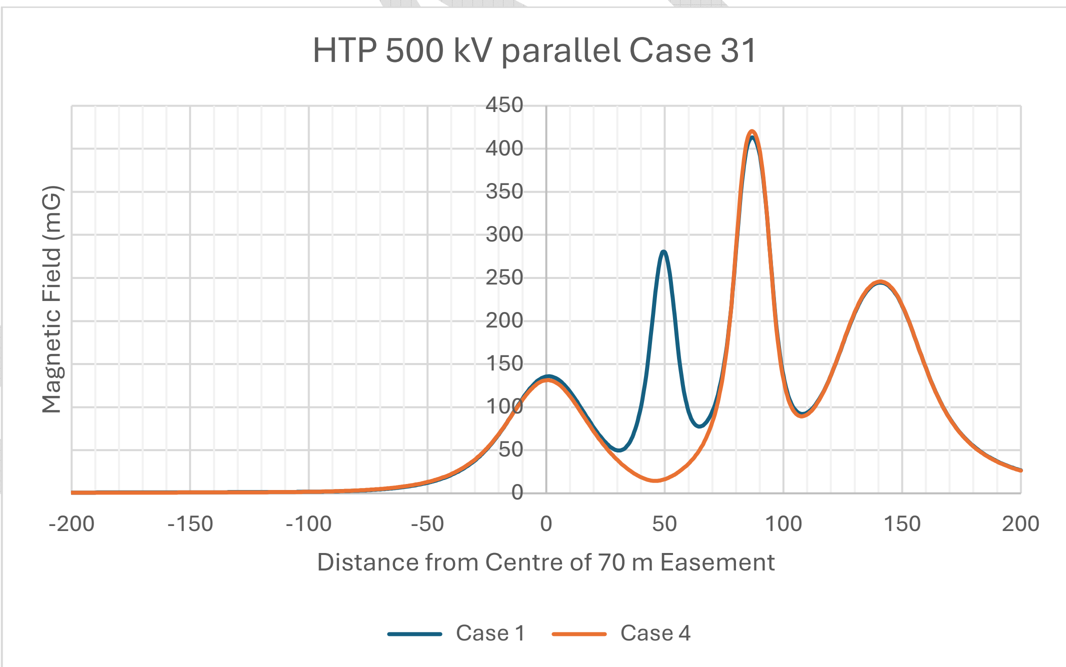

Figure D36: Parallel Circuits: Case 31, 1 x 330 kV Circuit, 1x 132 kV Circuit, and 1 x 66 kV Circuit, Various Energisations – Magnetic Fields

[21] Case 1) All circuits energized, Case 2) HTP outer circuit de-energised, Case 3) HTP inner circuit de-energised, Case 4) existing circuit close to HTP line is de-energised