Mirvac Victoria Pty ltd
08-Aug-2014

Waverley Park 220kV Transmission Line

Expert Witness Statement EMF and Earth Potential Rise

Waverley Park 220kV Transmission Line

Client: Mirvac Victoria Pty ltd

ABN: N/A

Prepared by

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08-Aug-2014

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1.0 Expert Witness Information

Name:	Stephen Boyle
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Qualifications	Bachelor of Engineering (Electrical), University of Melbourne (1978) Master of Business Administration (Technology Management), Deakin University (2001)
Affiliations	Chartered Professional Engineer MIE Aust
Expertise and Experience	Stephen is presently a technical Director with AECOM. He has had 35 years' experience in the high voltage transmission and distribution industry working in design and review for terminal stations, zone substations and lines. His work has included earthing of lines and HV substations and EMF studies of lines and cables. Notable projects include the engineering review of the EHV supply options for the Desalination Plant at Wonthaggi and feasibility study work for SP AusNet on the Mirvac underground cable options.
Relationship With Mirvac	AECOM has performed a number of studies for both SP AusNet and Mirvac considering the options for power lines at the site. The projects in which Stephen Boyle has had a direct involvement are:- - Underground Cable at Waverley Park – Engineering Study and Preliminary Design (2007) : Role – reviewer - Waverley Park 220KV Cable Project – Report for Above ground Pole Option (2009) Role:- Authoriser - Waverly Park 220kV 220 kV Overhead Transmission Line Project (2009): Role – Authoriser - EMF Modelling 220 kV Overhead Options (2012): Role – Authoriser Those AECOM reports that Stephen Boyle has not been involved with are:- - Mirvac Line Diversion – Cost Plan (2013) - Mirvac Line Diversion – Cost Plan (2014)

2.0 Scope of the Statement

An overhead 220kV transmission line of lattice tower construction traverses the Waverley Park development site and Mirvac, the site developer, is required by its planning permit to replace the towers with an underground cable across the site. Mirvac is seeking to vary its planning permit so as to retain the existing overhead transmission line mounted on poles instead of the underground cable.

The engagement is to prepare an expert witness statement considering the Electromagnetic Field (EMF) and Earth Potential Rise (EPR) outcomes of the alternate comparators, being:

- The undergrounding of the power lines with the required transition enclosures: and
- Retaining the power lines above ground mounted on poles, with the slight realignment of the easement and the movement of the poles.

3.0 Documents Referenced in this Statement

The documents referenced and relied upon in this statement are as follows:

- Electromagnetic Fields
  - Interim Guidelines on Limits of Exposure to 50/60Hz Electric and Magnetic Fields (1989) National Health and Medical Research Council.
  - Public Consultation Draft Radiation Protection Standard: Exposure Limits for Electric & magnetic Fields – 0 Hz to 3 kHz (ARPANSA Dec 06)
  - Inquiry into Community Needs and High Voltage Transmission Line Development. (Sir Harry Gibbs 1991)
- Earth Potential Rise
  - AS/NZS 60479 Effects of current on human beings and livestock
  - ENA EG0 Power system earthing guide, Part 1: Management principles
  - ENA EG1 Substation earthing guide
  - IEEE Std80 IEEE guide for safety in AC substation grounding
  - IEEE Std81 IEEE Guide for measuring earth resistivity, ground impedance, and earth surface potentials of a grounding system
  - AS 2067 Substations and high voltage installations exceeding 1kV a.c.
  - AS/NZS 3000 Electrical installations (known as the Australian/New Zealand Wiring Rules)
  - AS/NZS 3835 Earth potential rise – Protection of telecommunications network users, personnel and plant
  - AS/NZS 7000 Overhead line design detailed procedures.
  - Waverley Park Cable Termination Station – Earthing System Design (Safe Earth Consulting Dec 2010)

4.0 Background

A double circuit 220kV transmission lines presently crosses the Mirvac development site at Waverley Park in Melbourne. The lines form part of the transmission network that runs from Rowville Terminal Station near the corners of Stud and Wellington Roads to Springvale Terminal Station near the corner of the Princess Highway and Westall Road. The lines are owned and operated by SP AusNet.

The lines supply power to the south east suburbs via both Springvale and Heatherton Terminal Stations. The existing lines are of overhead construction and the conductors are strung either side of a single lattice structured tower. Each line is on one side of the tower and consist of three phase with each phase consisting of a bundle of two conductors.

The lines also have two conductors on the top of the towers (called earth wires) that do not carry current but act to shield the line from lightning strikes.

Mirvac's planning permit as part of the redevelopment of the Waverley Park site requires it to reconstruct the lines replacing it with underground cables. Mirvac is seeking to vary its planning permit to provide an overhead transmission line mounted on poles instead of the underground cable.

The transmission line will not be above any houses and the easement will occupy public space and parkland.

Figure 1 220kV Transmission Line Towers, Dinah Parade East Keilor, Victoria

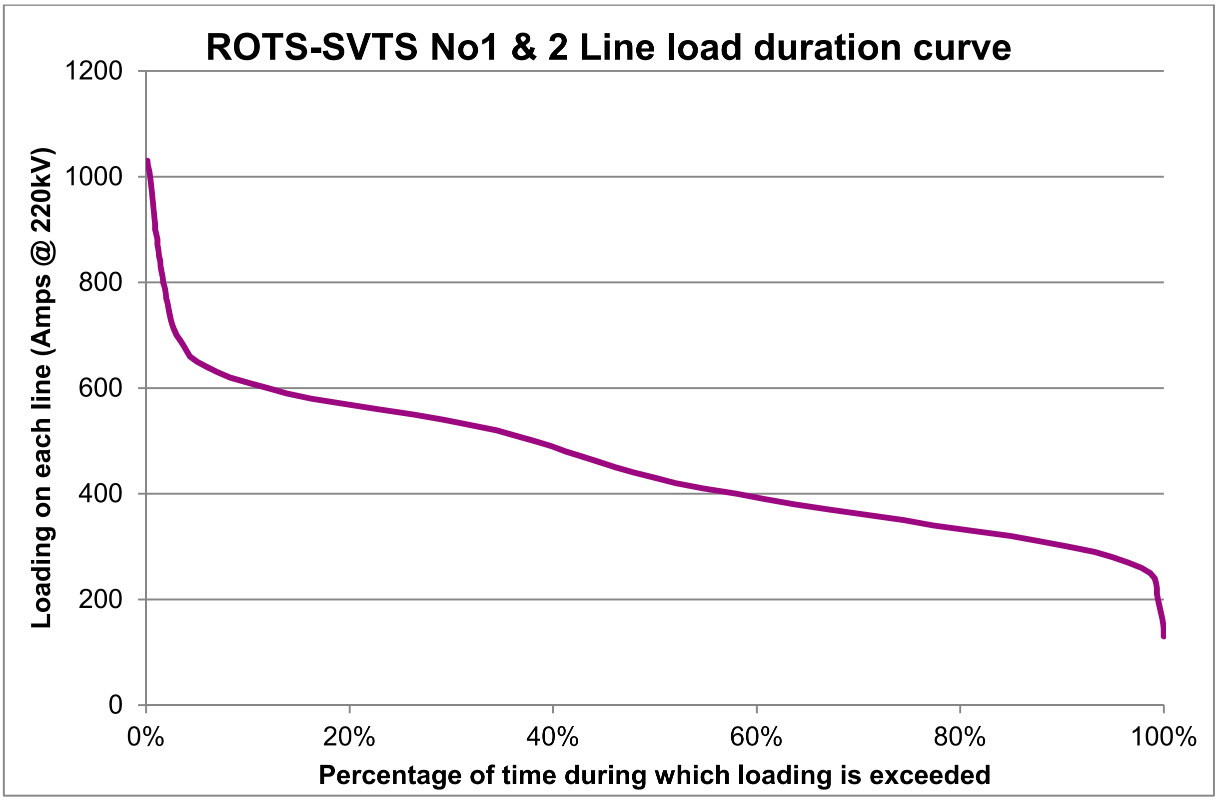
It is not uncommon for transmission towers to be located in public spaces such as road reserves and parks and for them to operate safely, with negligible risk to the general public.

The above picture shows the transmission line in Dinah Parade East Keilor

5.0 General Assumptions

The line usually carries between 300 and 700 amps of current but currents of up to 1100 Amps may occur for a few hours on a select number of hot days in summer.

Figure 2 ROTS-SVTS load duration curve



The above graph of line load and duration has been provided by SP AusNet, I have assumed that the loading of the line does not change significantly.

My assessment assumes a maximum ground fault level for the transmission line in the area of Waverley Park is approximately 30,000 amps.

The Reference Design is for a 220 kV overhead transmission line on steel poles and 220kV underground cables. The cable analysis assumes two transition enclosures one to be located near the Monash Freeway and the other near Jackson's Road. The underground section is 530 meters in distance between the transition enclosures, consisting of three cables in parallel for each phase of the two circuits. Installed with the 18 cable sections will be six earth continuity conductors bonded to the earthing system at each transition point.

For the pole line option, It is assumed that pole 11A will be of dual circuit construction but two single circuit poles will be located at positions 10 A (subject to separate permit) and 12A near Jackson's Road and the Monash Freeway respectively.

A full list of assumptions is provided in Appendix A.

I believe that all the assumptions made are reasonable and realistic.

6.0 Electromagnetic Field Issues

6.1 Guidelines and Standards

Electric and magnetic fields caused by power use are present in relatively small amounts in our general working and living environments. The main sources of these fields are electrical wiring, power line conductors and cables and electrical appliances. In general, higher levels of these fields are recorded near to high voltage transmission lines and terminal station lines.

In Australia, the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) is the federal government agency responsible for protection the health and safety of people and the environment from the effects of EMF. ARPANSA has advised that the "Interim Guidelines on Limits of Exposure to 50/60 HZ Electric and Magnetic Fields (1989)" issued by the National Health and Medical research Council (NHMRC) are the guidelines currently applicable in Australia.

The Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) has also published a Public Consultation Draft for the Radiation Protection Standard for Exposure Limits for Electric and Magnetic Fields 0 Hz to 3K Hz. This also sets out the guidelines for extremely low frequency fields, both for occupational and general public exposure. It also sets out the scientific basis for the electric and magnetic field exposure limits in Schedule 1 of the Standard. Limits of safe exposure are the same in both documents.

The Interim Guidelines on Limits of Exposure to 50/60 HZ Electric and Magnetic Fields (1989) provides the following recommended exposure level for EMF.

Magnetic Fields

	Long Term Exposure	Few hours/day
Occupational Exposure	500 µT [1] (per working day)	5000 µT
General Public	100 µT	1000 µT

For open spaces in which the general public might be reasonably expected to spend a substantial part of the day, such as in recreational areas an exposure level of 100 µT applies.

Electric Fields

	Long Term Exposure	Few hours/day
Occupational Exposure	10 kV/m (per working day)	30 kV/m
General Public	5 kV/m	10 kV/m

6.2 Electric Fields

Electric fields are created by the electric charges on high voltage equipment. They diminish rapidly with distance and are shielded by common materials such as trees or buildings. Electric fields have not been identified as a public health issue, however, they can potentially cause a number of effects such as audible noise, RF noise and interference and sparks and shocks.

According to the IEEE at the level proscribed at for general exposure, around 7% of adults would experience a spark in a 5KV electric field. The ARPANSA draft standard states " *…since this sensation is similar to that experienced from sparks when touching, for example a door handle after acquiring static from crossing a carpet or getting out of a car seat, this is deemed tolerable*."

[1] Magnetic fields are measured in units of Teslas and Gauss and the strength of fields associated with High Voltage power lines is in the micro Tesla (µT) and milligauss range (mG) where 1 µT = 10 mG. Tesla is the unit used in the standards and in the scientific community and has been used in this report.

Electric field strengths associated with 220 KV transmission lines typically are in the range of 1 to 3 kV/m under the power lines - well below that of the recommended safe levels - and, at these levels, it is very uncommon for contact shocks to occur. At the edge of the transmission line easement, typically 20 to 30 metres from the power line poles, the electric fields are typically in the range of 0.1 to 1.0 kV/m.

It is also possible for voltages to be induced in long metallic structures that are aligned so that they run parallel to the transmission lines. The induction is small and structures need to be continuous for hundreds of metres for voltage large enough to be felt by humans to be developed. However, it can occur in long metal fences (for example farm fences) and other structures. I am not aware that structures of sufficient length are planned for the Mirvac development and if it were to occur it can be addressed simply by proper earthing practices.

The ground itself provides an effective shield for electric fields associated with underground cables and as a result they effectively do not produce electric fields that would be experienced by the general public.

Because there is no evidence that electric fields at the strengths associated with an overhead transmission line cause harm to humans and because the fields can be readily shielded, electric fields do not pose risks to the general public.

6.3 Magnetic Fields

Magnetic fields arise from the moving electric charges – current. These fields are not shielded by most common materials and easily pass through them. In a similar way to electric fields, magnetic fields also diminish with distance from the source. However, the fields do readily pass through the ground so magnetic fields are associated with underground cables.

The size of the magnetic field will vary during the day as the amount of current varies with the power requirements of the transmission system. Typically current for the lines that cross the Mirvac property will vary from a minimum of about 300 Amps to a maximum of 700 Amps. The magnetic field is proportional to the current carried by the line.

SP AusNet's publications report that the level of magnetic field created by a transmission line is typically 1– 8 μT under a transmission line and 0.2 – 2.0 μT at the edge of the transmission easement. These levels conform with the modelling I have done for the Mirvac transmission lines.

The level of magnetic fields from above ground and underground transmission lines is similar to that created by some common household appliances such as hair dryers, electric stoves and electric blankets. In fact, magnetic fields produced by appliances which are held close to the body, such as hair dryers, electric shavers and can sometimes exceed those found in transmission line easements.

Table 1 Typical magnetic field values for household appliances

Device	Typical Value (μT)	Range of Measurements (μT)
Hair Dryer	2.5	1.0 – 7.0
Electric Blanket	2.0	0.5 – 3.0
Electric Stove	0.6	0.2 – 3.0
Computer Screen	0.5	0.2 – 2.0
Toaster	0.3	0.2 – 1.0
Electric Jug	0.3	0.2 – 1.0
Refrigerator	0.2	0.2 – 0.5
Television	0.1	0.02 – 0.2
Electric Fan	0.1	0.02 – 0.2

6.4 Magnetic Fields and Health

A number of studies have been conducted investigating the association between magnetic fields and certain medical conditions. Around 20 epidemiological studies have been performed just looking at a possible link between leukaemia and EMFs. Some of these have shown an association between an increase in childhood leukaemia and magnetic fields at low levels but some have found no association. The evidence supporting the association is not conclusive. Animal and *in vitro* experiments have not provided evidence to support the epidemiological studies nor have they established a biophysical induction mechanism for the development of cancer. A causal relationship has not been established.

Electric Utilities have adopted a policy of “prudent avoidance” to avoid and manage perceived health risks. This means taking simple, easily achievable, low cost measures to reduce exposure to EMF, even in the absence of demonstrable risk. Mirvac has adopted this principal by providing an additional buffer outside the easement as shown in their Waverley Park Propose Power Line Plan drawing No TL TP1000a revision D.

6.5 Reducing Magnetic Fields

There are a number of ways to reduce EMF effects: Firstly, as the magnitude of the EMF is inversely proportional to the distance from the current carrying elements, one can increase the distance of the public from the conductors. Hence by increasing the width of an easement, increasing the height of a transmission line or increasing the distance to the boundary of the terminal station will reduce the magnetic field strength magnitude. Higher transmission poles will produce a lower EMF, so there is a potential trade-off between the height of a transmission pole and its effect on visual amenity and the reduction in EMF. There are practical limits to the physical height of poles and size of the easements and substation sites so this solution, whilst generally practical, does not suit every situation.

Cancellation of magnetic fields between different conductors is possible because of the phase relationship between the conductors. This means that the spatial arrangement of conductors can be used to reduce the EMF. Cancellation offers the best opportunity to cost effectively reduces EMF and is commonly applied as part of a utilities prudent avoidance practice.

More compact structures have lower EMF as better cancellation of the fields occurs if the conductors are close together but there are engineering limits to how close conductors can be place to each other. Generally speaking, construction is more compact at lower voltages so less EMF will be produced for a 66kV transmission line than a 220kV transmission line for a given current.

EMF shielding is possible using materials of high magnetic permeability. However, this solution is expensive and usually only used to solve specific local problems.

Other solutions, such as current cancellation loops may offer alternative, but less proven options for addressing magnetic field problems.

The various solutions are applied during detailed design. Generally speaking physical separation will provide appropriate EMF levels and this particularly applies to transmission lines through rural areas where the lines are well away from areas frequented by people. Special design can be applied for local problems.

6.6 Options and EMF

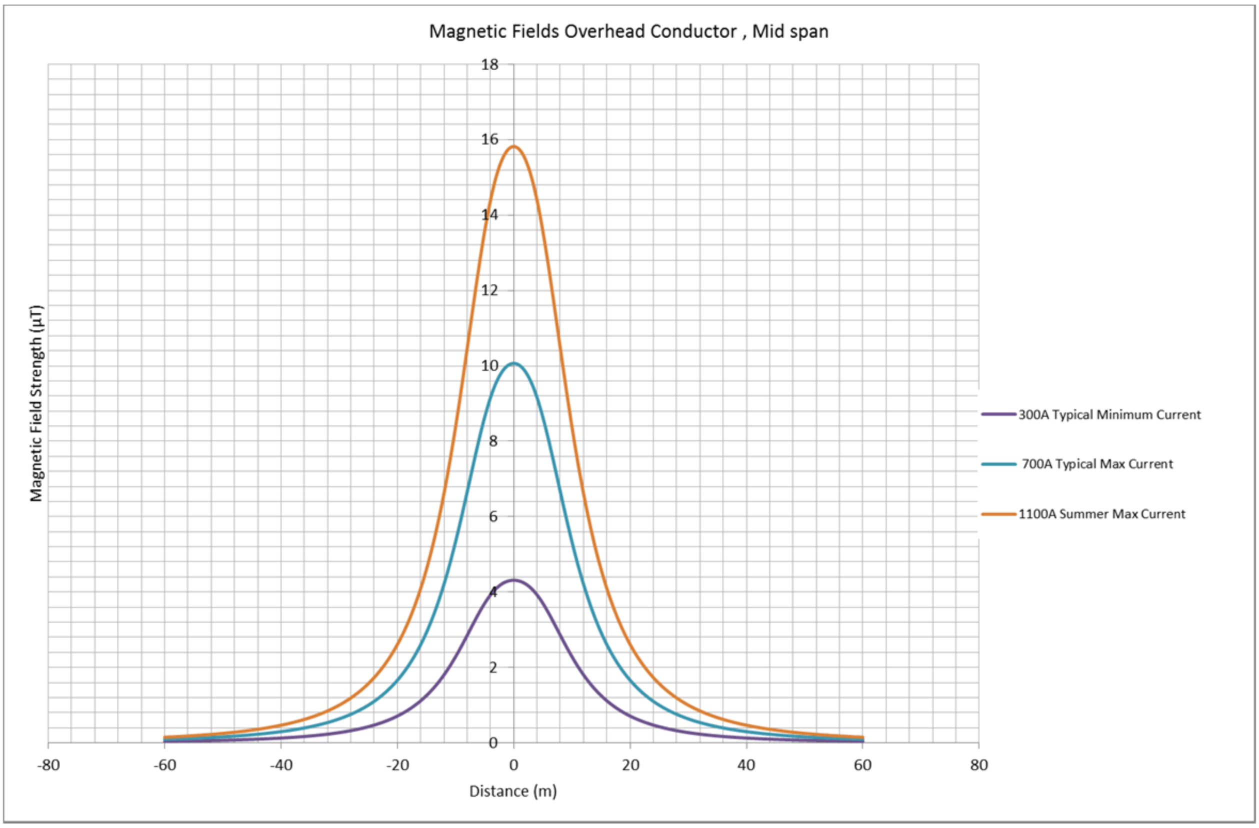
6.6.1 Overhead Transmission Lines

The magnetic field strengths across the transmission line easement have been modelled.

For both overhead lines and underground cables, the magnetic field strengths are highest at the closest points to the current carrying conductor. For overhead lines, the field strengths vary with the height of the conductor and are largest at the mid span point between the poles where the conductors are closest to the ground but much smaller at the poles.

The field strengths will also vary depending on the amount of current flowing through the conductors. This is demonstrated in the following graphs.

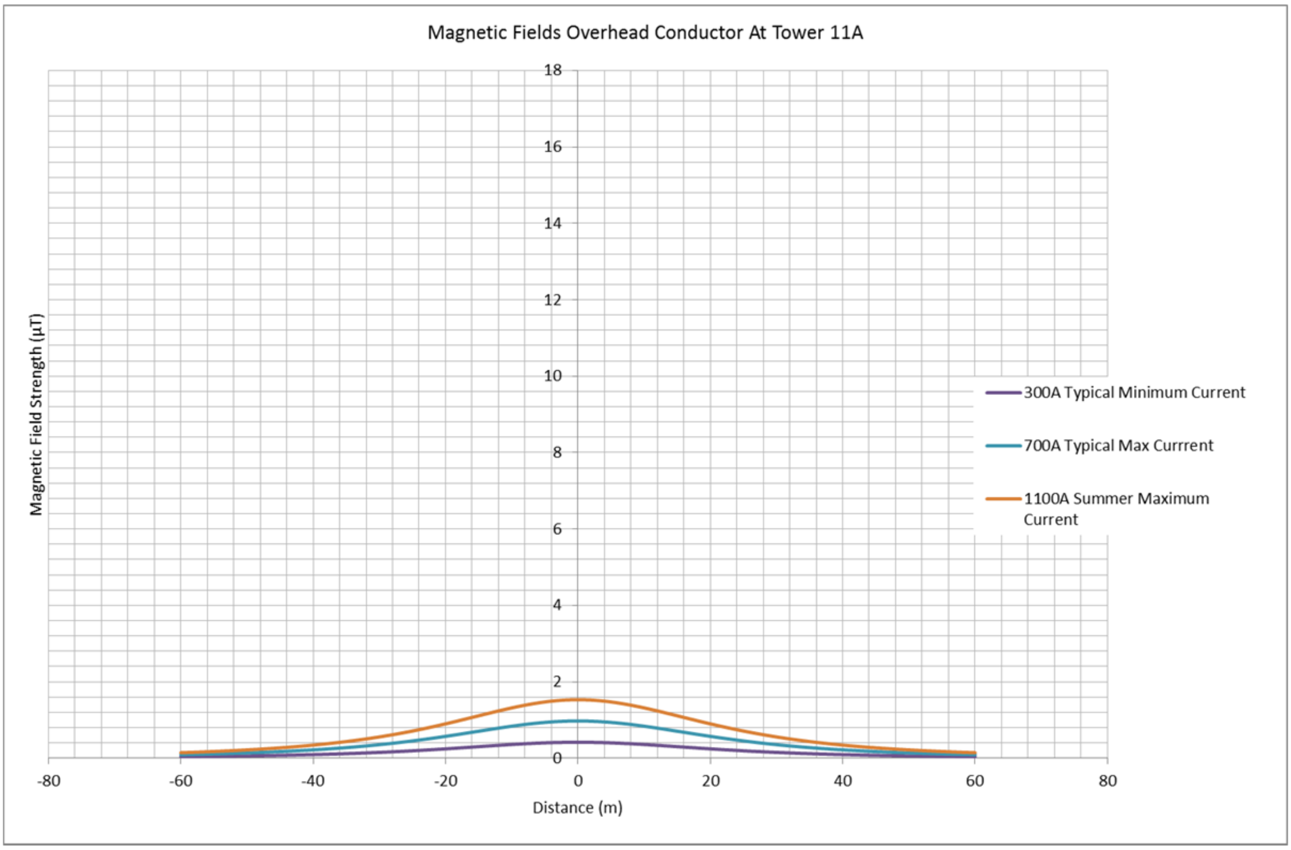
Figure 3 Magnetic field strength across easement for overhead option with various levels of current



The magnetic field strength varies considerably between the poles and the midpoint span – at 700 Amps line current from about 10 µT at the mid span to less than 1µT at the pole 11A. This compares with the level allowed by the Guidelines of 100ut.

Typical field strengths for mid-span and pole locations are shown in figures 3 and 4 respectively, plotted on the same scale.

Figure 4 Magnetic field strength at structure 11A



6.6.2 Underground Transmission Cables

Magnetic fields are not shielded by being buried and fields will remain and be at their maximum especially directly above the cables and within the cable easement. As magnetic fields are caused by the current flowing in the cable, EMF produced will be determined by the current and not by the voltage of the cable. Underground cables are generally laid quite close to one another so good cancellation between the fields created by each cable phase is achieved which reduces EMF

A trefoil arrangement, where three cables are laid in a triangular group will have a lower EMF than those laid flat in a row. This is the arrangement proposed for the Mirvac cable.

Figure 5 Trefoil Cable Arrangement

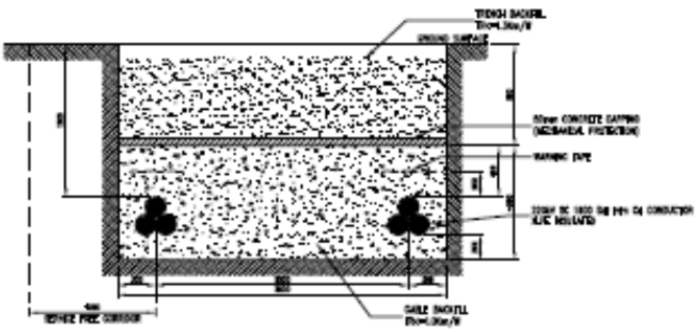
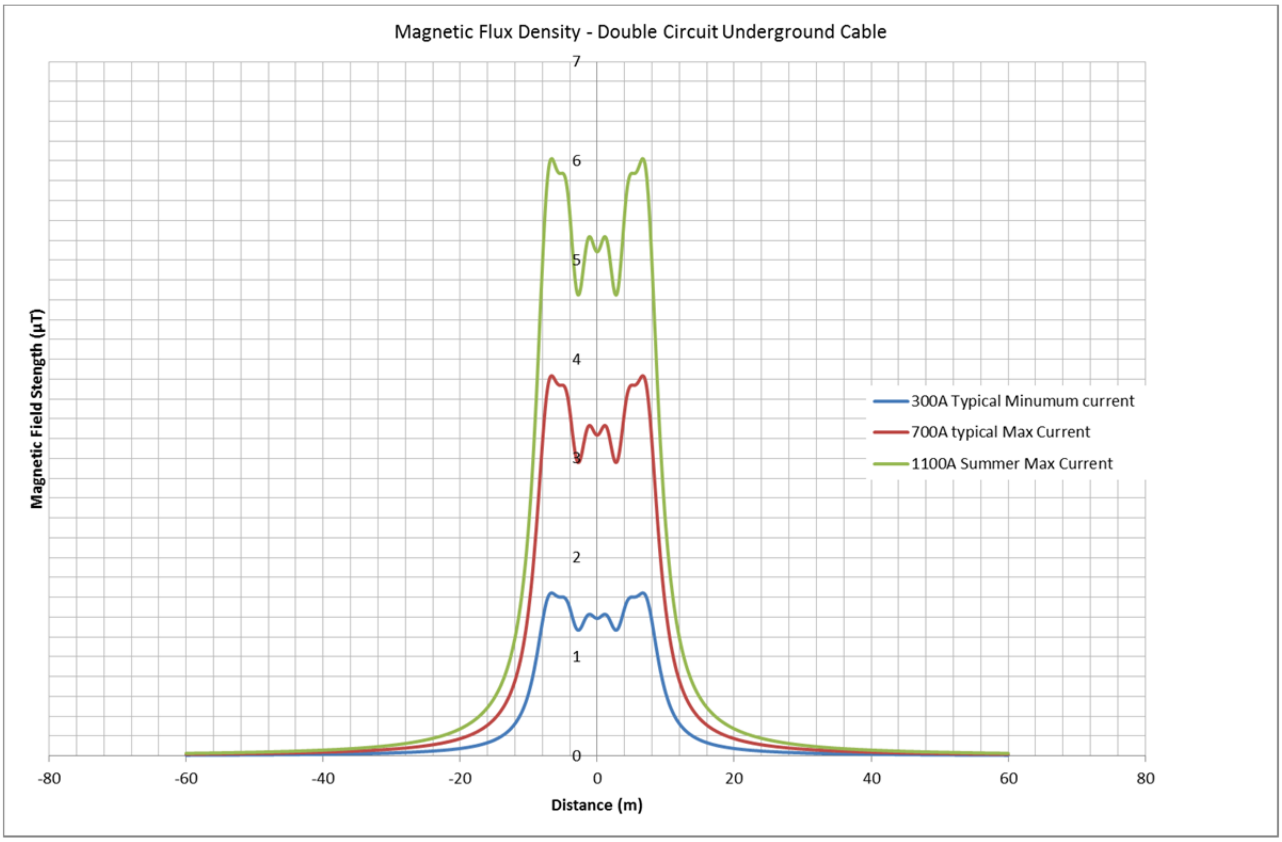


Figure 6 Magnetic Flux Density profile for 220KV UG cable



The above graph shows magnetic field strengths across the easement for an underground cable at various conductor currents. For cables, the magnetic field strength falls much more rapidly than for overhead lines.

The graphs below compares Magnetic fields of poles and tower lines and underground cables calculated for EMF at the mid span point and near the poles. They demonstrate that the cable field is lower and less widespread at the midpoint, but the reverse is true near the poles where the greater distance between conductor and ground reduces field strengths.

For much of the distance along the proposed pole line the EMF caused by the underground cable option is higher than that produced by the pole line. It is estimated that for about 75% of the line the maximum EMF of the underground cable will exceed that of the overhead line, albeit that all EMF levels are well within recommended exposure levels for both overhead and underground cable options.

Figure 7 Comparison of EMF between overhead line and underground cable at Mid Span

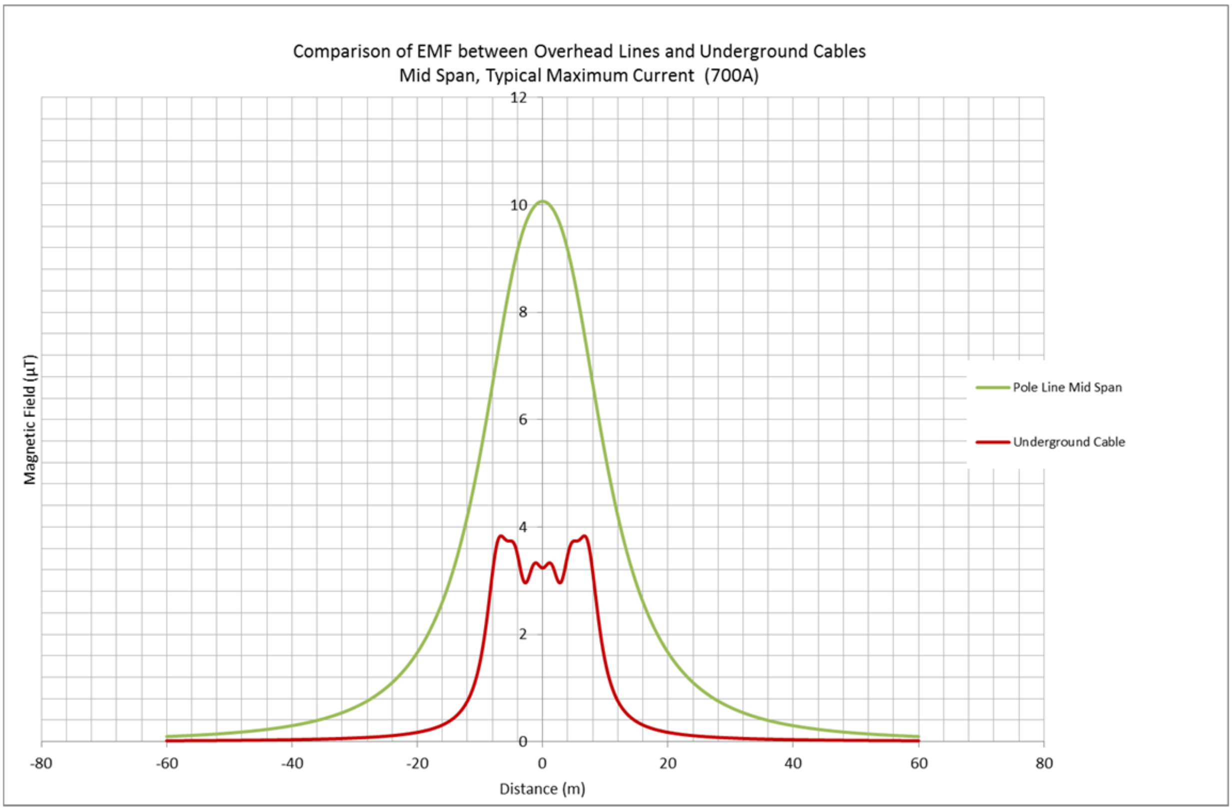
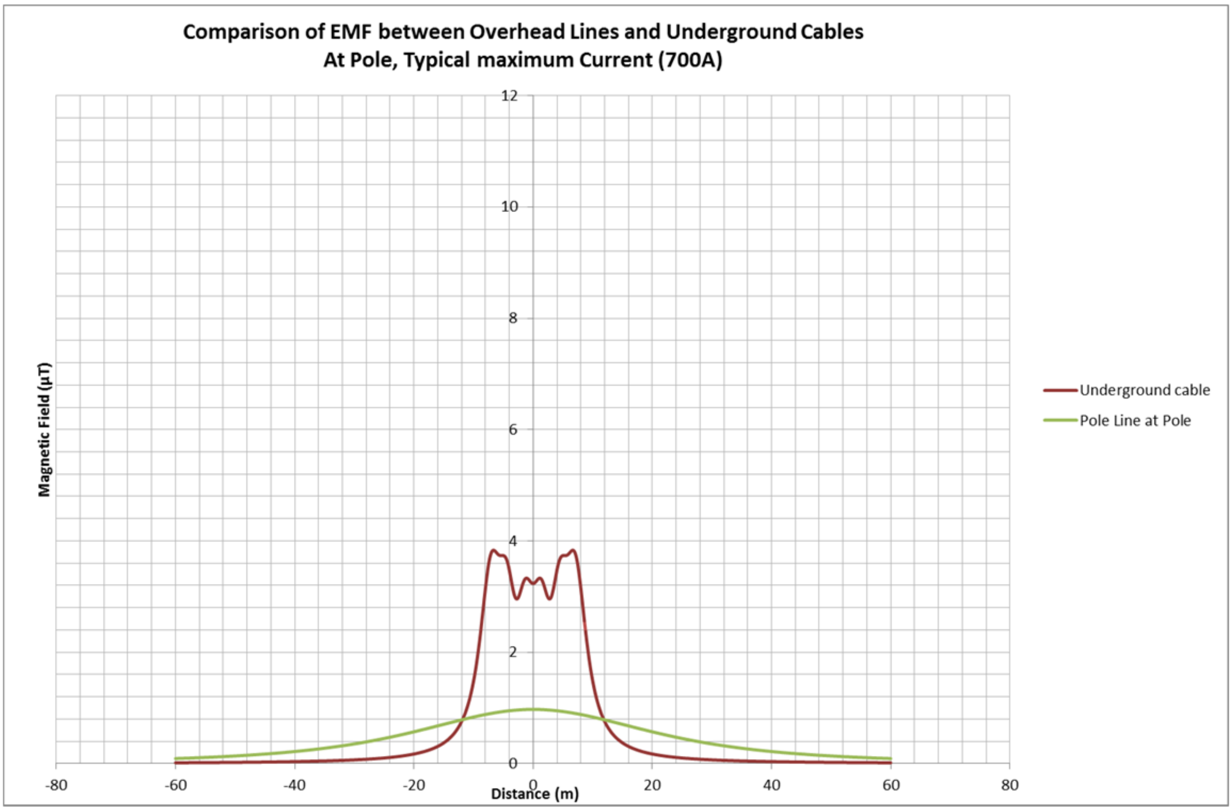


Figure 8 Comparison of EMF between overhead line and underground cable at pole



6.6.3 Transition Enclosures

The underground cable requires transition enclosures at each end of the cable. The electric and magnetic fields within the underground to overhead transition enclosure are a function of the geometry of the transition equipment, the voltages at which the equipment is energised and the current that passes through it.

The transition enclosures are a working environment and they are designed so that the occupational guidelines of the Radiation Protection Standard are met. Equipment within the transition enclosures is located far enough from the enclosure fence so that field exposure to the general public is well within recommended levels. .

As the proposed design of the two enclosure stations for this project have been previously completed, it is possible to model the compound for EMF. This modelling has shown that the public exposure to fields will be similar to at those experienced at the edge of the transmission line easement.

6.6.4 Precautions for the General Public

Where public exposure exceeds the reference exposure levels, the ARPANSA standard recommends that the precautions taken to protect the public might include:

- Determination of the boundaries of the areas where general public exposure limits may be exceeded.
- Restriction of public access to those areas where general public exposure limits may be exceeded.
- Appropriate provision of warning signs or notices
- Taking measures, as appropriate to the risk involved to limit or eliminate the fields.

However, as the likely exposure levels are significantly less than the reference levels, these measures are not required.

A prudent avoidance philosophy has been implemented during the preliminary design of both the cables and overhead lines. In particular, Mirvac has chosen to allow an additional buffer between the transmission line and cable easements and the nearest houses. The pole line buffer proposed by Mirvac is shown on Waverley Park Proposed Power Line Plan drawing number TL-TP1100a rev D. Prudent avoidance reflects the Electricity Industry's desire to err on the side of safety even in the absence of demonstrable risk.

6.7 EMF Conclusions

For both the underground cable option and the overhead line options, the line routes will pass through public space. For both options the electric and magnetic field strengths experienced by the public are well within those recommended by the Standard and Guidelines.

For electric fields, the underground cable option will not produce electric fields as the ground provides an effective shield.

For the overhead line option, the field strengths are at a maximum within the transmission easement and will have a level of approximately 1-3kV/m, about half the recommended level. At the edge of the transmission line easement, typically 20 to 30 metres from the power line poles, the electric fields will be even smaller and are typically in the range of 0.1 to1.0 kV/m. In my opinion, these electric fields will not pose a risk to the public.

For magnetic fields, the standards recommend a safe level of exposure of 100μT for constant exposure, 24 hours per day and 100μT is also the recommended exposure level for public areas such as parks and recreational areas. The magnetic field strength will vary from day to day and throughout the day as the power flow in the transmission line increase.

For overhead lines, the maximum values will occur at the lowest conductor point, mid span between the poles. Typically these values will be between 4 and 10 μT. At the poles, the conductors are higher above the ground and the fields experienced by the public will be much less, typically in the range 0.4 to 1.6 μT.

For the underground cable option, the ground will not shield the magnetic field. The cable is buried at a constant depth and magnetic field will be constant across the cable length except varying with the power flow. Typically the magnetic field strength from cables will be in the range 1.6 – 3.8 μT.

All the magnetic fields are at least an order of magnitude lower than the safe levels provided by the standard. In my opinion, magnetic fields associated with the transmission line do not pose a risk to the public.

7.0 Earth Potential Rise

During a fault on a transmission line, current may flow into the local earthing system on its way back to the source. These current can cause the potential (or voltage) rise on the local earthing systems and earthing systems must be properly designed to deal with the hazards.

It is impossible to prevent the presence of hazardous voltages at all times. However with careful earthing design acceptable solutions can be found that reduce risks to a negligible amount.

Overhead lines have earth wires that run above the power carrying conductors. The purpose of the earth wire is both to provide shielding from lightning and to form part of an extended earthing system along the pole line. These earth wires are connected through the pole structures to a local earthing point. Current will flow into local earthing points for earth faults that occur on the line and for earth faults that occur elsewhere, but whose current flow through the line earth wires. This current will flow through the earth wires to the local earthing point at the base of poles.

For the proposed underground cable options, transition enclosures will be required at the end of the cables where the cables are attached to the transmission line. An extensive earth grid is provided at the transition enclosure to provide safe operating conditions for SP AusNet staff. The earth grid at each transition enclosure is connected to the other by earthing cables running underground with the power cables. The transition enclosure earths will also be connected to the overhead line earthing conductors on the poles.

7.1 Standards for Earth Potential Rise

There are a number of standards that address the requirement for safe earthing. Some of the standards are:-

- AS/NZS 60479 Effects of current on human beings and livestock
- ENA EG0 Power system earthing guide, Part 1: Management principles
- ENA EG1 Substation earthing guide
- IEEE Std80 IEEE guide for safety in AC substation grounding
- IEEE Std81 IEEE Guide for measuring earth resistivity, ground impedance, and earth surface potentials of a grounding system
- AS 2067 Substations and high voltage installations exceeding 1kV a.c.
- AS/NZS 3000 Electrical installations (known as the Australian/New Zealand Wiring Rules)
- AS/NZS 3835 Earth potential rise – Protection of telecommunications network users, personnel and plant
- AS/NZS 7000 Overhead line design detailed procedures.

The documents all have the same basis but the recommended allowable EPR does differ between standards used for terminal stations and substations on the one hand and transmission lines on the other. The earth grids of terminal and substations are generally designed in accordance with IEEE Std 80 guidelines which are generally more onerous than the transmission line standard AN/NZS 7000. This is because the substations inherently are exposed to more fault events than lines. The potential of their station earth grids will rise for each fault on all transmission lines connected to it whereas a transmission line earthing caters for fewer faults, only those associated with the line itself.

SP AusNet has indicated that, for the underground cable option, it would like the transition enclosure's earthing system to be designed to the IEEE Std 80. In addition SP AusNet's rule of thumb design criteria is to keep the 1000V EPR contour within the boundary of the terminal station (in this case transition enclosure) fence. This meets the requirements for earth potential rise in AS/NZS 3835 table 2.

Another Standard, ENA EG-0, was released in August 2010 and it introduces a direct, probabilistic development of earthing system safety criteria. The criteria are derived by assessing the probability of the coincidence (of a subject being placed in a reasonably foreseeable contact scenario during a fault) and the probability of the fibrillation (the voltage hazard leading to a ventricular fibrillation). By considering probability the standard seeks to provide a better engineering solution for very rare events that may pose an earthing hazard.

The probability of a fatality is compared to the likelihood of occurrence, with a risk below 1 x 10^{-6} being referred to as negligible risk. A risk determined to be in the negligible range does not negate the need to undertake reasonable practical risk reduction measures.

Standard AS/NZS 7000 for overhead line design has also adopted a risk based approach based on ENA EG0.

7.2 Earth Potential Rise Guidelines

7.2.1 Standard AS/NZS 3851

Standard AS/NZS 3851 applies to the telecommunication network users and defines EPR hazard limits of 1500V, 1000V and 430V as per the table below:

Table 2 AS/NZS 3851 EPR hazard limits

	Limit category		
	Category A	Category B	Category C
Reliability	High	High	Not High
Fault Duration	≤ 0.35 sec	≤ 0.5 sec	Any
EPR Hazard Voltage Limit	1500 V or 1000V	1000 V	430 V

The Rowville to Springvale transmission line can be considered as category A. – A high reliability circuit with a fault duration ≤ 0.35 sec. For category A circuits, the HV line structures > 200KV, the 1500V limit applies except where telecommunication equipment cannot with stand 1500V, when 1000V should be used.

7.2.2 Standard AS/NZS 7000

Standard AS/NZS 7000 applies to overhead line design. It recommends the following EPR limits. This standard provides curves of acceptable voltage touch criteria plotted against fault clearance times. Data points in the following table are used to generate that curve.

Table 3 AS/NZS 7000 EPR hazard limits

Curve		Voltage (V)	Clearance Time (s)
Transmission Urban < 1S	TU	8000	0.2
Transmission Urban > 1	TU	800	1
Distribution Urban	DU	800	1
Transmission Distribution Backyard	TDB	181	1
Transmission Distribution MEN	TDMEN	121	1

Under this standard the Rowville to Springvale transmission line would be considered category TU. The recommended EPR voltage is 8000V.

The standard also indicates the basis of each curve and scenarios used in developing the curves. These are shown in the table below.

Table 4 AS/NZS 7000 basis of EPR hazard limits

Curve		Fault Frequency/Y	Contact scenario	Footwear
Transmission Urban	TU	0.1	Urban – 100 contacts per year for 4 s for clearing times to 1sec >66kV	Standard
			135 contacts per year for 4 s clearing times above 1 s (<66kV)	
Distribution Urban	DU	0.1	135 contacts/y for 4 s	Standard
Transmission Distribution backyard	TDB	0.1	Back yard – 416 contacts per year for 4 s	Standard
Transmission Distribution MEN	TDMEN	0.1	Men – 2000 contacts/year for 4 sec	Standard
Remote	N/A	0.1	Less than 60 off (4 s) contacts for 1 S fault duration, or less than 75 off (4 s) contacts of 0.2 s fault duration	Standard

7.2.3 IEEE Std 80

The IEEE std 80 defines the method of calculation of allowable step and touch voltage in terms of clearing time, body weight, the resistivity of both earth and surface layer and surface layer thickness.

The table below was produced by Safearth Consulting for transition enclosure associated with undergrounding the line in accordance with IEEE std 80. It provides the allowable voltages for a 50kg (child) and a 70KG (adult) person. Soil resistivity level of 20 Ωm and 2000 Ωm represent typical resistivities of soil and crushed rock surface respectively with crushed rock typically being used in substations.

Table 5 Allowable voltages for persons (Safearth Report)

Fault Scenario	Clearing time	Body weight	Local Soil Resistivity (Ωm)	Allowable Limits (V)		
				Touch Voltage	Step Voltage	Hand to Hand
220KV Earth Fault	0.1	50kg	20	378 V	411 V	367 V
			2000	944 V	2676 V	
		70kg	20	511 V	556 V	405 V
			2000	1280 V	3622 V	

The three examples above provide an example of the varying EPR requirements of the various standards. Standard AS/NZS 3851 address the needs of the communications industry. Standard AS/NZS 7000 is for overhead lines and considers the likelihood of a hazard in determining the practical voltage level. IEEE Std 80 calculates the EPR that will cause a hazard.

For overhead pole line design, SP AusNet will typically use the Standard AS/NZS 7000 and earthing at the pole will be sufficient to provide an EPR of < 8000 V. At this EPR a hazard may exist but it would be very rare and the likelihood of serious harm from a fault is negligible.

SP AusNet’s approach is to use the IEEE Std 80 for calculations within the station and to then check that the 1000V contour does not go outside the station boundary, effectively meeting Standard AS/NZS 3851 outside the station.

I believe these approaches are reasonable and will produce a safe earthing design in accordance with the Standards and with negligible risk to the public.

7.3 Earth Potential Rise – Overhead Lines

Pole structures are connected to an earth grid at their base. When earth current flows through the pole to the earth grid, an earth potential will be caused by the current flowing into the ground. It is expected that these transmission lines would have been designed to the criteria in AS/NZS 7000 with an allowable touch voltage of not more than 8000 V. The standard recognises that high voltages only occur in very rare circumstances and that the danger occurs only in the immediate vicinity of the pole. Dangerous voltages generally do not extend beyond the transmission line easements and circumstances that would expose a person to these voltages very unlikely. If poles are built, they too would be designed to comply with the standard.

Typical fault rates for overhead transmission lines occur at the rate of less than one fault per 100km of line length per year. Hazardous voltage on the pole line caused by earth potential rise will only occur for local faults – those within three spans or about 750m of the pole. These faults will be isolated and cleared with 0.1 seconds. The exposure to a hazardous event is in the order of 0.1 seconds every 100 years.

In my opinion, the risk associated with hazardous EPR for power lines is negligible.

7.4 Earth Potential Rise – Underground Cables

Earth potential rise hazards in the underground cable options occur at the transition enclosures. A larger earth grid is required to control the EPR so that it is safe to work within the transition enclosure. The effect of the larger earth grid is to extend dangerous EPR beyond the enclosure boundary, and perhaps into the surrounding houses where it may cause a hazard.

In addition, the larger earth grid means that faults that occur in a wider area will cause an earth potential rise large enough to cause a hazard at the transition enclosures. Faults that occur anywhere along the transmission line between Rowville and Springvale as well as faults that occur on the transmission lines between Springvale and Heatherton Terminal station will cause EPR at the enclosures.

In my opinion, the combined effects of the EPR occurrence being more likely and the number of people being exposed to EPR being greater means that the risk of an EPR hazard for the transition enclosures will not be negligible.

7.5 Earthing System Design

SP AusNet commissioned an earthing design for the two transition enclosures from Safearth Consulting in 2010 (see Appendix B). The report provided an analysis of the proposed earthing design for the two transition enclosures. It considered the earth potential rise for both through faults (beyond the Waverley Park section of line which cause EPR) and faults within the Mirvac Waverley Park section of the line.

Their report states that the proposed installation met the requirements for AN/SZS 7000 for transmission lines but *"that the touch voltages in the nearby MEN area may be present during a fault that does not satisfy the criteria of ENA EG-1".*

The report also performed a probabilistic assessment of the installation in accordance with ENA EG-0 and found that for a through fault, the risk of fatality exceeded 1.0×10^{-6} at both the Jacksons Road and Monash Freeway transition points and recommended that further mitigation should be taken to reduce the risk.

The mitigation measures proposed by Safearth Consulting were to improve the earthing resistance around four adjacent towers. The measures are at a reasonable cost and have the effect of reducing the EPR by a further factor of 10. Once this mitigation is carried out, Safearth Consulting has estimated that the risk will be reduced and fall into the negligible risk category.

In my opinion, the mitigation measures recommended by Safearth Consulting will meet the ENA EG0 guidelines in a probabilistic sense but the danger remains in an absolute sense. Even with mitigation measures applied at the transition enclosures, the overhead line option provides an EPR safety outcome that is an order of magnitude less likely to occur that for the underground cable option and for that reason is safer.

7.6 EPR Conclusion

Earth potential rise hazards are associated with both overhead line and underground cable options. For the overhead line options, the hazards will occur in vicinity of the poles and will occur for earth faults that occur within a few spans of the pole.

For the underground cable option, the hazards are associated with EPR emanating from the transition enclosures. Hazards will occur more often and will affect a wider area, with the hazards area extending to residential houses near the enclosures. For the transition enclosures, it is possible to meet the requirements of the ENA EG-0 guidelines with mitigation measures but they will continue to pose a higher risk. All other things being equal, I would recommend the pole line option over that of the underground cable option on the basis of safety risk.

8.0 Conclusion

For both overhead pole line and underground cable construction options for Mirvac's Waverley Park development there are two issues where members of public may have concern about the health and safety risks. These are Electromagnetic Fields (EMF) and Earth Potential Rise (EPR).

For both EMF and EPR there are Australian Standards and Guidelines for safe levels of exposure and proper design. For both overhead and underground line options, the requirements of these standards and guidelines can be met.

Power lines produce both electric and magnetic fields but only magnetic fields have been associated with health risks. Recommended safe field strength for public exposure to magnetic fields is 100 μT. Across the Mirvac development site, maximum field strengths are typically in the range of 3 – 7 μT directly under overhead lines and 4 μT for underground cables - both well within safe limits.

The issue posed for EPR is that it is possible for dangerous voltages to arise around the poles and transition enclosure during earth fault conditions. The levels of EPR recommended by the standards and guidelines vary depending on the location of the fault and higher levels are permitted for lines than for terminal stations. The underground cable option requires the establishment of transition enclosures at the end of the cables, where the overhead line is connected to the underground cable. Without mitigation measures the EPR at these transition enclosures meet the criteria set out in the standards for overhead lines, but not those for terminal stations.

In recent years, some Australian Standards and guidelines for earthing have been changed to incorporate probabilistic safety criteria. They provide a methodology for assessing risk and if the likelihood of a fatality is less than 1×10^{-6} the risk is referred to as negligible and regarded as acceptable.

Engineering solutions exist that will mitigate the risk associated with both underground and pole options to negligible values at moderate incremental cost. However the risk associated with a pole line will remain an order of magnitude less likely to occur than the underground option because

- hazardous voltages do not occur outside the power line easement with pole line whereas with the underground cable solution they are likely to extend into residential areas and hence expose more people to risk.
- hazardous voltage will be produced at the transition enclosures by faults on the wider transmission network and will therefore be more likely to occur.

For this reason the pole line option, is in my opinion, inherently safer than the underground cable option.

In producing this statement, for the EMF assessment, I relied on my own calculations and have performed modelling of line and cable EMF. However, for the EPR calculations, I have relied on the report produced by Safearth Consulting in 2010.

I have made all the inquiries that I believe are desirable and appropriate and that no matters of significance which I regard as relevant have to my knowledge been withheld from the Tribunal.

Signed

Date: 08/08/2014

Appendix A

Assumptions

Appendix A Assumptions

Required Power

It is assumed that the Rowville – Springvale 220kV transmission line will transmit on average 300 – 700A of power supply between terminal station ends, but that its ultimate load capacity will be 1100A (which equates to approx. 420MVA assuming a 0.9 power factor). This assumption is based on real time currents receive from SP AusNet for the transmission line load over the last 365 days.

Based on actual ratings received from SP AusNet, maximum current will be carried along the line for short periods of a few hours per day, amounting to a total of 24hrs per calendar year. The durations of "maximum load" usually occur for a few hours on the hottest days of the year, when daytime temperatures are at their peak.

For modelling purposes, we have assumed that current, up to a line rating of 1100Amps will be carried.

Power (assumed 0.9 power factor)	Current in each circuit	Maximum current (one circuit out of service)
115 MVA (average low)	300 Amps	600 Amps
265 MVA (average high)	700 Amps	1100 Amps
380 MVA (maximum demand)	1100 Amps	Not Applicable

1) 220kV Underground Transmission Line Option

Underground cables are capable of carrying approx. 900 Amps. In a 220KV cable option, three cables per phase would are required.

2) 220kV Overhead Transmission Line Option

The proposed option is to maintain an overhead line across the Mirvac development using steel poles in place of existing tower structures. The overhead solution would include two new spans of conductor along the diversion and maintain the same current rating as the existing line.

Conductor Height and Transmission Line Dimensions

EMF is affected both by the spatial relationship of the conductors to each other and the distance from the conductors to the ground. The following assumptions have been assumed in our calculations.

Line Description	Minimum Conductor Height Above/Below Ground	Vertical distance between conductors	Cross Arm Width (Double Circuit)	Easement Width
220KV Lattice	10m	4.9m	9.4m	40m
220KV Pole	9.5m	5.6m	9.5m	40m
220kV U/G cable	1.2m	Trefoil formation	2.8m between cable groups	17m

3) Other Assumptions

- Ground currents have been ignored. This is a valid assumption as they will have negligible effects on the EMF for distances less that 100m from the centre line.
- Earth wire currents and their effect on EMF have not been considered for the overhead lines. These may increase EMF.
- The locations of terminations and transpositions along the line will also affect and vary EMF.
- Zero sequence currents will also affect EMF. They should not be present under normal conditions if lines have been well designed and load is balanced.
- The above issues need to be addressed in the detailed design phase so that a low EMF result is achieved.

Appendix B

Safearth Report

Safearth Consulting

Waverley Park
Cable Termination Station

Earthing System Design

SP AusNet

ENGINEERS AUSTRALIA Professional Engineers MEMBER

Safearth Consulting
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Waverley Park Cable Termination Station

Earthing System Design

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GLOSSARY

Clearing Time:	Time taken for the protective devices and circuit breaker to isolate the fault current
Coupling Factor:	Percentage of fault returned on a faulted feeders' earth return path (cable screens and sheath or OHEW) expressed as a percentage of the fault current magnitude.
Earth Grid:	A connection to the greater mass of the earth, usually made by burying metallic conductors in the soil.
Earth Potential Rise (EPR):	The maximum voltage that a station earth grid will attain relative to a distant earthing point assumed to be at the potential of remote earth.
Earth Continuity Conductor (ECC)	Earth conductor connecting two earth grids or to achieve connection between an OHEW termination and an earth grid. Typically used alongside power cables of the same circuit.
Fault Current:	The current flowing as the result of a line to ground fault on the power system.
FOP:	Fall of Potential. A method used to measure an earth grid EPR.
LFI:	Low Frequency Induction. The voltage on a metallic structure resulting from the electromagnetic or electrostatic effect of a nearby power line
MER:	Mutual Earth Resistance. The effect a nearby test earth grid has on reducing the resistance of the grid being measured.
OHEW:	Overhead Earthwire
Prospective Step Voltage:	The open-circuit voltage difference between two points on the earth's surface separated by a distance equal to a man's normal step (approximately one metre).
Prospective Touch Voltage:	The open circuit voltage difference between an earthed metallic structure (within 2.4 metres of the ground), and a point on the earth's surface separated by a distance equal to a man's normal horizontal reach (approximately one metre)
Shielding Factor:	One hundred percent minus the magnitude of the current not returned on a faulted feeders earth return path (cable screens and sheath or OHEW) expressed as a percentage of the fault current magnitude.
Step Voltage:	The difference in surface potential experienced by a person's body bridging a distance of one metre with his feet without contacting any other grounded object.
System Impedance:	The thevenin equivalent earthing impedance as seen at the fault location. Z_{sys} = EPR / fault level.
Touch Voltage:	The voltage across a body, under fault conditions, in a position described as for the Prospective Touch Voltage but allowing for the voltage drop caused by a current in the body.
Transfer Voltage:	A special case of Prospective Touch Voltage where the metallic structure is connected to a remote point or alternatively is connected to the station grid and is touched at a remote location.

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1. EXECUTIVE SUMMARY

Safearth Consulting has carried out an earthing system design for two cable transition stations in Waverley Park, Victoria. The configuration of the 220kV twin circuit feeder between Rowville Terminal Station and Springvale Terminal Station is proposed to be changed and a section of the presently installed above ground feeder run underground for approximately 700m.

Analysis has been carried out for two fault scenarios, a through fault and a local fault.

During a through fault on the transmission the change in coupling factor between the underground cable and the overhead feeder results in current flowing into the local earthing systems. During a local fault, current flows into the local earthing system to return to the source.

Current flowing into the ground will result in EPR at each transition point, a proportion of which will transfer away from thc transmission points and into the nearby MEN system.

From the analysis carried out during the design process the following conclusions have been made.

☞ ***The proposed installation is expected to comply fully with ENA C(b)1. If SP AusNet are comfortable to apply ENA C(b)1 to the entire transition stations and the surrounding residential areas then the transition points could be built as proposed.***

✔ Touch voltages inside and to the fence directly outside of the transition points are expected to be below the ENA EG-1 50kg touch voltage allowable.

☞ ***We believe that touch voltages in the nearby MEN area may be present during a fault that do not satisfy the criteria of ENA EG-1, but would be below the allowable ENA C(b)1 criteria.***

☞ ***Probabilistic safety criteria analysis shows that if the transition points are constructed as proposed, the calculated increased risk to a person contacting the nearby MEN during a through fault on the line will be in the ALARA region and consideration of further mitigation is required.***

✔ A physically smaller earth grid around the transition point results in less voltage transfer to the nearby MEN. The use of a 33m x 24m earth grid lowers the calculated increased risk to 1.8×10^{-7} for Jacksons Road TP and to 2.2×10^{-7} for Monash Freeway TP for contacts to the MEN. These values are considered to be in the negligible risk region.

☞ ***Further mitigation can be achieved by lowering the tower impedances for two towers either side of the proposed transition points. Towers 9, 10, 13 and 14 could have their grid resistance lowered from 2.7Ω to 1.5Ω, and it would be expected the EPR at the transition points would reduce by approximately 10%.***

☞ ***The addition of four x 10 metre electrodes placed 5m diagonally away from the tower corners and connected by bare copper would achieve a tower impedance of 1.5Ω.***

✔ If the EPR was reduced by 10%, voltage transfer to the MEN would also reduce. It is expected that the calculated increased risk would reduce to 1.0×10^{-7} for Jacksons Road TP and to 1.3×10^{-7} for Monash Freeway TP for contacts to the MEN. These values are considered to be in the negligible risk region.

2. INTRODUCTION AND SCOPE

Safearth Consulting has been engaged by SP AusNet to carry out an Earthing System Design for two cable transition stations in Waverley Park. The transition stations are part of a project to underground a section of twin 220kV transmission line between Rowville TS and Springvale TS. The transition stations are located in close proximity to a new residential development, and concerns have been raised by the client as to the hazards arising from faults at the transition stations.

The agreed scope for the assessment was documented in Safearth's proposal SC11-009-07 R1 and includes preparing a report outlining the results of our modelling of the transmission lines, the EPR and resultant voltage contours for the applicable faults along the transmission line.

This report documents our analysis for the applicable faults and our conclusions and recommendations for the design of the transitions points at Waverley Park.

3. DESIGN INPUTS AND CONSIDERATIONS

3.1 Supplied Documents

The following documents have been utilised in the assessment and process.

Table 3-1: Supplied Documents

Document No	Title
T1/880/1	220kV Transitioning Enclosure Waverley Park Monash Freeway Site Plan
T1/880/5	220kV Transitioning Enclosure Waverley Park Monash Freeway Site Earthing and Cable Easements Plan
T1/880/10	220kV Transitioning Enclosure Waverley Park Jacksons Road Site Plan
T1/880/14	220kV Transitioning Enclosure Waverley Park Jacksons Road Site Earthing and Cable Easements Plan
T14/834/101	Circuit Data Sheet ROTS-SVTS 220kV Circuit No 1
T14/834/102	Circuit Data Sheet ROTS-SVTS 220kV Circuit No 2
Fax	Fax from Tim Tse of cable data for proposed installation details for underground cable section
email	Email from Adam Klebanowski to Tim Tse dated 13/8/08 detailing with fault level information

3.2 Earth Fault Data

The following section outlines the fault and protection details for Waverley Park Cable Termination Station as provided by SP AusNet.

3.2.1 System Configuration

The 220kV dual circuit transmission line presently supplies Springvale Terminal Station and is fed from Rowville Terminal Station. Three spans are presently installed Waverley Park near the intersection of Monash Freeway and Jacksons Road and the proposal is to remove towers 11 and 12 and replace the three spans with buried cable.

Two transitioning points are proposed, one to be located near Monash Freeway and the other near Jacksons Road. The underground section is proposed to be approximately 700 metres long, consisting of three cables in parallel for each phase of each of the two circuits. Installed with the 18 cable sections will be six earth continuity conductors (ECCs) bonded to the earthing system at each transition point.

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After the underground cable section is installed, it is expected that the overhead section from Rowville to the transition point near Jacksons Road will consist of 10 towers, and from the Monash freeway transition point to Springvale will consist of 14 towers. The overhead section is configured as a twin circuit line, and installed with one galvanised steel and one OPGW overhead earth wire bonded to each tower and also bonded to the respective terminal stations.

3.2.2 Earth Fault Levels

The amount of earth fault current that will flow during an earth fault is a significant input into any design, review or assessment of an earthing system. In addition to fault current magnitudes, consideration must also be given to the current distribution from the fault location, the contribution of each source (where multiple sources exists), and the degree of asymmetry in the current waveform. In many cases conservative simplifications can be made however such simplifications can only be safely made after building a clear picture of the range of actual fault scenarios.

An accurate understanding of the earth fault clearing details is also important. In a single stage clearing it is usual to use the backup clearing time for equipment selection and to use primary clearing time for the specification of safety criteria. Consideration should also be given to selecting the worst case of clearing times, for example on the line side of a feeder circuit breaker. Where fault clearing is in stages with reducing earth fault current (stepped faults) further analysis is required.

The applicable earth fault levels are presented in Table 3-2.

Table 3-2: Waverley Park Cable Termination Station

FAULT SCENARIO	FAULT CURRENT (Amps)	CLEARING TIME (Sec)
Through Fault - Single line-to-ground fault at Springvale TS	22000 from Rowville TS	0.1 / 0.3[1]
Local Fault - Single line-to-ground fault at transition point	20000 from Rowville TS 10000 from Springvale TS	0.1 / 0.3[1]

1. Backup Clearing time.

3.3 Soil Resistivity Considerations

To correctly design and analyse Earthing Systems it is necessary to understand the electrical structure of local soil. Soil resistivity testing is often used to determine some electrical characteristics of the soil in which the earth grids are buried and upon which the structures stand. Test data should always be considered in conjunction with past test data from the region, published soil resistivity range data and other available geo-technical data. Possible

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sources of local error such as excavations, fences, buried pipelines and transmission systems should also be considered.

Safearth Consulting carried out soil resistivity testing using the Wenner method on 9 November 2010. The location of the test is displayed in the following image exported from Safearth proprietary software **DIRT**.

Figure 3-1: Waverley Park Soil Resistivity Test Locations

Safearth carried out testing at locations and in the directions indicated by the green, blue and red traverses. Previous testing has been carried out onsite by others at locations approximated by the orange and grey markers.

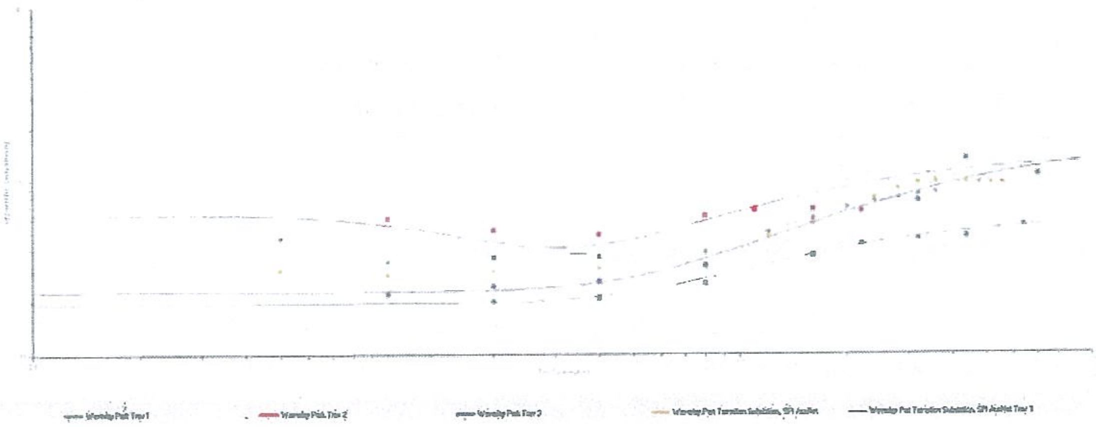

Figure 3-2: Waverley Park Soil Resistivity Results

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3.3.1 Soil Resistivity Discussion

Testing was carried out at the locations of the proposed transition points and also in the cable trench at Waverley Park. Analysis of the results shows a similar low on high soil model trend for all three tests carried out by Safearth as well as strong correlation to the two tests carried out onsite previously by others. The strong correlation of the five tests allows an increased level of confidence in the overall soil model.

Construction work onsite has altered the surface layer to varying degrees across the three locations. The Jacksons Road transition point testing was carried out along a compacted roadway and the top layer resistivity measured was slight higher than found during other tests.

During the construction of the cable trench the surface layer has been removed to a depth of one to two metres and testing at this location showed a lower top layer resistivity than testing at the Jacksons Road transition point site.

Measurements taken at longer spacings during testing at the Monash freeway transition point site may have been influenced by a nearby construction dam, resulting in lower resistance measurements as shown in the green line on the graph in Figure 3-2.

From the analysis of soil resistivity results we can conclude the area can generally be described with a two layer model, consisting of a low upper layer on a higher lower layer.

An equivalent electrical soil model has been derived and the following soil resistivity model will be used throughout the design process.

Table 3-3: Soil Resistivity Model – Waverley Park Cable Termination Station

Resistivity Test Site	Layer	Resistivity (Ωm)	Layer Depth
Monash Freeway Transition point	1	20	9
	2	130	∞
Jacksons Road Transition point	1	30	7
	2	130	∞

3.4 Safety Criteria

3.4.1 Applicable Safety Standards

In Australia there are a number of sources of voltage based earthing safety criteria for HV installations which are covered in a range of standards. Some are clearly applicable in various situations; sometimes the applicable criteria are not easily determined. In any case the overriding responsibility is that of due care based on the recognised best practice and current research.

The most commonly used and widely accepted standards for Australian utility HV installations include:

- ENA C(b)1 [1] 'Guidelines for Design and Maintenance of Overhead Distribution and Transmission Lines'
- ENA EG-1 [2] 'Substation Earthing Guide'
- ENA EG-0 [3] 'Power System Earthing Guide Part 1: Management principles'

For a fault at a tower structure, touch voltages generated will be compared to criteria defined in ENA C(b)1. The ENA C(b)1 Guide for Design and Maintenance of overhead Distribution and Transmission Lines defines the allowable touch and step voltage limits for different locations and expected frequency of personnel being present during a fault. It is believed the location criteria for towers between Rowville and Springvale should be considered as *Frequented* (rather than *special* or *remote*) and therefore the criteria defined by curve B2 of figure 11.1 of the guideline should apply.

Table 3-4: Allowable Prospective Step and Touch Voltage from ENA C(b)1

FAULT CASE (kV) (Secs)	CURVE	TOUCH VOLTAGE	STEP VOLTAGE
220kV (0.1 Sec Clearing Time)	B2 Frequented	8000 V	16000 V

We expect the transmission line would have been designed to comply with the criteria in ENA C(b)1.

C(b)1 may still be the most appropriate criteria after the installation of two transition points in their proposed locations, however some may argue the most appropriate safety criteria to apply should be drawn from ENA EG-1 'Substation Earthing Guide'. The ENA Substation Earthing Guide defines the allowable prospective step and touch voltage as a function of clearing time, body weight, the resistivity of both the earth and the surface layer and the surface layer thickness. The equations presented in ENA EG1 are consistent with the requirements outlined in IEEE Std 80 [4].

A surface resistivity of 20Ωm has been applied to the calculations for allowable limits on local soil and it has been assumed crushed rock has a resistivity of 2000Ωm. They are presented in Table 3-5 below.

Table 3-5: Allowable Prospective Step and Touch Voltage from ENA EG-1

Fault Scenario	Clearing Time	Body Weight	Local Soil Resistivity (Ωm)	Allowable Limits (V)		
				Touch Voltage	Step Voltage	Hand to Hand
220kV Earth Fault	0.1	50kg	20	378 V	411 V	367 V
			2000	944 V	2676 V	
		70kg	20	511 V	556 V	405 V
			2000	1280 V	3622 V	

After the installation of the cable termination station the expected fault rate of the entire transmission line is still expected to be low and the allowable voltage limits in EG-1 could be considered very conservative for this scenario.

ENA EG-0 is a standard which introduces a direct probabilistic development of earthing system safety criteria. EG-0 was released in August 2010.

Direct probabilistic earthing system safety criteria are derived by assessing the probability of the coincidence (of a subject becoming placed in a reasonable foreseeable contact scenario during a fault) and the probability of fibrillation (the voltage hazard leading to ventricular fibrillation). The resultant increased probability of fatality is compared to the commonly used criteria for risk. In the case of EG-0 a risk below 1×10^{-6} is referred to as negligible risk. A determined risk in the negligible range does not negate the need to undertake reasonably practicable risk reduction measures (where assessments of reasonably practicable may include cost effectiveness and how common the practice is).

Considered as part of the probabilistic assessment are a number of variables, namely:

- soil resistivity
- footwear
- fault clearing time
- fault frequency
- contact frequency
- contact duration

Released with ENA EG0 was a software tool named **Argon** which assists with direct probabilistic risk assessment. A screen shot of the application is shown below.

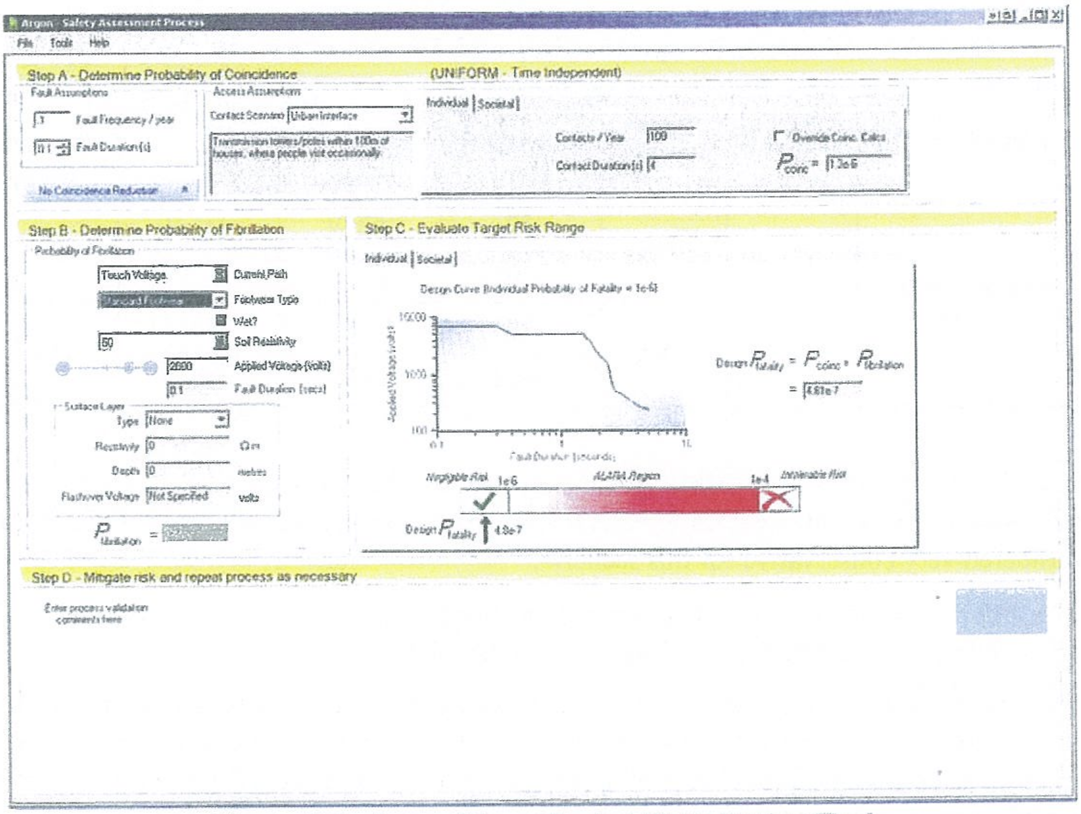

Figure 3-3: Argon Direct Probabilistic Design Tool

4. EARTHING SYSTEM DESIGN

4.1 Earth Grid Design

An earthing system will be installed at the base of each transition point consisting primarily of buried copper conductors. Drawings indicate the available area for an earthing system at the base of the Jacksons Road transition point is approximately 60m x 64m and the base of the Monash freeway transition point is approximately 82m x 51m. Some preliminary drawings show the full available area is intended to be used to construct an earth grid.

Modelling has been performed using Safearth propriety software AVC, to estimate the grid resistance of both areas using approximately eight metre mesh spacing and including eight by 10m electrodes placed around the edge of the earth grid. The calculations have been performed with the grid buried 500mm below the surface and installed in the soil resistivity model defined in section 3.3.

Table 4-1: Grid Resistance calculated with AVC

Location	Area	Calculated Grid Resistance
Jacksons Road Transition Point	60 x 64m^2 with 8 electrodes	0.55Ω
Monash Freeway Transition Point	82 x 51m^2 with 8 electrodes	0.41Ω

4.2 Tower Footing Resistance

Modelling has been performed using Safearth propriety software AVC, to estimate the footing resistances of towers in the overhead sections of the transmission line. The towers were modelled as four 5m electrodes in the soil model defined in section 3.3.

Table 4-2: Tower Footing Resistance

Tower	Modelled Footing Resistance
Towers in overhead section of line	2.7Ω

Whilst onsite at Waverley Park performing Soil Resistivity testing, Safearth carried out resistance testing of tower 12 which also indicated a footing resistance of approximately 2.7Ω.

4.3 Cable Section and Transition points

Drawings indicate that 18 cable sections approximately 700m long will be installed in a trench between the two transition points. The cable sections are shown as being laid side by side 1.5m below the surface in six groups of three. Within each group, the cables are 250mm apart, and the distance between each of the groups varies between 1.5 and 1.8m.

Also located in the trench, drawings indicate six covered earth continuity conductors (ECCs) are to be installed. Each ECC runs with a group of three phase conductors. It has been assumed the ECC is laid in the trench such that it is located 100mm away from each group of three cables.

Phasing is shown on the drawings with each group of three conductors phased the same and in the phasing order Blue, White, Red.

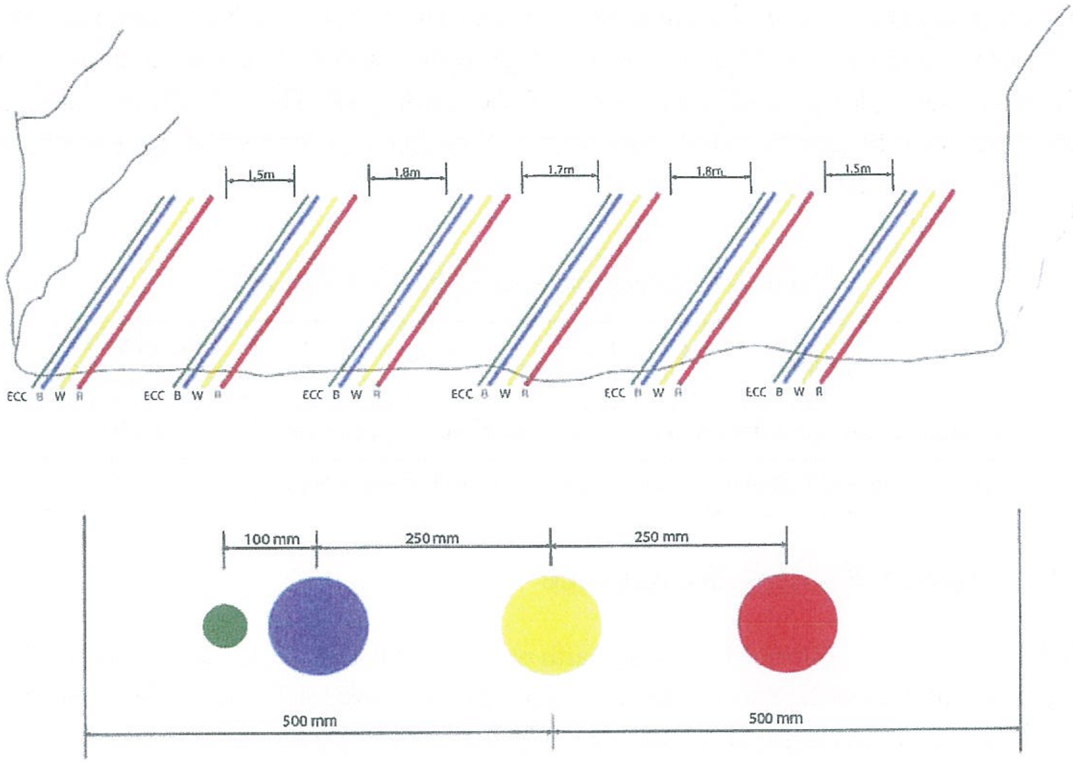

Figure 4-1: Model of cable section with 18 phase conductors and 6 ECCs

We consider the worst case through fault conditions will exist when the bottom phase on the overhead section continues as the closest phase to the ECC in the underground section.

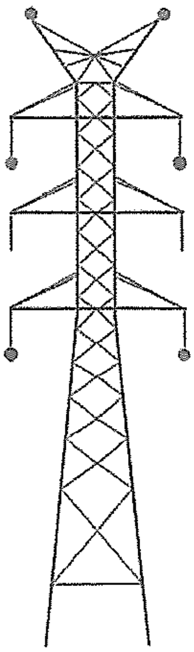

Figure 4-2: Model of overhead section showing configuration of faulted circuit

We have analysed two fault scenarios which could cause an EPR at the transition points. A through fault is represented by a fault at Springvale TS supplied from Rowville TS. A local fault is considered to be a fault at a transition point, with current supplied from Rowville TS and Springvale TS.

4.3.1 Through Fault Analysis

For a through fault on either circuit of the 220kV line the change in coupling factor between the underground cable section and the overhead feeder section will cause current to flow into the earthing systems installed at each transition point. For this fault, protection information shows the fault level at the transition points is 22kA and is supplied from Rowville.

Modelling has been carried out for one circuit only using Transmission Design Studio to assess the expected EPR at the transition points during a through fault.

Table 4-3: EPR at Transition Points during a through Fault

Fault Scenario	Jacksons Road TP EPR	Monash Freeway TP EPR
Through Fault A phase	**1450 V**	1320 V
Through Fault B phase	1320 V	1190 V
Through Fault C phase	1230 V	1110 V

! The highest EPR expected at the Transition Points during a through fault is 1450V.

✓ The expected EPR at the Transition Points during a through fault is below the ENA C(b)1 allowable touch voltage of 8000V.

By way of comparison, the EPR at existing towers on the line in the approximate locations of the proposed transition points have been calculated and are shown in the table below.

Table 4-4: EPR at existing Towers during a through Fault

Fault Scenario	Location	EPR
Through Fault A phase Tower 9	Tower 9	160 V
Through Fault A phase Tower 10	Tower 10	112 V
Through Fault A phase Jacksons Road	Jacksons Road Transition Point	1450 V
Through Fault A phase Monash Fway	Monash Freeway Transition Point	1320 V
Through Fault A phase Tower 12	Tower 12	21 V
Through Fault A phase Tower 13	Tower 13	22 V

! During a through fault, the EPR at the proposed transition points would be higher than the EPR at existing nearby 220kV towers already located in the vicinity.

4.3.2 Local Fault Analysis

During a local fault current will return to the source via the earthing system installed at the transition point as well as conductively and inductively via the overhead earth wires connected to each tower structure. For this fault, protection information shows the fault level at the transition points is 30kA with 20kA supplied from Rowville TS and 10kA supplied from Springvale TS.

Modelling has been carried out using Transmission Design Studio to assess the expected EPR at the transition points during a local fault at both the Jacksons Road Transition point, and the Monash Freeway Transition point.

Table 4-5 shows the expected EPR for a local fault.

Table 4-5: EPR at Transition Points during a Local Fault

Fault	Local Fault at Jacksons Road TP		Local Fault at Monash Freeway TP	
	Jacksons Road TP EPR	Monash Freeway TP EPR	Jacksons Road TP EPR	Monash Freeway TP EPR
Local Fault A phase	1850 V	1750 V	**2950 V**	2250 V
Local Fault B phase	2100 V	1800 V	2850 V	2300 V
Local Fault C phase	1900 V	1650 V	2650 V	2200 V

! The highest EPR occurs during a local fault at the Monash Freeway transition point and is expected to be 2950V.

✔ The expected EPR at the Transition Points during a local fault is below the ENA C(b)1 allowable touch voltage of 8000V.

By way of comparison, the EPR at existing towers in the vicinity of the proposed Transition Points have also been calculated for a local fault at the tower. The calculated EPRs are shown in the table below.

Table 4-6: EPR at existing Towers during a local fault at the tower

Fault Scenario	Location	EPR
Local Fault A phase Tower 9	Tower 9	6790 V
Local Fault A phase Tower 10	Tower 10	6780 V
Local Fault A phase Jacksons Road	Jacksons Road Transition Point	1850 V
Local Fault A phase Monash Fway	Monash Freeway Transition Point	2250 V
Local Fault A phase Tower 12	Tower 12	6750 V
Local Fault A phase Tower 13	Tower 13	6740 V

✔ During a local fault to a tower, the expected EPR at the Transition Points is below the expected EPR of presently installed towers.

4.4 Transition Point Touch Voltage Analysis

A CWM security fence is proposed to be installed two metres outside the earth grid for both transition points. The fence is proposed to be separately earthed with two metre electrodes at a maximum spacing of 15 metres.

Outside of the CWM security fence a sound wall is proposed for the Monash Freeway transition point and a three metre high screening fence proposed at the Jacksons Road site. The screening fence at Jacksons Road is shown on drawings as bonded to the CWM fence.

The highest EPR at the transition points occurs during a local fault at the Monash Freeway transition point, and this fault scenario will be used for the following analysis.

4.4.1 Jacksons Road Touch Voltages

Using an EPR of 2950V (occurs during a local fault at the Monash Freeway transition point) and the soil model defined in section 3.3 touch voltages to the separately earth CWM fence at the Jacksons Road Transition point have been modelled using Safearth propriety software AVC.

Table 4-7: Touch Voltages to Fence at Jacksons Road Transition Point

Location	Touch Voltage to Fence	EG-1 50kg Allowable	Percentage of Allowable
Middle of shorter side	81V	378V	22%
Middle of longer side	78V	378V	21%
Corner	43V	378V	12%

✔ The highest touch voltages to the fence at Jacksons Road Transition Point were found to be 22% of the 50kg EG-1 allowable.

Inside the fenced area at the Jacksons Road Transition point, touch voltages to earthed objects such as conductive poles have been modelled using Safearth proprirty software AVC.

Table 4-8: Touch Voltages inside Jacksons Road Transition Point

Location	Touch Voltage to Conductive object	EG-1 70kg Allowable with Crushed Rock	Percentage of Allowable
Middle of largest grid spacing	152V	1280V	12%

✔ Touch voltages inside the fenced Jacksons Road Transition Point are expected to be 12% of the EG-1 70kg allowable with 100mm of crushed rock installed.

✔ It is worth noting that touch voltages inside the fenced Jacksons Road Transition Point are also below the EG-1 50kg allowable of 378V.

4.4.2 Monash Freeway Touch Voltages

Using an EPR of 2300V (which occurs during a local fault at the Monash Freeway transition point) and the soil model defined in section 3.3 touch voltages to the separately earth CWM fence at the Monash Freeway transition point have been modelled using Safearth propriety software AVC.

Table 4-9: Touch Voltages to Fence at Monash Freeway Transition Point

Location	Touch Voltage to Fence	EG-1 50kg Allowable	Percentage of Allowable
Middle of shorter side	59V	378V	16%
Middle of longer side	37V	378V	10%
Corner	50V	378V	13%

✔ The highest touch voltages to the fence at the Monash Freeway Transition Point were found to be 16% of the 50kg EG-1 allowable.

Inside the fenced area at the Monash Freeway Transition point, touch voltages to earthed objects such as conductive poles have been modelled using Safearth propriety software AVC.

Table 4-10: Touch Voltages inside Monash Freeway Transition Point

Location	Touch Voltage to Conductive object	EG-1 70kg Allowable with Crushed Rock	Percentage of Allowable
Middle of largest grid spacing	94V	1280V	7%

✔ Touch voltages inside the fenced Monash Freeway Transition Point are expected to be 7% of the EG-1 70kg allowable with 100mm of crushed rock installed.

✔ It is worth noting that touch voltages inside the fenced Monash Freeway Transition Point are also below the EG-1 50kg allowable of 378V.

4.5 Transition Point Voltage Transfer

As discussed in section 3.3 from analysis of the soil resistivity results we can conclude the area can generally be described as a two layer model, with a low upper layer on a higher lower layer. It is expected that the voltage contours around the transition points will be reasonably shallow, and the EPR will transfer some distance away.

4.5.1 Jacksons Road Voltage Transfer

Using an EPR of 2950V (occurs during a local fault at the Monash Freeway transition point) and the soil model defined in section 3.3 voltage contours around the Jacksons Road Transition point have been modelled using Safearth propriety software AVC.

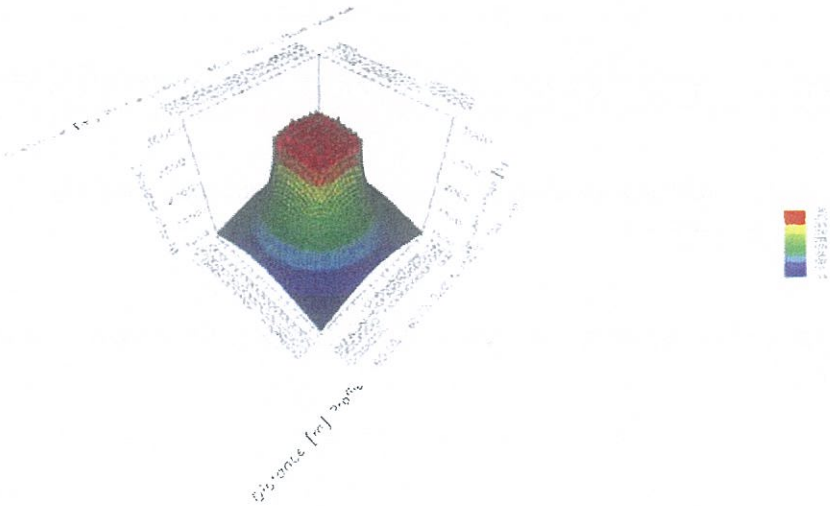

Figure 4-3: Soil Voltage Profile – Jacksons Road Transition Point

! The 1000V contour extends away from the Jacksons Road Transition Point approximately 74m.

! At 50m away (expected location of nearby houses) the expected voltage transfer is 1270V.

4.5.2 Monash Freeway Voltage Transfer

Using an EPR of 2300V (occurs during a local fault at the Monash Freeway transition point) and the soil model defined in section 3.3 voltage contours around the Jacksons Road Transition point have been modelled using Safearth propriety software AVC.

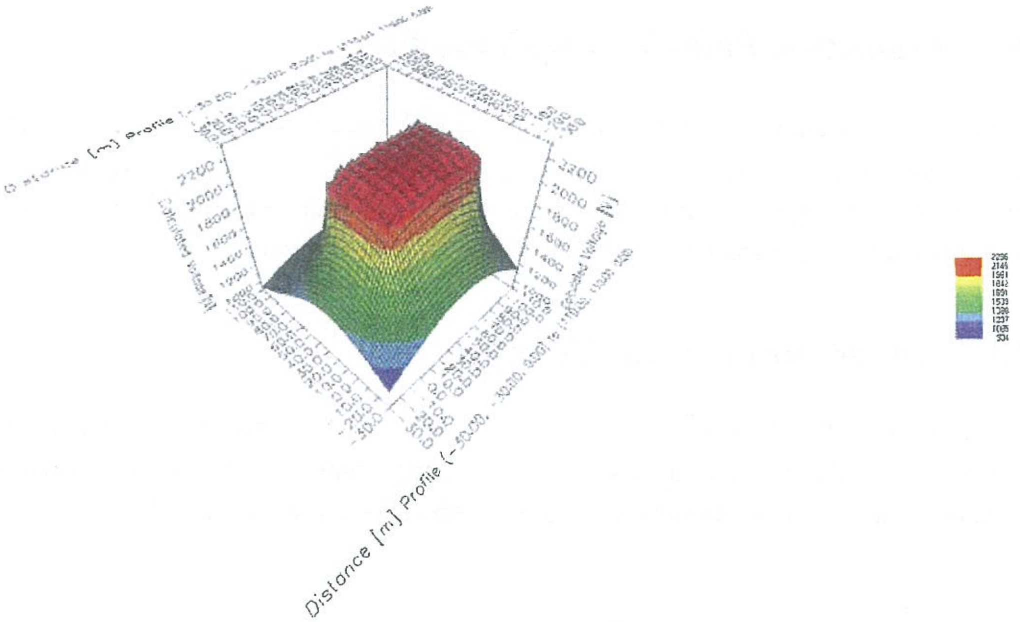

Figure 4-4: Soil Voltage Profile – Monash Freeway Transition Point

- The 1000V contour extends away from the Monash Freeway Transition Point approximately 65m.

- At 50m away (expected location of nearby houses) the expected voltage transfer is 1150V.

4.6 Probabilistic Safety Criteria

Analysis of the through fault and the local earth fault has been carried out for the proposed transition points at Waverley Park. While the EPR at the transition points for a local fault is above 2000 V, it is expected that touch voltages inside and outside of the yard will be below the EG-1 touch voltage allowable of 378V.

The low on high soil model at Waverley Park transfers the EPR a considerable distance and for the Jacksons Road Transition point the 1000V contour extends to 80 m. While a local fault at a transition point generates a lower EPR than a local fault on a nearly 220kV overhead transmission line tower, the size of the earthing system at the transition points distributes the EPR further than the smaller earthing system installed at the base of each tower.

While touch voltages in and around the transition points are below the EG-1 touch voltage allowable, it could be expected there is a small chance that touch voltages some distance away will not comply with the 50kg safety criteria.

We believe the existing transmission line would have been designed to comply with the criteria in ENA C(b)1 where the touch voltage allowable is 8000V. With the addition of two transition points is could be argued that the most appropriate safety criteria to apply be drawn from ENA EG-1 'Substation Earthing Guide'.

The safety criteria in ENA EG-1 are very conservative for a transmission line installation and even with the addition of the two Transition Points the fault rate on the line is still expected to be very low. We would argue safety criteria in ENA EG-1 are overly conservative for this site.

ENA EG-0 is a standard which introduces a direct probabilistic development of earthing system safety criteria. EG-0 was released in August 2010.

Direct probabilistic earthing system safety criteria are derived by assessing the probability of the coincidence (of a subject becoming placed in a reasonable foreseeable contact scenario during a fault) and the probability of fibrillation (the voltage hazard leading to ventricular fibrillation). The resultant increased probability of fatality is compared to the commonly used criteria for risk. In the case of EG-0 a risk below 1×10^{-6} is referred to as negligible. A determined risk in the negligible range does not negate the need to undertake reasonably practicable risk reduction measures (where assessments of reasonably practicable may include cost effectiveness and how common the practice is).

To allow a direct probabilistic assessment of the voltage hazard levels a number of key inputs need to be determined or estimated. The input data for this assessment is as follows:

- 220kV fault rate data of 1 fault/100km/year.
- For a through fault there is 3km of dual line (total 6km of line) from the transition points to Springvale TS. Another 10km of collection area for other feeders at Springvale TS at the present fault level has been included which we consider is

conservative. A total of 16km has been considered. The fault rate used for this assessment is 0.16 faults per year.

- For a local fault, any fault within 3 spans or 750m of dual circuit line can be considered a local fault. The fault rate used for this assessment is 0.015 faults per year.
- Fault cleared in 0.1 seconds
- Soil Resistivity of 50Ωm
- Contact scenario models contacts to the MEN – 2000 contacts per year
- Contacts of 4 seconds duration each

Table 4-11: Calculated Increased Risk of a fatality for through faults

Location	EPR	1000V contour	Transfer 50m	Fault Frequency per year	Calculated Increased Risk
Tower 10	112V	n/a	13 V	0.16	0
Jacksons Road TP	1450V	17 m	639 V	0.16	1.9×10^{-6}
Monash Freeway TP	1320V	15 m	657 V	0.16	2.2×10^{-6}

Table 4-12: Calculated Increased Risk of a fatality for local faults

Location	EPR	1000V contour	Transfer 50m	Fault Frequency per year	Calculated Increased Risk
Tower 10	6775V	39 m	838 V	0.015	4.2×10^{-7}
Jacksons Road TP	2950V	74 m	1272 V	0.015	1.0×10^{-6}
Monash Freeway TP	2300V	65 m	1145 V	0.015	8.4×10^{-7}

! For a through fault on the feeder, the increased risk for Jacksons Park Transition Point is greater than 1×10^{-6} and within the ALARA Region. Further mitigation of the risk should be considered.

! For a through fault on the feeder, the increased risk for Monash Freeway Transition Point is greater than 1×10^{-6} and within the ALARA Region. Further mitigation of the risk should be considered.

✔ For a local fault at either the Jacksons Park or Monash Freeway Transition Point, the increased risk is less than 1×10^{-6} and considered to be in the negligible risk region.

4.7 Earthing System Design Summary

Table 4-13: Earthing System Design Summary

	Jacksons Road Transition Point	Monash Freeway Transition Point
Grid Resistance	0.55 Ω	0.41 Ω
Highest EPR during a through Fault	1450 V	1320 V
Highest EPR during a local fault	2950 V	2300 V
Highest Touch Voltage to the fence	81 V	59 V
Highest mesh voltage inside fence	152 V	94 V
EG-1 50kg touch voltage allowable	378 V	378 V
ENA C(b)1 touch voltage allowable	8000 V	8000 V
1000V contour distance (local fault)	74 m	65 m
Transfer 50m away (local fault)	1272 V	1145 V
Increase in Risk for Through Fault	1.9×10^{-6}	2.2×10^{-6}
Increase in Risk for Local Fault	1×10^{-6}	8.4×10^{-7}

5. REMEDIATION

Safearth have considered a smaller Transition Point earth grid footprint to reduce the EPR transferred to nearby houses during a fault. Safearth have modelled a 33m x 24m grid with one x 10m electrodes at each corner. It is expected a 33m x 24m grid will encompass the proposed installation of the transition point poles and practically would be the smallest earth grid that could be installed.

Modelling has been performed to estimate the grid resistance with the grid buried 500mm below the surface and installed in the soil resistivity model defined in section 3.3.

Table 5-1: Grid Resistance calculated with AVC

Location	Area	Calculated Grid Resistance
Waverley Park Transition Points With smaller earth grid	33 x 24m^2 with 4 electrodes	1Ω

5.1 Fault Analysis – Jacksons Road Transition Point

Using 1Ω for the earth grid resistance for Jacksons Road Transition Point the two fault scenarios were modelled using Transmission Design Studio to assess the expected EPR.

5.1.1 Through Fault

The highest EPR at Jacksons Road TP during a through fault is expected to be 1550V. Using an EPR of 1550V and the soil model defined in section 3.3 voltage contours around the Transition Point have been modelled using AVC.

The 1000V contour is expected to be 8m and the voltage transferred 50m away is expected to be 444V.

Table 5-2: Calculated Increased Risk of a fatality for through faults

Location	EPR	1000V contour	Transfer 50m	Fault Frequency per year	Calculated Increased Risk
Tower 10	112V	n/a	13 V	0.16	0
Jacksons Park TP (60m x 64m grid)	1450V	16 m	639 V	0.16	1.9×10^{-6}
Jacksons Park TP (33m x 24m grid)	1550V	8 m	444 V	0.16	1.8×10^{-7}

5.1.2 Local Fault

The highest EPR at Jacksons Road TP is expected to be 3950V. Using an EPR of 3950V and the soil model defined in section 3.3 voltage contours around the Transition Point have been modelled using AVC.

The 1000V contour is expected to be 60m and the voltage transferred 50m away is expected to be 1132V.

Table 5-3: Calculated Increased Risk of a fatality for local faults

Location	EPR	1000V contour	Transfer 50m	Fault Frequency per year	Calculated Increased Risk
Tower 10	6775V	39 m	838 V	0.015	4.2×10^{-7}
Jacksons Park TP (60m x 64m grid)	2950V	74 m	1272 V	0.015	1.0×10^{-6}
Jacksons Park TP (33m x 24m grid)	3950V	60 m	1132 V	0.015	8.1×10^{-7}

5.2 Fault Analysis – Monash Freeway Transition Point

Using 1Ω for the earth grid resistance for Monash Freeway Transition Point the two fault scenarios were modelled using Transmission Design Studio to assess the expected EPR.

5.2.1 Through Fault

The highest EPR at Monash Freeway during a through fault is expected to be 1350V at Jacksons Road Transition Point. Using an EPR of 1350V and the soil model defined in section 3.3 voltage contours around the Transition Point have been modelled using AVC.

The 1000V contour is expected to be 5m and the voltage transferred 50m away is expected to be 461V.

Table 5-4: Calculated Increased Risk of a fatality for through faults

Location	EPR	1000V contour	Transfer 50m	Fault Frequency per year	Calculated Increased Risk
Tower 10	112V	n/a	13 V	0.16	0
Monash Freeway TP (82m x 51m grid)	1320V	15 m	657 V	0.16	2.2×10^{-6}
Monash Freeway TP (33m x 24m grid)	1350V	5 m	461 V	0.16	2.2×10^{-7}

5.2.2 Local Fault

The highest EPR at Monash Freeway TP is expected to be 3390V. Using an EPR of 3390V and the soil model defined in section 3.3 voltage contours around the Transition Point have been modelled using AVC.

The 1000V contour is expected to be 64m and the voltage transferred 50m away is expected to be 1157V.

Table 5-5: Calculated Increased Risk of a fatality for local faults

Location	EPR	1000V contour	Transfer 50m	Fault Frequency per year	Calculated Increased Risk
Tower 10	6775V	39 m	838 V	0.015	4.2×10^{-7}
Monash Freeway TP (82m x 51m grid)	2950V	74 m	1272 V	0.015	1.0×10^{-6}
Monash Freeway TP (33m x 24m grid)	3390V	64 m	1157 V	0.015	8.6×10^{-7}

✔ Reducing the area of the earth grid raises the EPR of the transition point but lowers the transferred voltage to the nearby houses and MEN.

✔ Using a smaller earth grid at Jacksons Park Transition Point reduces the Calculated Increased Risk for a through fault from 1.9×10^{-6} in the ALARA region to 1.8×10^{-7} in the negligible risk region and should be considered.

✔ Using a smaller earth grid at Monash Freeway Transition Point reduces the Calculated Increased Risk for a through fault from 2.2×10^{-6} in the ALARA region to 2.2×10^{-7} and should be considered.

6. CONCLUSION AND RECOMMENDATIONS

Analysis of the through fault and the local earth fault has been carried out for the proposed transition points at Waverley Park. Earth fault modelling has been carried out using the proposed earth grid size for each transition point as detailed in drawings supplied by SP AusNet. Existing overhead circuit configuration and the proposed underground cable arrangements have also been modelled using information supplied by SP AusNet.

Touch voltages at the proposed transition points are expected to be below the allowable ENA C(b)1 safety criteria. If SP AusNet are comfortable with applying ENA C(b)1 throughout this installation, then analysis suggests it can be built as per the drawings supplied.

Touch voltages to the separately earthed fence, and to equipment located within the transition points are expected to be below the allowable ENA EG-1 safety criteria. However we believe that touch voltages in the nearby MEN area may be present during a fault that do not satisfy the criteria of ENA EG-1, but would be below the allowable ENA C(b)1 criteria. If SP AusNet is comfortable with this, then analysis suggests the transition points can be built as per the drawings supplied.

The use of ENA EG-0 and probabilistic earthing system safety criteria analysis shows that if the transition points are constructed as proposed in the supplied drawings, the increased risk to a person will be in the ALARA region for contacts to the MEN and further mitigation is required.

A physically smaller earth grid around the transition point results in a higher EPR at the transition point, but less voltage transfer away from the transition point and to the nearby MEN. The use of a 33m x 24m earth grid reduces the calculated increased risk to a person to 1.8×10^{-7} for Jacksons Road TP and to 2.2×10^{-7} for Monash Freeway TP for contacts to the MEN. These values are considered to be in the negligible risk region.

Further mitigation can be achieved by lowering the tower impedances for two towers either side of the proposed transition points. Towers 9, 10, 13 and 14 could have their grid resistance lowered from 2.7Ω to 1.5Ω and it would be expected the EPR at the transition points would reduce by approximately 10%. The addition of four x 10 metre electrodes placed 5m diagonally away from the tower corners and connected by bare copper strap would achieve 1.5Ω.

If the EPR be reduced by 10%, voltage transfer to the MEN would also reduce. It is expected that the calculated increased risk would reduce to 1.0×10^{-7} for Jacksons Road TP and to 1.3×10^{-7} for Monash Freeway TP for contacts to the MEN. These values are considered to be in the negligible risk region.

In Summary,

☞ ***The proposed installation is expected to comply fully with ENA C(b)1. If SP AusNet are comfortable to apply ENA C(b)1 to the entire transition stations and the surrounding residential areas then the transition points could be built as proposed.***

✔ Touch voltages inside and to the fence directly outside of the transition points are expected to be below the ENA EG-1 50kg touch voltage allowable.

☞ ***We believe that touch voltages in the nearby MEN area may be present during a fault that do not satisfy the criteria of ENA EG-1, but would be below the allowable ENA C(b)1 criteria.***

☞ ***Probabilistic safety criteria analysis shows that if the transition points are constructed as proposed, the calculated increased risk to a person contacting the nearby MEN during a through fault on the line will be in the ALARA region and further mitigation is required.***

✔ A physically smaller earth grid around the transition point results in less voltage transfer to the nearby MEN. The use of a 33m x 24m earth grid lowers the calculated increased risk to 1.8×10^{-7} for Jacksons Road TP and to 2.2×10^{-7} for Monash Freeway TP for contacts to the MEN. These values are considered to be in the negligible risk region.

☞ ***Further mitigation can be achieved by lowering the tower impedances for two towers either side of the proposed transition points. Towers 9, 10, 13 and 14 could have their grid resistance lowered from 2.7Ω to 1.5Ω, and it would be expected the EPR at the transition points would reduce by approximately 10%.***

☞ ***The addition of four x 10 metre electrodes placed 5m diagonally away from the tower corners and connected by bare copper would achieve a tower impedance of 1.5Ω.***

✔ If the EPR was reduced by 10%, voltage transfer to the MEN would also reduce. It is expected that the calculated increased risk would reduce to 1.0×10^{-7} for Jacksons Road TP and to 1.3×10^{-7} for Monash Freeway TP for contacts to the MEN. These values are considered to be in the negligible risk region.

7. BIBLIOGRAPHY

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