BEFORE THE BOARD OF INQUIRY

IN THE MATTER of the Resource Management Act 1991

AND

IN THE MATTER of applications for resource consent and notices of requirement by Transpower New Zealand Limited for the North Island Grid Upgrade Project

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STATEMENT OF EVIDENCE OF ANTHONY CYRUS MITTON FOR TRANSPOWER NEW ZEALAND LIMITED

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INTRODUCTION

1. **MY** name is Anthony Cyrus Mitton. I am the General Manager of Mitton Electronet Ltd (**MEL**). My role as General Manager is to manage the company which provides design and investigation services, provide assistance to project staff, monitor health and safety and provide quality assurance support. I hold the following qualifications:

   (a) Bachelor of Engineering (Electrical), Canterbury; and

   (b) I am a member of the Institution of Electrical Engineers and Technicians (London).

2. I have worked in the power industry and trained and worked with the Electricity Corporation of New Zealand Limited and its successors since 1979. I have also worked for three years for a consulting company in the United Kingdom and South America.

3. **MEL** was formed in April 2007 as a result of a merger between Mitton Consulting Ltd and the design office of Electronet Services Ltd. Mitton Consulting Ltd was established in 1990 to provide consulting electrical engineering and project management services to the electric power industry. Electronet Services Ltd is the distribution network service provider for Westpower Ltd, based in Greymouth.

4. **MEL** provides consulting services relating to high voltage substations and powerstations, including feasibility studies, conceptual and detailed design and site construction management, control and protection systems, lightning protection and earthing systems. One of the company's specialist activities relates to power system earthing and electromagnetic fields (EMF), its modelling, and associated site investigations for substations, power stations and transmission lines.

5. **MY** staff have extensive experience in applying the CDEGS™ suite of modelling tools to analyse earthing systems and EMF and have carried out associated field testing to confirm the accuracy of the modelling. CDEGS™ software is world renowned in the high voltage power industry and is used by over 500 utilities and consultancies throughout the world. I have developed

practical and reliable test procedures and equipment to carry out on site testing of earthing systems. I have also assisted the Electricity Engineers' Association in preparing a risk based guide to earthing design.

6. I have tested the earthing systems of almost all of the power stations in New Zealand, as well as many substations in New Zealand and Australia. I have also investigated earthing related incidents and accidents for the power industry.

7. **SOME** typical relevant earthing projects that I have worked on include:

   (a) the design and testing of earthing systems of transmission towers, power stations and substations, in order to determine the adequacy of the earthing in relation to earth potential rise (**EPR**) hazards;

   (b) the measurement and computer modelling of the earthing of transmission towers in order to determine appropriate modifications necessary to ensure proper lightning protection of the transmission line;

   (c) modelling of fences, telecommunications cables, gas and fuel pipelines located near power lines to determine the levels of induced voltage in these items; and

   (d) modelling and measurement of EMF levels under transmission lines and around HV substations.

8. I confirm that I have read and agree to comply with Code of Conduct for expert witnesses in the Environment Court Consolidated Practice Note (2006). I have approached the preparation of this evidence in the same way I would for the Environment Court.

SCOPE OF EVIDENCE

9. **MY** evidence (section 1) will address the following matters concerning EPR (which includes touch and step voltages):

(a) EPR arising from a tower earth fault and the extent and nature of any risk from EPR on the proposed 400 kV capable Whakamaru to Brown Hill (WKM – BHL) transmission line initially operating at 220 kV;

(b) EPR arising from an earth fault and the extent and nature of any risk from EPR around the joint bays along the two 220 kV underground cable routes Brownhill to Pakuranga (BHL – PAK) and Brownhill to Otahuhu (BHL – OTA); and

(c) EPR arising from an earth fault and the extent and nature of any risk from EPR around the substation boundaries Whakamaru (WKM), Whakamaru North (WHN), Brownhill (BHL), Otahuhu (OTA) and Pakuranga (PAK);

10. **MY** evidence (section 2) will also address the following matters concerning coupled and induced voltages from EMF which I have separated into electric fields and magnetic fields (EF and MF):

(a) EF coupled and MF induced voltages and the nature and extent of any hazard that may appear on infrastructure along the 400kV capable transmission line; and

(b) EF coupled and MF induced voltages and the nature and extent of any hazard that may appear on infrastructure near the 220 kV underground cable routes.

11. **MY** evidence (section 3) will further address the following matters concerning EF and MF levels (I will not describe any physiological aspects of EF and MF on humans):

(a) acceptable EF and MF levels for public exposure;

(b) the calculated level of EF around the underground cables and substations; and

(c) the calculated level of MF around the underground cables and substations.

SOURCES OF INFORMATION

12. I have relied on the following sources of information in preparing my evidence:

(a) AS/NZS 60479:2002 Parts 1, General Aspects and Part 3, Effects of current on Human Beings and Livestock;

(b) AS/NZS 4853:2000, Electrical Hazards on Metallic Pipelines;

(c) BS EN 50341-1:2001, Overhead Electrical Lines Exceeding AC 45 kV;

(d) NZECP34:2001 New Zealand Electrical Code of Practice for Electrical Safe Distances;

(e) AS/NZS 4360:2004 Risk Management and HB436:2004 Risk Management Guidelines - Companion to AS/NZS 4360:2004;

(f) Electricity Engineers' Association NZ (EEANZ) Guide to Risked Based Earthing System Design;

(g) TP.DS 52.01 2005 Design of Substation Earthing;

(h) International Telecommunication Union, ITU-T K.53. Values of induced voltages on telecommunication installations to establish telecom and a.c. power and railway operators responsibilities; and

(i) ICNIRP Guidelines for Limiting Exposure to Time-Varying Electric, Magnetic, and Electromagnetic Fields (up to 300 GHz). Health Physics 74 (4): 494-522; 1998.

GLOSSARY OF TERMS

13. **THE** following terms and associated abbreviations are referred to within this evidence:

(a) Cable screen: A metallic shield under the outer jacket of a 220 kV cable providing a path for fault currents ensuring that there is no electric field outside the cable;

(b) CDEGS™: Current Distribution, Electromagnetic Fields, Grounding and Soil Structure Analysis;

(c) Earth fault: the connection or flashover of one or more conductors to earth;

(d) Earth potential rise (EPR): the voltage (or potential) found on the earth measured with respect to remote earth. EPR arises due to fault current flowing through the earth back to the power source;

(e) Electric field (EF): a force that exists in space between two objects of different voltages. It is measured in volts per metre (V/m);

(f) Hazardous Voltage: a voltage that may result in electric shock which in turn may result in harm to a human or animal or damage to electrical equipment;

(g) Impedance: a measure of the opposition to current flow;

(h) Insulation: materials that prevent or restrict the flow of current;

(i) Joint bay: Location where buried cables are joined together;

(j) Magnetic field: the force experience in a region of space around a current carrying conductor. It is measured in amperes per metre (A/m). The density of this field is often expressed in the unit Tesla (T);

(k) Overhead Earth Wire (OHEW): conductor which is installed between towers to provide lightning shielding for the transmission line;

(l) Phase: an AC power system has three phases, each phase is carried by one conductor set or cable;

(m) Resistance: a material's opposition to the flow of electric current:

(n) Resistivity: a measurement of resistance of a material per unit length;

(o) Soil resistivity: measure of soil's opposition to current flow;

(p) Steady state: refers to the normal ac operation of the line;

(q) Step voltage: voltage difference experienced between a person's feet, where feet are 1 m apart;

(r) Touch Voltage: voltage difference experienced between a person's hand and foot, where the foot is 1 m horizontal distance from the object being touched;

(s) Tower footing resistance (TFR): the resistance of a tower's foundation. This value is dependent on soil resistivity and tower foundation type;

(t) Transferred voltage: potential rise of an *earthing system* caused by a current to *earth* transferred by means of a connected *conductor* (for example, cable metal sheath, pipeline, rail) into areas with low or no potential rise to reference earth;

(u) Transmission towers: structures which support transmission lines and OHEWs;

(v) Units used:

  (i) A: ampere, unit of current;

  (ii) Ω: ohm, unit of resistance;

  (iii) Ω-m: ohm metre, unit of soil resistivity;

  (iv) V: volt, unit of voltage;

  (v) VA: volt-ampere, unit of power and

(vi) V/m: volt per metre, unit of electric field

(vii) T: tesla, unit of magnetic flux density.

Note: the seven symbols just mentioned above, also often use the prefixes μ, m, k and M to denote, micro (10^{-6}), milli ($x10^{-3}$), kilo ($x10^{3}$) and mega ($x10^{6}$) respectively.

SECTION 1: EPR, TOUCH AND STEP VOLTAGES

14. I will cover the issue of EPR, touch and step voltages and transferred voltage hazards, in this section of my evidence.

EPR, TOUCH AND STEP VOLTAGES AND TRANSFERRED VOLTAGES AROUND TRANSMISSION TOWERS

15. I turn firstly to EPR, step and touch voltages and transferred voltages around towers.

Description of possible hazards

16. **IN** the following paragraphs, I will discuss possible hazards that may be present around transmission towers in the event that an earth fault occurs at a tower. Faults on individual towers do not occur often. Transmission lines are designed, maintained and protected to minimise the occurrence of faults. In addition, should a fault occur, the current will be interrupted to clear the fault, by the protective devices at each end of the line, in a fraction of a second.

17. **TRANSMISSION** towers pass through rural and urban areas in almost all countries around the world. It is generally considered that they are a safe, robust and efficient way of transmitting electricity. However, due to the extremely high voltages that are carried on transmission lines, there is the possibility that if a person, animal, or item of equipment, is in the "*wrong place at the wrong instant of time*", then injury or damage could occur.

18. **TO** the best of my knowledge, throughout the industry in New Zealand, no members of the public have been injured as a result of indirect electric shock during a fault at a nearby transmission tower. I am aware of a small number of cases in New Zealand where stock have been killed as a result of such incidents. This is can occur since livestock tend to linger in one place for significantly greater periods of time. In addition, damage to farm fences has also occurred where fences are located close to or touching the tower.

19. **DUE** to the low occurrence of transmission tower faults, but nevertheless possibly serious consequences, the subject is best investigated using risk analysis. This approach is in reality no different to any aspect of life where potential to cause harm exists.

20. **AS** the industry has matured and the public have become more aware of electric power and transmission lines, the issues surrounding the effects and risk of earth faults and electric shock have begun to be analysed. The transmission industry in New Zealand and world wide is still developing clear guidelines and practices with respect to risk analysis of transmission line faults. However, it is generally agreed that risk levels associated with overhead transmission lines are extremely low.

21. **IT** is important that the concept of risk is kept in mind when considering my evidence on EPR. My evidence will address the relatively straightforward technical analysis of worst case electric shock hazards and the more complicated aspect of associated risk. However, this analysis should not be taken out of context, that being that while outcomes may be serious (e.g. comparable with a car crash or being struck by lightning), the probability of electrical shock/harm happening are extremely low.

22. **IT** should be highlighted that the technical analysis which I undertake in my evidence, uses conservative, worst case assumptions, which effectively builds in added safety margins.

23. **ONE** of the main modelling tools which I have used is the CDEGS™ software package. This was developed by a team of engineers from a company called SES in Canada. It is a powerful set of integrated engineering software tools designed to accurately analyse problems involving grounding/earthing, electromagnetic fields, electromagnetic interference including ac/dc interference mitigation studies, and various aspects of cathodic protection, starting literally from the ground up. Extensive scientific validation of the

software using field tests and comparisons with analytical or published research results have been conducted for over twenty years. The validation conducted by SES and ourselves as well as other independent researchers is documented in technical papers published in many reputed international journals.

Description of EPR

24. **AN** earth fault at a tower will result in an EPR. An earth fault occurs when an energised phase conductor comes in physical contact with, or flashes over to, an earthed object. Typically this is through an insulation failure on a tower, caused by lightning, pollution, or fauna.

25. **DURING** an earth fault, there is significant current (e.g. 2 - 20 times normal) flowing in the faulted line from the power source into the fault point. This current returns to the source (e.g. the power station) through the ground. Its path is illustrated in **Figure 1**.

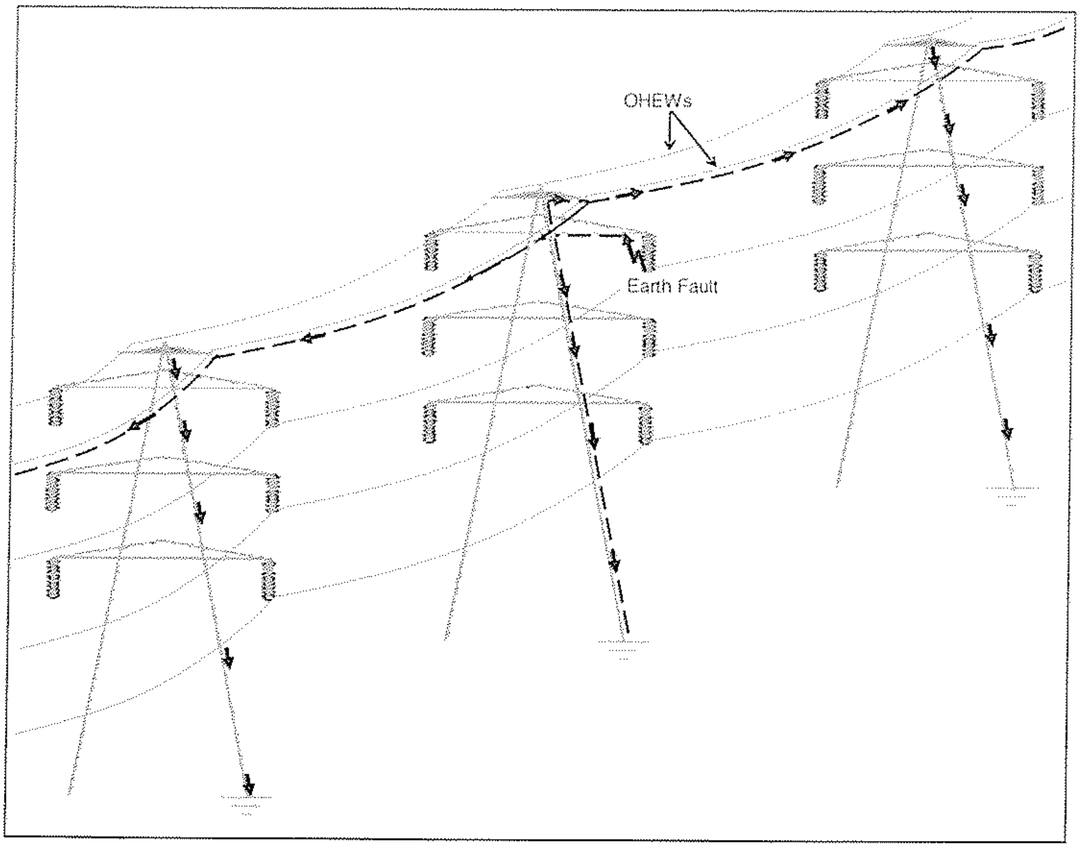

Figure 1: Fault Current Path From Phase Conductor Down OHEW and Towers

26. **EPR** occurs when current arising from an earth fault flows through the soil as it returns to the power source. The soil has some resistance and current flowing through a resistance results in a voltage appearing across the resistance (based on Ohms' Law V = I x R). As a result, the current causes voltages to appear on the soil (these voltages are measured with respect to "remote" earth or zero volt reference).

27. **THE** voltages are highest on the faulted tower and decrease as the distance from the fault location increases. A fault at a tower will cause a high voltage to appear on both the tower and the ground around the tower base. Voltage will appear on the ground at some distance from the tower and can be depicted as equi-potential contours. **Figure 2** illustrates this phenomenon.

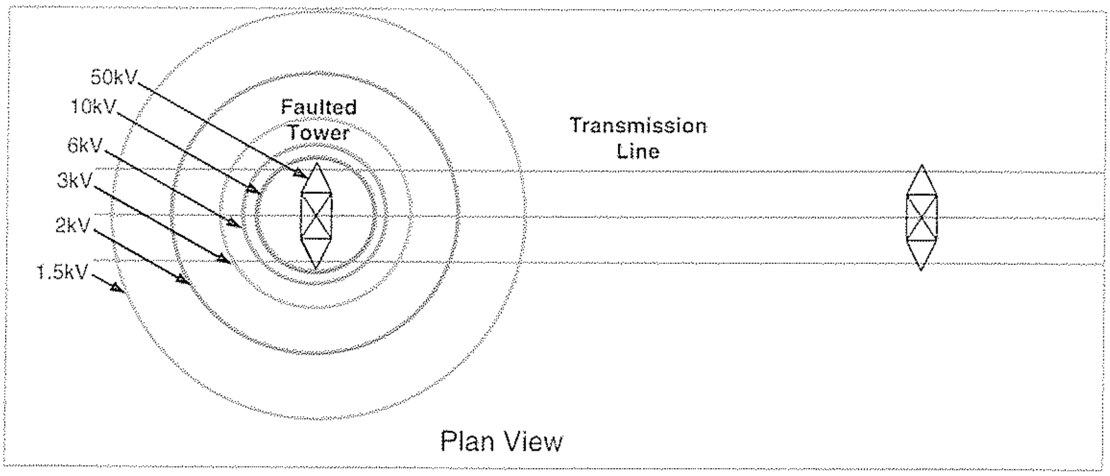

Figure 2: Earth Potential Rise

28. **THE** voltages on the ground can be measured and drawn in a similar way to altitude contours on a map. The closer the voltage contours are together, the "steeper" the voltage gradient. The voltages on the ground fall away at an exponential rate. Voltages can appear on any conductive object that bridges the voltage contours. The CDEGS™ software enables accurate modelling of this phenomenon. It must be understood that EPR and its effects are only present for a very short time during the rare event of a tower earth fault. Once the earth fault is interrupted by the protection system (also called "Fault Clearing"), no EPR is present.

Description of step and touch voltages

29. **IF** a human or animal contacts two different voltages simultaneously, a voltage difference will be applied across the body. This may cause a current to flow in the body (eg hand-to-hand, hand-to-foot, foot-to-foot). Depending on the magnitude of the current this may be felt as an electric shock.

30. **HAND-TO-HAND** or hand-to-foot voltages are known as "touch voltages". A touch voltage occurs when the surface a person is touching and the surface a person is standing on, are at different voltages.

31. **TOUCH** voltages arise directly on directly faulted equipment, such as a tower. However, touch voltage can also arise due to voltage transfer, where an energised structure, such as a stock fence, can transfer voltage onto another conductive structure. This structure may be located some distance away. The reverse can also occur, where a conductive structure may transfer a low voltage into an area of ground that has attained a high voltage as a result of a fault.

32. **FOOT-TO-FOOT** voltages are known as "step voltages". A step voltage occurs when a step (1 m) is taken and the ground surface under each foot is at different voltages. Both humans and animals may experience step voltages. Animals are more likely to experience a higher potential difference because of the larger distance between their fore and hind legs. A step voltage can only be experienced when both feet are in simultaneous contact with the ground and each foot is on a different EPR contour.

Description of Soil Resistivity

33. **SOIL** electrical resistivity influences the electrical characteristics of the tower earthing systems and the tolerable limits for touch and step voltage. Soil usually has various resistivity layers. The higher the soil resistivity, the higher the tolerable step and touch voltage.

34. **THE** soil resistivities along the transmission line can vary between just a few Ω-m to thousands of Ω-m. In my analysis, I have used a conservative soil resistivity value of 100 Ω-m.

35. **TOWER** footing resistance (TFR) depends on soil resistivity. The TFR forms part of the faulted circuit and is used to calculate the fault current through the tower footing. I have used a TFR of 10 Ω-m for all the towers. This is a typical value and is also a function of the desired level of reliability that the transmission line must achieve against lightning strikes. Mr Khot explains this in his evidence.

Step and touch voltage limits for towers

36. **THE** limits and corresponding consequences of short duration current flow through human beings and livestock are described in AS/NZS 60479.1:2002, "Effects of Current on Human Beings and Livestock". (AS/NZS 60479 is essentially identical to IEC 60479-1: 1997, which is referred to in the Electricity Regulations). The effects are principally dependent on shock current magnitude and duration. **Appendix A** contains an extract from this standard.

37. **I** have determined the touch voltage limits from BS EN 50341-1:2001 'Overhead Electrical Lines Exceeding AC 45 kV', which derives its limits from IEC 60479-1 body current limits.

38. **STEP** voltage limits are not defined in BS EN 50341-1:2001. Step voltage limits have been derived from first principles using the method in BS EN 50341-1:2001 for deriving touch voltage limits.

39. **AS** discussed in Mr Khot's evidence, the protection system will be designed to interrupt an earth fault in 0.12 seconds.

40. **USING** BS EN 50341-1, the touch and step voltage values for a fault duration of 0.12 seconds, are summarised in **Table 1**.

Table 1: Touch and Step Voltage Limits for Humans

Touch Voltage Limit (V)	Step Voltage Limit (V)
730	1,220

41. **IN** the rare event of a transmission line earth fault, the fault current will continue to flow until the line is disconnected. Mr Khot in his evidence discusses the way the protection system operates on a transmission line and in particular the performance of the protection system on the 400 kV capable line.

The Effect of Contact Resistance

42. **TOUCH** and step voltage limits are primarily affected by the foot's contact resistance with the ground, which in turn depends on the top-soil electrical resistivity. The touch and step voltage limits used in the analysis in this evidence are calculated using the conservative surface soil resistivity of 100 Ω-m.

43. **THE** limits will also increase if the contact with the surface is not direct to bare skin (i.e. with the use of gloves or footwear). As I have already stated however, a conservative approach has been adopted, which assumes a person standing on natural ground with no additional contact resistance (i.e. bare foot and bare hand).

44. **RELATED** international standards and technical papers also consider this additional series impedance in the electric shock circuit for humans. This reduces (or in some cases prevents) shock current flow which in turn permits a higher tolerable touch and step voltage. A resistance of 2,000 Ω for footwear (from BS EN 50341-1) is typically used (per boot). Synthetic soles and rubber gumboots may typically have much higher impedance. The step and touch voltage limits increase with the added contact resistance (but to an upper limit determined by the breakdown voltage of the footwear). Again, the fault duration is 0.12 seconds. For the purpose of this evidence, the beneficial effects of footwear impedance have not been included so as to determine "worst" case scenarios. However, for comparison the increased limits are shown in **Table 2**.

Table 2: Touch and step voltage Limits for humans

Footwear (2,000 Ω)	Touch Voltage Limit (V)	Step Voltage Limit (V)
no	730	1,220
yes	1,450	4,100

Description of transferred voltages

45. **FOR** the purpose of my evidence, the area encompassed by the 730 V contour will be referred to as the "zone of risk". During an earth fault at a tower, any conductive structure (e.g. fence), entering and/or earthed in the zone of risk may have a hazardous touch voltage transferred to it. I say "may" since this is the theoretical worst case. Actual voltages are dependent on the physical configuration of the conductive structure.

Touch voltage limits for transferred voltages

46. Within industry, a range of touch voltage limits for transferred voltages on various structures have been determined. There is still a lack of harmonisation within industry on appropriate levels, although recent work in Australia and New Zealand is seeking to remedy this. **Table 3** lists these limits and their sources, as well as the site specific touch voltage limits defined in **Table 1.**

Table 3: Touch Voltage Limits for Transferred Voltages

Structure	Touch Voltage Limit (Vac)	Source
Towers and Fences	730	Derived above for site conditions (Table 1)
Gas and water Pipelines	300	AS/NZS 4853:2000 "Electrical Hazards on Metallic Pipelines"– fault clearance time: > 0.1 ≤ 0.15 s (public access)
	1000	AS/NZS 4853:2000 "Electrical Hazards on Metallic Pipelines"– fault clearance time: ≤ 1.0 s (restricted public access)
Telecom and Railway Signalling Cables	650	Electricity Regulation 58 – fault clearance time < 0.5 s
Railway lines	4,200	BS EN 50341-1:2001 – fault clearance time 0.12 s, standing on railway ballast (5,000 Ω-m)

Cable and Line Insulation Ratings for Transferred Voltages

47. **COMMUNICATION** cables or LV distribution poles may be located in the zone of risk. To ensure hazardous voltages are not transferred onto these, via insulation break down, the insulation rating of them also needs to be considered.

Description of the WKM to BHL Transmission Line

48. **THE** proposed double circuit 400 kV capable transmission line from WKM to BHL is approximately 185 km long and consists of 426 pylons. The transmission line would initially operate at 220 kV, but at some future date the operating voltage would be increased to 400 kV.

EPR hazards associated with transmission towers

49. **AS** I have previously stated, touch voltages on a tower will arise during an earth fault. Modelling has been carried out for an earth fault on the 400 kV capable transmission line tower. Results show that in the unlikely event of an earth fault (most commonly single phase to earth fault), a voltage of up to 19 kV may exist on a tower. Touch voltages of up to 5 kV may be found on the faulted tower during this 0.12 second fault duration. This voltage will only appear on towers towards the ends of the line. The majority of towers will have a lesser voltage of up to 7 kV. All tower touch voltages exceed the touch voltage limit of 730 V.

50. **I** note that the transmission line includes an overhead earth wire (OHEW). These are used primarily to protect the transmission line from lightning strikes. The OHEW provides an added benefit in that it significantly reduces the tower EPR compared to a tower with no OHEW. A significant portion of the total fault current will divert through the OHEWs. This means that less current passes through the faulted tower itself, however the fault will transfer to adjacent towers at a progressively lesser voltage.

51. **THE** earth fault current will also cause EPR around the faulted tower, which in turn will result in step voltage hazards and transferred voltage hazards.

52. **HUMANS** or animals can only experience a step voltage while stepping in certain directions and when both feet are in contact with the ground. The concept of an EPR contour line was explained earlier in paragraph 27. For example, steps taken that are parallel with an EPR contour line will not be hazardous, just as walking along a height contour does not result in a gain or loss of altitude.

53. **STEP** voltages which exceed the limit of 1,220 V may be found up to 5 m from a tower leg. This is the worst case scenario where a soil resistivity of 100 ohm-m and the highest possible EPR on the tower has been used. As a comparison, when the tower voltage is 7 kV the area of hazard for step voltages extends only 2 m from the centre of the tower leg.

54. **THE** results relating to EPR on the transmission line are based on CDEGS™ software modelling. The modelling is based on parameters which are summarised in **Appendix B**. All models are considered to be conservative, adopting the highest current flows and conservative touch and step voltage limits to replicate and analyse a "worst–case" scenario.

55. **IT** should be noted that while these hazards may exist, for a human or animal to be affected, they must be in the "*wrong place at the wrong time*". As earth faults are very rare and are only present for 0.12 seconds or less (before the fault current is interrupted), the risk associated with a hazardous event occurring is very low. I will discuss the risks in more detail later in my evidence.

EPR transferred voltage hazards associated with nearby infrastructure along the WKM – BHL transmission line

56. **TRANSPOWER** have published a document on Corridor Management which highlights the safe distances defined in NZECP34:2001 for construction and minimum approach near transmission lines. A corridor of 12 m around towers, and a 24 m corridor under the lines has been defined as the "Red Zone", an area in which the land must remain clear to ensure safety to the public, efficient operation and maintenance for the line. Transpower intend to define a minimum 65 m easement for the 400 kV capable line, in which land use will be restricted. While this land use restriction will not remove all hazards, it will go

some way to significantly reduce the quantity. The following sections will analyse hazards at the proposed 65 m easement.

57. **WATER** and gas pipelines, telecommunications cables, railway signalling cables, fences, railway lines etc, may exist near the proposed 400 kV capable transmission line. If these structures pass through the zone of risk, hazardous voltages may be transferred to these structures during an earth fault on a tower. The zone of risk will change for each structure depending on the touch voltage limits defined in **Table 3**. For clarity, I will discuss each structure separately.

Fences

58. **TO** prevent direct coupling of tower fault current, NZECP 34:2001 requires, fences of conductive materials not be constructed within 5 m of any tower or conductive pole of a high voltage overhead electric line of 66 kV or greater. However, it should be noted that NZECP 34 is not written for 400 kV systems.

59. **TABLE** 4 shows that fences complying with NZECP 34 may still be in the zone of risk (730 V contour). Individual assessment and mitigation should be considered on a case by case basis for fences entering the zone of risk. Simple, practical mitigation needs to be considered in relation to existing and new fences within the contour. This may include isolation sections, insulators in the fences, or relocation of fences.

Table 4: Radius of Zone of Risk around a Faulted Tower for Fences

Operating Voltage (kV)	Touch Voltage Limit (V)	Radius of Zone of Risk from the centre of the tower (m)	
		Tower Voltage 15-19 kV	Tower Voltage 5-7 kV
220	730	140	40
400	730	175	70

Gas and Water Pipelines

60. **THE** touch voltage limits defined in **Table 3** identify the 300 V and 1000 V contours to be of interest for gas and water pipelines. **Table 5** shows that these contours may lie between 35 and 440 m of a faulted tower.

Table 5 Radius of Zone of Risk around a faulted tower for pipelines

Operating voltage (kV)	**Touch Voltage Limit (V)**	**Radius from the centre of the tower (m)**	
		Tower Voltage 15-19 kV	**Tower Voltage 5-7 kV**
220	300	350	115
400	300	440	165
220	1000	100	35
400	1000	130	50

61. **FOR** bare buried pipelines, touch voltage hazards will only be an issue if the pipeline can be touched, for example at a valve or during maintenance. During these periods, established work practices are followed by the pipeline operator to ensure any hazards are minimised.

62. **VECTOR** has insulated buried gas pipelines that will pass under the transmission line in two locations. These crossovers are in Morrinsville and Arapuni areas. The pipelines through Morrinsville and Arapuni pass approximately 60 m and 100 m from towers respectively.

63. **MY** investigations show that the towers near the gas pipeline crossovers will have a voltage of up to 5 kV on them during an earth fault. **Table 5** identifies the 1000 V EPR contour (touch limit for restricted access) to be 50 m from a faulted tower. There is no hazard resulting from the proposed 400 kV capable line, as the pipelines are at least 60 m from the towers. Buried pipelines will present no hazards to the public or workers.

Cathodic Protection and Pipelines

64. **CATHODIC** protection (CP) protects underground structures such as buried gas or water pipelines through the use of a low direct current (dc) voltage applied by an external source to the structure. The aim is to counteract any

corrosion current. Pipelines with CP are always insulated using plastic or other materials. Both pipelines themselves and consequently CP systems can be damaged by high voltages such as EPR around a tower.

65. **PIPELINE** insulation will exceed 5 kV. The 5 kV contour will be less than 3 m from the tower, where no pipelines can exist. Therefore there are no risks to pipelines and their CP resulting from EPR.

Telecommunications and Railway Signalling Cables

66. **TELECOMMUNICATION** or signalling cable access points that are located within a zone of risk will need to be considered to ensure safety for workers. **Table 6** summarises the radius of the zones of risk enclosed by the 650 V contour. Individual assessment and mitigation should be considered on a case by case basis for access points entering the zone of risk.

Table 6 Radius of Zone of Risk around a Faulted Tower for Communication Cables

Operating Voltage (kV)	Touch Voltage Limit (V)	Radius from the centre of the tower (m)	
		Tower Voltage 15-19 kV	Tower Voltage 5-7 kV
220	650	160	50
400	650	200	80

67. **MITIGATION** options typically used include, communication circuit electrical isolation, the use of site specific work practices (e.g. rubber mats and warning signs), or upgrading to fibre optic cables.

Railway Lines

68. **THE** main trunk railway near Morrinsville passes under the transmission line approximately 100 m from the nearest tower. The nearest tower is located near the middle of the BHL – WKM line, and therefore may experience a fault voltage of up to 7 kV. The zone of risk, defined by the 4,200 V touch voltage is an area of radius 14 m about the faulted tower.

Table 7 Radius of Zone of Risk around a Faulted Tower for Railway Lines

Operating Voltage (kV)	Touch Voltage Limit (V)	Radius from the centre of the tower (m)	
		Tower Voltage 15-19 kV	Tower Voltage 5-7 kV
220	4,200	30	12
400	4,200	35	14
220	730	145	40
400	730	175	70

69. **ALSO** included in **Table 7** is the touch voltage limit for the situation where the railway line is touched while standing on natural ground 730 V limit (e.g. during track maintenance). The zone of risk is in this case is 70 m from the tower.

70. **AS** the railway lines are located beyond the zone of hazard, the risk does not exist.

LV Distribution Systems

71. **DURING** an earth fault on the 400 kV capable line, hazardous voltage may be transferred to any LV distribution systems located within the 730 V zone of hazard. Mitigation should be considered on a case by case basis and generally would involve relocating poles or equipment and or replacement with underground cables.

Livestock and Step Voltages

72. **ANIMALS** (e.g. cattle) generally have a larger step separation than humans. For the purposes of my evidence, a 1.5 m step separation is used. This means animals will experience a correspondingly higher step voltage. The tolerable step voltage for cattle for a 0.12 second fault is therefore considered to be 1,320 V. This is derived in **Appendix C**.

EPR Risk Analysis on the 400 kV Capable Transmission Line

Quantifying the Risk

73. **THERE** is a requirement in the Electricity Regulations 1997 to ensure electrical works are safe. This is sensible since I believe safety must be considered paramount. Regulation 69 of the Electricity Regulations 1997 states that "*works must be designed, constructed.... so as to be electrically safe.... for the purpose of these regulations "electrically safe" means that there is no **significant risk** of injury or death to any persons.... as a result of use of the works*". This means that some risk may be accepted. This will be discussed in more detail in later sections.

74. **REGULATION** 87 states that works and electrical installations must be constructed so as to minimise the risk of electric shock.

75. **WHEN** analysing the risk associated with EPR events, the rarity of such events means that only a very serious or lasting injury (e.g. heart failure or death to humans or animals) will be considered relevant. Risks associated with lesser electric shocks, reversible injuries, and electrical sensations are not sufficiently consequential and is considered negligible.

76. **AN** analysis based on the EEANZ Guide to Risked Based Earthing System Design, which was developed from AS/NZS 4360:2004 and HB436, "Risk Management" (refer to **Appendix D**), indicates the risk may be considered low (acceptable) provided the combined probability of a fault and exposure to hazardous levels of EPR is less than one in one million.

77. **THE** design average earth fault rate for the section of line between WKM and BHL is 0.1 faults/100km/year. The line is approximately 185 km long and consists of 426 towers. This gives an average probability of a fault on any one tower of 0.0004 faults/ year. Modelling has shown that the OHEW will transfer hazardous touch voltage to 7 towers either side of the faulted tower. Therefore the fault rate is multiplied by 15. To achieve the low risk of one in one million, a person must be in a zone of risk for an approximately accumulative duration of 80 mins per year. Refer to **Appendix D** for calculation details.

78. I note that the risk analysis is based on predicted lightning outage rates since this is the primary cause of earth faults on high voltage transmission systems. The risk profile could change resulting from such activities as irrigation (which may increase bird life and so the opportunity to pollute insulators) or farm buildings (which may result in increased exposure times for humans or livestock). These issues have to be considered. Such issues should in my view be monitored, and appropriate mitigation implemented if needed, to retain the initial risk profile. Mitigation may involve bird spikes for towers, fencing off particular tower footings, or specific earthing designs for buildings or towers.

79. I also note that the exposure to EPR hazards for livestock and equipment may be significantly greater than for humans. This is primarily due to the fact that livestock and equipment may spend significant lengths of time around the vicinity of a tower. This does not necessarily mean the risk is increased, since serious harm to livestock ought not to be treated on the same basis as that for humans.

EPR, TOUCH AND STEP VOLTAGES AROUND UNDERGROUND CABLE JOINT BAYS

Description of the underground cable routes

80. **TWO** new 220 kV cable routes will be built; one from BHL – PAK (10.6 km) and the other from BHL – OTA (9.9 km). Each route consists of two parallel cable circuits. Cables will be laid approximately 1.5 m deep in existing roads, an existing tunnel and in rural areas. Further details of the cable route and joint bays is covered in Mr Wildash's evidence.

Description of joint bays and EPR around them

81. **CABLE** screens provide a low resistance return path for fault currents back to the source. The cable screens are connected to link boxes at each joint bay at approximately 600-800 m intervals. The metallic cable screens are cross-bonded at each joint bay location. This involves electrically connecting the sheaths of different cable sections to reduce power losses and minimize the induced circulating current in the cable screen.

82. **DURING** steady state operating conditions, no significant current passes through the joint bay earthing system and negligible EPR is generated. Therefore I will not comment further on EPR issues for steady state conditions.

83. **PHASE** to earth fault conditions will cause a voltage to appear on the cables' earthing systems and screens. EPR, similar to the tower EPR discussed in paragraphs 24 to 28, will appear on the soil surrounding the earthing system. Touch and step voltage hazards around joint bays will be discussed for both workers and public.

Touch and Step Voltages around Joint bays

84. **IN** the rare event of a joint bay earth fault, the voltage at the joint bay will depend on the joint bay location and resistance. Our modelling shows the voltage on the earthing system of faulted joint bays will range from 0.3 kV to 5.8 kV on the fault location.

85. **TOUCH** voltage hazards will not occur at the joint bays due the inaccessible nature of metallic parts during every day operation. During maintenance periods, workers will access the joint bays under established safety procedures when the cable is dead and earthed appropriately.

86. **FOR** an earth fault at a joint bay, the step voltage limit introduced earlier in Table 1 can be used. This 1,220 V limit is for a person standing on natural ground. Modelling results show the maximum step voltage that may be present at a faulted joint bay is 505 V. This is less that the step voltage limits on natural ground. There are therefore no step voltage hazards associated with the joint bays on the proposed 220 kV cable route between BHL – PAK and BHL – OTA.

87. **THE** modelling made by using CDEGS software is based on parameters which are summarised in **Appendix B**. All models are considered to be conservative, adopting highest current flows and conservative step and touch voltage limits to replicate and analyse a "worst–case" scenario.

EPR transferred voltage hazards associated with nearby infrastructure along the BHL – PAK and BHL – OTA underground cable routes

88. **WATER** and gas pipelines, communication signalling cables, fences etc may exist near the two cable routes. Hazardous voltages may be transferred to these metallic structures if they pass through or are earthed within the zone of risk during an earth fault at a cable joint bay.

Fences

89. **THE** 730 V contour defines the zone of risk around joint bays for transferred voltages for fences. This contour lies 26 m from the joint bay earth grid. Specific hazards cannot be identified until the precise locations of the joint bays are known. To ensure there are no hazards associated with metallic fences, they should not be positioned closer than 26 m to a joint bay without specific mitigation. Assessment and mitigation should be considered on a case by case basis for fences within the zone of risk. Mitigation may include isolation sections, insulators in the fences, or relocation of fences.

Gas and Water Pipelines

90. **THE** touch voltage limits defined in **Table 3** identify the 300 V and 1000 V contours to be of interest for pipelines. **Table 8** summarises where these contours lie, and hence the zone of risk for the pipelines.

*Table 8 Joint Bay **EPR** Contours for Gas and Water Pipelines*

Operating Voltage (kV)	Touch Voltage Limit (V)	Radius from the edge of joint bay earth grid (m)
220	300	68
220	1,000	20

91. **HAZARDOUS** touch voltages will not exist provided any pipeline access points are outside the zone of risk detailed in **Table 8**. Individual assessment and mitigation should be considered on a case by case basis for pipes entering the zone of risk. Mitigation may include specific work practices such as equi-potential work zones or the use of insulated mats.

Telecommunication and Railway Signalling Cables

92. THE touch voltage limit for communication and railway signalling cables is 650 V, from Table 3. Modelling has shown that the zone for risk for these cables is a radius of 32 m from the edge of the joint bay. If communication cable access points are located within this zone of risk, measures need to be taken to either relocate the access point, or employ site specific work practices (e.g. rubber mats and warning signs).

LV Distribution Systems

93. If any LV earths are located within the 26 m radius of the 730 V contour around the joint bay, a hazardous voltage may be transferred onto the LV earthing system. If this situation arises, the LV earths will need to be relocated.

EPR risk analysis along the cable route

94. Hazards arsing around joint bays associated with EPR should be assessed during the detailed design and positioning of the cable route. I believe that any residual risk associated with joint bays since any hazards can be adequately mitigated. Typical mitigation includes, notices of hazard, relocation of services, safe working practices (e.g. rubber mats), isolation of services or additional earthing for joint bay earth grids.

EPR, TOUCH AND STEP VOLTAGES AROUND SUBSTATIONS

Description of Substations and Associated Hazards

95. **MY** evidence relates to the following five substations:

(a) Otahuhu substation (**OTA**), an existing 220 kV substation which will be extended;

(b) Whakamaru substation (**WKM**) is an existing 220 kV substation which will be extended;

(c) Whakamaru North (**WHN**) is a new substation that will connect the new 400 kV capable overhead line to the existing 220 WKM substation;

(d) Brownhill substation (**BHL**) will connect the 400 kV capable overhead line to the underground cables leaving the Brownhill cable transition station; and

(e) Pakuranga substation (**PAK**) which is an existing 110 kV substation and will be upgraded to a 220 kV gas insulated substation (GIS).

96. **SUBSTATION** earth grids are designed, built and tested to ensure safety inside and outside the security fence in accordance with Transpower Standard TP.DS 52.01. Substations are designed, maintained and protected to minimise the occurrence of faults. Should a fault occur, the current will be interrupted to clear the fault, by the protective devices in a fraction of a second.

97. **AS** with all Transpower substation designs, metallic structures and services surrounding the substation are assessed and/or tested to ensure hazardous voltages will not be transferred to them in the event of an earth fault at the substation.

EPR Risk Analysis around Substations

98. **THE** EPR hazards associated with substations are mitigated by design. I consider there to be no risk associated with substation EPR.

SECTION 2: EMF INDUCED VOLTAGES

99. **IN** the following sections of my evidence, I will discuss the EMF induced voltages and currents that may be present on conductive objects near the proposed 400 kV capable transmission line, the 220 kV underground cable routes, and the 5 substations involved. For clarity as discussed in paragraph 10, I will separate EMF into Electric Fields (EF) and Magnetic Fields (MF) in my evidence.

Description of Electric and Magnetic Fields

100. **AN** EF is generated by the separation of two surfaces or objects each holding a different voltage. The greater the voltage difference, the stronger the electric field between the 2. A conductive structure located within an electric field may have a voltage rise on it due to capacitive coupling. This voltage however will not occur if the conductive structure is earthed in any way. The structure does not need to be solidly earthed, any loose coupling to earth is adequate. Voltages of this nature will be referred to as EF induction in my evidence. I note that, EF induction is a build up of charge on the conductive structure, which may be likened to the charge which sometimes causes a minor electric shock when exiting a car.

101. **A** MF is present when current flows through a conductor. As the current increases, so does the strength of the MF. If a conductive structure passes through a time-varying MF, a current may be induced on the structure resulting in a voltage rise on the structure. This will be referred to as MF induction in my evidence.

102. **EF** and MF are of interest when dealing with overhead transmission lines, substations and underground cables as all carry current and operate at high voltage.

103. **EMF** induced voltages and currents are present during both steady state and fault conditions.

Touch Voltage Limits for EMF Induced Voltages

104. **ALTHOUGH** their magnitudes may fluctuate, the EMF induced voltages will be present at all times due to the continuous flow of current in the transmission lines and underground cables. The touch voltage limits shown in Table 3 for short fault durations are therefore not applicable for steady state EMF induced voltages.

105. **THE** definition of Extra Low Voltage is 50 Vac or below in the Electricity Regulations. Extra Low Voltages are implied to be electrically safe. In my evidence I will use this voltage as the steady state voltage limit for fences.

106. **VARIOUS** other touch voltages have been defined within industries to ensure safety. **Table 9** summarises the relevant industry steady state touch voltage limits. The steady state touch voltage limit defined in paragraph 105 has also been included.

Table 9: Industry steady state touch voltages

Structure	Steady State Touch Voltage Limit (V)	Source
Fences	50	Electricity Regulations
Gas pipelines	32	AS/NZS 4853:2000, Electrical hazards on metallic pipelines
Telecom cables	60	International Telecommunication Union, ITU-T K.53, Protection Against Interference

107. **DURING** a fault, significantly more current will flow through a line momentarily and therefore the MF induced voltages will be noticeably greater for the fault duration. The MF induced voltage during a fault, will be considered using the limits defined in **Table 3**.

108. **ALL** computer modelled representations are considered to be conservative, using the highest current flow, lowest conductor height, and the minimum permitted separation between structures and conductors. The results in my evidence relating to EMF induced voltages are based on computer modelling using parameters which are summarised in **Appendix B**.

109. **IN** practice, other parallel metallic structures close to the structure of interest (e.g. cables or fences) will aid to reduce the voltage induced on the structure of interest by local cancellation of the MF. This effect can reduce the voltage by as much at 90%. As a conservative approach, the modelling has not included any local cancellation measures.

EMF INDUCED VOLTAGES ASSOCIATED WITH TRANSMISSION LINES

110. **FENCES**, overhead lines, cables, and pipelines etc, are constructed from electrically conductive material. Therefore if they are close to transmission lines, they may have current induced in them as discussed in paragraphs 100

and 101. The voltage will be higher for conductive structures that are long, parallel and close to the transmission line. The voltage will be lower for conductive structures that are parallel for a short distance or which are further away from the lines. The associated voltages are often insignificant and therefore are either, not detected by humans, animals or equipment, or may be experienced as nuisance micro-shocks.

111. **DUE** to the arbitrary nature of the installation of conductive structures, specific hazards cannot be identified. My approach has therefore been to determine the maximum parallel length a given structure may be at a given distance to the line, before a hazardous voltage will arise. A specific analysis should be carried out to identify and mitigate hazards that approach the defined limits.

112. **AS** discussed in paragraph 56, Transpower's corridor management approach seeks to ensure the land immediately under the transmission lines is clear. This will ensure efficient operation and maintenance of the new line. As a result, conductive structures will be analysed on the edge of the 65 m easement. I have also investigated hazards for fences constructed closer to the line.

Extent of Voltages Induced from EF

113. **VOLTAGES** resulting from the capacitive coupling of electric fields (**EF**) will not exist in relation to earthed structures including fences, pipelines since the "earthing" of them drains away any such voltage. I note that this applies to fences constructed of both wood and metal. Even though wooden posts may be seen to be insulators, they are in fact reasonable conductors and many in parallel constitute an overall low resistance and a good path to earth.

114. **HOWEVER**, a special case is an electric fence that may not be "earthed" during its installation or relocation. In this instance, a voltage from the capacitive coupling from the transmission line may exist on the electric fence. This voltage induced on the electric fence may be relatively high, but the energy behind it will be small and may result in nuisance micro-shocks which will not be hazardous. I suggest it is good practice to fit a temporary earth connection to an electric fence while it is being constructed or moved. This could involve connecting the fence to earth with a loose chain, or using a car battery jumper cable.

Extent of Voltages Induced from MF

Fences

115. **MY** company modelled a typical 200 m long stock fence under the transmission line. Table 10 shows the voltages induced for fences positioned 32.5 m from the centre of the transmission line and 5 m from the tower. For fault conditions, a 40 kA fault current has been used; however this worst case fault current only occurs near the ends of the line. For example, in the centre of the line the fault current is significantly less at 8 kA. The resulting induced voltages in the centre of the line will also be proportionately less.

Table 10: MF Induced Voltages on Single Point Earthed Fences

Line Condition	Fence Location	Induced Voltage (V)	Touch Voltage Limit (V)
Steady State Operation	5 m from tower	22.5	50
Steady State Operation	At 65 m easement	14.5	50
Earth Fault Condition	5 m from tower	590	730
Earth Fault Condition	At 65 m easement	380	730

116. **THE** steady state voltages summarised in Table 10 are not hazardous, but may result in nuisance micro-shocks. I note these values calculated in **Table 10** are theoretical and worst case due to the ideal conditions created by the model. Fence configurations which often have gaps (e.g. gates), do not exist as a single parallel section (i.e. paddock are off a rectangular form), and in many cases have post which are more conductive (i.e. metal waratahs). All these factors will reduce the induced voltages further.

Water and Gas Pipelines

117. **FOR** a water or gas pipeline, the touch voltage limits, defined by the industry, were summarised in **Table 3** and **Table 9**. Applying these limits, the maximum parallel length for a pipeline located on the 65 m easement boundary of the 400 kV capable line, is summarised in **Table 11**.

Table 11: MF Induced Voltage on Insulated Pipelines (earthed at one end, buried 0.5 m)

Line Condition	Induced voltage (V/km)	Maximum parallel length (km)	Touch Voltage Limit (V)
Steady State Operation	140	0.230	32
Earth Fault Condition	3,730	0.270	1000

118. IN practice, the steady state limit will determine the maximum parallel length. The fault condition limit determines the pipeline length permitted before specific work practices require implementation. Specific analysis should be considered for longer or closer pipeline configurations.

Telecommunications and railway signalling cables

119. Table 3 and Table 9 summarised the touch voltage limits for communication cables to be 650 V during fault conditions and 60 V during steady state operation. For a communication cable located on the 65 m easement boundary, the maximum parallel lengths are shown in **Table 12**.

Table 12: MF Induced Voltage on Communication and Railway Signal Cables (buried 0.5 m)

Line Condition	Induced voltage (V/km)	Maximum parallel length (km)	Touch Voltage Limit (V)
Steady State Operation	140	0.430	60
Earth Fault Condition	3,730	0.175	650

120. **SPECIFIC** analysis to provide mitigation should be considered for communication cables that are longer than 175 m or are located within the easement. The effects of local cancellation of the MF by other communication cables (i.e. in the bundle) should also be considered. This cancellation concept involves other induced voltages in nearby cables cancelling part of the MF.

121. **THE** calculations used to determine the induced voltages account for MF cancellation from the OHEWs, but do not account for local MF cancellation due to nearby fencing, cable screens, other cables, water pipes etc. Local cancellation factors from other metallic items may vary from 1 (no cancellation

as such as may occur in the countryside) to 0.1 (significant cancellation in large townships). The cancellation factor can only be accurately determined by testing. A cancellation factor can be estimated; however, the accuracy of this will not be known. I have not used a cancellation factor in my analysis.

Railway Lines

122. **THE** railway line near Morrinsville, will pass under the transmission line at approximately 90 degrees. The remainder of the railway is at a sufficient distance from the transmission line, that there will be no hazardous MF induced voltages.

Distribution and Reticulation Lines

123. **TABLE 13** shows the maximum parallel line length to ensure the voltage on lower voltage lines does not fluctuate by more than 5%, due to steady state operating currents in the 400 kV capable line. The lower voltage lines are assumed to be at the edge of the easement. Lower voltage lines exceeding the lengths summarised will required individual analysis to ensure acceptable operation of the lower voltage lines.

Table 13: Maximum Length Allowable for Lower Voltage Lines Running Parallel to a 400 kV Line - edge of easement

Line Nominal Voltage (kV)	Maximum Parallel Length Between 400 kV line and Lower Voltage Line (km)
0.4	0.33
11	10
22	24
33	32
50	48
66	62
110	100
220	200

EMF INDUCED VOLTAGES ASSOCIATED WITH UNDERGROUND CABLES

124. **CURRENT** may be induced from 220 kV cables into nearby circuits and services during steady state operation and during earth faults. The coupling effects onto communications cables, insulated gas pipelines, bare pipelines,

and fences have been studied. The longest length these metallic structures or services run in parallel to the 220 kV cable has been analysed.

125. **THE** modelling included in this section shows the coupled voltages and currents under maximum steady state and fault conditions. The voltages and currents shown account for magnetic coupling as calculated using the CDEGS™ software. The calculated values exclude shielding effects from nearby fencing, pipelines, lower voltage circuits or other telecommunications circuits.

EMF Induced Voltages Along the BHL – PAK and BHL - OTA Cable Routes

126. **TABLE 14** summarises the maximum allowable parallel length for metallic structures and services near the proposed 220 kV cable routes. Maximum lengths have been calculated for structures or services located 1 m from the cable route.

Table 14: Maximum Parallel Lengths of Conductive Structures and Services Near the 220 kV Cables

Metallic Structure or Service	Induced Voltage During Steady State (V/km)	Maximum Parallel Length (km)	Touch Voltage Limit for Steady State (V)	Induced Voltage During Fault Conditions (V/km)	Maximum Parallel Length (km)	Touch Voltage Limit for Fault Conditions (V)
Fences	13	3.8	50	350	2.1	730
Communications Cables	26	2.3	60	700	0.9	650
Water or Gas Pipeline	26	1.2	32	700	1.4	1000

127. For metallic structures that are closer or longer than the maximum lengths given in **Table 14**, a specific analysis and mitigation should be considered.

EMF INDUCED VOLTAGES ASSOCIATED WITH SUBSTATIONS

128. **EMF** induced voltages have not been considered around substations due to their relatively small longitudinal dimensions compared with a transmission line.

SECTION 3: ELECTRIC AND MAGNETIC FIELDS – PUBLIC EXPOSURE AND OTHER MATTERS

129. **IN** the following sections, I will discuss the EMF levels found around the proposed 220 kV cable routes and the 5 associated substations. EMF levels associated with the proposed 400 kV capable transmission line are covered in Mr Khot's evidence.

Reference Levels for EMF

130. **THE** NRL, a unit of the Ministry of Health, has recommended exposure *guidelines* as published by the International Commission on Non-Ionizing Radiation Protection (ICNIRP). The guidelines give reference levels for protection against adverse health effects. Health effects associated with exposure to EMF are covered in greater detail in Dr Black's evidence. **Table 15** summarises these levels for occupational and public exposure to 50 Hz EF and MF:

*Table 15: Reference Levels for **EMF***

Exposure Characteristics	Reference MF Levels		Reference EF Levels
	(microTesla, µT)	(milliGauss, mG)	(kV/m)
Occupational	500	5,000	10
General public	100	1,000	5

131. **MODELLING** has shown that the levels of EF and MF, during steady state operation, around underground cables and substations will not exceed the reference levels recommended by the National Radiation Laboratory (NRL) during steady state operation.

132. **THE** cables are buried approximately 1.5 m deep and the distance between the two cable circuits is varied between 3.5 and 5 m. The EMF levels have been analysed at ground level (GL) as a worst case scenario, and at 1 m above ground. This is common practice since the human body's vital organs are located at approximately 1 m above ground.

133. EF and MF studies have been carried out for steady state normal and peak loading conditions. Fault conditions have not been considered due to their infrequent occurrence and very short duration of the field they produce.

ELECTRIC FIELDS

Underground Cables

134. **THERE** will be no EF around underground cables since the cable screens provide complete EF shielding.

Substations

THE results from CDEGS modelling show that the EF levels outside the substation boundaries will not exceed the reference levels published by NRL. **Table 15** shows the EF levels at the security fence of each substation and at the closest dwelling. Worst case voltages of 220 kV (+10%) and 400 kV (+5%) are used. WHN and BHL are shown for both 220 kV operation and the upgraded 400 kV operation. The EF levels vary along the fence and are higher where the overhead lines enter the substation.

Table 15: EF Levels Around the Substations

Substation	Distance from substation security fence to closest dwelling (m)	EF at the substation security fence under the lines (kV/m)	EF at the security fence (kV/m)	EF at the closest dwelling (kV/m)
WKM	100	4.4	2.0	0.015
WHN (220 kV)	100	2.6	0.85	0.015
WHN (400 kV)		2.6	1.3	0.026
BHL (220 kV)	300	2.9	*	< 0.005
BHL (400 kV)		3.0	*	< 0.005
PAK	80	4.0	1.3	0.020
OTA	60	2.7	1.6	0.020

* BHL is a GIS substation so EF only appears directly under the overhead line entering the substation.

MAGNETIC FIELDS

Underground Cables

135. **THE** MF levels were studied for both underground cable routes: BHL – OTA and BHL – PAK.

136. **MF** are always present under steady state conditions; however the effects are low. Table 16 summarises the maximum MF found above the 220 kV cables for various spacing and loading arrangements.

Table 16 Summarised MF for spaced trefoil formation

Spacing between two circuits (mm)	Loading	Maximum MF at GL (μT)	Maximum MF 1m above GL (μT)
Single circuit operation	Normal	46	19
Single circuit operation	Peak	61	25
Double circuit operation, cable spacing 3,500	Normal	43	19
Double circuit operation, cable spacing 3,500	Peak	56	25
Double circuit operation, cable spacing 5,000	Normal	42	17
Double circuit operation, cable spacing 5,000	Peak	57	23

137. **THE** fields summarised in **Table 16** are the maximum values found above the cables. The fields rapidly decrease with distance from the cables. This is shown in **Figure 3** for the double circuit situation with a 3,500 mm spacing between circuits.

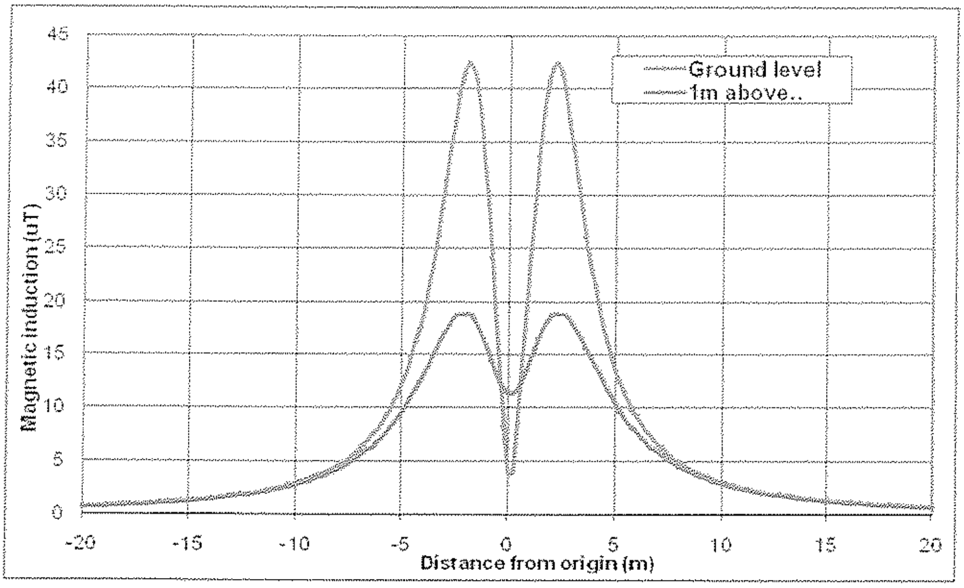

Figure 3 MF above 220 kV cable (3,500 mm separation, normal loading)

138. **THE** results show that the MF levels above the cables are below the ICNIRP guideline of 100 μT for public exposure.

Substations

139. **TABLE 17** shows the MF levels at the perimeter fence of each substation and at the closest dwelling. The MF levels will not exceed the NRL reference levels outside the substation boundaries. The MF levels vary along the fence and are significantly higher where the overhead lines and cables enter the substation.

Table 17 MF Levels Around Substations

Substation	Loading	MF at the security fence (μT) (under lines /over cables)	MF at the security fence (μT)	MF at the closest dwelling (μT)
WKM	Peak	22	10	< 0.1
	Normal	13	6	< 0.1
WHN (220)	Peak	10	6	< 0.1
	Normal	8	5	< 0.1
WHN (400)	Peak	30	21	< 0.1
	Normal	23	16	< 0.1
BHL (220)	Peak	32	13	< 0.1
	Normal	25	7	< 0.1
BHL (400)	Peak	31	15	< 0.1
	Normal	23	10	< 0.1
PAK	Peak	57	13	< 0.1
	Normal	43	9	< 0.1
OTA	Peak	65	14	< 0.1
	Normal	45	10	< 0.1

ISSUES RAISED IN SUBMISSIONS

140. A number of submissions raised issues in relation to EMF associated with the underground cables, and EPR, which I will address below.

Issues raised by Randal and Melanie McKenzie (Submission No. 1008)

141. MR and Mrs McKenzie raise issues in relation to undergrounding the line. Their submission relates to all NORs and resource consent applications. They submit that the electromagnetic field will be reduced if the line is placed underground and this will minimise the potential disruption to other land uses.

Response to Mr and Mrs McKenzie

142. MF will pass through soil without restriction in a similar way to MF in air and therefore MF levels will not reduced by burying. **Table 18** summarises the MF levels for Mr Khot's evidence from the transmission lines and the results of my MF study for the underground cables. I note that the cable MF levels are actually greater due to their closer proximity to the measurement location.

Table 18 Comparing MF levels from underground cables to MF levels from overhead line

MF levels	MF at 1 m above ground level (µT)
220 kV cable (3.5m circuit separation) normal load	19
220 kV cable (3.5m circuit separation) peak load	25
400 kV capable line operating at 220 kV normal load (Mr Khot)	15.7
400 kV capable line operating at 220 kV peak load (Mr Khot)	21.7

Issues raised by Harry McRae Seales (Submission No. 0250)

143. MR Seales raises issues in relation to all NORs and resource consent applications. Mr Seales submits that "*With towers you must not even build a fence parallel with the line or it will become live.*"

Response to Mr Seales

144. AS discussed in paragraphs 115 through 116 of my evidence, it is true that voltages may be induced into fences parallel to transmission lines. However these voltages are not hazardous and are more of a nuisance issue.

Issues raised by Lorraine Storey (Submission No. 0742)

145. MS Storey raises issues in relation to all NORs and resource consent applications. Mrs Storey submits that:

(a) stray voltage has been a costly problem in her dairy shed causing loss of production and stress and stock to staff;

(b) 90% of their land is dairying, and while they located a 5 year old 44 bale rotary cowshed as far as practicable from high tension lines because voltage loss can have a serious effect on the milking ability of cows, they anticipate this will worsen with an additional high voltage line running parallel and to the east of lines A, B and C;

(c) the farm has been reconfigured so that systems like spray irrigation of effluent can be used, there are a limited number of paddocks that can be used for this purpose and the towers and lines further reduce the economic use of the irrigators; and

(d) electric fencing is restricted by the Electricity rules and the lighting of fires in the proximity of the lines is discouraged.

Response to paragraphs (a) and (b)

146. **STRAY** voltage is most likely caused by the 230 V/400 V power supply system within the dairy shed. This may require separate investigation, but is often caused by inadequate main switchboard earthing, poor earth and neutral connections, leakage from hot water cylinder heaters, and lack of equipotential bonding within the dairy shed.

147. I note, if a fence is located parallel to a transmission line, and is connected to the cowshed, theoretically the voltage induced on the fence could send current through the cowshed. Onsite investigation would need to be carried out to assess if this is actually the case. However, this situation can easily be mitigated by isolating the fence from the cowshed by installing a wooden section, insulator, or air gap in the fence.

Response to paragraph (c)

148. **THIS** is an easement and paddock utilization issue and requires response from other witnesses. The new transmission line is unlikely to limit or restrict the installation of electric fences.

Response to paragraph (d)

149. **THE** lighting of fires requires response from other witnesses.

Issues raised by Telecom New Zealand Limited (Telecom) (Submission No. 1157)

150. **TELECOM** raises issues in relation to cables. Its submission relates to all NORs and resource consent applications.

151. **TELECOM'S** concerns relate to the risk of:

(a) hazardous induced voltages on Telecom cables;
(b) EPR hazards from towers;
(c) increased hazard from the WKM, BHL, PAK and OTA substations;

(d) EPR hazards from the 220 kV cable joint earthing systems; and

(e) noise interference to Telecom circuits.

152. I have covered item (a) in my evidence. I have partly covered hazards from EPR in my evidence, where I have discussed the issue of telecommunications cable access points within zones of risk.

153. **WITH** respect to EPR hazards and telecommunications cables, the 650 V, 1,500 V, 2,500 V and 4,000 V EPR contours, are usually of interest to Telecom in order to ensure cables are not exposed to hazardous voltages. Hazards that are identified can usually be mitigated using isolation equipment, replacement or repositioning of cables or using fibre optic cables.

154. I have been advised by Telecom engineers that the insulation ratings of various types of communications vary. These are summarised in the following table:

Insulation ratings for telecommunications cables

Structure	Insulation Rating (Vac)	Comment
PCUT or PEUT cables	1,500	Network access points
PEFUT, CPUB, PEUB or PCUB cables	2,500	
PRFUT, CPUB, PEUB or PCUB cables	4,000	Laid in pipe
HDPE Cables		Direct buried
HDPE Cables	7,000	Laid in pipe

155. **APPROPRIATE** investigation will be carried out where it is understood telecommunications cables may be exposed to EPR hazards. The issue of noise interference has been covered in Mr Cooper's evidence.

Issues raised by Vector Limited (Submission No. 0863)

156. **VECTOR** Limited raises issues in relation to EPR induced voltages. Its submission relates to all NORs and resource consent applications. Vector seeks that it be provided with further information concerning the investigation and proposed mitigation of EPR and induced voltages and currents in services, that could arise from the 220kV underground electricity cables, and assessment on the impact of Transpower's proposed 220kV double circuit

underground electricity cables on Vector's gas pipelines and any proposed mitigation measures.

Response to Vector

157. **THESE** issues concerning the underground cable route from BHL to OTA have been covered in my evidence. The issue of EPR and EMF induced voltages to gas pipelines have been specifically covered earlier in my evidence.

158. **VECTOR** also seeks further information from Transpower in relation to the Whakamaru to Brownhill overhead transmission line:

(a) location of the towers in relation to the gas transmission pipeline;

(b) investigation into EPR and induced voltages and currents in services that could arise from faults on 400kV overhead transmission lines; and

(c) assessment on the impact of Transpower's proposed 400 kV overhead transmission lines on Vector's gas pipelines and any proposed mitigation measures.

159. **THESE** issues have been covered in my evidence:

(a) there are two locations where the Vector gas pipelines cross the transmission line. The EPR issues at these locations have been discussed in paragraphs 62 and 63 of my evidence;

(b) the issue of EPR has been covered earlier in my evidence, as well as the issue of EMF induced voltages along the 400 kV capable transmission line; and

(c) I refer to (a) and (b) above.

CONCLUSIONS

160. I conclude as follows:

Transmission lines

161. I consider the risk associated with touch and step voltage hazards around the 400 kV capable transmission line to be low.

162. EPR and induction effects will arise that may result in hazardous voltages on third party infrastructure such as pipelines, fences and telecommunication cables. However, appropriate mitigation can be implemented and this, combined with risk assessment will eliminate or minimise any overall risk. On this basis, the new transmission line will not introduce any significant risk to persons or third party infrastructure.

163. **THE** levels of EMF are below the NRL suggested guidelines for public exposure.

Underground cables

164. **THERE** is no residual risk associated with underground cables and joint bays since any hazards can be mitigated. Specific hazards should be identified during the detailed design and positioning of the underground cable joint bays.

165. **THE** levels of EMF above the cables are below the NRL suggested guidelines for public exposure.

Substations

166. I conclude that there will no hazardous EPR or EMF issues arising from the construction or modification to any of the substations associated with the upgrade.

Anthony C Mitton
1 February 2008

APPENDIX A

Regulations and Standards Used

Standard AS/NZS 60479.1:2002 "Effects of current on human beings and livestock", defines the safe limits for current flow through the human body. The limits for humans and corresponding physiological effects are detailed in Figure 4. The area between curves C1 and C2 is considered the limit at which 5 % of the population may experience ventricular fibrillation (irregular heart beat).

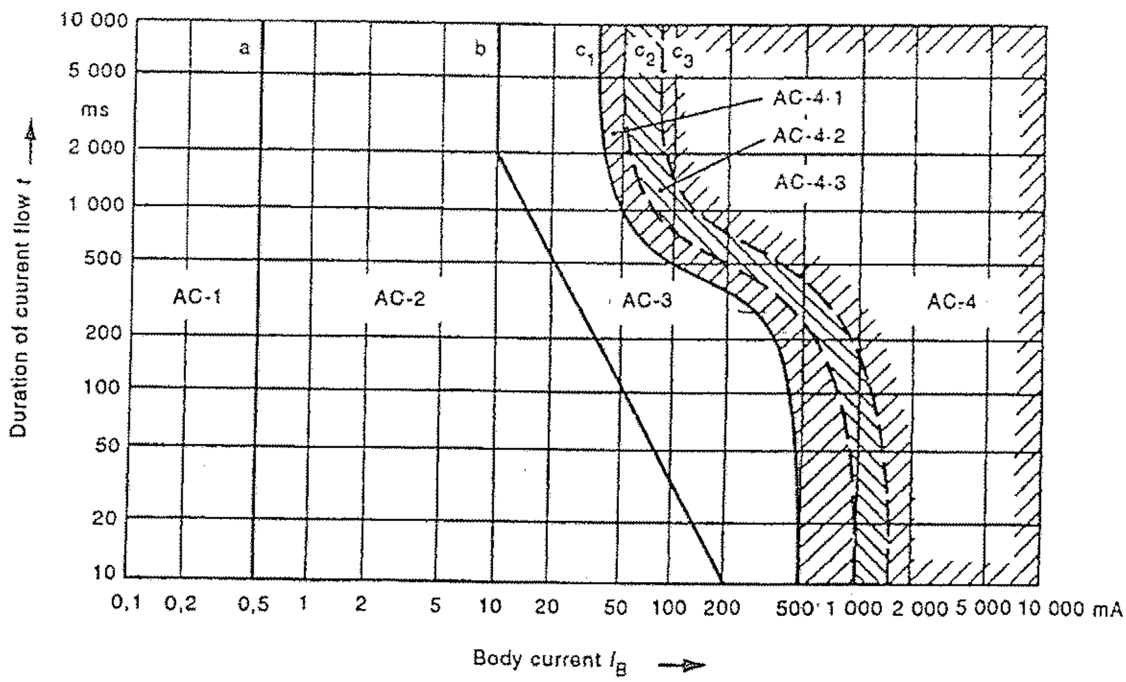

Figure 4: AS/NZS 60479.1:2002 Time/Current Zones of effects of ac current

Below Curve A	Usually no reaction
Curve A to B	Usually no harmful physiological effects
Curve B to C1	Increasing with current and time, reversible disturbances of formation and conduction of impulses in the heart may occur
Curve C1 to C2	Probability of ventricular fibrillation increasing up to 5%
Curve C2 to C3	Probability of ventricular fibrillation increasing up to 50%
Curve C3 and above	Probability of ventricular fibrillation above 50%

Electricity Regulation 55

55.Electrical interference with telecommunications lines, etc

(1) Where any telecommunications lines, or any other structure, device, or thing, designed or intended for use for telecommunications purposes, is being constructed in the vicinity of any works or electrical installation, the person constructing the lines, structure, device, or thing must ensure that the lines, structure, device, or thing is constructed so as to ensure that electricity conveyed through the works or electrical installation does not cause any induced voltage, earth potential rise, or shock currents, that is or are likely to cause damage to the lines, structure, device, or thing or a hazard to persons.

(2) Where any works or electrical installation is being constructed in the vicinity of any telecommunications lines, or any other structure, device, or thing, designed or intended for use for telecommunications purposes, the person constructing the works or electrical installation must ensure that the works or electrical installation is constructed so as to ensure that electricity conveyed through the works or electrical installation does not cause any induced voltage, earth potential rise, or shock currents, that is or are likely to cause damage to the lines, structure, device, or thing or a hazard to persons.

(3) Shock currents and induced voltages are deemed not to be likely to cause a hazard to persons where,-

(a) Shock currents and their duration cannot exceed the IEC shock currents standard; or

(b) In respect of a fault in an a.c. system of supply of electricity, induced voltages and their duration do not exceed-

(i) 430 volts a.c., for a duration of 5 seconds; and

(ii) 650 volts a.c., for a duration of 0.5 seconds; or

Electricity Regulation 69

69.Electrical safety

(1) Works, electrical installations, fittings, electrical appliances, and associated equipment must be designed, constructed, maintained, installed, and used so that they are electrically safe.

(2) Subject to subclauses (3) and (4), for the purposes of these regulations, "electrically safe "means that there is no significant risk of injury or death to any person, or of damage to any property, as a result of the use of the works, electrical installations, fittings, electrical appliances, or associated equipment, or the passage of electricity through those works, electrical installations, fittings, electrical appliances, or associated equipment, as the case may be.

(3) For the purposes of this regulation, fittings and electrical appliances that are designed and used for medical treatment are not electrically

unsafe merely because that medical treatment may cause injury to the patient.

(4) For the purposes of this regulation, fittings and electrical appliances that are designed and used for animal stunning, meat conditioning, or fishing are not electrically unsafe merely because they may injure animals or fish, as the case may be.

Electricity Regulation 87

87. Construction of works and electrical installations

(1) Subject to subclause (2), works and electrical installations are deemed not to be electrically safe for the purpose of regulation 69 where—

(a) The characteristics of any fittings are impaired in construction; or

(b) Conductors are not adequately identified; or

(c) Connections between conductors, and between conductors and other fittings, are not safe and reliable; or

(d) Fittings are installed in such a way that any designed cooling conditions are impaired; or

(e) Fittings which cause or are subject to high temperatures or electric arcs are placed in such a position or are unguarded so as to create a risk of ignition of flammable materials or of injury to persons or damage to property; or

(f) Cables, including underground cables, are not adequately protected against the risk of damage by nature of their covering or their method of installation; or

(g) Cables are bent beyond their design criteria; or

(h) There is insufficient space, access, or lighting to operate, maintain, repair, test, or inspect all fittings of the works or electrical installation, other than cables, in a safe manner.

(2) Works must be constructed so as to minimise the risk of—

(a) electric shock; and

(b) fire and burns.

(3) Subclause (2)(a) is satisfied,—

(a) for power system earthing, if ECP 35 is complied with:

(b) for works, if the supply of electricity within the works is limited so that shock currents and their duration cannot exceed the IEC shock currents standard.

(4) Works and electrical installations must be constructed and installed to take into account any special dangers that they create to persons and property.

(5) Subclause (4) is satisfied—

(a) for single-wire earth return systems, if ECP 41 is complied with:

(b) for retrofitting heaters into spa-pool installations, if ECP 52 is complied with:

(c) for recessed luminaires and their associated equipment, if ECP 54 is complied with.

ELECTRICITY REGULATIONS 1997

"extra-low voltage means any voltage normally not exceeding 50 volts a.c. or 120 volts ripple-free d.c.

NZECP 34:2001 NEW ZEALAND ELECTRICAL CODE OF PRACTICE for ELECTRICAL SAFE DISTANCES

INSTALLATION OF CONDUCTIVE FENCES NEAR OVERHEAD ELECTRIC LINE SUPPORTS

2.3.1 Fences of conductive materials shall not be attached to any tower or conductive pole of a high voltage overhead electric line.

2.3.3 Except with the prior written consent of the overhead electric line owner, fences of conductive materials shall not be constructed within 5 m of any tower or conductive pole of a high voltage overhead electric line of 66 kV or greater. As part of the consent, the overhead electric line owner may prescribe the design of any such fence to be constructed within this 5 m distance.

2.3.4 Where the construction of an overhead electric line would cause a contravention of the principles of clause 2.3.3, the line owner shall, at the line owner's cost, carry out an engineering study and undertake such remedial work as is necessary to maintain electrical safety.

AS/NZS 3014:2003 Electrical installations – Electric fences

5.9.2 *Protection against electromagnetic induction from overhead power lines*

When an electric fence is planned to run alongside a transmission line of greater than 220 kV a.c. RMS, at an angle of 45 degrees or less, the transmission line owner should be consulted for advice on the possibility of dangerous levels of electromagnetic induction occurring before construction of the fence begins.

APPENDIX B

General Model Setup

CDEGS™ software was used to model the proposed 400 kV line, the 220 kV cable routes, and the following five substation; OTA, WKM, WHN, BHL, PAK. These models were run for steady state and fault conditions to analyse EPR, EMF induced voltages and EMF fields.

The parameters for these models are summarised below.

Transmission Line Model

- Transmission line is 187 km long and constructed of (200mm dia + Quad Cicada for main, 200mm dia + Twin Cicada for the circuit connections).
- The line consists of 426 pylons.
- Transmission sources are run at 220kV + 10% = 242kV and 400 + 5% = 420 kV to allow for maximum allowed voltage.
- The minimum height above ground for a 400 kV phase conductor is 12.7 m.
- The average height above ground for a 400 kV phase conductor is 18.07 m.
- Average span length of 436 m.
- Steady state current of 3,912 A has been used in the line.
- Primary protection clearing time = 0.12s maximum.
- The tower model used a tower footing resistance of 10 Ω.
- Standard suspension tower foundation consisting of four, 0.9 m diameter, 5.0 m deep bored concrete piles with reinforcing. The foundations spaced on an 13.1 m square.
- Fault conditions have used a maximum fault current of 40 kA.

Underground Cable Model

BHL – PAK and BHL – OTA routes

- The cables are laid in single 3Ø circuit or two 3Ø circuit arrangements in spaced trefoil configuration.
- Each circuit is generally laid in separate trenches. The cable configuration is shown in *Figure 5*.

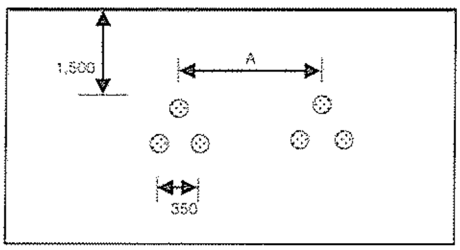

Figure 5 Spaced trefoil formation
(A is the distance between the two circuits)

- Part of the cable route BHL – PAK one of the cable circuits run in a tunnel while the other circuit runs along on the side of the tunnel. This configuration shown in Figure 6 has been used to define the MF levels at dwellings close to the cable route.

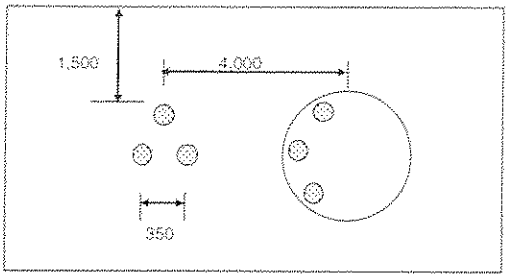

Figure 6 One cable circuit in a tunnel

- Circuit spacing will vary between 3.5 and 5 metres so I have modelled these two extremes and single circuit operation. (Except when one circuit is in a tunnel the separation distance is 4 metres.)
- The magnetic fields have been modelled for a normal load current of 1,645 A and peak load current of 2,188.
- The cable screens are be cross-bonded.

Soil Model

- A soil resistance of 100 Ω-m has been used for all models.

Fence Model

- Fences were modelled using the minimum separation allowed between them and the tower footing (defined in ECP34). This distance is 5 m to allow for worst situation. And at the 65 m easement.
- Fences are modelled as having wooden posts every 5 metres, each with 1000 Ω resistance.
- Fences are constructed of no 8 fencing wire and are 1 m high.
- Fences are either 200 m long fence and are parallel to the transmission line.

Pipelines and Communication Cables

- Have been modelled buried 1 m deep, insulated and earthed at one end, as a worst case situation.

APPENDIX C

Animal Step Voltage Calculation

1. There is little documentation on the safe step voltages for animals available. AS/NZS 60479.3:2002 Part 3: "Effects of current passing through the body of livestock", considers the foreleg to hind leg body impedance for cattle to be 850 Ω (50% chance). This value is for ac 50Hz voltages up to 230 V. The average minimum fibrillating current for a calf was documented at 0.31 A for three seconds. This standard does not give any other fibrillating currents for durations less than 3 seconds or any body impedances for higher voltages higher than 230 V.

2. AS/NZS 60479.1:2002 PART 1: "General Aspects", states that the difference in minimum fibrillation current for 0.12 seconds compared with 3 seconds for humans is an increase of the order 10. Statistical values for decreases in human body impedance as voltage increases show that above approximately 230 V, the impedance is fairly constant. Applying this principle and a more conservative minimum fibrillation current of five times the value for 3 sec, a step voltage of 1,320 V was calculated for animals for 0.12 s.

3. THE New Zealand dairy cow has a front to back leg separation of approximately 1.5 m. Therefore, this step voltage is over a distance of 1.5m.

APPENDIX D

Quantifying the Risk

THE matrix in Table 19 has been developed from the EEANZ Guide to Risked Based Earthing System Design. It suggests a frequency of occurrence verses the severity of the consequence to be used in the electricity industry. A similar matrix can be developed for livestock but clearly the consequences will not necessarily result in the same risk categorisation. From Table 19, it can be concluded that the risk to an individual is considered low if the probability of occurrence is less than 1 in 1 million.

Probability		Severity of Consequence			
		Individual Public Death	Individual Worker Death	Equipment Damage / Costs	
				Severe (> $10,000)	Minor (< $10,000)
Frequent	>1	H	H	H	H
Probable	$1 - 10^{-1}$	H		H	I
Occasional	$10^{-1} - 10^{-2}$	H	H	I	
Remote	$10^{-2} - 10^{-4}$	H	I	L	N
Improbable	$10^{-4} - 10^{-6}$	I	I	N	
Incredible	$<10^{-6}$	L	L	N	N

Table 19:Frequency of Occurrence Vs Severity of Consequence

Risk Level	Description	Risk Management Region	Risk Management Action
H	High	Intolerable	Must prevent occurrence regardless of costs.
I	Intermediate	ALARP	Must minimise occurrence unless risk reduction is impractical and costs are grossly disproportionate to safety gained.
L	Low		Minimise occurrence if reasonably practical and cost of reduction is reasonable given project costs.
N	Negligible	Acceptable	Prevent further occurrence, only if practical and low cost.

Table 20: Risk Levels

THE design average earth fault rate for the section of line between **WKM** and **BHL** is 0.1 faults/100km/year. For a 185 km line with 426 towers, this equates to an average probability of 0.0004 faults/tower/year. The OHEW transfer a hazardous voltage to approximately 7 towers either side of the faulted tower, therefore this fault probability must be multiplied by 15. Therefore the probability of a fault on any tower on the line is 0.0065, or 1/154. For this probability to be 1/1 x 10^6, the exposure must be 0.00015. This is equivalent to 80 mins/year.