APPLICATION GUIDE

SINGLE WIRE EARTH RETURN

HV POWER LINES

NZCCPTS

Issue 1

September 1999

Reprinted January 2021

The New Zealand Committee for the Co-ordination of Power and Telecommunication Systems Inc. (NZCCPTS)

The New Zealand Committee for the Co-ordination of Power and Telecommunication Systems was established in 1985 following the increasing need to implement efficient cost-effective measures for the limitation of hazard and interference to Power and Telecommunications Systems and Personnel.

Such measures not only require the determination of optimum engineering solutions consistent with minimum national cost, but also necessitate clear guide-lines covering the equitable allocation of responsibilities during all work phases from planning through to in-service operation.

The objective of the New Zealand Committee for the Co-ordination of Power and Telecommunication Systems is to meet these needs and, by means of publications and seminars, promote a greater awareness and understanding of the action that must be taken to ensure that Power and Telecommunication Systems coexist satisfactorily.

Membership of the Committee and its Working parties currently comprises representatives for each of the following organizations:

- Electricity Engineers' Association of New Zealand (Inc.)
- Energy Safety, WorkSafe NZ, Ministry of Business Innovation and Employment (MBIE)
- Chorus New Zealand Ltd
- Transpower New Zealand Ltd
- KiwiRail (KiwiRail Holdings Ltd)

For further information concerning this Committee and its published guides, contact the Secretary of NZCCPTS via email to secretary@nzccpts.co.nz, or via his contact details on the ‘Contact Us’ page of the NZCCPTS website (www.nzccpts.co.nz).

APPLICATION GUIDE

FOR

SINGLE WIRE EARTH RETURN

HIGH VOLTAGE POWER LINES

for the control of interference to telecommunication circuits

Published and issued by:

The New Zealand Committee for the Co-ordination of Power and Telecommunication Systems Inc. (NZCCPTS)

Issue 1

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Foreword

The guide sets out the conditions and procedures which should be used for the planning, design, construction and extension of single wire earth return high voltage power lines so that they may co-exist satisfactorily with telecommunication lines and systems.

Acknowledgements

NZCCPTS is indebted to the Electricity Engineers' Association of New Zealand, Chorus, Transpower, KiwiRail and Energy Safety (WorkSafe NZ) for their contributions in the formation of this handbook.

> **"The information contained in this guide has been compiled by the NZCCPTS for the use of its members from sources believed to be reliable, but neither the NZCCPTS nor any of the contributors to this booklet (whether or not employed by NZCCPTS) undertake any responsibility for any mis-statement of information in the booklet, and readers should rely on their own judgement or, if in doubt, seek expert advice on the application of the guidelines to work being carried out."**

Comments for revision of this guide are welcomed. Any comments or information that may be useful for inclusion in future issues should be forwarded to the Secretary of NZCCPTS by email to secretary@nzccpts.co.nz, or via his contact details on the 'Contact Us' page of the NZCCPTS website (www.nzccpts.co.nz).

A brief description of the objectives and organization of the New Zealand Committee for the Co-ordination of Power and Telecommunication Systems Inc. is printed inside the front cover of this publication.

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1 Introduction

1.1 Single Wire Earth Return (SWER) power lines use the earth as a return path for the load current. They carry unbalanced currents and voltages with respect to earth, the electromagnetic and electrostatic fields from which will produce interfering voltages in nearby telecommunication circuits. These voltages may be hazardous to personnel and plant or may cause degradation in the quality of communication transmission due to excessive noise.

1.2 This Guide defines the conditions to be met and the procedures to be followed in the planning, design and construction of SWER power lines operating at or above 6.35 kV above earth so that they may co-exist satisfactorily with telecommunication circuits. The term "Single Wire Earth Return Power Line" should be taken to mean any power line carrying alternating current where, under normal operating conditions, the load current or part thereof is designed to be carried through the earth.

1.3 Nothing in this Guide shall relieve all those who own and operate SWER power lines from complying with the provisions of the Electricity Regulations or any other statutory Act or Regulation. The statements in this guide do not apply to SWER power lines operating below 6.35 kV above earth.

2 Definition of Terms

Committee

For the purpose of this guide the term *Committee* means the New Zealand Committee for the Co-ordination of Power and Telecommunication Systems (NZCCPTS).

Duplex Power System

A multiple earthed neutral (MEN) *duplex power system* is a two-wire Power System fed from an isolating transformer in which the secondary winding is centre-tapped to earth, or fed from two isolating transformers connected so that the voltages with respect to earth in the two wires are 180 degrees out of phase. The fields associated with the currents in the two wires tend to cancel at the location of an exposed telecommunication circuit and interference is therefore reduced. Single wire spurs may be connected directly to such a system but they should be balanced closely between the two wires with regard to both line length and transformer rating.

Earthing System

A conducting Electrode usually made of (galvanized) steel rod or strip, or copper wire or strip, either driven into or buried in the body of the earth for the purpose of conducting electric current to the mass of earth.

Electricity Operator

Electricity Operator has the meaning defined in the Electricity Act. It includes all the Power Companies listed in Reference 1, and also includes operators of Electric Traction power systems.

Equivalent Disturbing Current

The *equivalent disturbing current* in a power line is a current at a frequency of 800 Hertz which, if it were to replace the current flowing in the power line, would produce the same amount of interference in a neighbouring telecommunication circuit as the actual current flowing.

It is defined as:

$$I_q = \sqrt{\left(\sum \left(I_f . P_f\right)^2\right)}$$

I_f is the current component at frequency f

P_f is the psophometric weighting factor at frequency f

Equivalent Disturbing Voltage

The equivalent disturbing voltage of a Power line is a voltage at a frequency of 800 Hz, such that if it were to replace the voltage present on the power line it would produce the same amount of interference in a neighbouring telecommunication circuit as the actual voltages present. It is defined as:

$$V_q = \sqrt{\left(\sum \left(V_p . P_f\right)^2\right)}$$

where V_p is the voltage component at frequency f.

P_f is the psophometric weighting factor at frequency f

In-Service Balance

The *in-service balance* of a *telephone line* is defined as the ratio of the measured *transverse psophometric weighted* noise voltage to the measured *longitudinal psophometric weighted* noise voltage. Measurements to be made at the customer's end of a t*elephone line* with the customer's line terminated with an impedance of 600 ohms at or near the premises. Measurements should be made with a telephone call made over the line to a quiet termination.

$$\textit{In-service balance} \text{ in dB's} = 20.\text{Log} \frac{\text{Transverse Psophometric Voltage}}{\text{Longitudinal Psophometric Voltage}}$$

Note 1 Suitable noise measuring equipment with good balance characteristic must be used for these measurements.

Note 2 A *quiet termination* is defined as an electrically quiet telecommunication line termination in the exchange which can be used when carrying out noise measurements.

Psophometric Frequency Weighting

The *psophometric frequency weighting* factor gives a measure of the relative interfering effect of harmonic components of voltage and current in a *telecommunication line*. The weighted value of a voltage at a given frequency is given by the expression:

$$Wp = \sqrt{\left(\sum \left(X_f . P_f\right)^2\right)}$$

where X_f is the voltage or current component at frequency f.

P_f is the weighting factor at frequency f.

The effect of noise interference in the telephone system is not uniform over the audio-frequency spectrum. The ITU (formerly CCITT) has determined that the human ear responds to signal levels within the audio frequency range in accordance with the weighting factors defined by the psophometric weighting curve.

An instrument with a *psophometric weighting* filter will give a direct reading of the weighted value of the voltage between the two points to which it is connected. When the applied voltage has several components of different frequencies the reading of the instrument is equal to the square root of the sum of the squares of the weighted components.

Service Voltage

The *service voltage* of a Power System is the rms value of voltage between phases in a three-phase system or between phase and neutral (earth) in a single-phase system. In a SWER high voltage system the *service voltage* will be measured between phase and neutral (earth).

Shielding Factor

The *shielding factor* is the reduction in induced voltage that results when a *Telecommunication circuit* is shielded from the effects of a disturbing power line by an adjacent earthed conductor. It is defined as:

$$K = \frac{T(s)}{T}$$

where T(s) = Induced longitudinal voltage in the *Telecommunication circuit* with shielding conductors.

T = Induced longitudinal voltage in the *Telecommunication circuit* without shielding.

Conductors insulated from earth which follow the path of the SWER line for part of its route will be cut by the residual unbalanced magnetic flux produced by the currents associated with the SWER line. Partial cancellation of the SWER line residual flux will result from current flowing in the shield conductor. The extent of the reduction depends upon the magnitude of the shield circuit current which can flow. Generally the resistance of the shielding circuit must be low, usually less than 1 ohm per kilometre, to be of significant effect, the ends of the shielding circuit must have a low impedance connection to earth and the mutual coupling between the shielding conductor(s) and the telecommunication conductor(s) must be high.

Standard Telephone Line Termination

The term *standard telephone line termination* is used in this guide and refers to a 2 wire line termination with typical telephone exchange line connection impedances to earth and wire to wire.

Telecommunication Line or Circuit

For the purpose of this Guide, the term "*telecommunication line or circuit*" means a two wire circuit used for the purpose of transmission of telegraph, data or telephone electric signals.

Telecommunication Power Co-ordinator

In this guide the term *Telecommunication Power Co-ordinator* means the officer of a *Telecommunications Network Operator (TNO)* who is responsible for evaluating the Electricity Operator’s (and the TNO’s in-house) construction / alteration proposals for earth potential rise and induction hazards to the TNO’s network. Contact details for current Telecommunication Power Co-ordinators is given in Appendix G..

Telecommunications Network Operator (TNO)

An organisation who owns and operates a Telecommunication network.

This includes the following organisations:

- Telecom New Zealand Limited
- Trans Rail Limited
- TransPower New Zealand Limited
- Clear Communications Limited
- Saturn Communications Limited

Telephone Form Factor

The ratio of the *equivalent disturbing voltage* to the *service voltage* is called the *telephone form factor* of a power line voltage. It is a measure of the extent of voltage waveform distortion.

Transverse Psophometric Voltage

The *transverse psophometric voltage* of a t*elecommunication circuit* is the psophometric weighted value of the voltage appearing across a 600 ohm resistor terminating the line at the place of measurement, when the other end of the line is terminated on a *standard telephone line termination.*

Weighted Induced Longitudinal Voltage

The *weighted induced longitudinal voltage* in a *telecommunication circuit* is the *psophometric weighted* value of the voltage between one wire of the *Telecommunication line* and earth due to electromagnetic induction.

3 Scope of Guide

3.1 This guide describes how to determine and calculate the level of interference caused by the earth return current of a SWER power line on nearby *Telecommunication circuits* and identifies methods by which excessive interference may be reduced. It defines a co-ordination procedure for use by the affected Parties.

3.2 The return current of the SWER power line can produce hazardous touch and step potentials around earthing electrodes and connections due to earth potential gradients. The procedures defined within this guide have been designed to control these earth potential rise hazards.

3.3 Further details on the effects of earth potential rise is given in the NZCCPTS Application Guide for EPR. Reference should be made to this document if it is necessary to depart from the limits given in this guide.

4 Description of Factors Relating to Interference

4.1 An operating SWER power line carries currents which may interfere with a neighbouring telecommunication line. Single wire earth return power lines (SWER lines) use the earth as a return path for the load current. The resultant earth current spreads out over a large volume of earth and generally follows the path of the SWER line to return to the power source. The average depth of this current is proportional to the square root of the earth resistivity and can be a significant distance below the surface (1km deep for 100Ω-m soil, 3km deep for 1000Ω-m soil).

4.2 The electromagnetic flux of the SWER line current is in consequence not balanced by that of the earth return current near the earths surface. The residual electromagnetic flux will link to any metallic telecommunication circuit in the vicinity and induce voltages which may be hazardous to personnel and plant or may cause degradation to the quality of audio frequency transmission by producing excessive noise. This danger can be minimised if metallic telecommunications cables and railway tracks are not exposed to long lengths of SWER lines.

4.3 The characteristics of human speech and the response of the human ear are such that noise interference in telecommunication circuits is typically greatest over the frequency range 450 Hz to 1600 Hz. Only in rare situations have problems been caused at frequencies outside this band.

4.4 The principal interference in *telecommunication circuits* from power system harmonics normally occurs in the frequency band 450-850 Hz and for practical reasons it is usual to do all representative calculations at a frequency of 800 Hz. In some circumstances it may be necessary to carry out detailed calculations using actual harmonic voltages and currents.

4.5 Interference to a *telecommunication circuit* may be caused by:

- Electromagnetic induction due to the magnetic fields associated with the currents in the Power line.
- Electrostatic induction which is a function of the voltage on the power line and is due to capacitive coupling between the power line and the telephone line.

4.6 Electromagnetic induction between a typical rural earth return power line and a metallic *telecommunication circuit* can be significant at separations of up to 3 km. Electrostatic induction between such lines is insignificant to buried plant, or at separations in excess of approximately 30 m.

4.7 An operating SWER line will induce a longitudinal voltage onto any neighbouring metallic *telecommunication line*. The resultant transverse voltage at the end of the *telecommunication line* is a function of the longitudinal voltage, the balance to earth and the distribution of impedance to ground along that line.

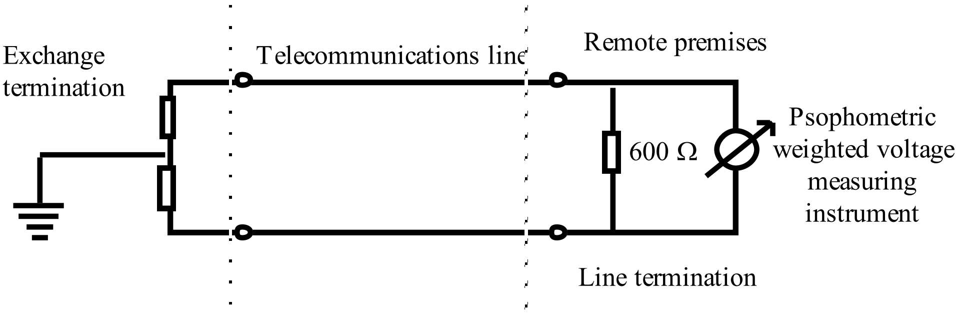


Fig 1.Transverse Psophometric Line Voltage Measurement.

5 Operating Conditions

5.1 Allowable Limits

5.1.1 Noise Voltage Limits

SWER power lines shall not induce transverse and longitudinal noise voltages in a telecommunication line beyond the following maximum allowable limits.

Transverse Noise Voltage

The maximum allowable psophometric weighted value of transverse noise voltage, as measured at the customer premises end of a telecommunication line, is 0.5mV (= -64dBmp, 26dBrnp).

[This comes from the ITU (formerly CCITT) noise limit of 1.0mV on a telecommunication line - when measured across a 600Ω resistor, terminating a normal telecommunication line with a characteristic impedance of 600Ω, this corresponds to a **measured** value of 0.5mV.]

Longitudinal Noise Voltage

The maximum allowable psophometric weighted value of longitudinal noise voltage measured at the end of a telecommunication line is 500 millivolt (-4dBmp, 86dBrnp).

[This is the minimum longitudinal voltage that could cause a telecommunication line with GOOD in-service balance (i.e. 60dB or better) to exceed the above transverse voltage limit.]

5.1.2 Hazard Voltage Limits

Continuous Voltage Limit

The maximum allowable (longitudinal) voltage that can be induced continuously on a telecommunication line is 60 Vrms. This can occur either during normal operation of the line, or under a fault condition such that the protection device on the SWER line does not trip. Any voltage lasting longer than 5 sec. is considered to be "continuous".

Fault Voltage Limit

The maximum allowable (longitudinal) voltage that can be induced on a Telecommunication line during a fault on the SWER line is 430 Vrms. Such a fault must have a duration of < 5 seconds, otherwise the 60 Vrms "continuous" limit applies.

5.2 Measurement Criteria

5.2.1 Longitudinal Noise Voltage

The weighted induced longitudinal voltage can be measured by:

- Connecting both wires of the line to earth at the telephone exchange end of the line.
- Use a high impedance psophometric weighted voltage measuring instrument to measure the weighted longitudinal voltage by connecting between the line and local earth at the telephone instrument termination of the line .

Note. Never take this measurement at the telephone exchange end of the line.

5.2.2 Transverse Noise Voltage

Measure the transverse psophometric voltage on a line as follows:

- The telephone exchange end of the circuit should be terminated on a standard telephone line termination.
- The telephone instrument at the customers end of the line should be disconnected and if the measurement instrument does not have a 600 ohm termination impedance, the line should be terminated with a 600 ohm resistor.
- The transverse psophometric voltage measurement should then be made by placing a high impedance psophometric weighted voltage measuring instrument across the 600 ohm resistor.

Note. Most psophometric voltage measurement instruments have the 600 ohm termination resistor built in.

5.2.3 Line Termination

A suitable line termination is provided by setting up a call into the telephone exchange. The line should then be terminated in the telephone exchange either:

- Manually with a 600 ohm resistor; or
- automatically with a special automatic line termination unit.

5.2.4 Telephone Form Factor

The telephone form factor (TFF) may be measured as follows:

- Connect a suitable step down transformer to the 230 v outlet at the point where the TFF is to be measured.
- Measure the service voltage with a suitable RMS voltmeter.
- Measure the equivalent disturbing voltage by using a high impedance psophometric weighted voltage measuring instrument.

The TFF is then given by:

$$TFF = \frac{\text{equivalent disturbing voltage}}{\text{service voltage}}$$

Figure 2 illustrates a typical measuring arrangement. A step down transformer with a voltage ratio of 8:1 is recommended to ensure the measured voltage 'V' is within safe working limits.

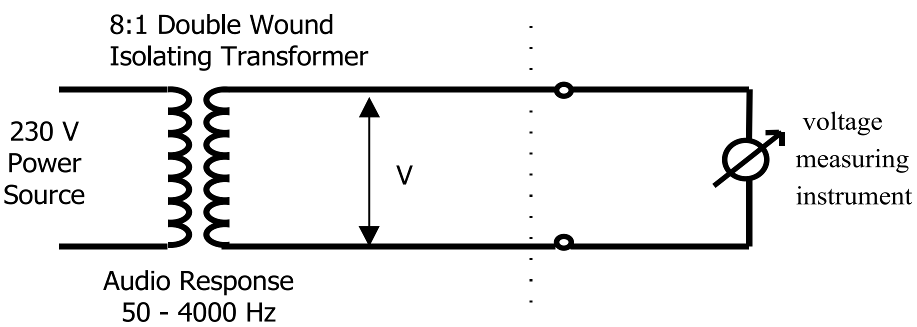


Fig. 2. Typical TFF Measurement Circuit

5.3 Construction Conditions Additional to the Electricity Regulations and ECP 41

5.3.1 The angle of a crossing or approach within 80 metres of a telecommunication circuit shall be as near as practicable to a right angle and shall not be less than 45 degrees unless by special agreement in each case.

5.3.2 SWER power lines are to be supplied from double wound transformers (referred to as isolating or insulating transformers). These lines are to supply only double wound step down transformers whose secondary windings are connected to a multiple earthed neutral system, usually in a 3 wire 400/230 volt or a 2 wire 230 volt configuration.

5.3.3 Isolating and step down transformers used in SWER systems shall incorporate windings which are fully-insulated from their tanks. The connection of these windings with earth shall be made externally by means of duplicate conductors of stranded copper each having a cross-sectional area of not less than 16 square millimetres (or its imperial equivalent 0.0225 sq.in.). These duplicate conductors shall be installed as unbroken continuous lengths, without through joint, preferably following different routes and shall have a separate and independent attachment to the earth connection.

5.3.4 The SWER power line earthing system shall meet the following requirements:

- The earthing system at a distribution transformer shall be of resistance not greater than 5 ohms to earth and shall give a volt drop no greater than 40 volts under operating conditions.
- The earthing system connection at an isolating transformer shall preferably be of a resistance not greater than l ohm to earth.
- The earthing system and all earth conductors and metalwork etc. connected thereto, shall be so installed as to prevent danger from rise in their potential with respect to earth and shall be so installed as to prevent danger from voltage gradients at ground level. If it is not possible to achieve an earth resistance of 5 ohms or the 40 volts limit under normal conditions then special protection arrangements including the use of low resistance earths to avoid hazardous touch potential must be used.

5.3.5 The earthing system may be used for earthing a transformer tank, lightning arrestors, metalwork, the low voltage neutral or other conductors requiring earthing. Any such use may be by direct attachment or by means of a junction with either of the duplicate conductors provided that the main earth connection conductors remain as unbroken continuous lengths without through joints.

5.3.6 The distribution transformers shall be so designed and constructed that the psophometric weighted value of the magnetising current referred to the 230 volt winding shall not be more than 3.0 milliamperes per rated kVA at rated voltage and not more than 9.0 milliamperes per kVA at a voltage 10% above the rated voltage.

5.3.7 The separation between any high voltage earth connection and any telecommunication earthing system or cable, whether existing or proposed, shall be greater than 15 metres, except where via application of the Earth Potential Rise Guide a lesser distance is proved to provide acceptable safety.

5.3.8 The arrangement of protective devices on SWER power lines shall be such that any fault on these lines will not cause a longitudinal voltage in excess of 60 Vrms to be

continuously induced onto a neighbouring telecommunication line. (Note - any longitudinal voltage in excess of about 32 Vrms is likely to cause problems on telecommunication lines, by driving the electronic line cards the lines terminate on into a non-linear state, causing them to become unbalanced and resulting in a major increase in noise.)

5.3.9 It is assumed that danger exists if a person is in contact simultaneously with the earth or an earthed conductor, and with the conductor(s) of a telecommunication line carrying an induced longitudinal voltage in excess of 60 Vrms, the disturbing line being in a normal working condition.

5.3.10 It has been found in practice that a satisfactory arrangement usually prevails if the time of operation of the fuse link, circuit breaker or other protection device is no more than 2 seconds when a short circuit current flows to earth, equal to 7 times the maximum load current.

6 Responsibilities of Parties

6.1 Responsibilities of the Electricity Operator

6.1.1 The Electricity Operator shall be responsible for building all SWER power lines to meet the requirements of this Guide and the Electricity Regulations currently in force.

6.1.2 Except in the case described in 6.1.3, the Electricity Operator shall consult with the Telecommunication Power Co-ordinator at the design stage of a SWER Power line proposal and the application for approval shall contain sufficient information and details of design calculations to show that interference to telecommunication line is unlikely to occur.

6.1.3 The Electricity Operator is not required to consult with the Tranz Rail or Telecommunication Power Co-ordinator where the proposed line route for SWER power lines is greater than 1600 metres from Railway land or track. This distance is reduced to 800 metres if the SWER line current does not exceed 8 amps under normal operating conditions.

6.1.4 The Electricity Operator shall co-operate with the Telecommunication Power Co-ordinator in the testing and taking of measurements to determine compliance with this Guide.

6.1.5 In the event that maximum allowable noise voltages are exceeded subsequent to the construction, extension or alteration of the SWER power line, the Electricity Operator shall arrange remedial action at no cost to the Telecommunications Network Operator.

6.2 Responsibilities of the Telecommunication Network Operator

6.2.1 If requested, the Telecommunication Power Co-ordinator shall make available to the Electricity Operator all information as to the location and type of telecommunication line within the sphere of influence of a proposed SWER high voltage power line. It is expected that this information will be made available within 15 working days.

6.2.2 The Telecommunication Power Co-ordinator shall calculate the voltages that will be induced on neighbouring Telecommunication lines, to determine the need for protection to be applied.

6.2.3 The Telecommunication Power Co-ordinator shall undertake, with the co-operation of the Electricity Operator, all necessary tests and measurements on telecommunication lines to determine the extent of any interference that occurs.

6.2.4 If required, the Telecommunication Power Co-ordinator shall measure the telephone form factor of the voltage waveform at the point in the existing power system at which the proposed SWER line will commence. A minimum value of 0.003 should be used for calculations when measurements indicate a lower value. The measurement will be made at a normal 230 V outlet. The Electricity Operator shall provide suitable facilities for the measurement. An illustration of the type of measurement circuit required is given in Figure 2. Normally, an outlet in a nearby consumer's premises will suffice.

6.2.5 The Telecommunications Network Operator shall be responsible for ensuring that any telecommunication line constructed, extended or altered after the enlivenment of a SWER power line, be so designed, constructed and protected as to avoid interference problems from that power line.

7 Planning, Design and Approval Procedures

7.1 Planning

- The potential hazards and interference that may occur between SWER lines and Telecommunication systems must be taken into account when siting Telephone exchanges, isolating transformers and SWER power line routes. Early advice of initial possible sites and routes should be communicated between the Electricity Operator and the *TNO* to ensure that potential mutual interference problems can be identified early in the feasibility stages of development and that this aspect of design will be taken into account when siting plant.
- For normal routine activities the following design and approval procedures are to be adopted between the parties for any new work
- In a limited number of locations where specific known problems exist the notification procedures detailed below may not be appropriate and after consultation and by mutual agreement by all affected Parties in writing, may be varied to suit the local conditions.

7.2 Design and Approval of a SWER Power Line Construction / Alteration Proposal

7.2.1 The Electricity Operator shall plot the location of the intended consumers on a suitable map and sketch the proposed line route, together with any planned future SWER power lines in the area. Two copies of this map, termed a "SWER line exposure map", are to be forwarded to the Telecommunication Power Co-ordinator.

7.2.2 The Telecommunication Power Co-ordinator shall evaluate the proposal for hazard and for noise interference, and inform the Electricity Operator accordingly.

7.2.3 When the Telecommunication Power Co-ordinator objects to a power line extension or alteration, the matter shall be resolved between the Parties expeditiously in a competent and professional manner. If requested by the Electricity Operator, the Telecommunication Power Co-ordinator shall provide full details of his calculations.

7.3 Design of a New Telecommunication Circuit in an Area Served by a SWER Power Line

7.3.1 The Telecommunication Power Co-ordinator shall request from the Electricity Operator appropriate details of the SWER line to allow him to evaluate the Telecommunication proposal for hazard and noise interference.

7.3.2 If the limits specified in Section 5.1 are not met, the Telecommunication Power Co-ordinator shall investigate the options for resolving the problem, including:

- A change to the route of the telecommunication line.
- The use of suitably shielded cable.
- The use of an alternative transmission medium, e.g. - a radio bearer, a fibre optic cable.

7.4 Calculations

7.4.1 The electromagnetic field associated with the current in a SWER line causes a voltage to be induced longitudinally in any nearby *telecommunication line*. The value of the longitudinal voltage due to a section of an exposure at a reasonably uniform separation is given by the general expression:

$$V_S = C \cdot L \cdot I \cdot K \text{ volts}$$

where

C = mutual impedance (at frequency f) between the power line and Telecommunication circuits in ohms per kilometre for the exposure section
L = length of exposure section in kilometres
I = power line earth return current in amps at frequency f for the exposure section
K = shielding factor of telecommunication circuits (at frequency f)

Now

$$C = 2 \cdot \pi \cdot f \cdot M \quad \text{ohms per kilometre}$$

where

M = the mutual inductance between the power line and Telecommunication circuits in henrys per kilometre for the exposure section.

$$= 10^{-4} \times Log_e \left[1 + \left(\frac{6 \times 10^5 \times \rho}{s^2 \times f} \right) \right]$$

ρ = earth resistivity in ohm-metres
s = separation in metres
f = frequency in Hertz

7.4.2 For hazard calculation purposes, "I" is the fundamental power line current at a frequency of 50 Hertz. For noise calculation purposes, "I" is the equivalent disturbing current of the power line at a frequency of 800 Hertz.

- Appendix B gives the mutual impedance, C, at 800 Hertz.
- Appendix C, Figs 1 to 4, give examples of how to break up the total line exposure length of a “non-parallel” line into a number of separate exposure sections, each with a calculated “average separation”. Fig 5 illustrates the effect of spur lines on the disturbing current value.

7.4.3 For a SWER line that has spur lines within the exposure, calculate an equivalent disturbing current (I_{qs}) for each portion of the SWER line exposure between spur attachments as illustrated in Appendix C, Fig 5.

7.4.4 The following formula should be used for calculating the equivalent disturbing current (I_{qs}) of an exposure section:

$$I_{qs} = \sqrt{I_{dL}^{\;2} + I_{dc}^{\;2}} \qquad \text{(mA)}$$

where

I_{dL} = I_L . TFF . 10^3 (mA)

I_{dc} = 1.57 . TFF . L_{beyond} . V . 10^{-2} (mA)

I_L = maximum design line load current (Amps)

TFF = telephone form factor

L_{beyond} = total length of the SWER power line, including all spurs, beyond the *centre* of the exposure portion being considered (km)

V = voltage of the SWER power line (Volts)

7.4.5 Calculate the mutual impedance between the SWER line and the telecommunication line. To do this it is usually necessary to divide the exposure to any one line into "crossings" and "sections".

7.4.6 A "crossing" is considered as comprising that portion of the telecommunication line, for which the separation from the power line is less than 80 metres on both sides of the crossing point. The mutual impedance C of a crossing can be read directly from Appendix B .

7.4.7 A "section" is considered as a part of an exposure in which the maximum separation S_{max} is not more than three times the minimum separation S_{min}, and the telecommunication line and power line are reasonably straight between the points at which S_{max} and S_{min} are measured. In practice "crossings" are drawn first, and then the "sections" are determined working away from the crossings or the ends of the power line.

One section ends and a new one begins where any one of the following condition's occur:

- The telecommunication line or SWER power line changes direction.
- There is a branch in either the Telecommunication line or SWER power line.
- When Smax is equal to three times Smin.
- Where there is a change in equivalent disturbing current due to a spur.
- Where the earth resistivity changes significantly. Refer to Appendix A.

Figures 2 & 3 Appendix C illustrate how crossing sections and non intersecting sections of the exposure are shown on a SWER line exposure map.

7.4.8 For each section find the mutual impedance in ohms as follows:

- For non intersecting sections calculate as follows:

1. The mean separation

$$s = \sqrt{s_{max} \text{ x } s_{min}} \quad \text{metres}$$

2. The mutual impedance per unit length, C, (ohms per km) at 800 Hz

$$C = 0.503 \times Log_e\left[1 + \left(\frac{6 \times 10^5 \times \rho}{800 \times s^2}\right)\right]$$

where

ρ = earth resistivity in ohm-metres at the location of the section in question. If this is not known from measurements, choose a suitable value from the Table in Appendix A.

s = mean separation of the section in metres.

3. The length of the section L_S in kilometres measured along the power line.

4. The mutual impedance, for each section, $M_S = C \cdot L_S$ ohms.

- For crossing sections determine the mutual impedance M_S from the graph in Appendix B .
- Calculate the induced longitudinal psophometrically weighted voltage, V_S for each section and crossing:

  $V_S = (M_S \times I_{qs} \times K)$ mV

  where

  K = Telecommunication circuit shielding factor

7.4.9 The sign convention is that V_S is positive when the direction of the current feed in the Power line is the same as the direction "exchange to subscriber" or "major exchange to minor exchange" in the telecommunication line, and V_S is negative when the directions oppose one another.

7.4.10 Add algebraically the longitudinal voltages (V_S) for all the sections in the exposure to give the total longitudinal induced voltage, V_X, for each telecommunication line.

7.4.11 If more than one SWER line passes near to a telecommunication line, add algebraically the V_X contributions from all the SWER lines to give the total longitudinal induced voltage, V_t, in that telecommunication line.

7.4.12 If the calculated longitudinal induced voltage V_t found in 7.4.11 above does not exceed the maximum allowable voltage given in 5.1, for each of the hazard and noise limit situations, the proposed layout is acceptable.

7.4.13 If the calculated longitudinal induced voltage V_t exceeds the maximum allowable voltage given in 5.1 then action must be taken to reduce V_t. Suggested methods for reducing V_t are:

- Examine the exposure to determine the sections contributing the greatest longitudinal induced voltage. Adjust the route of the power line over these sections by increasing the separation or making crossings more nearly at right angles.
- Revision of the positioning of the isolating transformer may be desirable. This could involve moving the isolating transformer further out in the Power System, or feeding the SWER line from both ends.
- The erection of a second wire over part of the circuit and feeding it in the duplex mode will significantly reduce the level of interference. This requires at least one additional transformer, usually two.
- If the problem sections are short and low impedance earths are available, either run a well earthed low resistance shielding conductor close to the telecommunication line or a well earthed low resistance shielding conductor on the SWER line poles.

The former is usually more effective. (In practice, this is not usually very effective, due to the difficulty in getting low impedance earths).

- Check that there are no harmonic resonance effects on the SWER line or isolating transformer.
- Consider the installation of harmonic filters to reduce the predominant harmonic currents in the power line, to reduce the telephone form factor and thus I_{qs}.

7.4.14 If the exposure study identifies a problem that would involve high costs to mitigate, then it is recommended that field measurements be undertaken to check the calculated values.

7.4.15 If the TNO objects to a new power line proposal the matter shall be resolved between the parties expeditiously in a competent professional manner.

8 References

8.1 Reference 1

Addresses of NZ Power Network, can be obtained via the Electricity Networks Association website http://www.electricity.org.nz (network companies webpage).

Appendix A: Selection of Earth Resistivity Value

Selection of an Appropriate Value of Earth Resistivity for Calculation of Mutual Impedance.

A1 The resistivity of the earth normally varies with depth, depending on the geological formation.

A2 Earth return currents follow a path of minimum impedance, which involves a compromise between the resistance of the earth path and the self inductance of the circuit. The deeper the current spreads into the ground the lower will be the resistance, but the higher the reactance. It follows that high earth resistivity will result in increased depth of current penetration, and hence the circuit inductance and mutual coupling with exposed telecommunication lines will also increase.

A3 By the same reasoning, as the frequency of the earth return current increases the inductive reactance becomes controlling, and the current tends to be confined to the upper earth layers, which have less inductance. Values of earth resistivity applicable in considering noise induction at harmonic frequencies are therefore different to the values appropriate to consideration of the dangerous voltages which may be induced at fundamental frequency during the passage of fault currents in a power line.

A4 The only accurate way to determine the value of mutual impedance appropriate to a particular exposure is to measure the voltage induced in an exposed wire from a known current in the disturbing line. This may not be practical when a line is being designed.

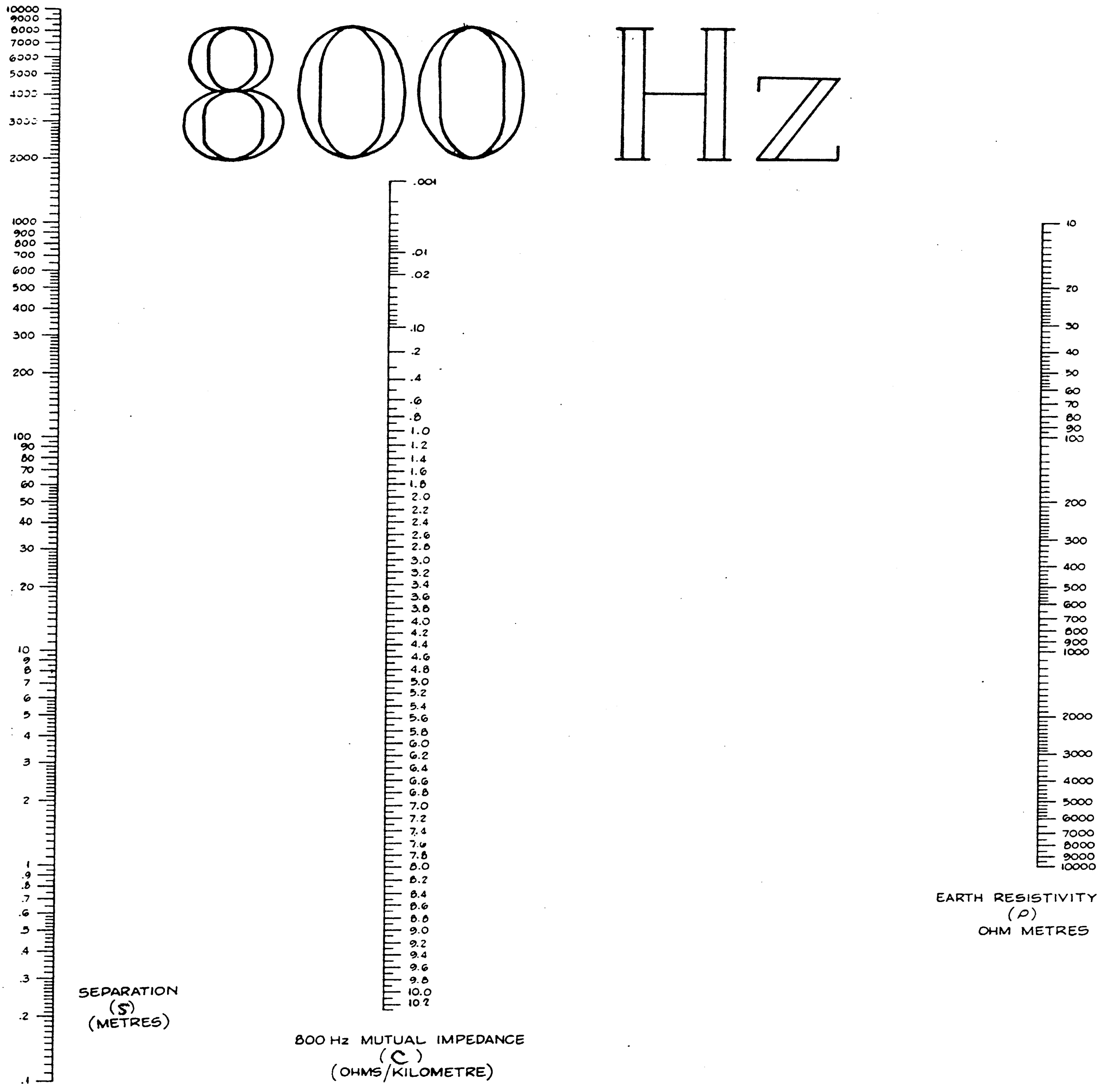
An alternative is to measure the deep soil resistivity of the soil in the region of the exposure using the Wenner four-electrode method. If possible a number of measurements should be made at the region of interest and results averaged. Electrode separation of 50 to 100 metres should be used to obtain an accurate value for the deep soil resistivity used in mutual impedance calculations.

A5 The table below gives an indication of resistivity for some typical types of terrain, however it should only be used for calculation purposes when actual measurement is impractical.

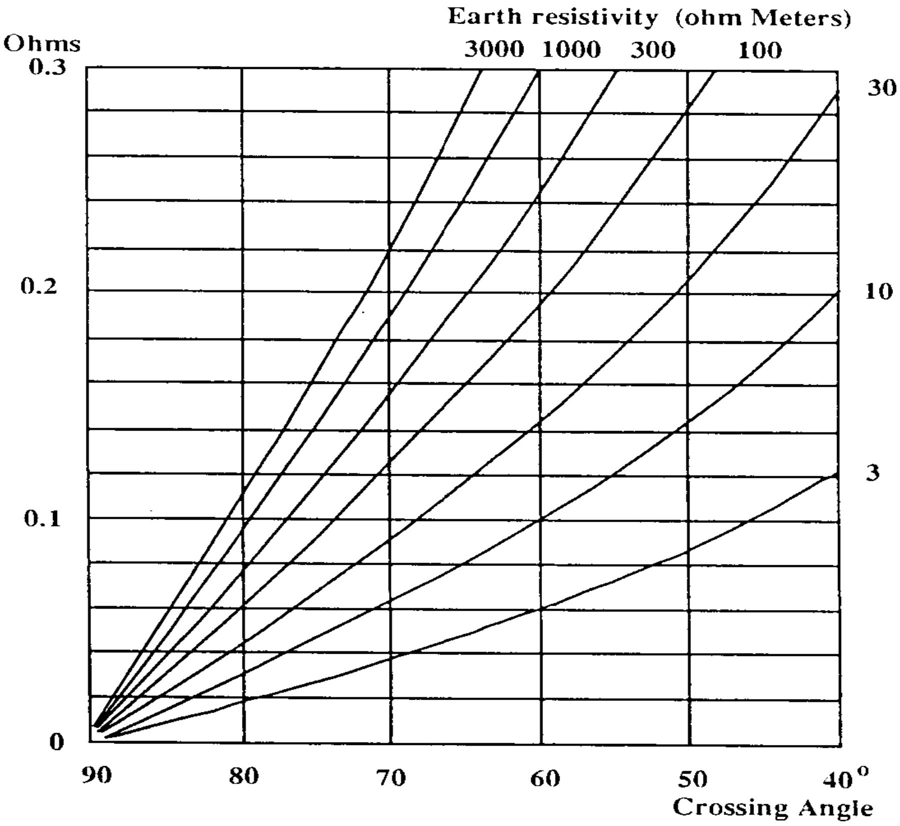
Type of Terrain	**Earth resistivity at 50 Hz (Ω-m)**	**Earth resistivity at 800 Hz (Ω-m)**
Mountainous, rocks leached by heavy rain or melting snow	3000	1000
Steep, hilly	1000	300
Rolling, hilly	300	100
Flat	100	30
River flat, deep loam soil	30	10

Appendix B: Mutual Impedance at 800 Hz

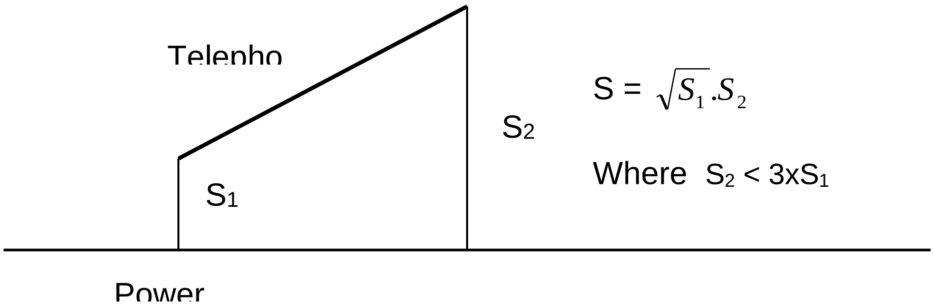
NOMOGRAM



Mutual Impedance of Crossings at 800 Hz



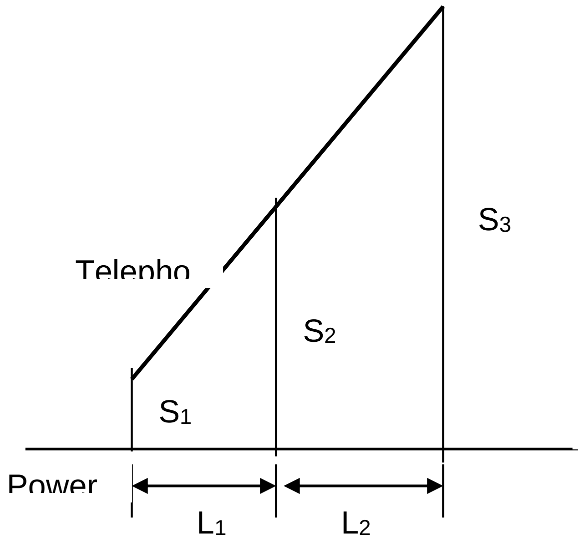
Appendix C: Illustrations of Crossings and Exposures



S = $\sqrt{S_1.S_2}$

Where $S_2 < 3xS_1$

Fig. 1a



For the exposure L_1

S = $\sqrt{S_1.S_2}$

For the exposure L_2

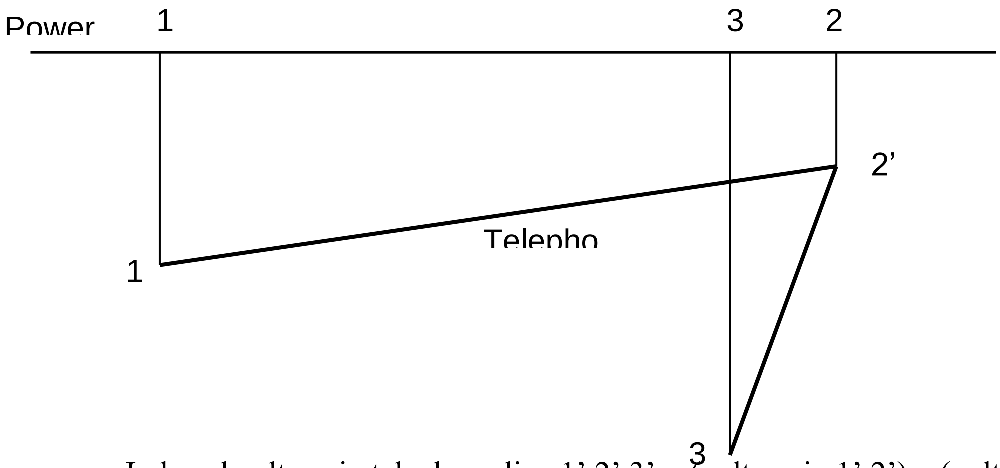
S = $\sqrt{S_2.S_3}$

With $\frac{S_2}{S_1} < 3$, $\frac{S_3}{S_2} < 3$

and $\frac{S_3}{S_1} > 3$

Fig 1b. Subdivision into acceptable sections.

Subdivision of exposures into sections



Induced voltage in telephone line 1' 2' 3' = (voltage in 1' 2') – (voltage in 2' 3')

Fig 2. Telephone line doubles back

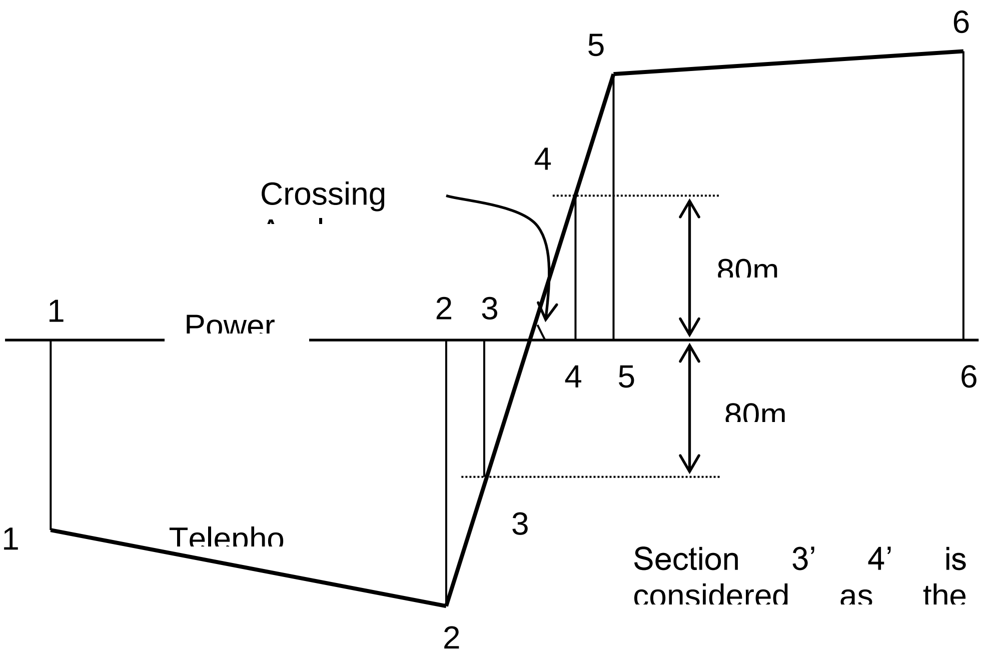
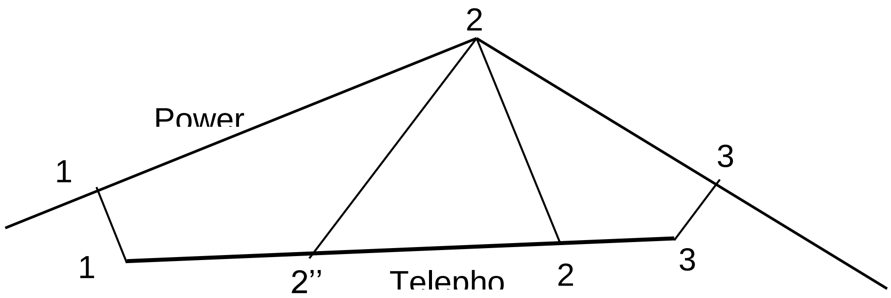
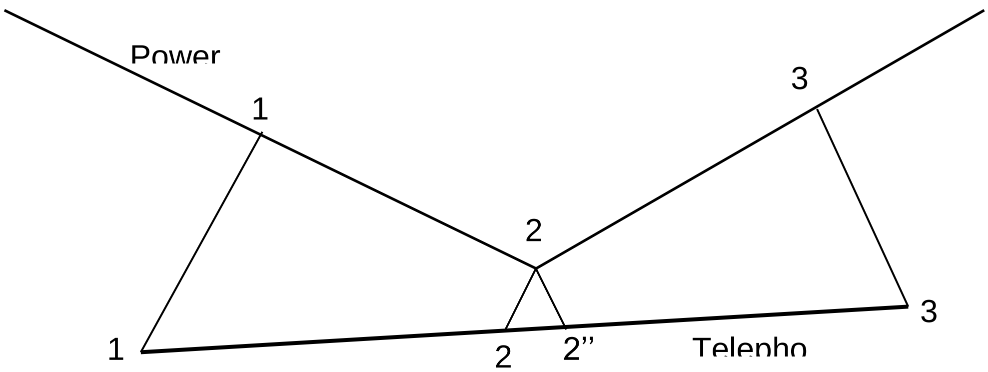


Fig 3. Crossing in a section



Section 2’ 2’’ is induced twice. Induced voltages in 1’ 2’ and 2’’ 3’ are added.

Fig 4a.



Section 2’ 2’’ is not induced.

Fig 4b.

Figs 4. Examples of complex exposure section.

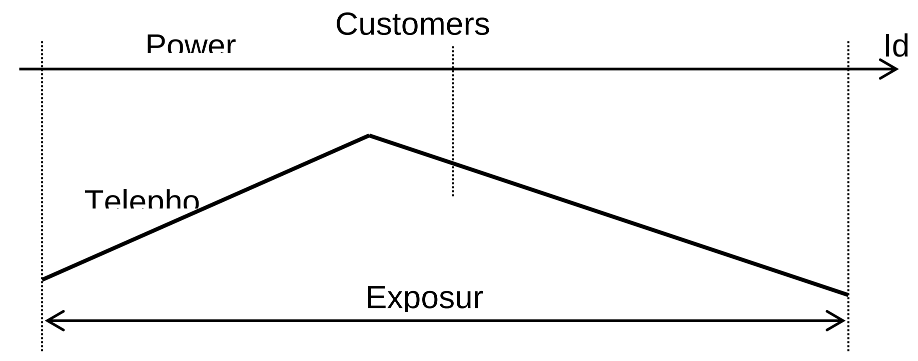


Fig 5a. SWER Line with no spurs.

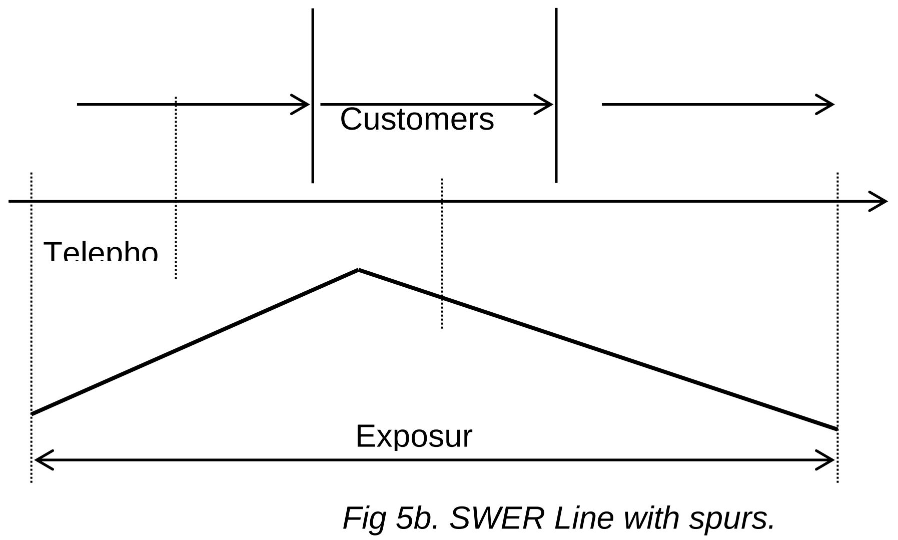


Fig 5b. SWER Line with spurs.

Fig 5. Illustration of SWER line division for calculation of disturbing current.

Appendix D: SWER Line Check List

SWER line information Check List

1. Locality drawing showing SWER and Telecommunication circuits.

2. Isolating transformer location.

3. Power line voltage kV

4. Total connected transformer capacity kVA

5. Telephone form factor. (measured/assumed)

6. Earth resistivity Ω-m (measured/assumed)

7. Telephone circuit type.

Appendix E: Sample SWER Exposure Calculation

First Guess Simplified SWER induction calculation sheet

This table will give an indication of the worst case induced voltage levels into nearby Telecommunication circuits.
Typical values for earth resistivity, SWER line load, SWER line length, spur line effect have been used in determining the multiplying factors.

Separations (m)	Length. (km) A	800Hz induced noise		50 Hz induced voltage	
		factor B	Induced Voltage (mV) A x B	factor C	Induced Voltage (V) A x C
0 to 50m		145		2	
51 to 200m		100		1.5	
201 to 500m		38		0.9	
501m to 1 km		12		0.44	
over 1 km		3.5		0.19	
		Sum		Sum	

If the total induced 800Hz voltage exceeds 500mV, or the total induced 50Hz voltage exceeds 36V, the installation is likely to cause problems to the Telecommunication circuits.

If this table indicates there will be a problem, a more thorough analysis is required.

Example of Full SWER Exposure Calculation.

General

Figure E1 shows the route of the Tuhua Road power line in relation to telecommunication circuits as marked by the Communications Company, and the position, length and load currents of the SWER power line and spurs as provided by the Power Network owner. The Check List (Appendix D) sets out the other information required to carry out this calculation.

The Tuhua Road isolating transformer feeds approximately 21km of Single Wire Earth Return Power Line.

Calculation of Induced Longitudinal Noise Voltage.

Data

1. Power Network owner.	- Waitomo Electric Power Board
2. Name of SWER line.	- Tuhua Road
3. Isolating transformer location	- SH 4
4. ESA drawing numbers, Scale.	- 1 :15000
5. Power line voltage.	- 11kV
6. Earth resistivity	- 300 Ω-m (assumed)
7. Telephone form factor	- 0.006 (assumed)
8. Maximum line current at sending end.	- 6.8 amps
9. Telephone line number	- 884 x 3. Te Kuiti Exchange.
10. Telephone circuit type.	- Buried cable and open wire.
11. Telephone line shielding factor.	- 1.0

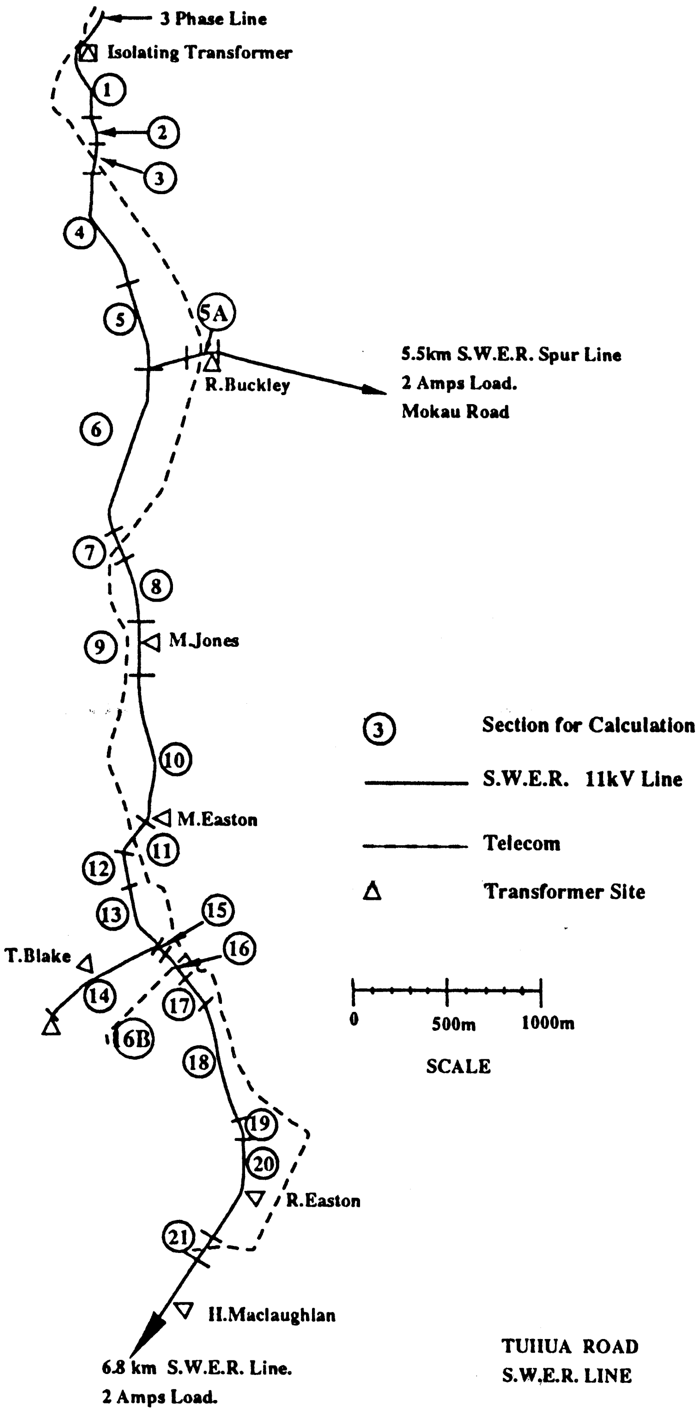
The line has been divided up into exposure sections as described in Section 7.4.7 and Appendix C of this guide.

Each exposure section has a reference number (circled) which appears in sequence in the left hand column of the attached Table. Each row of the Table has the measured or calculated data for determining the electomagnetic induced longitudinal psophometric weighted voltage in the exposure section whose reference number is at the left hand end of the row.

The total induced longitudinal (psophometric weighted) voltage in any one conductor of the Telecommunication line is the algebraic sum of the voltages calculated for each exposure section, the sign being allocated according to 7.4.9.

Results

The total psophometric weighted longitudinal induced voltage, 286.4 mV is within the required limits, ref. 5.1.



3 Phase Line
Isolating Transformer
1
2
3
4
5
5A
6
5.5km S.W.E.R. Spur Line
2 Amps Load.
Mokau Road
R.Buckley
7
8
9
M.Jones
10
M.Easton
11
12
13
14
15
16
16B
17
18
19
20
21
T.Blake
R.Easton
H.Maclaughlan
6.8 km S.W.E.R. Line.
2 Amps Load.
Section for Calculation
S.W.E.R. 11kV Line
Telecom
Transformer Site
0
500m
1000m
SCALE
TUHUA ROAD
S.W.E.R. LINE

Fig. E 1

SAMPLE CALCULATION: SECTION 1 - Voltage Induced at 800Hz

$$s = \sqrt{s_{max} \text{ x } s_{min}}$$

$$= \sqrt{270 \times 100}$$

$$= 164.32 \text{ metres}$$

$$C = 0.503 \times Log_e \left[1 + \left(\frac{6 \times 10^5 \times \rho}{800 \times s^2} \right) \right]$$

$$= 0.503 \times Log_e \left[1 + \left(\frac{6 \times 10^5 \times 300}{800 \times 164.32^2} \right) \right]$$

$$= 1.1235 \ \Omega/\text{km}$$

$$I_{dL} = I_L \text{ x TFF x } 10^3$$

$$= 6.8 \text{ x } 0.006 \text{ x } 10^3$$

$$= 40.80 \text{ mA}$$

$$I_{dc} = 1.57 \text{ x TFF x } L_{beyond} \text{ x V x } 10^{-2}$$

$$= 1.57 \text{ x } 0.006 \text{ x } 20.72 \text{ x } 11000 \text{ x } 10^{-2}$$

$$= 21.47 \text{ mA}$$

$$I_{qs} = \sqrt{I_{dL}{}^2 + I_{dc}{}^2}$$

$$= \sqrt{40.8^2 + 21.47^2}$$

$$= 46.1 \text{ mA}$$

$$Vs = C \text{ x } L \text{ x } I_{qs} \text{ x } K$$

$$= 1.1235 \text{ x } 0.225 \text{ x } 46.1 \text{ x } 1$$

$$= 11.65 \text{ mV}$$

Section Sequence No.	Maximum Separation. (Metres)	Minimum Separation. (Metres)	Geometric Mean Separation. (Metres)	Length of Section (km)	Angle of Crossing (Degrees)	Line Current Beyond Section (Amps)	Length of Line Beyond Section (km)	Disturbing Current due to Load (Ide, mA)	Disturbing Current due to Charging Current (Idc, mA)	Total Disturbing Current. (Iqs, mA)	Mutual Impedance (C, Ω/Km)	Mutual Impedance of Section (C x L, Ω)	Induced Longitudinal Voltage. (mV)
1	270	100	164.31	0.225		6.8	20.72	40.8	21.47	46.1	1.1235	0.2528	11.65
2	100	80	89.44	0.14		6.8	20.61	40.8	21.36	46.05	1.6959	0.2528	11.65
3		crossing		0.76	50	6.8	20.46	40.8	21.2	45.98		0.7	32.19
4	225	80	134.16	0.66		6.8	20.05	40.8	20.78	45.79	1.3092	0.8641	39.56
5	300	225	259.81	0.4		6.8	19.52	40.8	20.23	45.54	0.7376	0.295	13.43
6	225	80	134.16	0.84		4.8	13.4	28.8	13.89	31.97	1.3092	1.0997	35.16
7		crossing		0.16	60	4.8	12.9	28.8	13.37	31.75		0.24	7.62
8	135	80	103.92	0.42		4.8	12.61	28.8	13.07	31.63	1.551	0.6514	20.6
9	100	80	89.44	0.24		4	12.28	28.8	12.72	31.48	1.6959	0.407	12.81
10	240	80	138.56	0.75		3.6	11.78	24	12.21	26.92	1.2792	0.9594	25.83
11		crossing		0.16	55	3.6	11.33	21.6	11.74	24.58		0.3	7.37
12	90	80	84.85	0.13		3.6	11.18	21.6	11.58	24.51	1.7472	0.2271	5.57
13	165	80	114.89	0.42		0.9	10.91	21.6	11.3	24.38	1.4551	0.6112	14.9
14	No contribution. At right angles to the SWER line.												
15	120	90	103.92	0.06		2.6	10.11	15.6	10.48	18.79	1.551	0.0931	1.75
16		crossing		0.16	95	2.6	10.01	15.6	10.37	18.73		0	0
17	135	80	103.92	0.165		2.6	9.1	15.6	9.43	18.23	1.551	0.2559	4.66
18	225	80	134.16	0.615		2.6	7.99	15.6	8.28	17.66	1.3092	0.8051	14.22
19	330	225	272.49	0.135		2.6	7.64	15.6	7.72	17.5	0.7011	0.0946	1.66
20	330	105	186.15	0.615		2	7.27	15.6	7.53	17.32	1.013	0.623	10.79
21		crossing		0.16	50	2	6.88	12	7.13	13.96		0.7	9.77
5A	Spur line crossing.				70	2.6	5.5	12	5.7	13.29		0.16	2.13
16B	240	80	138.56	0.16			10.01	15.6	10.37	18.73	1.2792	0.2047	3.83
	NOTE: 5A and 16B contribute to Longitudinal											**TOTAL**	**286.4 mV**

Appendix F. Conditions for Operation of SWER Lines.

To comply with the Electricity Regulations, the Electrical Code of Practice for SWER systems (ECP 41), and this guide, a SWER high voltage line needs to meet the following conditions:

1. The load current shall not exceed 8 amps.

2. The SWER line shall not be closer than 80m to an overhead open wire Telecommunication line (except at crossings).

3. At crossings over Telecommunication lines or cables, the angle of approach within 80m of the Telecommunication circuit shall be as near as practical to a right angle, and shall not be less than 45° unless by special agreement in each case.

4. The earthing system at each distribution transformer shall have an earth resistance not greater than 5Ω.

5. The maximum longitudinal 50Hz voltage that may be induced onto a telecommunication circuit by normal SWER line load current is 2Vrms.

6. The maximum longitudinal 50 Hz voltage that may be induced onto a telecommunication circuit from "continuous" faults (i.e. faults for which the protection does not operate within 5 seconds) is 60 Vrms (reducible to 32 Vrms for circuits connected to SPC exchanges).

7. The maximum longitudinal 50 Hz voltage that may be induced onto a telecommunication circuit during a fault with a duration of less than 5 seconds, is 430 Vrms.

8. The maximum longitudinal psophometrically weighted voltage that may be induced onto a telecommunication circuit under normal operating conditions is 500mV.

Appendix G Contact Details for Telecommunication Power Co-ordinators

1. Telecom NZ Ltd. (as at November 2010)

Primary Contact:		**Back Up Contact:**	
Rod Goodspeed Engineering Consultant KAYROD Services Ltd. P.O. Box 4090 NAPIER		Alan Marshall Engineer (Lightning and Power Protection) Opus House Opus International Consultants Ltd. P.O. Box 1482 CHRISTCHURCH	
Ph:	0-6-835 3289	Ph:	0-3-371 9453
Fax:	0-6-835 3689	Fax:	0-3-365 7858
Mob:	027-211 0023		
Email:	kayrod@xtra.co.nz	Email:	alan.marshall@opus.co.nz

2. Clear Communications Limited

Head Office
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49 Symonds Street
Private Bag 92-143
AUCKLAND

3. KiwiRail (NZ Railways Corporation)

Allan Neilson
Manager Traction & Electrical Engineering
KiwiRail Network
3rd floor, Wellington Railway Station
Bunny Street
PO Box 593
Wellington 6011

Ph: 0-4-495 3000 (x48424)
Mob: 027-443 3055
Email: allan.neilson@kiwirail.co.nz