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Lightning, Earthing and Surge Protection

Wednesday 14 January 2026

Presented by

Steve Mackay PhD | ECT & EIT Managing Principal and

Samkelo Nene | ECST Electrical Engineering Lecturer

UKPRN: 10089771

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Introduction – Presenter

Steve Mackay

ECT & EIT Managing Principal

Introduction – Presenter

Steve Mackay

FIE(Aust) CPEng GCC BSc (ElecEng), BSc (Hons), MBA, MMR, PhD

How entrepreneurship and resilience define me.

- My passion for engineering and education has led me into many entrepreneurial ventures.
- My curiosity drives me to study and learn every day – AI is a key tool.
- This love for education means that I truly admire high quality teaching and dedicated teachers who put students at the centre of all they do.
- Through my career I have overcome a huge number of failures and set backs and I believe my resilience has assisted me through these times; it has enabled me to look ahead with optimism.
- As we face unprecedented weather extremes our communal resilience is being tested. I believe tackling population growth, weak economies, pollution, exploitation and climate change will present our greatest engineering challenges and opportunities.

Introduction – Presenter

Samkelo Nene

ECST Electrical Engineering Lecturer

Introduction – Presenter

Samkelo Nene

- Candidate Engineering Technologist registered with ECSA
- BEng Tech (Hons) in Electrical Power Engineering; Golden Key Honour Society inductee
- Expertise in power systems, electrical machines, power electronics, and energy policy
- Former tutor and lab facilitator at Durban University of Technology
- Experience with SANEDI supporting G20 Energy Transitions Working Group
- Involved in energy policy dialogue, workshops, and sustainable energy initiatives

Agenda

1	Today’s objective
2	Lightning and Surges
3	Protection Principles against Lightning
4	Introduction to Earthing/Grounding
5	Case Studies in Earthing/Grounding
6	Conclusion

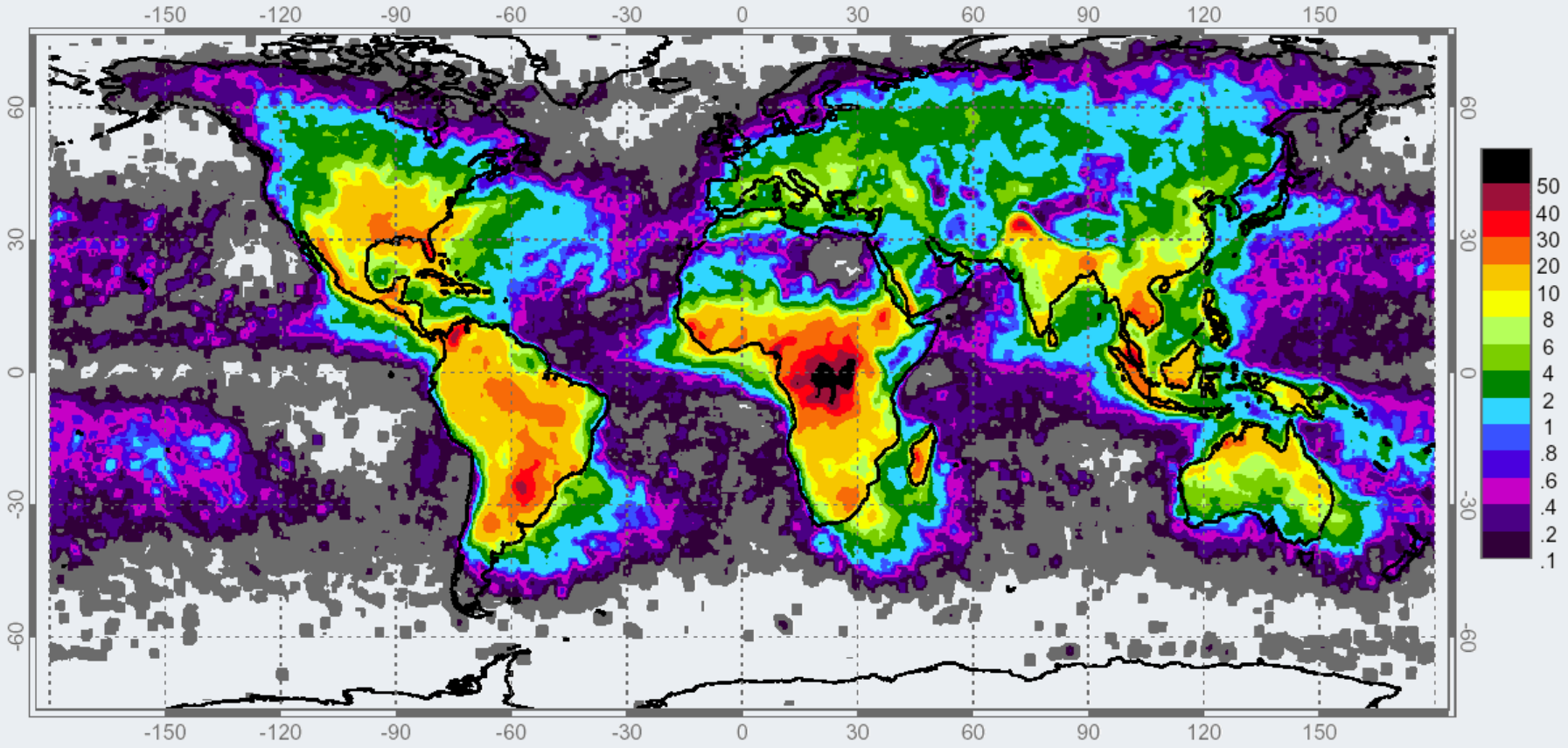
1. Today’s Objective

This webinar explores the risks lightning strikes and transient surges pose to electrical systems and infrastructure. It provides a clear overview of effective earthing practices and the engineering principles behind safe system design. Participants will also learn how surge protection strategies can reduce equipment damage and improve long-term reliability.

Key takeaways from this webinar:

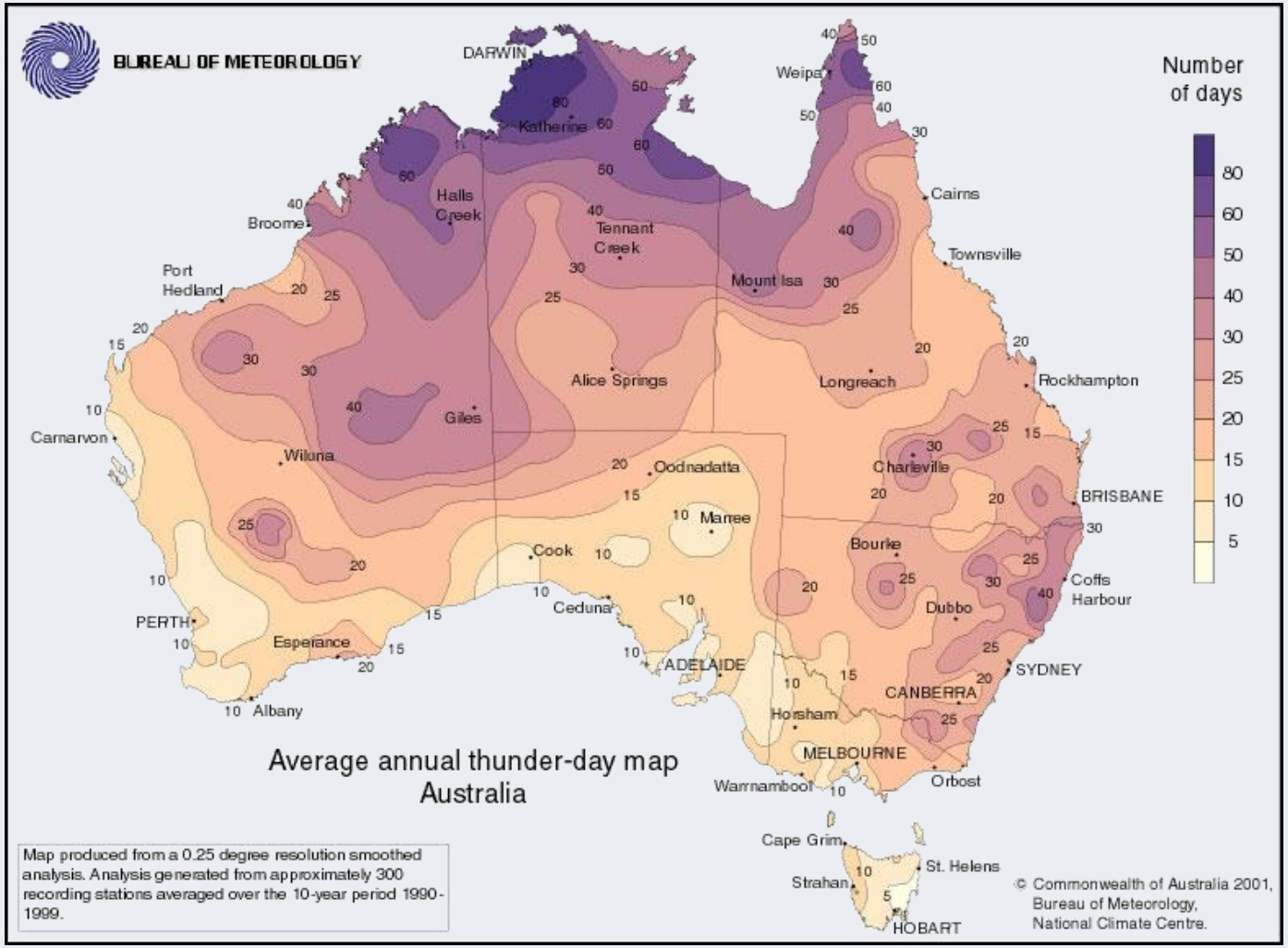
- Lightning & Surge Risks – Understand how lightning and transient surges impact electrical installations.
- Effective Earthing Design – Learn the principles of earthing systems that enhance personnel and equipment safety.
- Protection Strategies – Explore surge protection devices and design methods that reduce damage and downtime.

2. Lightning & Surges



Data from space-based optical sensors reveal the uneven distribution of worldwide lightning strikes. Units: flashes/km2/yr.

Image credit: NSSTC Lightning Team.


BUREAU OF METEOROLOGY
Number of days
80
60
50
40
30
25
20
15
10
5
DARWIN
Katherine
Weipa
Cairns
Townsville
Halls Creek
Broome
Tennant Creek
Mount Isa
Port Hedland
Alice Springs
Longreach
Rockhampton
Giles
Carnarvon
Wiluna
Oodnadatta
Charleville
BRISBANE
Marree
Bourke
Cook
Coffs Harbour
Dubbo
Ceduna
PERTH
Esperance
ADELAIDE
SYDNEY
CANBERRA
Albany
Horsham
MELBOURNE
Warrnambool
Orbost
Cape Grim
St. Helens
Strahan
HOBART
Average annual thunder-day map
Australia
Map produced from a 0.25 degree resolution smoothed analysis. Analysis generated from approximately 300 recording stations averaged over the 10-year period 1990-1999.
© Commonwealth of Australia 2001, Bureau of Meteorology, National Climate Centre.

Comparative Probability of Death for an Individual per Year of Exposure (Order of Magnitude)

Activity	Chance of Occurrence
Smoking (10 cigarettes per day)	1 in 400
All accidents	1 in 2,000
Traffic accidents	1 in 8,000
Work in Industry	1 in 30,000
Drowning	1 in 30,000
Poisoning	1 in 100,000
Natural Disasters	1 in 500,000
Driving 80km by road	1 in 1,000,000 (per occurrence)
Being struck by lightning	1 in 2,000,000

In Australia:

Between 6 and 10 people are killed each year by lightning. Most common causes:

- Playing golf
- Swimming, sailing, fishing, being in large open areas

Source: BS 6651:1992

Myths about lightning

- **Lightning never strikes twice** (Truth: it hits the Empire State Building about 25 times a year.)
- **Rubber (tyres) will insulate me from lightning** (Truth: it has travelled miles through space…a few inches of rubber mean nothing at all.)
- **You should never touch someone after he/she has been hit by lightning** (Truth: It is perfectly safe.)
- **Lightning can be prevented** (unconfirmed/sheer advertising.)
- **First strikes from lightning can be predicted** (unconfirmed/sheer advertising.)
- **New high-tech types of lightning rods can control lightning** (unconfirmed/sheer advertising.)
- **Bolt from the blue** (Misconception)

Source: National Lightning Safety Institute (USA)

The localized nature of lightning

“Bolt from the blue” phenomenon

“Bolt from the blue” phenomenon

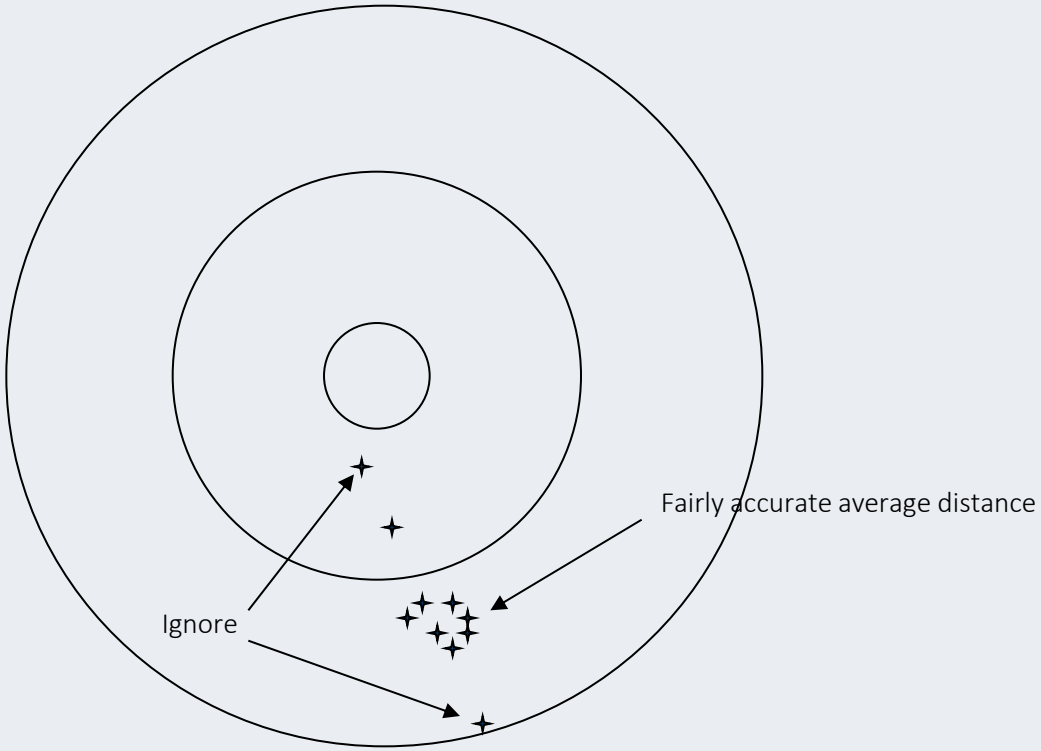
Facts about lightning

- Lightning is a random, statistical phenomenon.
- Lightning is unpredictable.
- No cost-effective, practical lightning protection system is able to provide 100 % protection.
- No early warning system is able to provide reliable first-strike warning.

The unpredictability of lightning

Boltek StormTracker Lightning Detector

- RF type detector
- Direction accurate if antenna installed correctly
- Distance only approximate indication: Strong strikes appear closer than what they really are, weak strikes appear further away.



When is lightning an immediate threat?

- AS1768 suggests 5 km
- New research in USA found distance between subsequent strikes greater than previously thought: frequently up to 8km and sometimes more
- NLSI recommends 30/30 rule: Employ safety measures / seek shelter when Flash-to-Bang time is 30 seconds or less (10 km); wait 30 minutes after last local lightning
- Sound of thunder travels approx. 1 km every 3 seconds
- Audible range of thunder approx. 8 – 13 km
- Safe shelters: Substantial buildings, fully metal enclosed vehicles, large metal sheds
- Unsafe shelters: TREES, vehicles with open sides or non-metal roofs / canopies, tents, fibre-glass cubicles, close to isolated towers / masts
- Surface arc: May be lethal up to 40m from object struck (step potential) – mitigated by good earthing

Effects of lightning discharge currents in the ground

3. Protection Principles Against Lightning

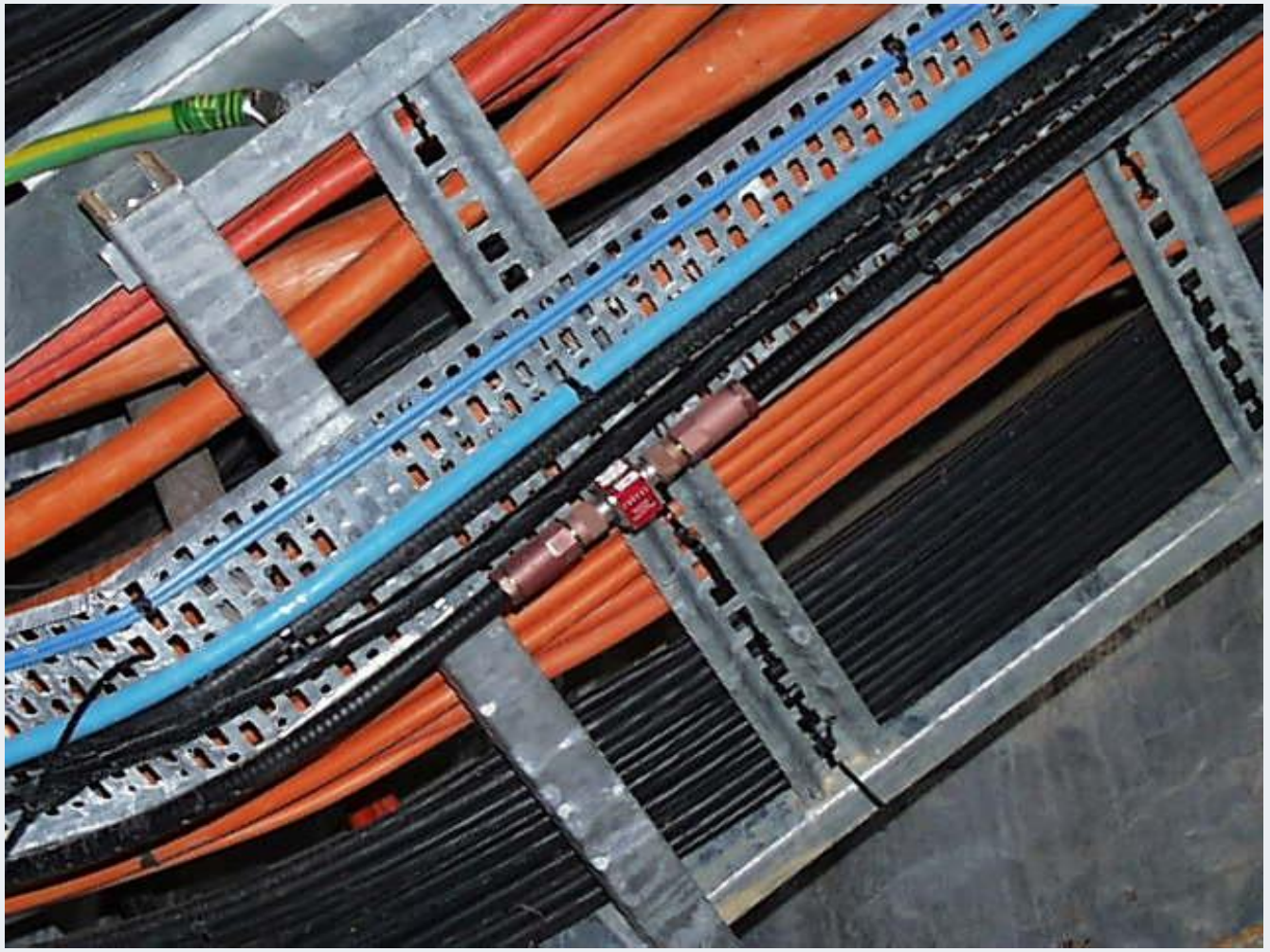
- Air Terminal
- Downconductor
- Earthing and Bonding
- Surge Protection
- Safety Procedures

Incorrect / Unnecessary: Air terminal on top of metal structures

Incorrect / Unnecessary: Air terminal on top of metal structures

Incorrect / Unnecessary: Air terminal on top of metal structures

Incorrect earthing practice: Earth conductor coiled – high impedance



Incorrect practice: Surge arrester not earthed adequately

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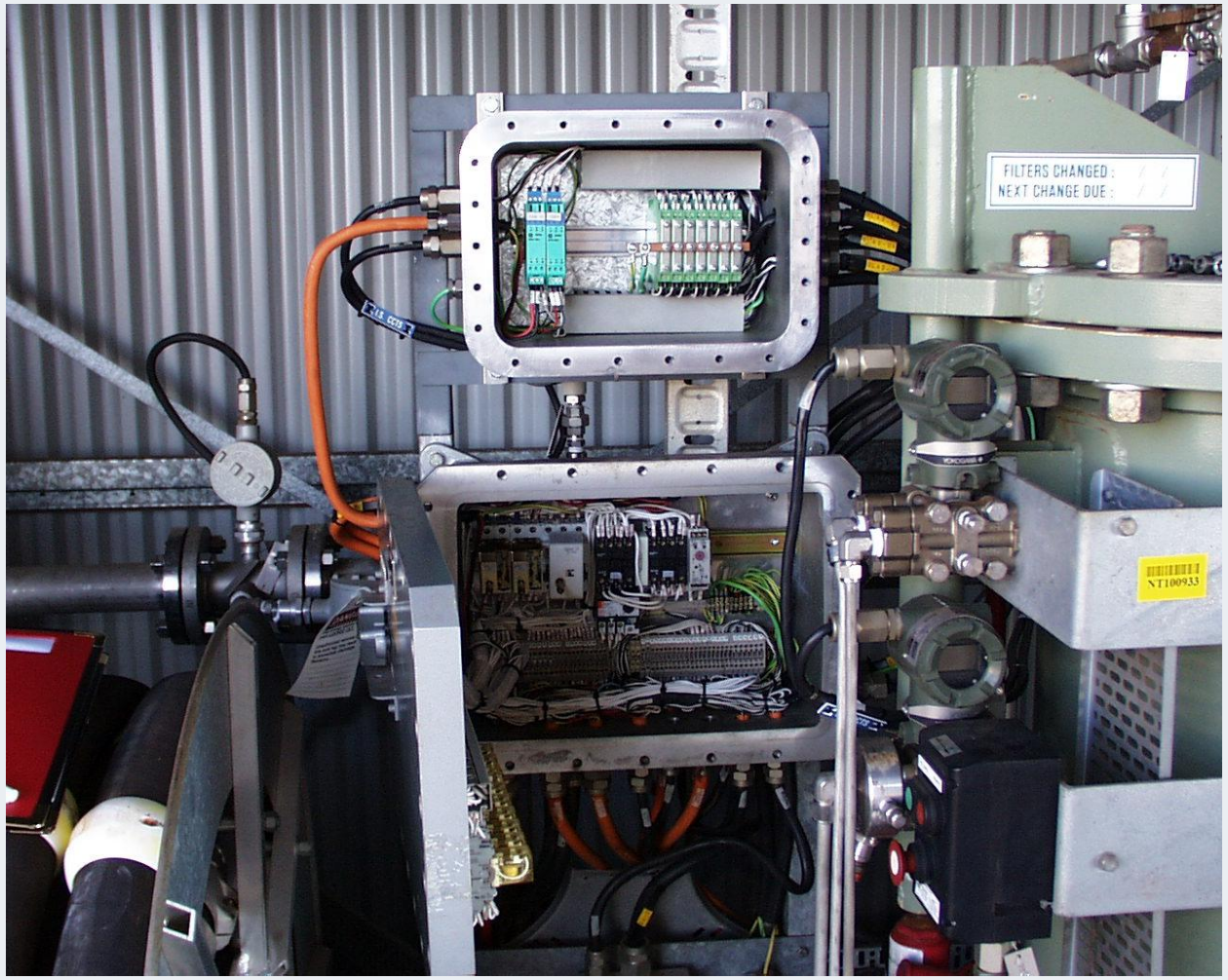
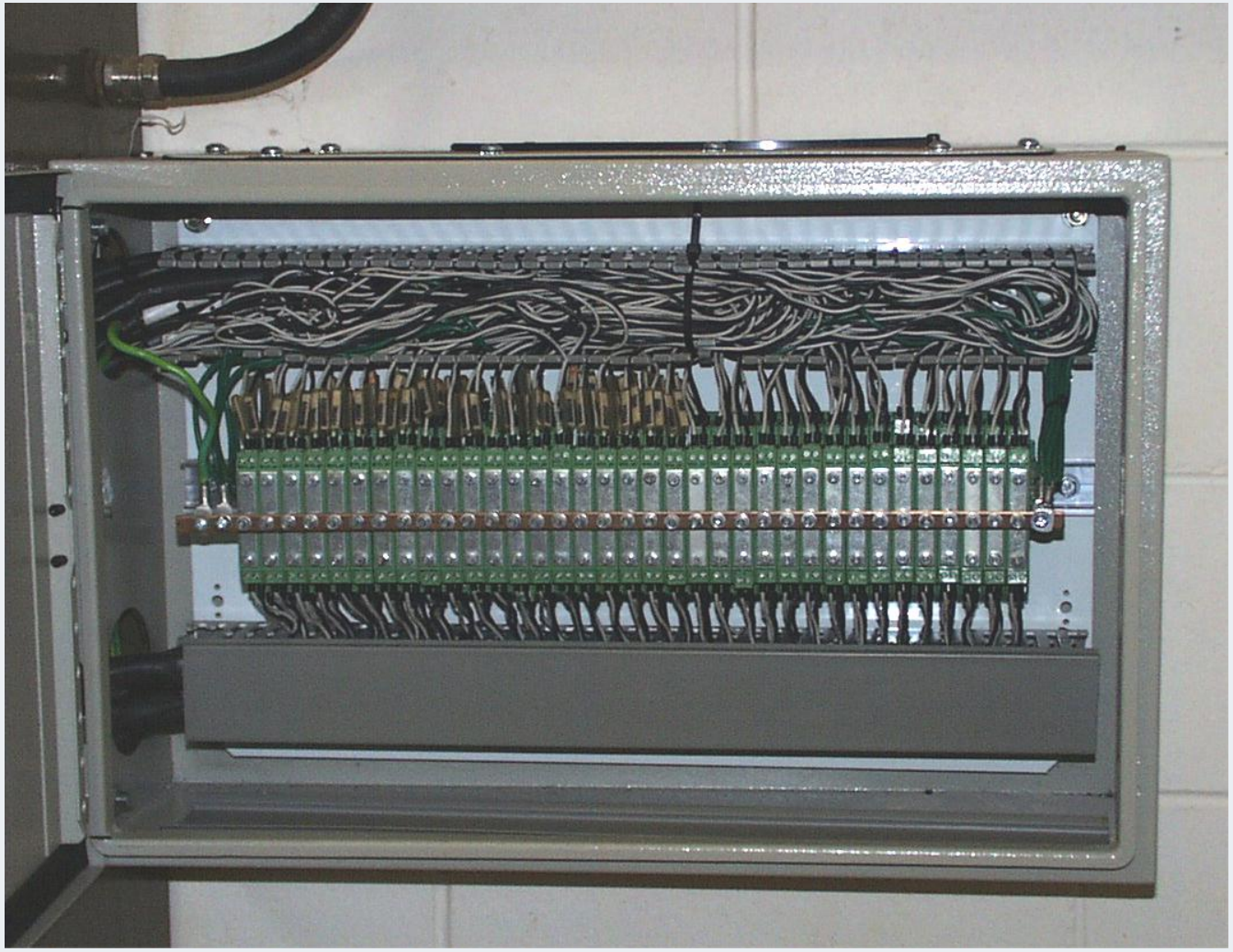
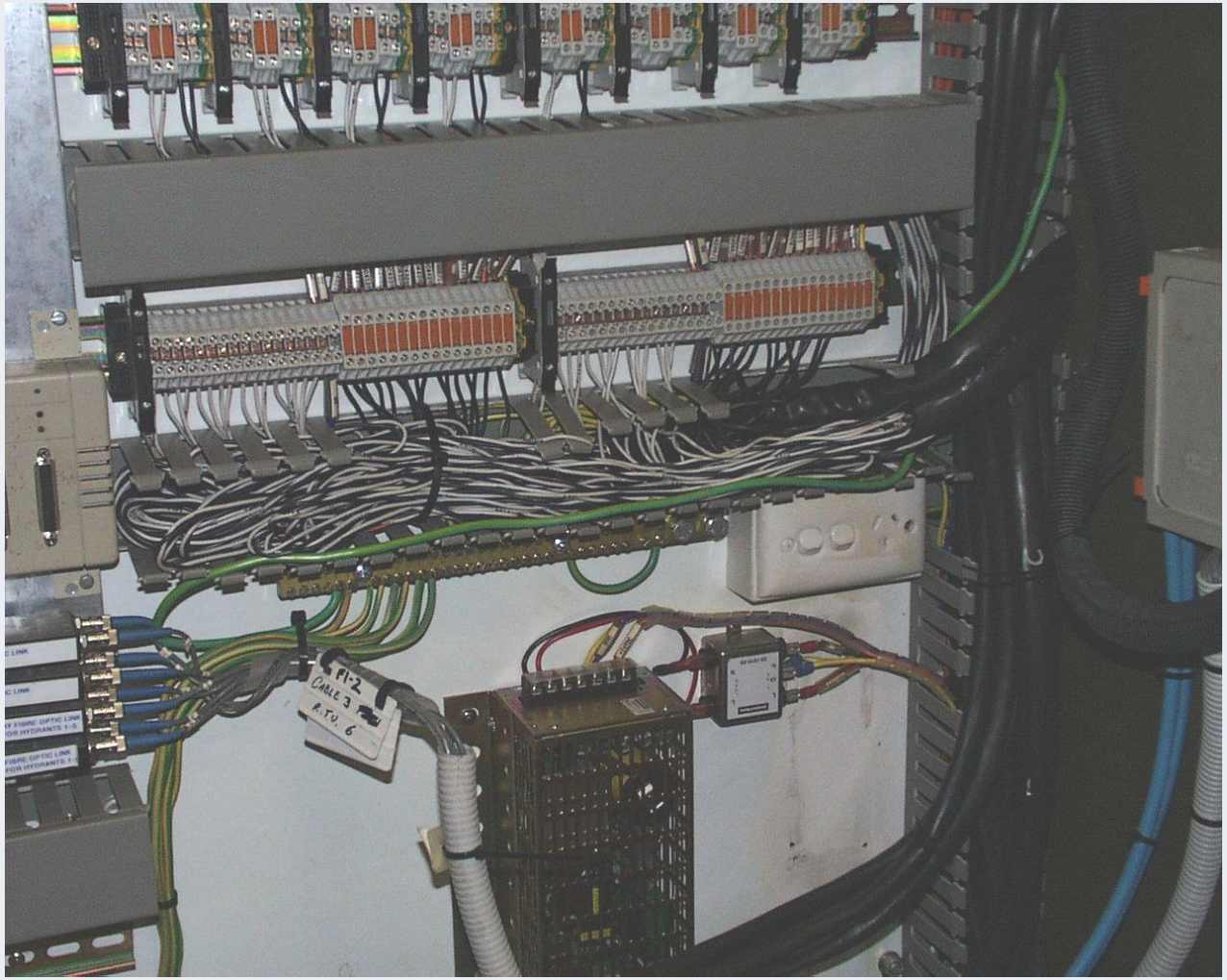


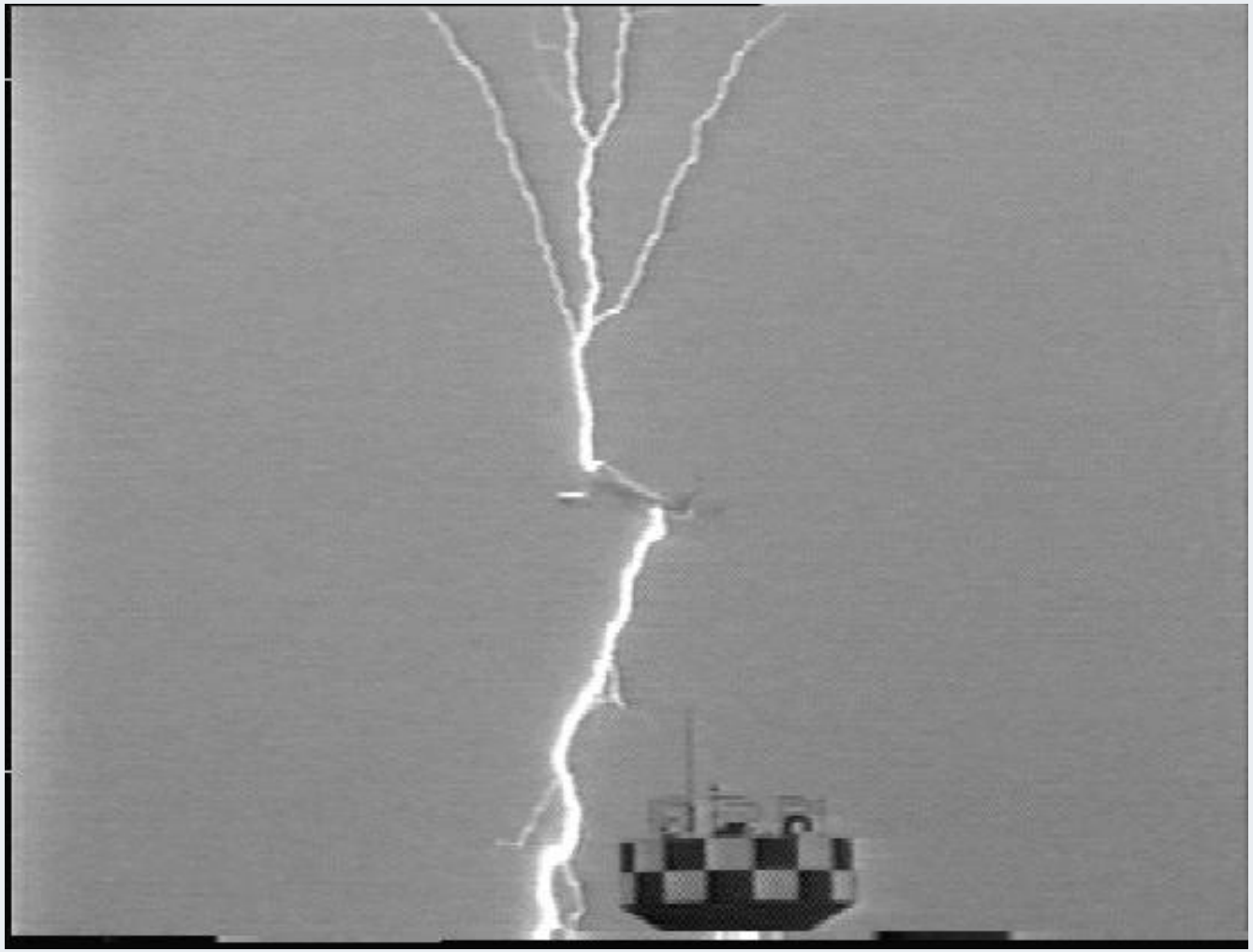
Incorrect practice: Surge arrester earthing introduces surges again into wiring



Incorrect practice: Surge arrester earthing introduces surges again into wiring



Incorrect practice: Surge arrester earthing introduces surges again into wiring



Interest: Plane hit by lightning

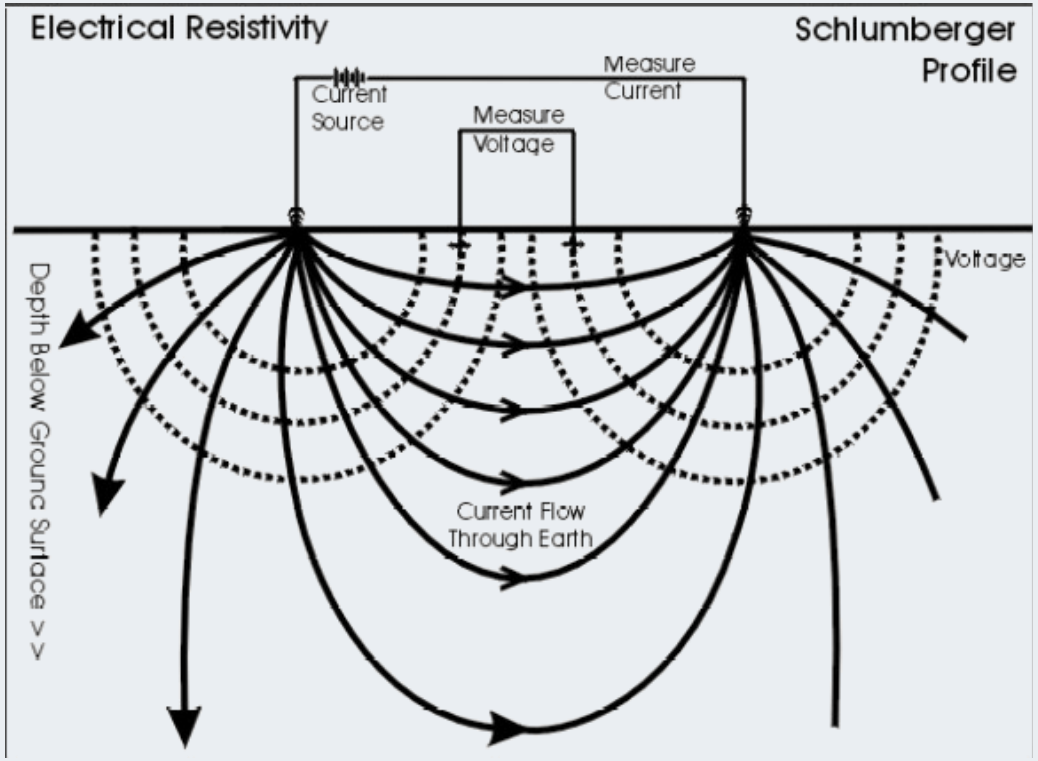
4. Introduction to Earthing/Grounding

Design Requirements:

- Reliable operation of protection systems
- Personnel, public and plant safety

Other Considerations:

- Practical
- Constructible
- Maintainable
- Cost effective

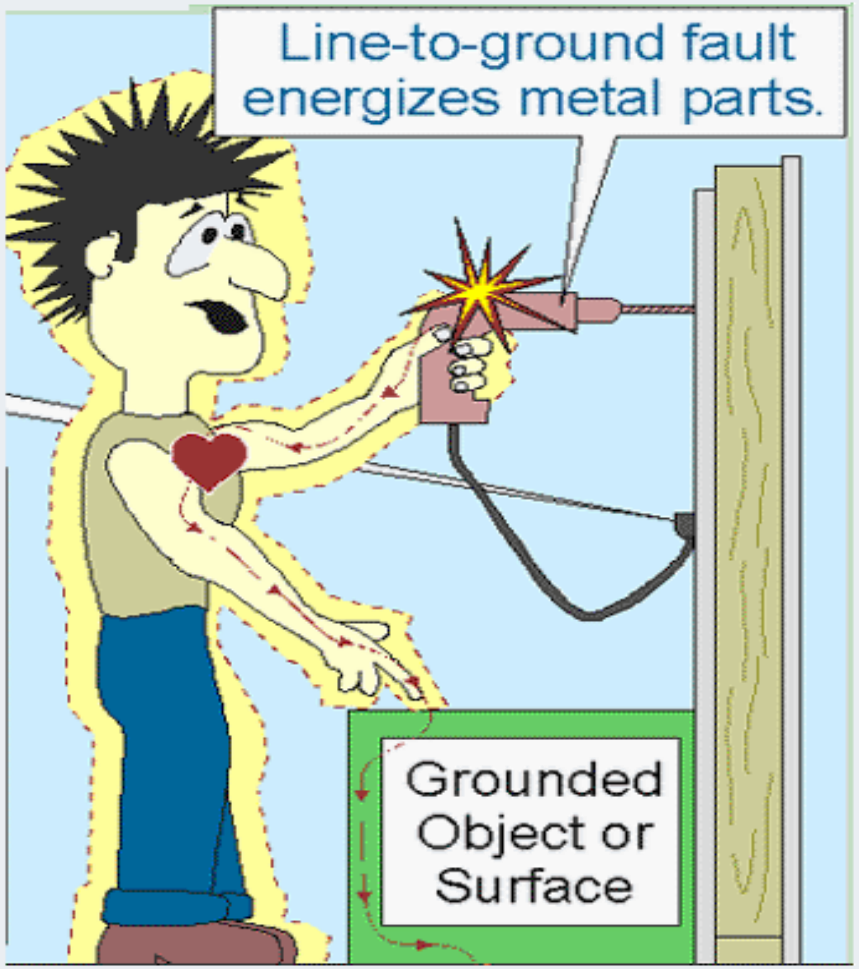


3.0 Earthing/Grounding

Need for Earthing

The primary goal of earthing system is SAFETY.

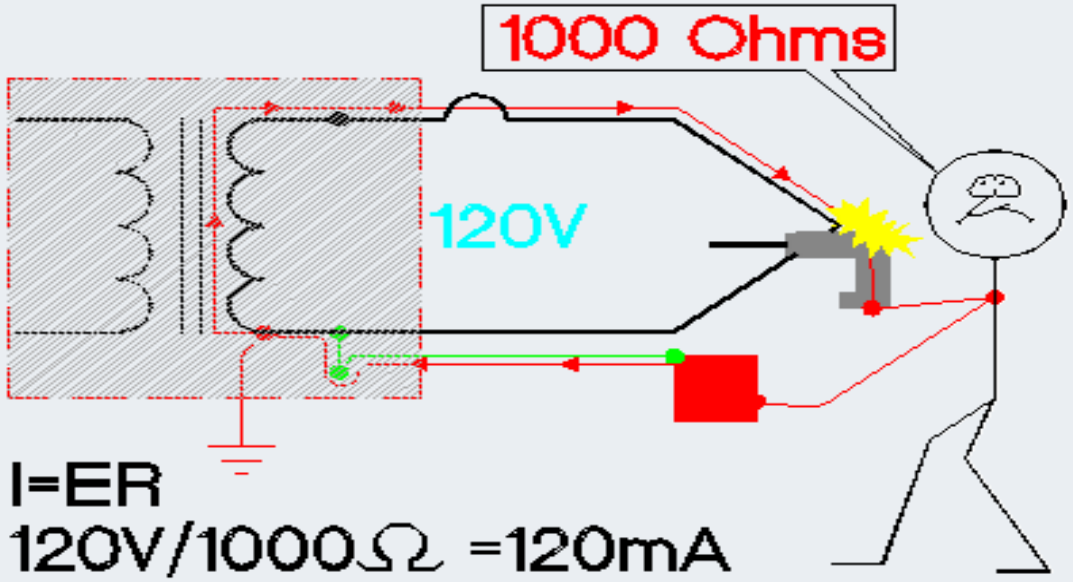
Secondary goals are effective lightning protection, diminishing electromagnetic coupling (EMC), and the protection against electromagnetic pulses (EMP).



Need for Earthing

Earthing reduce the risks of fires and personnel injuries.

To provide a low impedance route for high frequency leakage currents.



Introduction (continued)

Earthing requires a specific design process:

- Need to accommodate uncertainty in inputs to ensure adequate performance
- Minimizing uncertainty reduces overall cost
- Variations in soil resistivity most significant source of uncertainty
- Site specific soil resistivity test plan required
- Other data to support soil modelling

Theory and Practice

- Soil resistivity is the key factor determining the resistance of the electrode
- Wide variation and seasonal change
- Resistivity largely determined by electrolytes (moisture/minerals/dissolved salts)
- Resistivity of soil changes rapidly with 20% or more moisture content

Ground electrode size and depth

- Resistance of electrode = Resistance of metal electrode + Contact resistance + Resistance of soil
- Increasing diameter of rod doesn't reduce resistance
- Doubling the rod length reduces resistance by up to 40%
- Multiple parallel electrodes reduce resistance but not dramatically less
- R_g (Rod) Ohms = ρ (ohm-cm)/298 cms for 3m rod by 16mm diameter

Current Loading capacity

Earth can dissipate high currents for short durations

Serious heating and vaporisation of moisture can occur with *smoking*

$I = 1140 \times d / \sqrt{\rho \times t}$

Where I = max current in A/m

d = rod diameter in mm

ρ = earth resistivity in ohm-cm

t = seconds

Question

Why is crushed rock spread all over the surface of the soil within a substation grid area ?

For housekeeping reasons perhaps ?

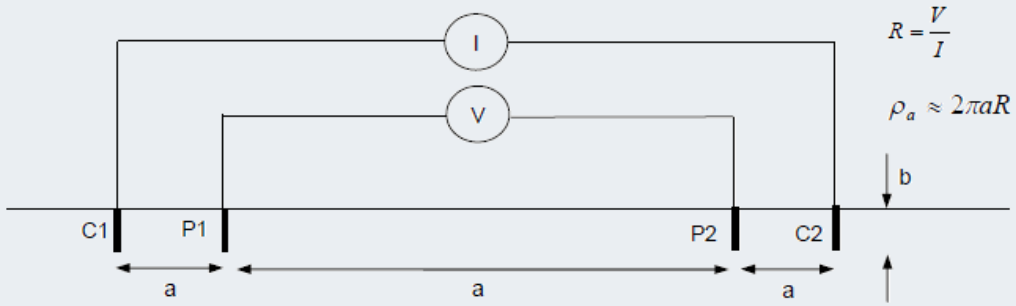
Suggested Answer

The crushed rock provides a high resistance surface to reduce the hazard from a step potential to persons within this area during a severe fault. Granite rock, even when wet from rain, has a high insulation resistance of 4.5×10^5 ohm-cm when wet.

Soil Resistivity Test Methods

Wenner Method

Test Details	
Location	Feeder 7W4 Pole 8A
Date	04/11/2009
Time (start)	14:50
Time (finish)	15:20
Test Conditions	Warm, cloudy, no rain
Method	Wenner
Test Setup	
Instrument	AEMC 6471 Digital Ground Tester
Max. voltage	32V
Max. current	200mA
Frequency	128Hz
Measured Data	



$$R = \frac{V}{I}$$

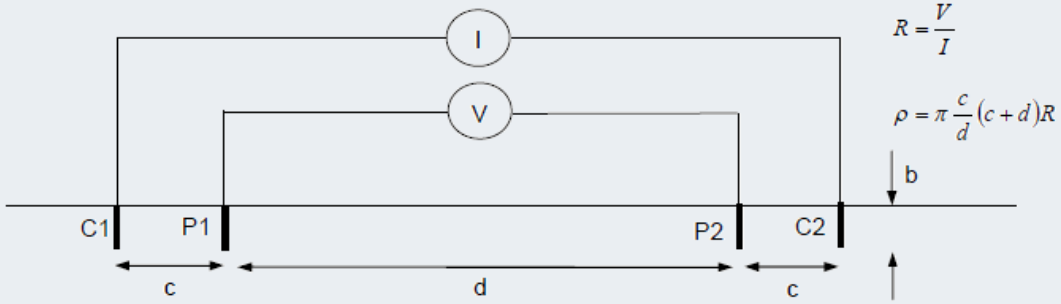
$$\rho_a \approx 2\pi a R$$

a [m]	b [m]	R [m]	ρ_a [Ω.m]
0.5	0.025	9.26	29.1

Soil Resistivity Test Methods

Schlumberger Method

Test Details	
Location	Between Wondabyne Station and Pole 51 (feeder 832)
Time (start)	13:00
Time (finish)	14:00
Test Conditions	Warm, sunny day, no rain
Method	Schlumberger
Test Setup	
Instrument	Fluke 1625 GEO Earth Tester
Max. voltage	48V
Max. current	50mA
Frequency	128Hz
Measured Data	



$$R = \frac{V}{I}$$

$$\rho = \pi \frac{c}{d}(c+d)R$$

b [m]	c [m]	d [m]	R [m]	ρ [Ω.m]
0.025	0.5	0.5	52.60	162.3
0.05	1	1	23.20	146.1

Soil Resistivity Test Plan

Main constraints:

- Physical site constraints (barriers, rivers etc)
- Buried metal services and structures
- Limited site access
- Private/public land access restrictions

Electrified rail corridors have significant constraints:

- Hazards (trains)
- Shared services corridors

Soil Resistivity Test Plan

Input Data

- DBYD (Dial-before-you-dig) and site surveys
- Construction data for buried services
- Geotechnical data
- Meteorological data

Three Case Studies Presented

- Using geotechnical input data
- Accommodating probe spacing restrictions
- Influence of buried services

Question

What is a transferred earth potential and how does one deal with it at a substation ?

Suggested Answer

EPR of a substation can be ~5000 V, which can be transferred to a non-fault location by a ground conductor (metal pipe, rail).

Bond together ground mats (30m to 90m) and use isolation transformers

5.0 Case Studies in Earthing/Grounding

Case Study 1

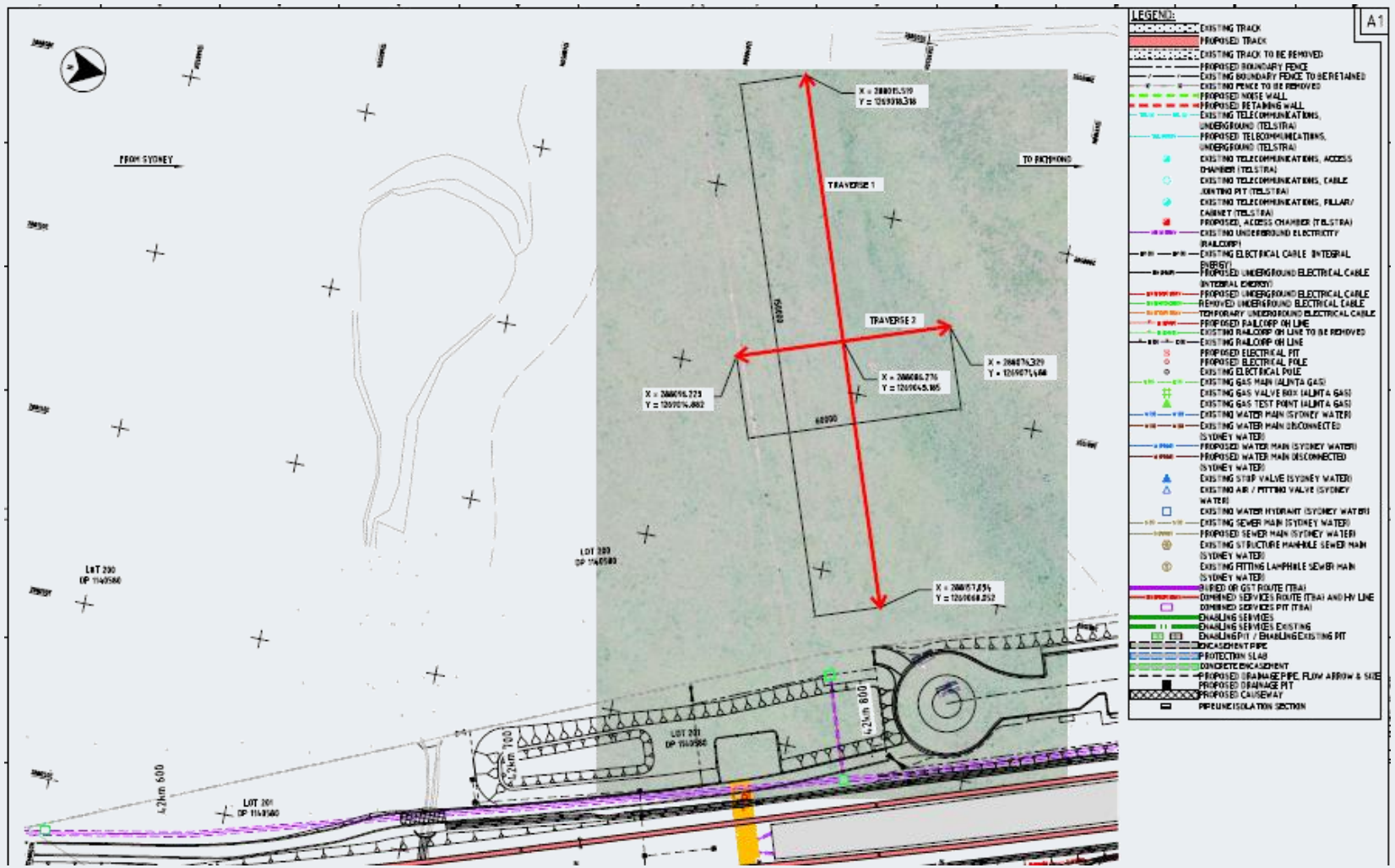
Project description:

- 5km duplicated track Western Sydney
- New traction substation
- New passenger station with 11kV supply
- Upgraded signalling supply at two existing stations

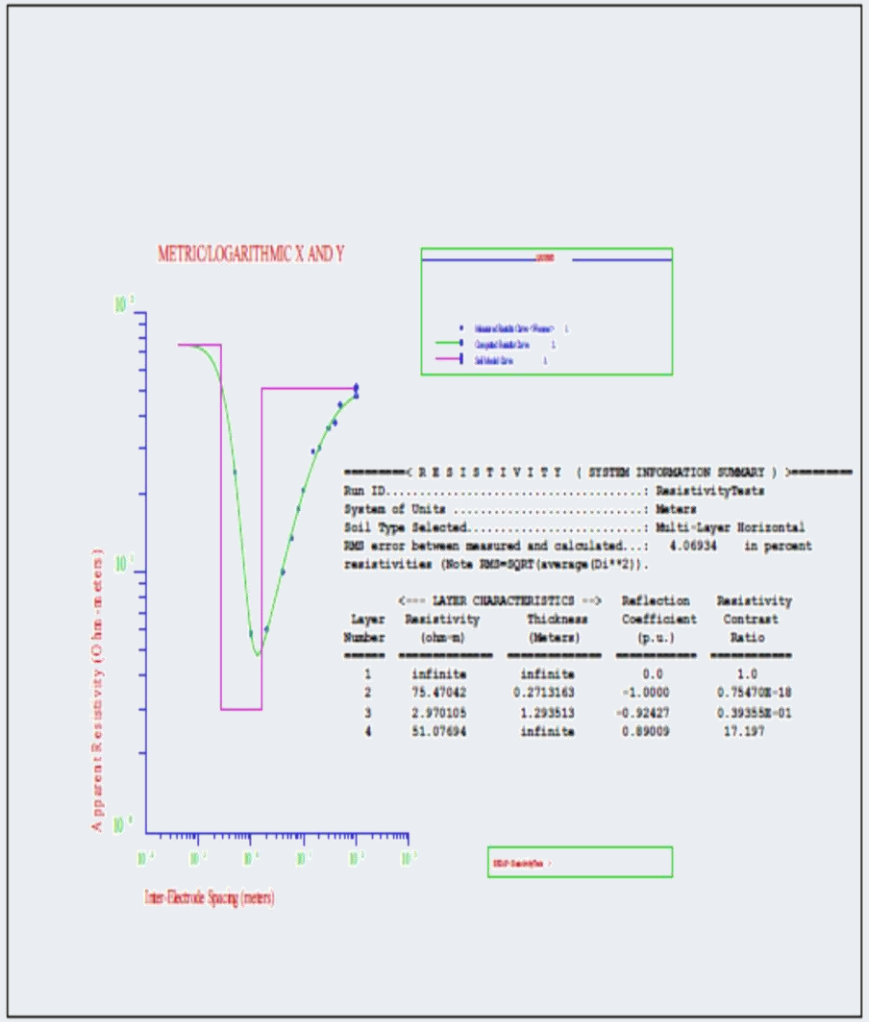
Data available:

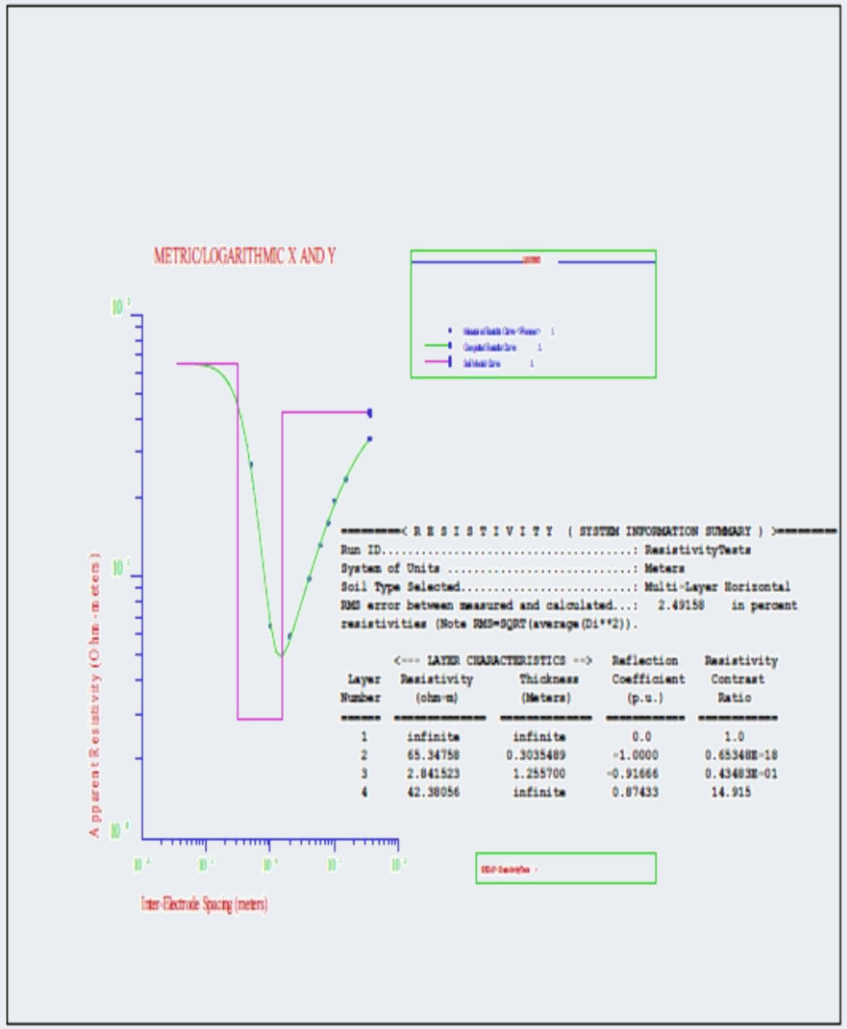
- Geotechnical data / reference material
- NSW Earthing Handbook

Case Study 1



Case Study 1


METRIC/LOGARITHMIC X AND Y
Apparent Resistivity (Ohm-meters)
Inter-Electrode Spacing (meters)
========< R E S I S T I V I T Y (SYSTEM INFORMATION SUMMARY) >========
Run ID.....: ResistivityTests
System of Units .....: Meters
Soil Type Selected.....: Multi-Layer Horizontal
RMS error between measured and calculated...: 4.06934 in percent
resistivities (Note RMS=SQRT(average(Di**2)).
<=== LAYER CHARACTERISTICS ==> Reflection Resistivity
Layer Number | Resistivity (ohm-m) | Thickness (Meters) | Coefficient (p.u.) | Contrast Ratio
1 infinite infinite 0.0 1.0
2 75.47042 0.2713163 -1.0000 0.75470E-18
3 2.970105 1.293513 -0.92427 0.39355E-01
4 51.07694 infinite 0.89009 17.197


METRIC/LOGARITHMIC X AND Y
Apparent Resistivity (Ohm-meters)
Inter-Electrode Spacing (meters)
========< R E S I S T I V I T Y (SYSTEM INFORMATION SUMMARY) >========
Run ID.....: ResistivityTests
System of Units .....: Meters
Soil Type Selected.....: Multi-Layer Horizontal
RMS error between measured and calculated...: 2.49158 in percent
resistivities (Note RMS=SQRT(average(Di**2)).
<=== LAYER CHARACTERISTICS ==> Reflection Resistivity
Layer Number | Resistivity (ohm-m) | Thickness (Meters) | Coefficient (p.u.) | Contrast Ratio
1 infinite infinite 0.0 1.0
2 65.34758 0.3035489 -1.0000 0.65348E-18
3 2.841523 1.255700 -0.91666 0.43483E-01
4 42.38056 infinite 0.87433 14.915

Case Study 1

Location	GPS	Layer	Resistivity[Ω·m]	Thickness[m]
Quakers Hill Station (test 2)	X = 289277.485 Y = 1266561.495	Top	105	0.4
		Middle	4	4.5
		Bottom	66	∞
Relocated Schofields Station (test 3 & 4)	X = 288086.276 Y = 1269043.185	Top	76	0.3
		Middle	3	1.3
		Bottom	42	∞
Reycroft (midway) (test 1)	X = 288086.276 Y = 1269043.185	Top	49	0.5
		Middle	16	10.5
		Bottom	48	∞
New Schofields Substation (test 5)	X = 288086.276 Y = 1269043.185	Top	48	0.3
		Middle	3	1.3
		Bottom	42	∞

Case Study 1

Very low resistivity clay aquifer

Resistivity and geotechnical test data correlation

100% increase in resistivity used in initial designs – soil drying

Additional soil testing and verification testing indicated no soil drying

Final earthing design conducted without soil resistivity testing

Question

Why is galvanic corrosion a problem for electrodes and how does one deal with it ?

Suggested Answer

Galvanic corrosion caused by electrically connected dissimilar metals to form a galvanic cell. Copper (usually used for rods) can seriously damage underground structures such as iron or steel that are electrically connected.

Use a different metal to copper (something closer to iron, say)

Case Study 2

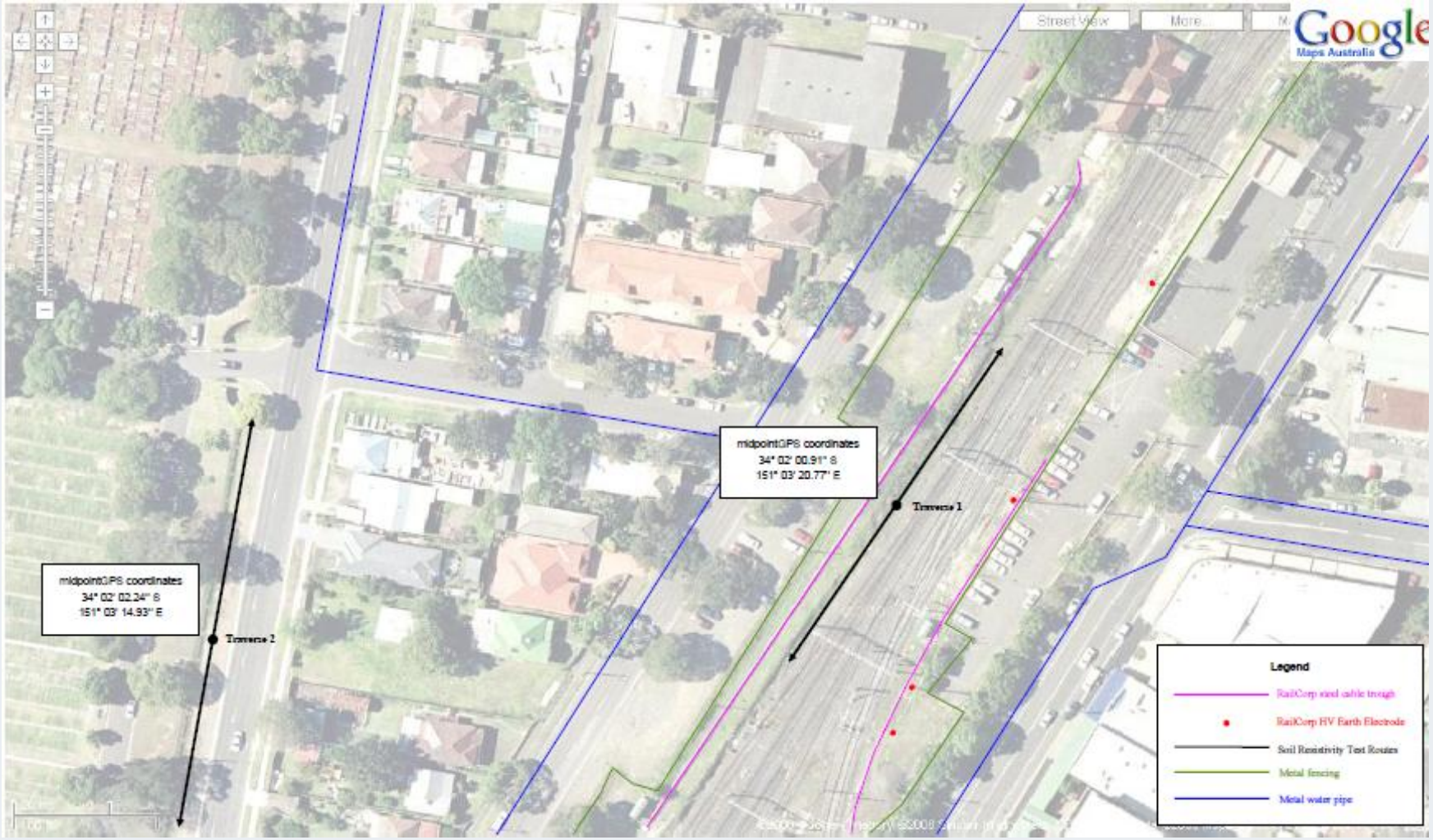
Project description:

- Signalling upgrade project in southern Sydney
- New padmount substation
- UGOH pole near traction substation
- UGOH pole near signalling equipment

Data available:

- Services layout
- Geotechnical data

Case Study 2


Street View
More...
Google
Maps Australia
midpointGPS coordinates
34° 02' 00.91" S
151° 03' 20.77" E
Traverse 1
midpointGPS coordinates
34° 02' 02.34" S
151° 03' 14.93" E
Traverse 2
Legend
RailCorp steel cable trough
RailCorp HV Earth Electrode
Soil Resistivity Test Routes
Metal fencing
Metal water pipe

Case Study 2

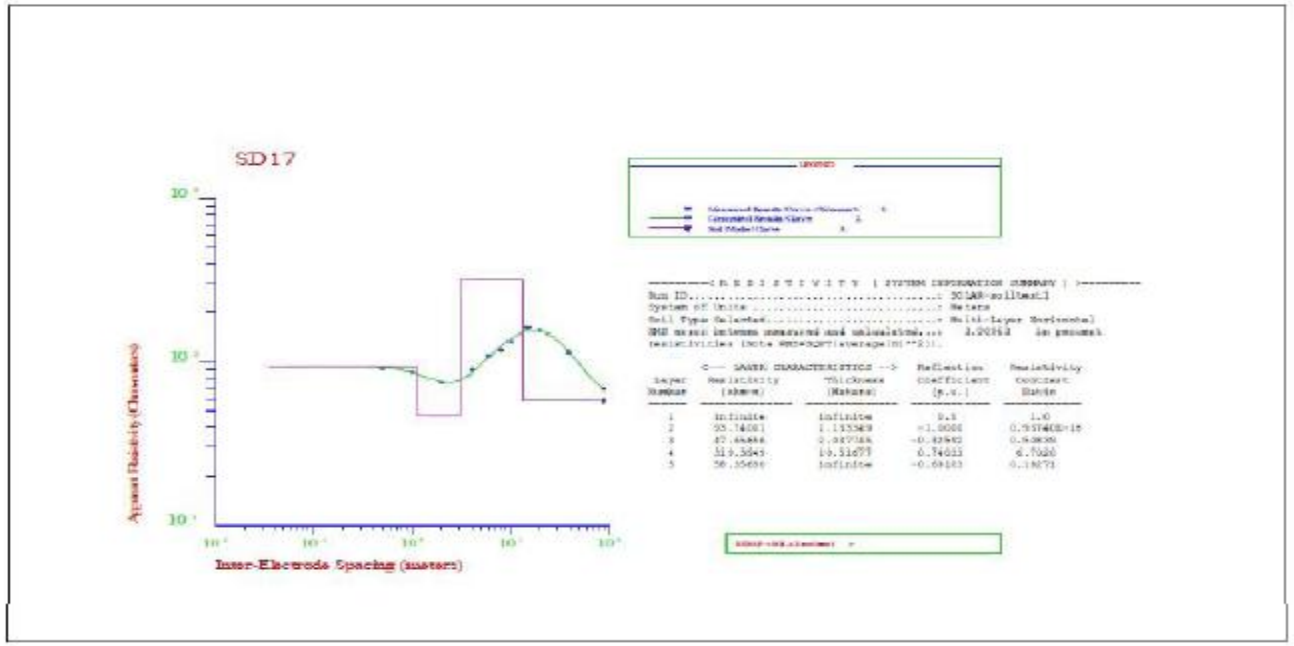


Figure 6: RESAP report for soil resistivity test traverse for case study 2

Location	GPS	Layer	Resistivity [Ω·m]	Thickness [m]
SD17	34° 01' 41.38" S 151° 03' 33.87" E	Top	98	1.13
		Middle 1	48	2.04
		Middle 2	319	10.5
		Bottom	58	∞

Case Study 2

Wenner method with probe spacing of 40m (space limitations)

18m vertical electrode to penetrate bottom layer (insulated from top layer)

Critical design parameters = depth and resistivity of the bottom soil layer

Case Study 2

Results and Learnings

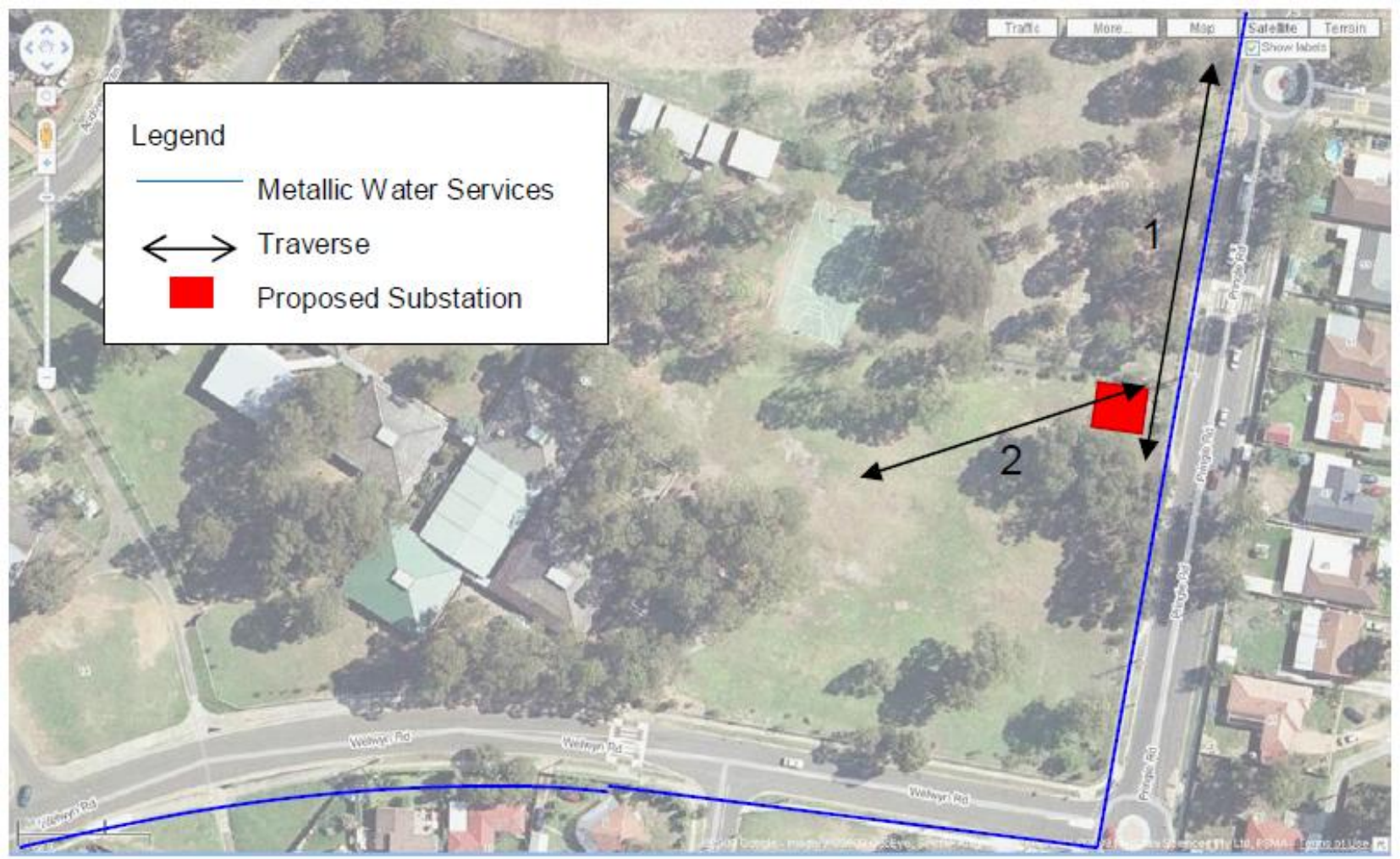
Traverse location/extent appropriate

Plot measured data at time of measurements

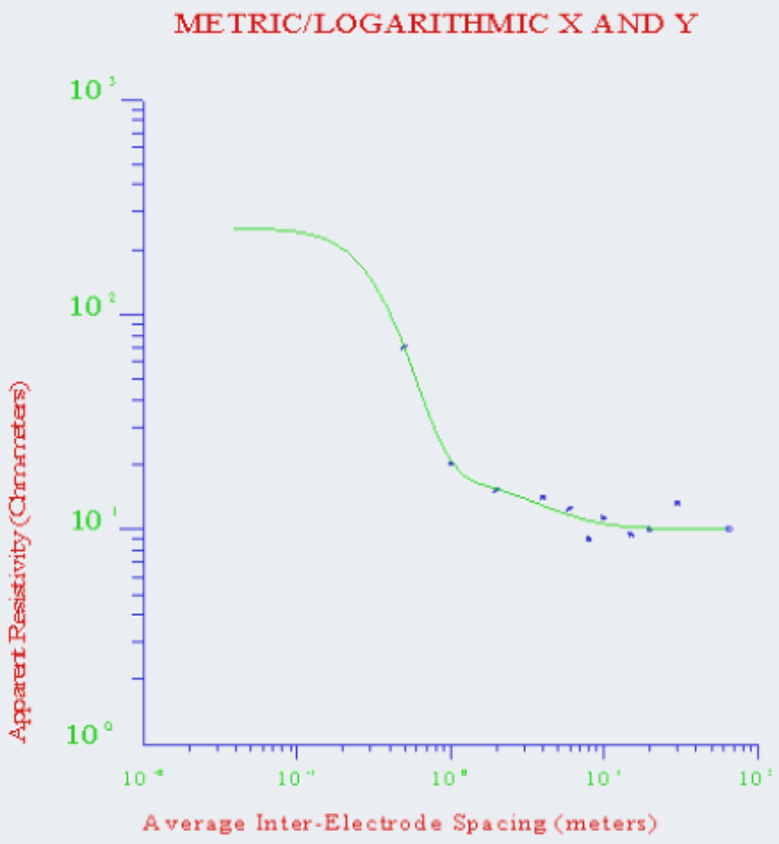
Identify critical design parameters from plotted data and refined probe spacing between 15m and 40m

Better interrogated depth and resistivity of the bottom soil layer

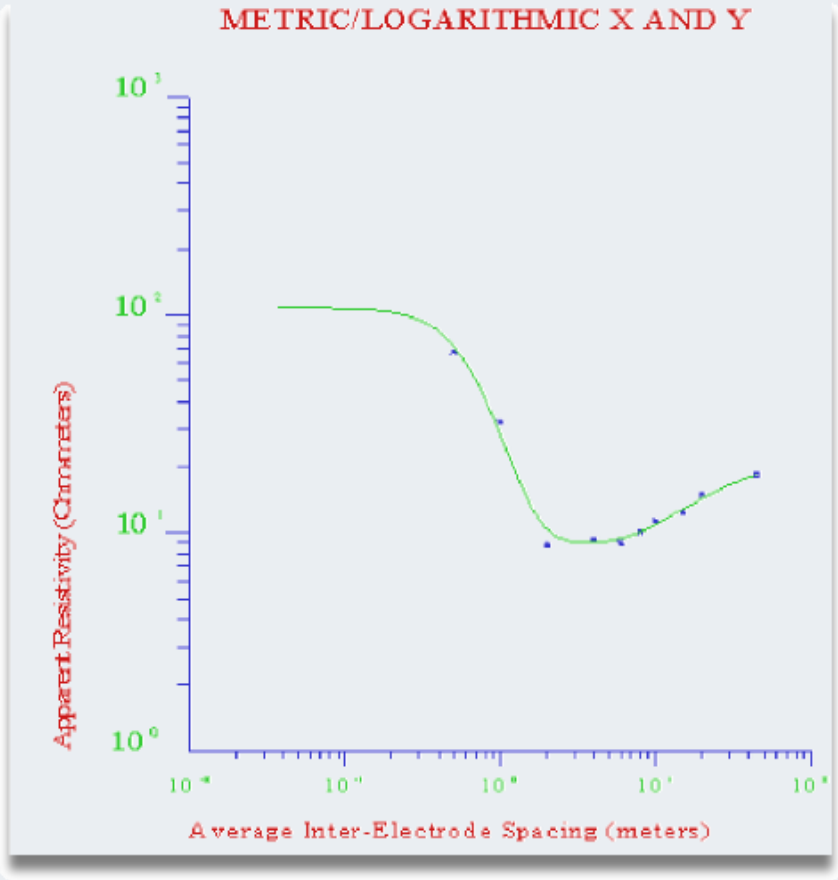
Case Study 3


Legend
Metallic Water Services
Traverse
Proposed Substation
1
2

Case Study 3



Traverse 1



Traverse 2

Case Study 3

Traverse	Layer	Soil Resistivity [Ωm]	Depth [m]
1	Upper	252	0.24
	Middle	16	2.18
	Underlying	10	Infinite
2	Upper	89	0.56
	Middle	4.6	1.89
	Underlying	14.8	Infinite

Water pipeline parallel to main test traverse interfered with test data (lower middle & bottom layer resistivity)

6. Conclusions

Variations in soil resistivity are most significant source of uncertainty

Effective design must accommodate uncertainty = cost effective

Comprehensive test plan required

- Identify site constraints
- Make use of other available data
- Plot data during measurements

Q&A

Wrap Up

Acknowledgements

- The first section on lightning & surge protection is copyright and courtesy of Cobus Strauss of RDW Electrical Engineering
- The second section on earthing is copyright and courtesy of Rodney Urban of AECOM (from a paper: Accurate Soil Resistivity Testing for Power System Earthing

Thank You!

Upcoming Courses

Engineering College of Technology (ECT) *UK-Recognised Qualifications*	Start Date
Bachelor of Engineering (Honours) in Industrial Automation	16 February 2026
Bachelor of Engineering (Honours) in Electrical Engineering	16 February 2026
Master of Science (Power System Analysis and Renewable Integration)	9 February 2026
Master of Science (Industrial Automation and Instrumentation Control)	9 February 2026

Certificate of Attendance

To receive your digital certificate of attendance for participating in this webinar, please fill out the form and survey here (or scan the QR Code):

https://forms.office.com/r/j6P8gi7wvs

Q & A

Contact Us:

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www.ect.ac.uk

Courses
https://www.ect.ac.uk/programmes/

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