VEC Resource Manual

July 2014
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1 Definitions and Abbreviations

1.1 Definitions

Definitions are in accordance with the Electricity Safety Act 1998, the Electricity Safety (Cathodic Protection) Regulations 2009 and the Australian Standard “Cathodic protection of Metals - Part 1Pipes and Cables, AS 2832.1:2004”, as amended from time to time.

For the purposes of this manual, the following additional definitions apply –

Area test *“is a co-ordinated monitoring program of all underground metallic structures in the vicinity of a traction substation, which may be affected by the stray currents from the operation of the traction system.”*

Cathodic protection system *“means a prescribed system designed to use direct current to protect metallic structure from corrosion”. This can comprise of a galvanic anode cathodic protection system or an impressed current cathodic protection system.”*

Electrolysis *“is the effect of stray electrical currents on buried metallic structures.”*

Feeder *“is defined as the total length of the feeder cable from the connection to the traction system (substation or rail) to the drainage point at the underground structure.”*

Licensed pipeline “is a pipeline licensed under the (Victorian) Pipelines Act 2005.”

Mitigation system *“means a prescribed system designed to reduce the effects on metallic structures of the leakage of stray electrical currents”. It comprises the feeder cables, the substation equipment and drainage bonds connected to such feeders, installed to minimise the effects of stray traction currents. This includes the TDU, VCDB and/or Direct Current (DC) supplies for VCDBs connected to the system and also the electrolysis box and panel at the structure connection point.”*

Railway *“includes a railway or a tramway and has the same meaning as in section 3(1) of the Rail Safety Act 2006”*

Underground structures *“are metallic objects buried underground, such as water or gas pipes, telecommunication or power cables, metal tanks, etc.”*

1.2 Abbreviations

DB	Drainage bond
ESV	Energy Safe Victoria
TDU	Thyristor drainage unit
TSC	Technical Sub-Committee
VCDB	Variable conductance drainage bond
VEC	Victorian Electrolysis Committee
VECOG	Victorian Electrolysis Committee Operations Group

2 Electricity Safety Act 1998

The Electricity Safety Act 1998 (the Act) was given Royal Assent in May 1998.

Part 2: Section 6(d) of the Act provides that it is one of the objectives of Energy Safe Victoria "to protect underground and underwater structures from corrosion caused by stray electrical currents".

Part 9 of the Act establishes the Victorian Electrolysis Committee (VEC).

Section 91 of the Act defines the composition of the VEC as 8 members representing Energy Safe Victoria, Train operators, Tram operators, Electricity, Water, Gas, Telecommunications and the Oil industries. The Minister appoints these members for a period not exceeding 3 years.

The Minister appoints one of these members to be chairperson of the VEC.

Each member of the VEC may nominate an alternate member, who may act in their place should the member be unable to attend a meeting.

Under section 92 of the Act the functions of the VEC are to:

(a) Establish and maintain standards for systems for cathodic protection and for the mitigation of stray current corrosion; and

(b) Provide advice to Energy Safe Victoria, on any matter related to electrolysis and the regulations relating to cathodic protection and to the mitigation of stray current corrosion, when requested to do so by Energy Safe Victoria; and

(c) Encourage the development of new methods and technology to increase the efficiency of systems for the mitigation of stray current corrosion.

The VEC operates:

- In areas, particularly in the Melbourne metropolitan region, where underground metallic structures are shown to be affected by stray traction currents;
- Where cathodic protection systems are used; and
- Where requested by the public to provide advice on corrosion caused by stray electrical currents.

To assist in this work, Section 94 of the Act requires "a person who is the operator of a railway system must ensure that that system is designed, installed, operated and maintained in such a manner as to minimise the risks to safety of any person and the risks of damage to property arising from the leakage of stray electrical currents from that railway."

2.1 Electricity Safety (Cathodic Protection) Regulations 2009.

Under section 155 of the Act, the Governor in Council may make Regulations for or with respect to:

(a) Standards and requirements for the design, installation and operation of cathodic protection systems and systems for the mitigation of stray current corrosion;

(b) Requiring and regulating the installation, use and maintenance of cathodic protection systems and systems for the mitigation of stray current corrosion;

(c) The registration of cathodic protection systems and systems for the mitigation of stray current corrosion.

The Regulations established from the above clauses are "Electricity Safety (Cathodic Protection) Regulations 2009.

2.2 VEC Code of Practice

The Victorian Electrolysis Committee Code of Practice defines the operating procedures and organisation of the VEC:

- Performance targets for Victorian Electrolysis Committee Operational Group (VECOG), traction operators and structure owners
- Cost sharing arrangements
- Registration of cathodic protection systems process
- Registration of mitigation systems process
- Health and Safety issues relevant to Committee activities
- Testing standards and criteria
- Dispute resolution.

3 Stray current corrosion

3.1 Introduction

Stray current corrosion (usually termed "electrolysis" with reference to buried or submerged metallic structures) presents a special type of corrosion problem.

Stray current corrosion is the damage that occurs when a direct current leaves a structure, such as a railway track and returns to the current source through another structure,

Stray current corrosion differs from natural corrosion in that the damage is caused by an electric current from external sources leaving the grounded metal and is independent of the oxygen concentration of the environment.

3.2 Basics

In this part of the manual, stray traction current corrosion is considered to be corrosion caused by track leakage current from DC powered rail return railway and tramway systems using the running rail as the return conductor.

Stray current corrosion can also be caused by a cathodic protection system that is not appropriately setup and co-ordinated with other structure owners.

The mitigation of stray current effects will only be considered as relating to a single isolated structure. The adjustment of stray current drainage in reality involves multiple structures and can be very complex and must be considered in a manner somewhat analogous to interference testing and adjustment in the commissioning and operation of cathodic protection systems.

Corrosion of a buried metallic structure may occur whenever "conventional" electric current flows from the structure surface and enters the surrounding soil electrolyte. Under such conditions the metal is consumed, eventually leading to inability of the structure to perform its design purpose.

In Melbourne, both the railway and tramway systems are powered by electric direct current systems, utilising an overhead (positive) supply with the track itself serving as the negative return conductor.

As the peak current flowing in this circuit can at times be of the order of 1000A, a volt drop along the rail track can correspondingly reach some tens of volts.

Leakage currents can be up to 10% of the load current, depending upon the many variables, such as soil resistivity, weather conditions, etc.

Leakage currents over typical track lengths between adjoining substations can become quite substantial. It is not uncommon to find peak drainage current requirements of up to 100A or more.

Tests of the railway system show that rail to earth resistance was highly dependent on prevailing weather conditions, ranging from well under 1 ohm/km up to about 10 ohm/km for a twin rail single track system.

The leakage current from the rail results in a positive soil gradient in this region with respect to remote earth. A pipeline intersecting this gradient will become cathodic in this region, resulting in current pick up. This picked-up current may be discharged at a remote point on this or an adjacent pipe, or, as shown in Figure 1, in the relatively negative soil potential region of the track near the traction system substation.

It should be kept in mind that the stray current pick up and discharge zones tend to move along the pipeline as the position of the train (or tram) varies along the track. The discharge zones are generally more fixed near the substation or another structure.

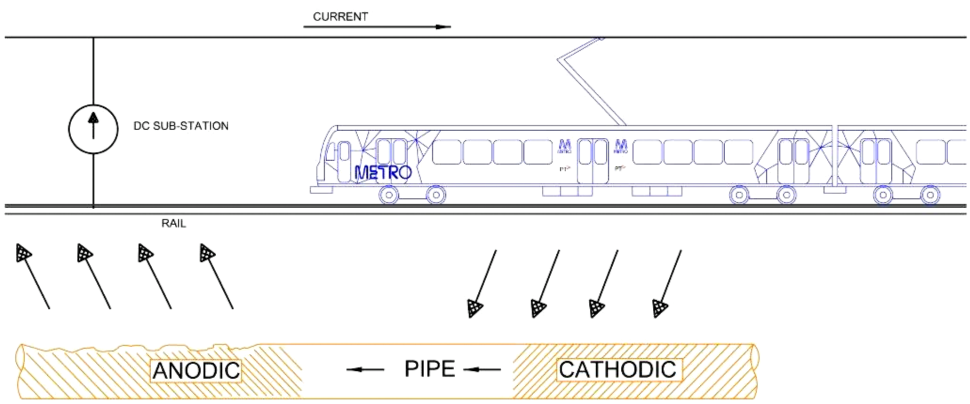


Figure 1 - A schematic diagram illustrating the stray current corrosion problem, showing metal loss occurring at the anodic location on the pipeline.

3.3 Rail to earth voltages

The early traction distribution systems had fewer substations and were spaced further apart, which ensured a substantial negative rail to earth voltage at the substation.

Following the increase in the number of traction distribution systems with a corresponding reduction in feeder lengths since the 1930's, dramatic effects on rail to earth voltages at substations have occurred.

In Tram substations with remote track negative feeders installed, a negative voltage at the negative bus of the substation was able to be maintained, due to the resistor installed in the local track negative feeders as shown in Figure 4.

With the change from Mercury Arc Rectifier to semi conductor Diode Rectifier substations, the characteristic of the load sharing between substations was changed. Higher loading at one substation on a line, resulting from either system demand, higher AC supply voltage or substation outage, can cause a substantial change in positive rail to earth voltages.

With the introduction of regenerative braking on the trams, a dramatic change has occurred on the rail to earth voltages (Refer Fig 2), due to :
(i) Changes to substation loading resulting in reduced negative bus to earth voltages.
(ii) Introduced negative rail to earth voltages when braking, resulting in associated anodic potentials on adjacent underground metal structures, as seen in the chart in Figure 3.

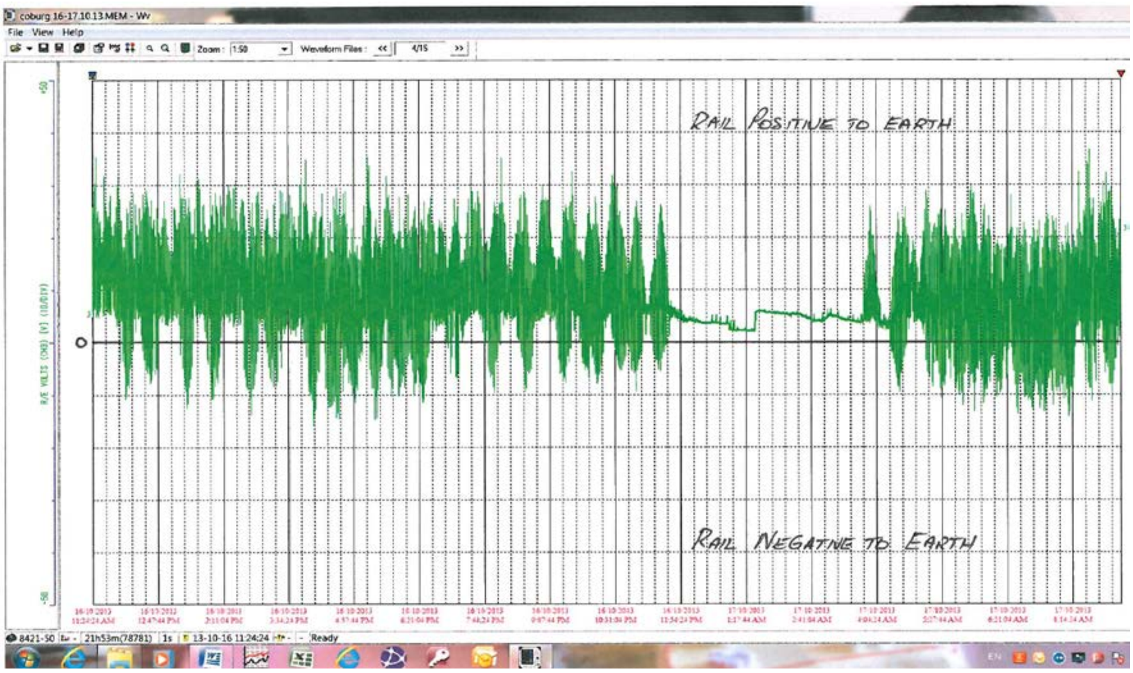


Figure 2 - Chart showing railways rail to earth voltage, including negative excursions due to the regenerative braking trains.

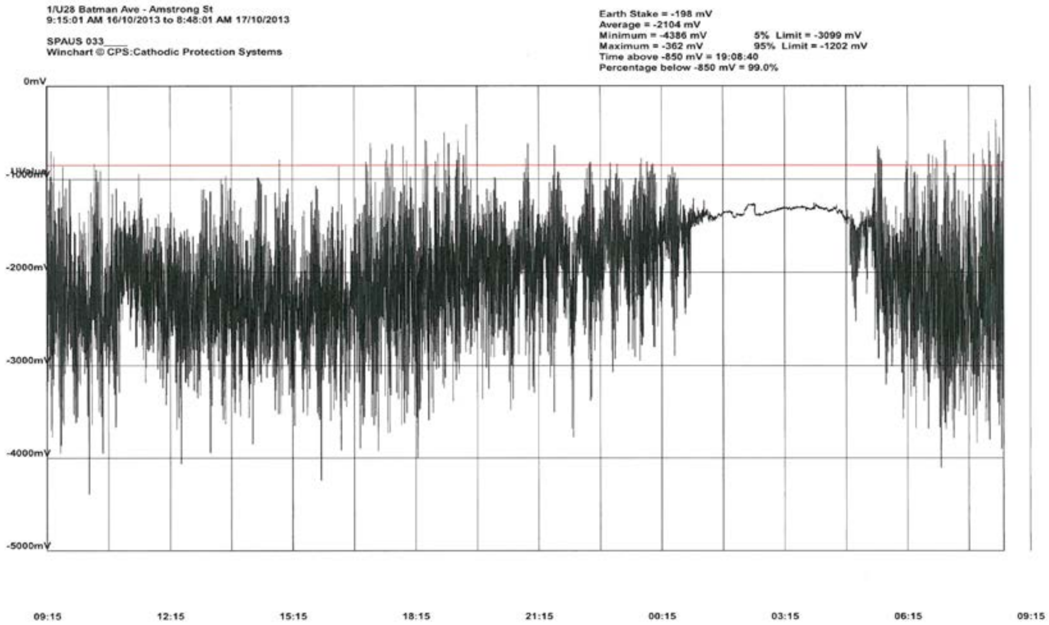


Figure 3 - Chart showing the adverse affects of rail potential on adjacent high pressure gas main.

3.4 Stray current mitigation systems

3.4.1 Straight drainage

In around 1943, it was considered by the Victorian Electrolysis Committee that the mitigative system had to be improved in its efficiency of its operation.

Prior to this it was realised that the bond conductance had to be increased and consequently the copper oxide rectifiers which were in the drainage circuits at the time to prevent discharge of current from the structure when the point of connection at the rail (usually at an impedance bond on railway systems) went positive, were replaced with contactors. These contactors closed when the structure potential to feeder became greater than approximately 13 millivolts positive. At some substations where the rail was significantly negative, the system comprises two elements in the operational circuit - a resistance for adjustment of current magnitude, and a diode to prevent reverse current flow should the rail become positive with respect to the structure. Refer Fig 4.

It was necessary to consider further refinements and it was considered that the difficulties could be overcome by connecting the structure to a point in the rail system where the leakage current had to return. The substation negative bus was the obvious point which would be negative to earth when the substation was supplying load.

Extensive feeder systems were designed and installed at the majority of substations, incorporating Water, Gas and Telephone structures at convenient locations. It was necessary to use contactors at the drainage bonds and copper conductors up to 330 Square Millimetre cross sectional area to reduce voltage drop and improve drainage.

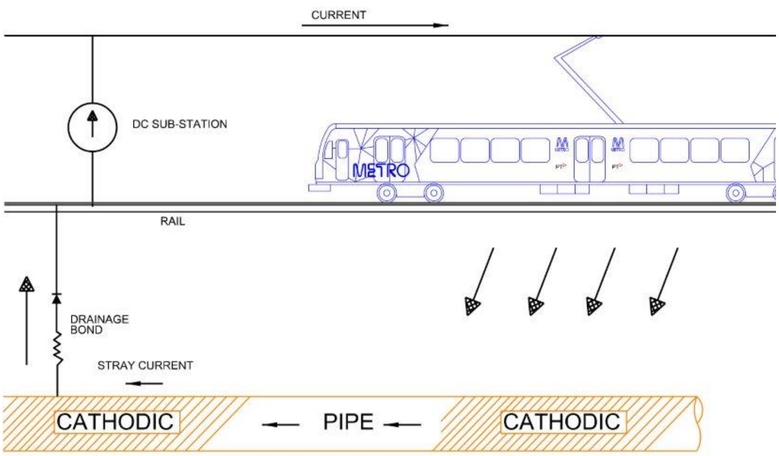
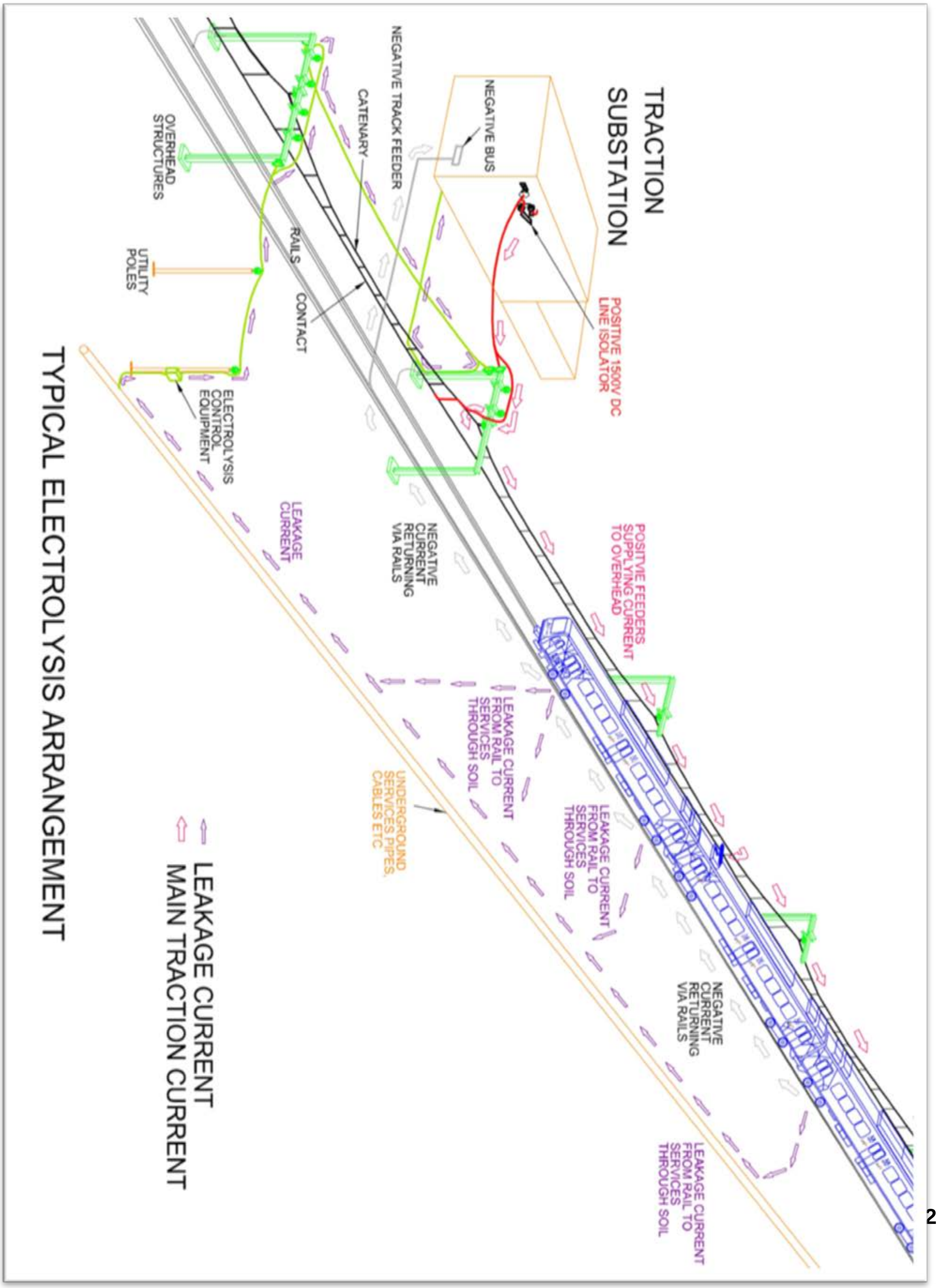


Figure 4 - A schematic diagram of a diode controlled drainage bond



TYPICAL ELECTROLYSIS ARRANGEMENT

3.4.2 Negative resistor

Effective drainage was maintained at Tram Substations with remote track negative feeders and "negative resistors" in the local track negatives. This resistor was adjusted to balance currents in the negative feeders, which resulted in a negative voltage to earth at the substation negative busbar, as shown in Figure 5.

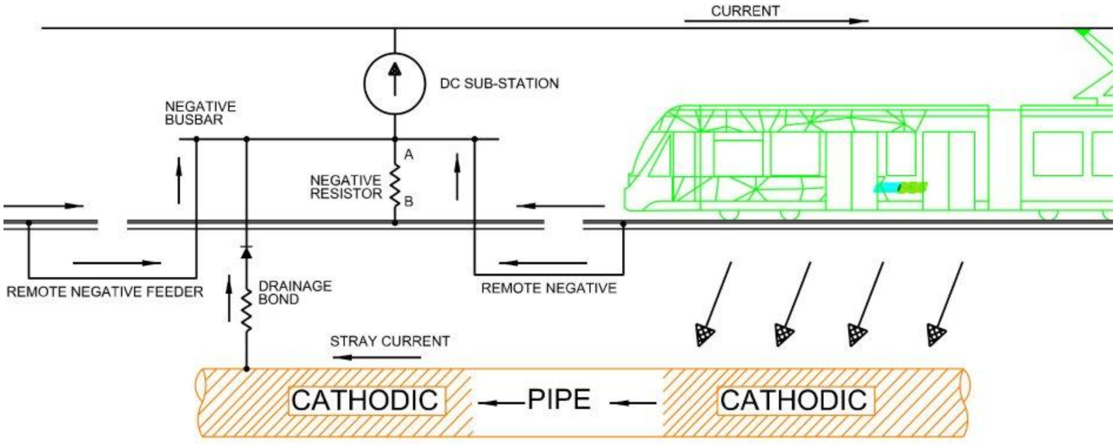


Figure 5 - schematic diagram of a tram substation showing negative resistor, local and remote negatives.

In many instances, stray current mitigation by straight drainage can prove to be impractical, and alternative measures need to be considered. In circumstances where the rail is insufficiently negative with respect to the pipeline or where the resistance of the feeder cable becomes too high due to the cable length required, a system of forced drainage may be used.

In a forced drainage system, current flow is assisted by applying a DC voltage in series with the feeder cable.

3.4.3 Boosted drains

As the drainage system was extended to an increasing number of structures, the current sharing became critical and it was found structures and their connection to rail resulted in a limitation on the drainage current in the drainage cable, consequently, some current leakage still occurred on the underground structure.

Because the conductance of the drainage feeder became inadequate, it was found necessary to install a boost voltage in the system to increase the drain current and hence enable the structure potential to be depressed to a point below the soil line. This was called a "Boosted Drainage Bond".

The boost potential is derived from an AC supply through a step down transformer and rectifier. It gives a constant output except that variations in the rail to earth potential (caused by the potential drop of the return traction current) will modify the amount of boost. It gives rise to circulating current at times of no traction load.

This was actually a cathodic protection system using the rail as the anode. Therefore the boosted drainage bond was two systems combined together, the cathodic protection system and the rail mitigation system, thus the straight drainage current was added to by current supplied from the boost transformer.

As the structures remained substantially at earth potential, there was a rise in the rail potential, not only at the point of correction but also at considerable distances away due to the low longitudinal rail resistance.

The potential that was supplied by the boost then caused a circulating current to occur which flowed in the circuit made up of the rail, earth and the structure connected to rail by the boosted bond. This current in turn altered the potential of the structure in which it flowed with respect to other adjacent structures, consequently causing corrosion effects on those structures.

The boosted bond required careful design to prevent interference to structures which were not included in the scheme, however, it was difficult to achieve this aim and consequently more structures were connected into the boost scheme which then required either more boost units or larger boost units to cater for the effect of more structures.

This process was cumulative and resulted in a continual increase in positive rail potential over the whole traction system. This tended to defeat the purpose of draining back to a negative bus and therefore, as the number of boosts grew, the consequence was that the boost current became as big an interference problem as the stray traction current. The boosts were turned off around 1941 and straight drainage was again employed.

3.4.3.1 Thyristor drainage unit (TDU)

To overcome the reduced effectiveness of the Railway feeder systems and problems associated with the above "Boosted Bonds", it was necessary to introduce forced drainage which is varied in a controlled manner, as shown in Figure 5.

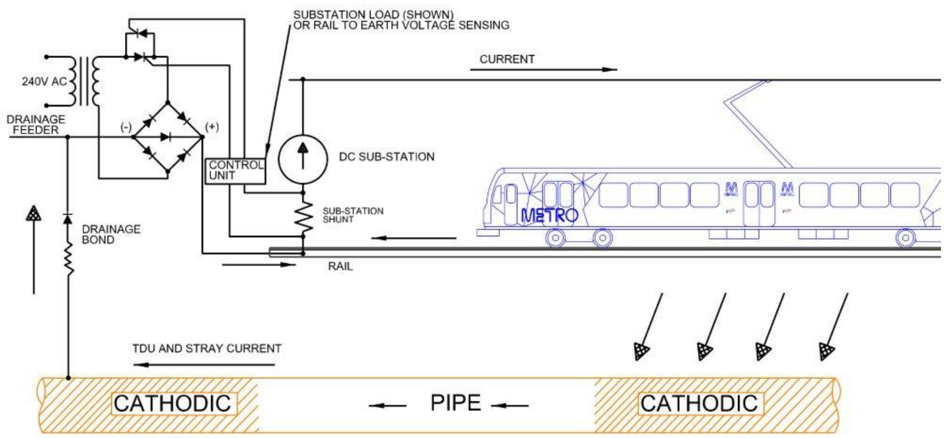


Figure 5 - Typical forced drainage system (substation load sensing).

In most instances, as shown, the voltage is increased in linear proportion to substation load, usually with a small initial offset to counteract the effect of diode forward voltage drop. A typical output characteristic of such a system is illustrated in Figure 7. A typical chart from a structure that is part of a stray current drainage system which incorporates a TDU sensing substation load is shown in figure 6.

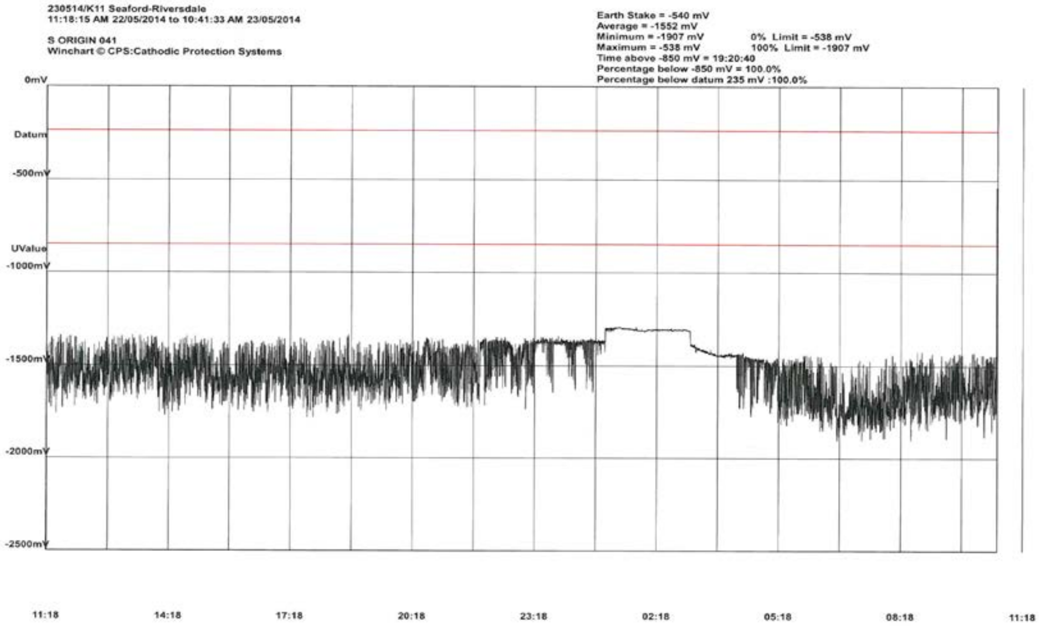


Figure 6 – Typical structure chart showing the results of stray current drainage incorporating a TDU and the effects of the TDU being turned "off" during the quiescent traction period.

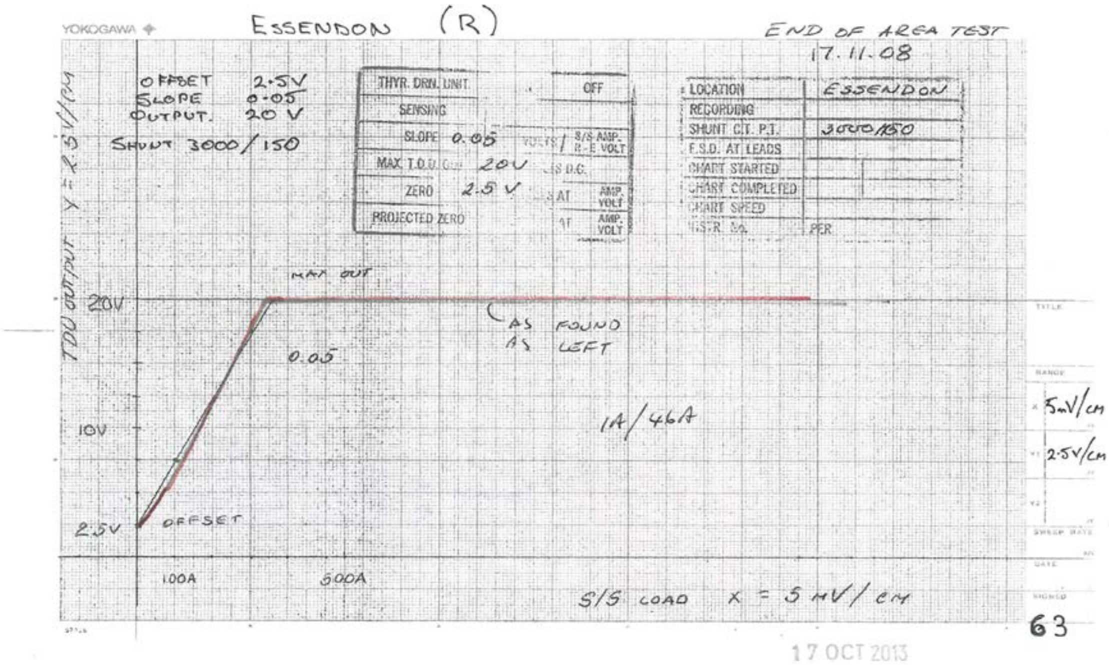


Figure 7 - Typical TDU output curve.

Alternatively, although infrequently used, the voltage may be varied in proportion to the rail to earth voltage.

Regardless of the form of control voltage sensing employed, the series voltage equipment is essentially the same, and is commonly referred to as a "Thyristor Drainage Unit" or TDU.

The TDU basically comprises a transformer rectifier unit, capable of producing over 100A at up to 30V, controlled by Silicon Controlled Rectifiers (SCR's) triggered by a sensing unit operating according to substation load or rail to earth voltage.

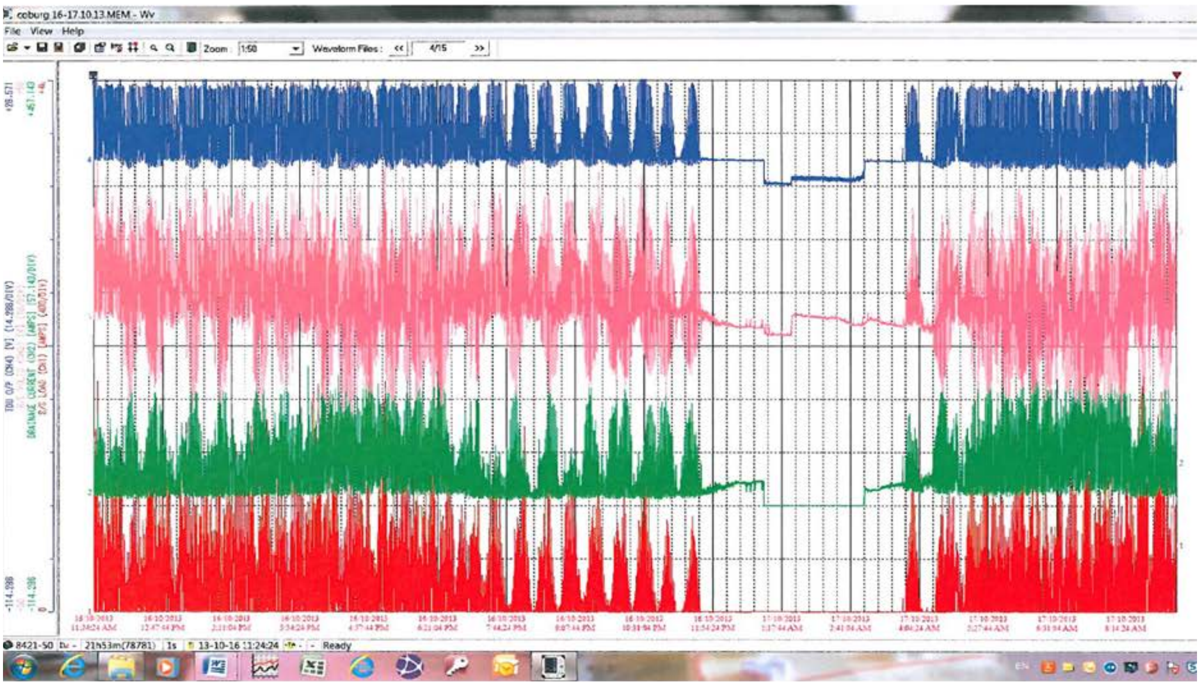


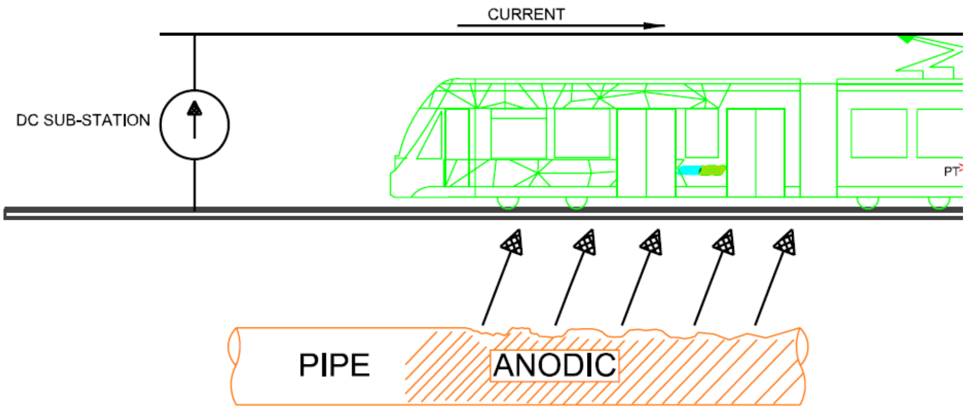
Figure 8 - Chart showing the relationship between substation load, rail to earth voltage, drainage current and TDU output at a railways substation.

3.4.3.2 VCDB with DC supply unit

The introduction of the regenerative braking trams has resulted in anodic conditions on structures which has no correlation with substation load and hence protection provided by the TDU.

With development of the Variable Conductance Drainage Bond (VCDB) by Telecom in 1987 and used in conjunction with a DC Supply Unit, correlation can be achieved.

The Variable Conductance Drainage Bond (VCDB) senses the potential of the structure and varies the resistance of the drainage bond to allow only that current required to remove the anodic potentials to a non traction reference.



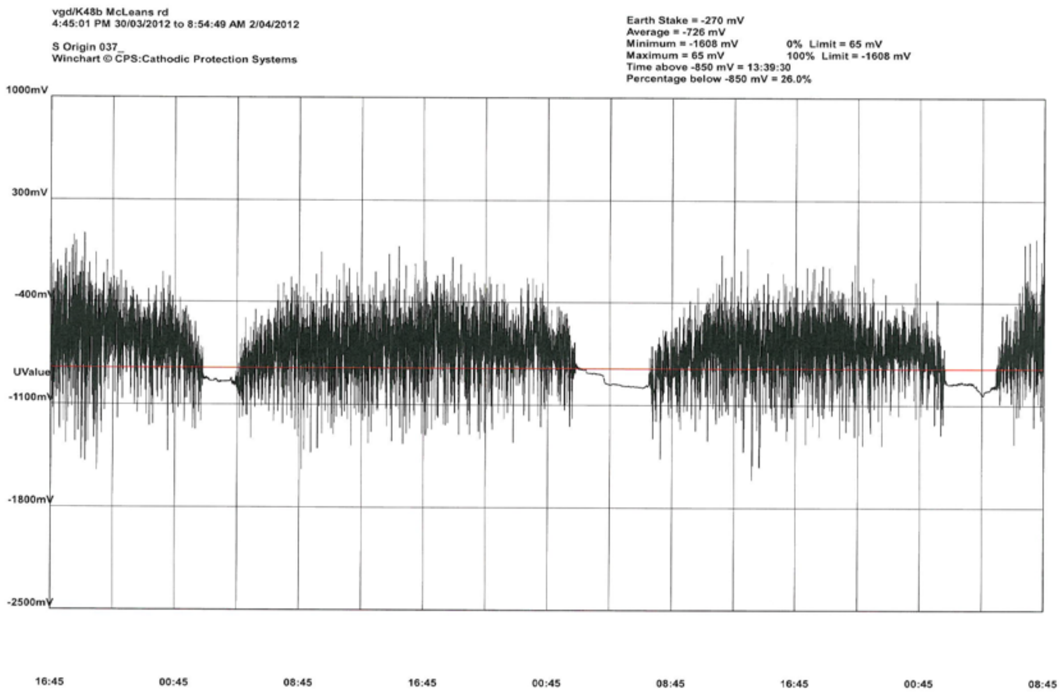


Figure 9 - Shows anodic conditions when tram is using regenerative braking and subsequent anodic structure chart.

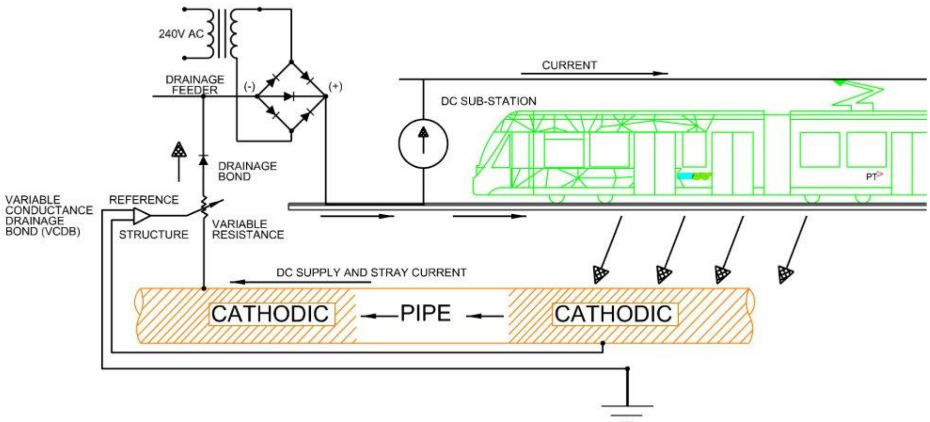


Figure 10 - Shows DC supply unit used with a VCDB

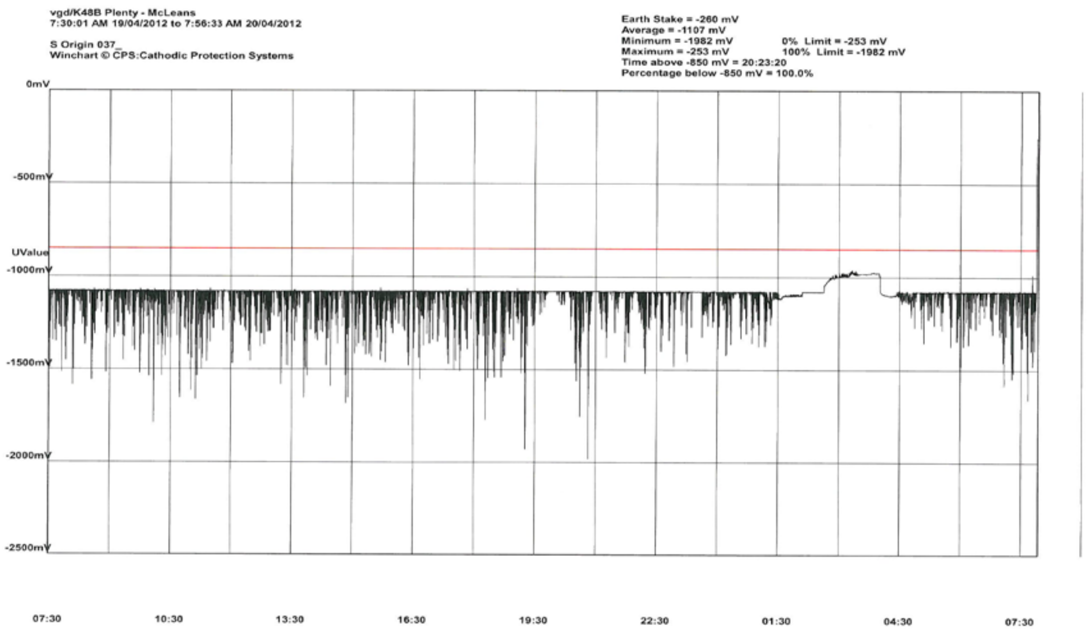


Figure 11 - Typical VCDB drainage chart

3.4.3.3 Cathodic protection

Cathodic protection is used by structure owners to remove anodic traction effects beyond the electrolysis feeder systems. Use of cathodic protection for this purpose and the output of an impressed current unit required to remove these effects, has been approved at certain locations by the Victorian Electrolysis Committee.

3.5 Other protective measures

Although stray current corrosion can, at least in principle, be mitigated by either "Straight" or "Forced Drainage", it is also necessary to adopt practices which minimise leakage of current from the rails and current pick up on the structures.

For example, track leakage currents can be reduced by procedures which maintain a high rail to earth resistance, such as ballast cleaning or replacement, drainage and track insulation (sleepers/fittings).

The extension of the tramway to Box Hill used an insulated track section that proved highly effective in eliminating the stray currents from the traction system in that section of track. The cost of installing an insulated track can be much more expensive to install than more conventional track, but has a lower ongoing cost in relation to stray current mitigation.

Resistance of the track itself can be minimised by maintaining rail/track electrical bonding, such that the voltage drop along the rail is kept as low as possible.

Rail to earth potentials can also be reduced by substation location, load sharing and negative feeders. Stray current pick up may be reduced by techniques such as maintaining a high resistance structure coating, location of galvanic anodes to limit pick up, eliminating inadvertent contact with other structures, location of structures, use of non metallic structures and judicious placement of insulated sections (flanges, joints etc) to avoid creating discharge points.

Electrolysis becomes of special importance in cities and other locations where buried metallic structures come in more or less close association with electric railways or tramways having rails not well insulated with the earth. The methods of dealing with this form of corrosion are somewhat unique, in that the factors involved in other types of corrosion, such as the quality of the material and the nature of the surroundings become, as a rule, of secondary importance. The chief factors involved in dealing with stray current electrolysis comprise the ongoing testing for and the control of these currents.

4 Components of the stray current mitigation systems

4.1 Feeders

Feeders provide a connection from the substation to various locations of the traction supply or from the rail at various locations along the track.

The types of feeders that can be found on a traction system include:

- Positive feeders
- Negative feeders
- Electrolysis feeders.

4.1.1 Positive feeders

Positive feeders provide the positive supply from the substation to the traction wire. This could be close to the substation or at various locations within the zone supplied by the substation. The positive feeder helps improve the electricity supply to the traction system, particularly in the tramways where the traction wire is not normally supported by a current carrying catenary wire.

4.1.2 Remote Negative feeders (tram only)

Negative feeders connect from the substation to the rail of the traction system.
The negative feeder is connected to the rail near to the substation. On some tramway systems, additional remote negative feeders are installed from the substation to various locations in conjunction with positive feeders and also along the rail to reduce the voltage increase as the tram travels along the track.
The effectiveness of negative feeders on reducing the effects of stray currents can be increased by connecting a negative resistor into the negative feeder connected to the rail closest to the substation. Refer Fig 12.

4.1.3 Electrolysis feeders

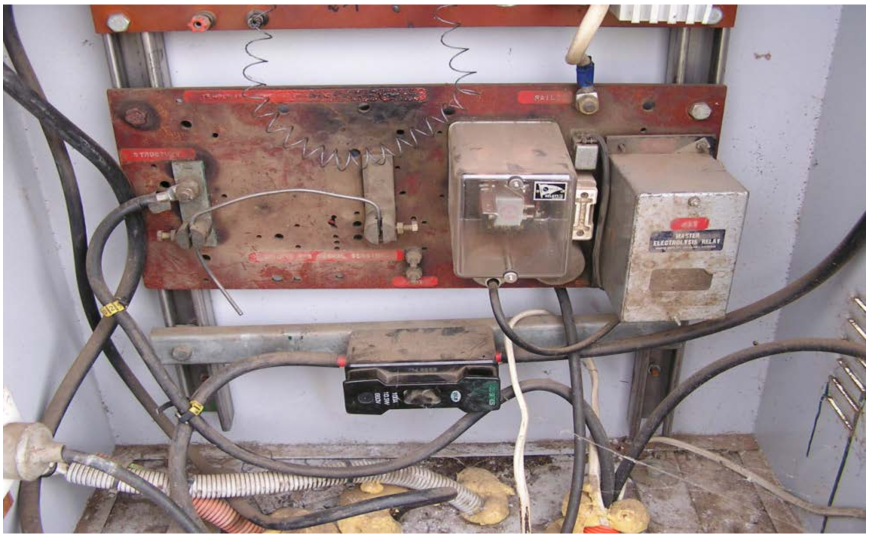
The Electrolysis feeder is defined as the total length of the feeder cable from the connection to the traction system (substation or rail) to the drainage point at the underground structure.

Figure 12 - Typical tramway substation showing negative resistor.

4.2 Relay and contactor

Relays were used to control the connection of a structure to the rail when the rail became more positive than the structure.

The relay was used to sense the voltage of the structure in relation to the rail and when the structure became more positive than the rail, the high current contactor was closed to enable current to drain back to the traction system.



Photograph of typical relay and contactor installation.

4.3 Forced drainage systems

4.3.1 Thyristor drainage unit

The Thyristor Drainage Units (TDU) has a DC power supply that supplies a DC output which is controlled by two thyristors. The gates of these thyristors are connected to a thyristor control unit (TCU) which controls the length of time for which the thyristors pass current, and consequently, the average value of the DC output.

The TCU input is usually supplied from a shunt installed in the negative side of the substation output, therefore the system provides a DC drainage voltage output which varies in proportion with the load on the substation. Some TCU's are supplied with a rail to earth voltage, which subsequently controls the output of the TDU in relation to the R-E voltage, either positive or negative rail sensing.

One TDU can be connected to a number of feeders which in turn drain a number of underground structures.

The Thyristor Control Unit (TCU) is mounted on the front panel of the TDU. It supplies pulses to the gates of the thyristors of a duration proportional to the DC millivolt input from the substation load shunt. The TCU can be adjusted to vary the characteristic of the curve with a combination of offset, slope and maximum output. These settings are determined from the results of combined area testing. The TDU's at the substations are monitored and controlled by the traction control and indication system.

TDU offset
This is normally set at 1.5-7.5 volts however with regenerative braking the offset voltage can now be as high as 10 volts (depending on the circumstances in the each traction substation area under test), and means that if the substation load is small (or no substation load at all), there is still a TDU voltage output and hence some drainage current will flow back to the substation. (This small voltage assists in breaking down the forward bias of the diode and allows full conduction through the diode - approximately 700 mV.)

A base load at the substation is an advantage because the TDU will operate on the slope and not rely solely on the offset.

TDU slope
Adjustment of the slope of the TDU results in changing the ratio of the output voltage from the TDU compared to the load on the substation.
The slope is usually adjusted to give the required TDU output voltage for the substation output load.

TDU maximum output
This limits the maximum voltage that the TDU can provide during periods of heavy substation load. Higher voltages are usually specified when there are long drainage feeders involved. The maximum output is also used to maintain the output of the TDU within the capacity of the equipment (i.e. the TDU transformer is normally rated at 80 amperes continuous current).

The thyristor drainage units (TDU) are usually mounted on the inside walls of the railway and tramway substations.

Due to the lack of available room inside the substation, some TDU's at the tramway substations have had to be installed in cabinets adjacent to the outside walls of the substations, Refer Fig 6.

Photograph of a typical TDU installation (old type).

Photograph of a typical TDU installation (new type).

4.3.2 Variable conductance drainage bond

The main attribute of a Variable Conductance Drainage Bond (VCDB) is that it only allows drainage current to flow when the structure is positive to the set potential (soil line). This is especially helpful in reducing over drainage, but testing has indicated that there are limitations on the use of a VCDB to protect structures over a broad area. The VCDB has proved to be extremely successful in Tramway areas subject to the effects of regenerative braking, especially when used in conjunction with a DC back up supply. The structure at a VCDB location only becomes excessively cathodic when there is “pick up” of current from a positive to earth rail without any drainage current present and only becomes anodic when there is insufficient drainage feed potential. The back up DC supply has overcome this feed potential problem.

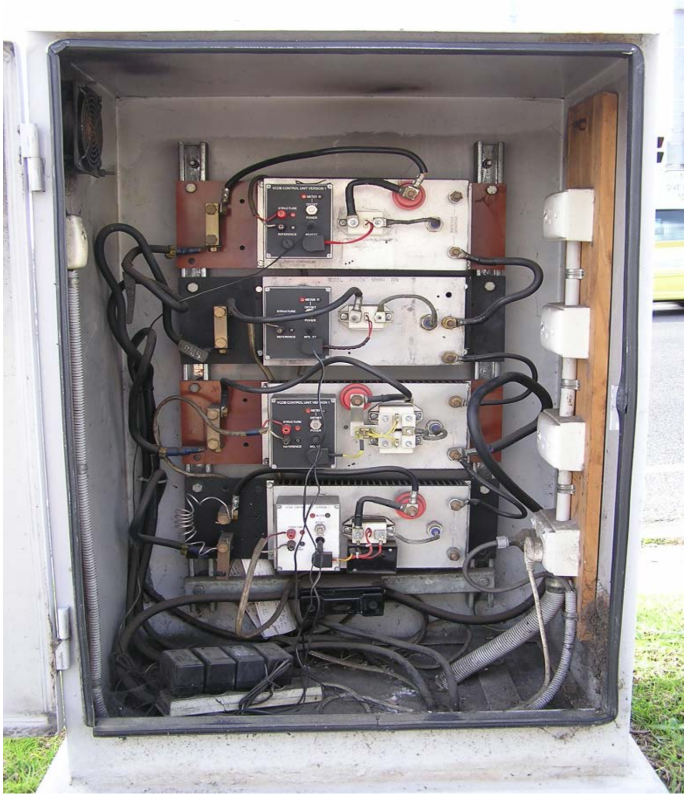
There were previously six types of VCDB's available for use on the stray current drainage system.

These were the Taywood Mark 1 and Mark 2, and the CARD 150 Watt and 50 Watt in both self-powering and external powered models. A problem that was identified with the Taywood units was the generation of a high frequency signal that severely interfered with the Telstra network. The CARD units were developed to successfully overcome this problem.

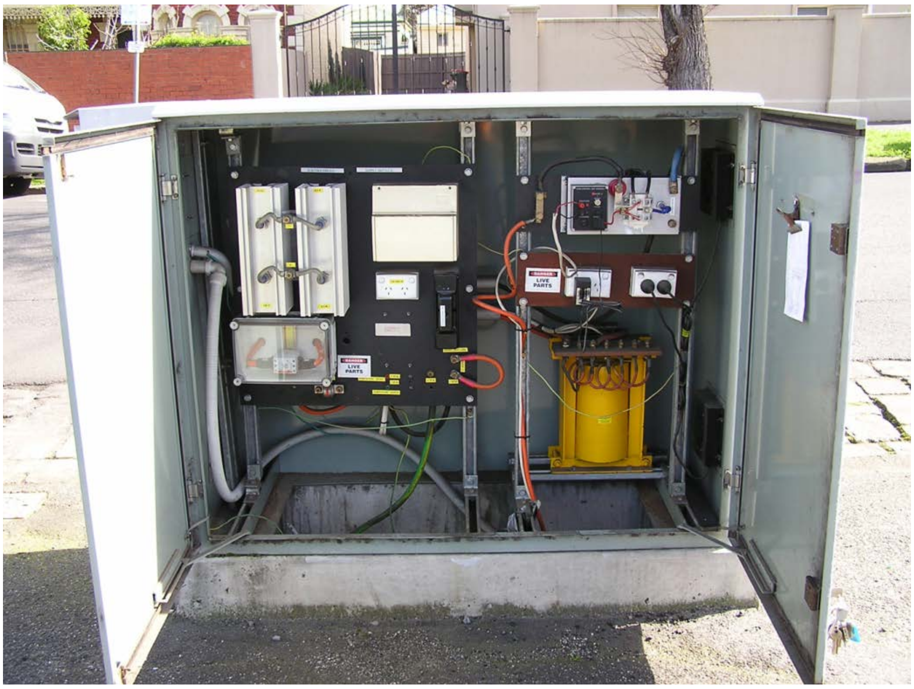
The CARD units both employ the same controller system but are identified by the number of mosfets and hence the size of the heat sink. The smaller of the two units is "self powering" in that it obtains the power to operate it's circuitry from the potential difference between the structure and the feeder.

A new unit was developed by Wilcom which incorporated more modern and robust circuitry. The limitations with the early VCDB’s was their inability to handle the “power” required to operate on the stray current system. The Wilcom units were developed to handle greater power by incorporating two Mosfets in parallel.

Apart from a couple of locations, all the units in operation are presently Wilcom units. A Wilcom self powering unit is being developed that will replace the CARD self powering units which are nearing the end of their useable life.



Photograph of typical VCDB installations with DC supply at the substation.



Photograph of typical VCDB installation which includes DC supply.

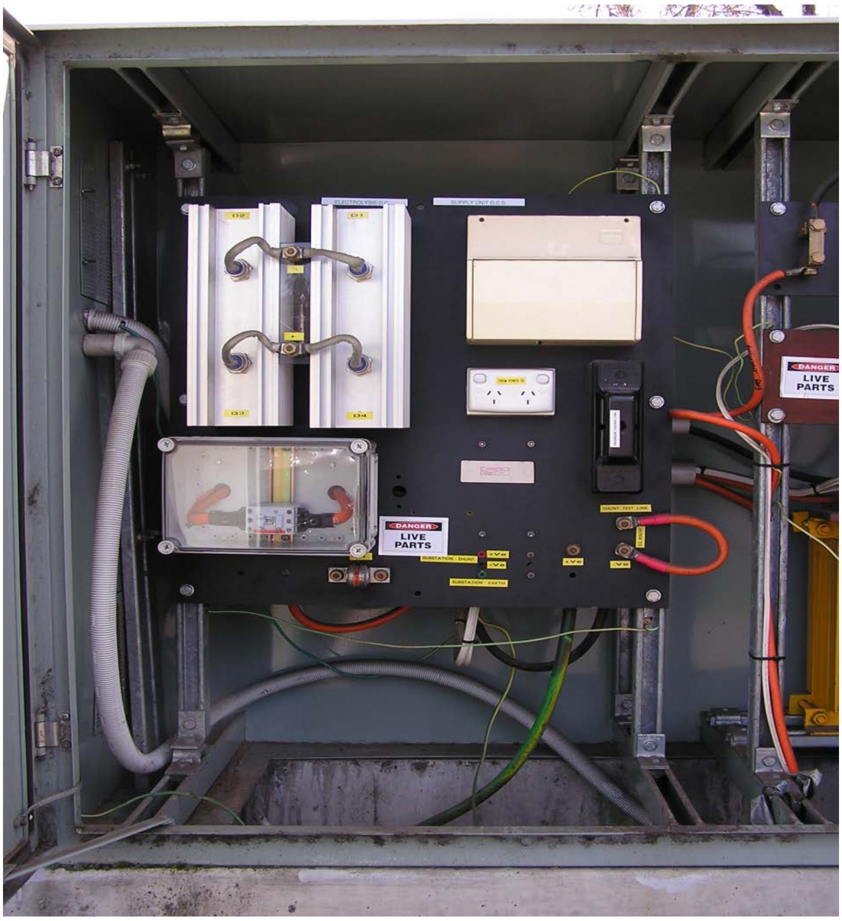
4.3.2.1 DC supplies

The introduction of a fixed output DC power supplies into the drainage system is relatively new in Victoria and has been instigated by the introduction of VCDB's.

As the VCDB's are at times required to supply high drainage currents to remove anodic spikes caused by regenerative braking, it is necessary to bias the drainage system with an additional DC supply.

The DC power supply is basically the same as a TDU power supply except that the output is constant and therefore does not vary with the substation load.

The DC supplies are installed in the same manner as a TDU and when installed in substations, are connected into the traction control and indication system.



Photograph Of typical DC supply installation.

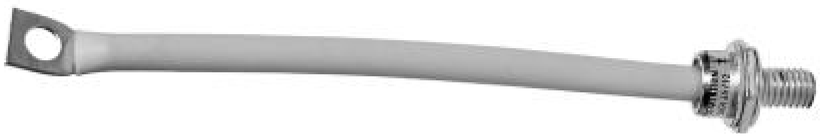
4.3.3 Remote monitoring

The stray current drainage system has two TDU’s that are remotely monitored, providing charts for substation load and drainage current on a monthly basis. The first is at Bendigo which was proven necessary to offset the cost of travelling to site to test the TDU and monitor the drainage system. The second is at the Crombie Lane Tramway substation which was necessary due to the substation being many levels below ground and therefore very difficult to access via a narrow stair case. These two systems have proved to be very effective and may be the forerunner of other similar systems.

4.4 Diodes

Diodes are used to prevent the reverse current flow from the structure to the rail should the rail become more positive than the structure and are connected in series with the drainage bond.

The usual diode used in the tramway system has a reverse voltage rating of 400 volts and a current rating of 70 amps. The tramways used diodes with the anode connected to the stud of the diode. (ie. the current flows from the base of the diode to the tail of the diode.) A typical diode of this rating is the Semikron SKN 70/04



Typical 70 ampere rated tramways diode - Semikron SKN 70/04

The latest design tramway drainage bond utilises a diode with the same rating as used in railway drainage bonds. These diodes have a reverse voltage rating of 1200 volts and a current rating of 130 amperes.

The majority of railway drainage bonds have only one diode, but it in some instances two structures are drained through the one diode.

A typical high current tramways diode was the Semikron SKN 130/12 with the anode connected to the stud, however the present arrangement is to use diodes with the cathode connected to the stud as used in the railways. The railways use the diode with the anode connected to the stud, such as the Semikron SKR 130/12. Care must be taken to ensure the correct diode is used in the actual arrangement for the drainage bond.

***Typical 130 ampere rated tramways diode - Semikron SKN 130/12 (anode to stud)* or railways diode Semikron SKR 130/12 (cathode to stud).**

4.5 Resistance wire

There are three types of resistance wire used with drainage bonds. Each has a different electrical characteristic with respect to the change in wire temperature.

The three types of wire and their uses are:

- Copper wire - has a negative temperature characteristic - ie resistance decreases when temperature increases. Usually used for zero resistance links (14 SWG)
- Nichrome Resistance Wire - The main attribute of this wire is that its resistance will remain constant no matter what value of current is flowing through it (up to the fusing value of the wire)
- Nickel Resistance Wire - The resistance of this wire increases proportionally with the amount of current flowing through it. This attribute is used for removing current peaks, which in turn should remove excessive voltage peaks.

Although not used in Melbourne, in some other locations incandescence light globes are used as a resistance wire. Incandescence light globes have a positive temperature coefficient.

The resistance of the wire used can be determined by the diameter and length of the wire.

4.5.1 Resistance wire specifications

NOTE: These specifications are for imperial wire sizes. As this wire is no longer available, the closest metric equivalent is used.

NICHROME 5

GAUGE	RESISTANCE @ 20C Ohm/Foot	CURRENT CAPACITY 500C	1000C
4 SWG	0.0159 Ohm	97 A	
10 SWG	0.0404 Ohm	50 A	104 A
12 SWG	0.0613 Ohm	37 A	75 A
14 SWG	0.104 Ohm	26 A	55 A
16 SWG	0.163 Ohm	20 A	39 A
18 SWG	0.289 Ohm	14 A	26 A
22 SWG	0.846 Ohm	6.2 A	13 A
26 SWG	2.05 Ohm	3.5 A	6.5 A

NICKEL "A"		CURRENT @ 600C
16 SWG	0.0133 Ohm	29 A
24 SWG	0.112 Ohm	10 A

Resistance wires can be installed to act as a fuse preventing excessive current to flow into or out of structure which can result in damage to the structure. This excessive current can occur due to many causes including:

- Loss of supply from a traction substation requiring adjacent substations to provide additional current to the adjacent zone
- Loss of the negative feeder
- Lightning strike on a structure or in the vicinity of the structure

- High voltage injection from a distribution or transmission electric line.

4.6 Capacitors

In some instances a drainage bond may create some electrical interference to radio receivers in close proximity to the bond.

In these instances a capacitor can be installed across the diode in some drainage bonds to overcome any electrical interference that may be generated by the circuit.

These are usually installed in drainage bonds adjacent to residential areas. They are not installed in all drainage bonds but are usually installed after a complaint from a resident adjacent to a drainage bond box. The most common type used are similar to those that are installed to reduce the radio interference from the alternator in cars.

The most common value of those installed is 0.47 Microfarad.

Photograph of typical noise suppression capacitor

4.7 Varistors

The components of the drainage system are subject to damage from electrical "spikes" and surges which are generated from various sources. These may be from the power companies’ switchings, lightning activity or accidental injection due to outside influences.

The diode is the most susceptible component to electrical spikes and surges as they have a designated peak inverse voltage. Therefore it is desirable to install a device to protect the diodes from most forms of electrical interference.

The varistor is seen to be a practical method to provide protection to the diodes.

A varistor is a non-linear variable resistor which varies its resistance and is dependent with the voltage across the device. When the voltage across the varistor gets to a predetermined level the varistors resistance drops allowing increased current flow through the varistor thereby reducing the voltage spike.

The varistors have only been installed in railway drainage bonds as it has been deemed unnecessary on the tramways drainage system.

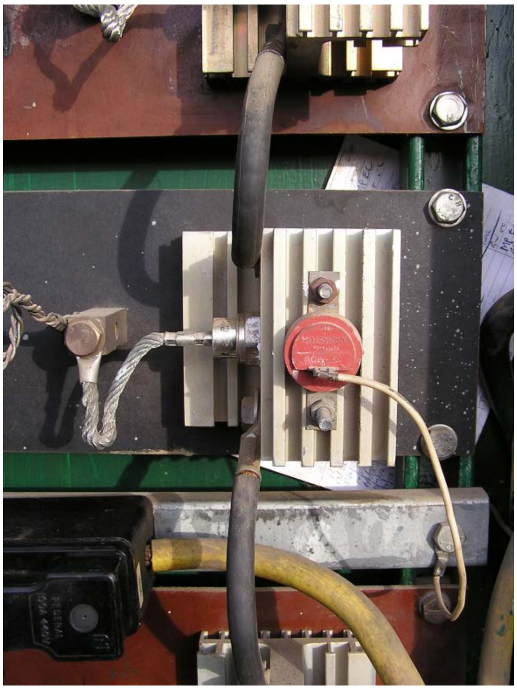
Initially the drainage bonds had a Selenium Rectifier connected between the railways drainage feeder and the drainage bond "earth". This system was never totally successful as the "earth" was usually very poor and therefore not a good path to discharge any electrical "spikes".

As technology improved, the "Varistor" was seen as a better way to protect the diodes as it operated much faster than the Selenium Rectifier. The problem of the drainage bond "earth" still existed.

It was decided that to install the "Varistor" across the diode would be far more effective in protecting the diode. This connection effectively shorts out the diode allowing the current from the spike to flow to the structure. This system uses the structure as the path for the "spike" to discharge to earth.

Only one Varistor is installed per drainage bond box, most commonly across the water main diode.

The common type of Varistor installed is the V250PA40A. This device has a working voltage of 330 Volts DC and a peak pulse current of 4500 amp.



Photograph of typical varistor installation

5 Combined area testing

5.1 Area testing

Area testing, or coordinated testing within traction substation areas has been shown to be the most appropriate method of testing the mitigation system. This method involves all structure owners and the traction operator in a co-ordinated test within one or more adjacent traction substation areas.

The aim of an area test is to:

- Minimise the effect of stray current on the underground metallic structures, while keeping the amount of stray current flowing within the earth to a minimum
- To adjust and balance the mitigation system towards the objective of each test point on every structure being cathodic to the soil line, within an acceptable testing timeframe
- Test all traction substation areas in an orderly sequence within a 5-6 year interval between successive tests.

5.1.1 Advantages of area testing

To traction operators:

- Allows an assessment of the electrical loadings between their adjacent substations to be made on a regular basis
- Enables the identification of defects on the traction system associated with the negative return and the mitigation system
- Allows electrolysis equipment to be checked for its compliance with ratings.

To structure owners:

- Provides opportunity for stray electrical currents to be monitored on a co-ordinated basis by ensuring all structures are monitored in the same time interval
- Provides the opportunity for co-ordinated solutions to be determined to solve problems found during the test work
- Provides the opportunity for structure owners to verify the electrical continuity their structures, including the status of their insulated flanges
- Provides the opportunity to audit cathodic protection systems within the area for compliance with the interference criteria and the Certificate of Registration current
- Provides the structure owners with the opportunity to ensure the effectiveness of their cathodic protection systems.

5.1.2 Area testing procedure

For detailed description of area testing please refer to the "Code of Practice".

The TSC determines the schedule and priority of the area tests. Each area test will involve all structure owners in the designated area in the production of a composite map of their assets under test within that area.

The VECOG and VEC members shall organise the area testing by:

- The establishment of a mobile site office (MSO)
- The appointment of an area test co-ordinator for the testing work

- Monitoring of the traction substation by the submission of charts to the co-ordinator on an agreed basis, preferably daily
- Monitoring the structures by the submission of daily charts to the co-ordinator. Data loggers used on an area test must comply with the specification in Appendix 2 of the Code of Practice
- Assessment of the traction system loadings and their effect on the drainage system.
- Adjustment of the drainage system to minimise the traction effects
- Conducting a site meeting to discuss testing and develop the recommendations for changes to the mitigation system
- Obtaining an agreement to the completion of the testing of this area
- Producing an area test report and submitting it to the TSC for ratification.

5.1.3 Criteria to be used for assessment of the submitted charts

The major criteria to be used in the assessment of the structure charts are % anodic or cathodic to the soil line (i.e. cathodic, 10% anodic, 25% anodic, 50% anodic, 75% anodic and 100% anodic).

The soil line is defined as the potential of the structure to earth when the rail to earth voltage at the traction substation is zero and the mitigation system is isolated.

The soil line is determined by the coordinator as soon as possible after the area test starts.

5.1.4 Maps used in area testing

During the preparation of an area test, maps are produced that show the structures under test, the configuration of the drainage system and traction substations. These maps can also have the location of insulating flanges, regulator pits, valves, ICCP systems etc. The condition of structures as assessed by the above criteria are shown on the maps, with the amount of red on a green pin indication how anodic a structure has been assessed. Below is a sample of an area test map.

A typical map showing drainage bonds, electrolysis feeders, test points, ICCP systems and underground structures as used during combined area testing.

5.2 Mobile site office

For each area test, a suitable location is established that is used to locate the mobile site office (MSO). This site office is used as the central hub for all operations relating to the conducting of the area test. Daily the representatives of each asset owner deliver the gathered data of the pipe to earth potentials of their structures taken at the nominated test points to the MSO where this data is assessed by the area test coordinator

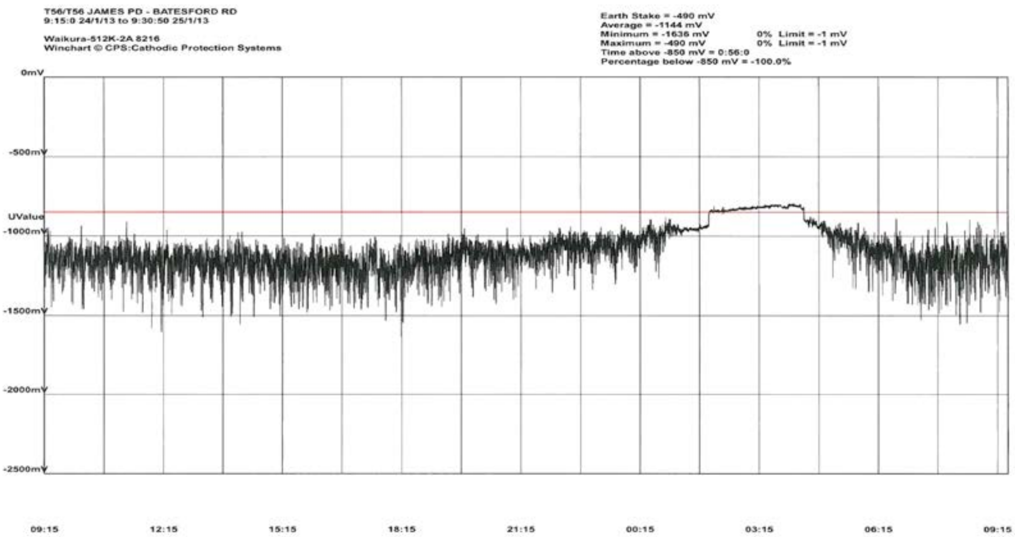
After the completion of the field testing, a site meeting of the structure representatives is held at the MSO to formulate recommendations for changes to the stray current drainage system which are submitted to the TSC for ratification.

Photo of Mobile Site Office

Area test coordinator discussing area testing results with structure owner's representative inside the Mobile Site Office.

5.3 Data logger charts

Charting during area testing is predominantly carried out using data loggers to record the structure to earth potential. The chart below indicates that the structure is protected to the soil line as well as to -850mV to a $Cu/CuSO_4$ reference electrode.



A Typical Data Logger Chart as Supplied to the Coordinator at the mobile site office.

5.4 Adjusting a drainage bond

On checking a chart and finding it anodic in any way, the coordinator can adjust this condition by taking resistance out of the drainage bond, or if it is over-drained, by putting more resistance into the drainage bond.
(The current chart should be studied in conjunction with the potential chart before deciding upon what action should be taken.)

Refer section 4.6 for the specifications of the various resistance wires used by VECOG.

6 Historical Background

6.1 World experience

Stray current corrosion was by no means unknown prior to the electrification of the Melbourne railways and tramways in the early 1900's.

In August 1899, Mr. Arthur Vaughan Abbott published a paper on "Electrolysis from railway currents" in the Electric Railway Number of Cassiers Magazine. The document has been reproduced by the Light Rail Transit Association with the comment that "Despite having been written 100 years ago it is still relevant today, especially with the current concern (in the UK at any rate) with leakage currents.

In Great Britain, there were several instances where legal action was initiated, leading to the establishment of a joint parliamentary select committee to inquire into the problem. Although this committee led to empirical rules being established under the Board of Trade Regulations, fundamentals of the problem had not been fully understood, and compliance with the rules did little to reduce the incidence of stray current corrosion.

Substantial damage due to stray current corrosion was also experienced in America, commencing shortly before the turn of the century. In 1910 the US National Bureau of Standards embarked on a systematic study of stray current corrosion.
The United States Bureau of standards issued a paper on Electrolysis and its Mitigation by E.B. Rosa, chief Physicist and Burton McCollum Electrical Engineer of the Bureau of Standards on the 27th December 1915 and in the following year a paper entitled Leakage of currents from electric railways by Burton M'Collum, Electrical Engineer, and K.H. Logan, Assistant Physicist, Bureau of Standards was issued on the 14th March 1916.
These papers provided a sound theoretical analysis of leakage current behaviour. The Bureau of Standards maintained a high level of interest in stray current corrosion throughout the 1920s and 1930s, contributing significantly to the depth of understanding of the problem and encouraging development of practical engineering solutions.

In 1921 the American Institute of Electrical Engineers published a very comprehensive "Report of the American Committee on Electrolysis" which was a subcommittee of that Institute. The report, in Chapter 2- Design, Construction, operation and maintenance comments that:

> *"In many cities it has been found advantageous to form joint committees, composed of technical representatives of several utilities concerned, to investigate the local electrolysis situation and determine by agreement a course of procedure to be followed. Such committees should attack the problem on an open and fair minded manner with the object of effecting, in the most economical way, mitigation of all the troubles resulting from the presence of stray currents in the earth, including corrosion, fire and explosion hazards, heating of power cables, and operating losses and difficulties. To this end, they should be composed of men, or men associated with them, who are trained in the technique of electrolysis. Active committees of this kind described are now existent in Chicago, Kansas City, Omaha, St Paul, New Haven, Milwaukee and Syracuse. The principal of cooperation has been recognized by the Railroad Commission of Wisconsin in an order authorizing an Electrolysis Committee of Milwaukee. Such committees act as clearing houses of information and keep all interested companies informed as to changes in their systems which may affect the electrolysis situation. Under the direction of such a committee joint electrolysis surveys may be conducted and unified methods of mitigation installed and maintained."*

This is very similar to the basis that the Victorian Electrolysis Committee operates.

6.2 Victorian experience

In C.M Longfield's comment on the early historical development of stray current electrolysis in his book "Stray Current Corrosion, with special reference to the work of the Melbourne Electrolysis Committee", the following is noted:

"Since electrolysis occurs on the plant of one authority, generally as a result of the operations of another, the question of legal rights naturally came into prominence as soon as the phenomenon became clearly recognised. In actual fact, much of the early history of the subject is now to be found only in public inquiries and in court proceedings, none of which appears to have contributed much, if anything, to the solution of the complex problem."

Stray traction current corrosion first became significant in Melbourne in about 1914, when the first phase of electrification and linking of the tramway network was approaching completion. By 1919 damage to water mains, gas mains and telephone cables was causing considerable concern, and in 1920 reached proportions sufficient to warrant the attention of the Melbourne newspaper "The Argus" of Monday 21 June 1920 in the following article.

"Leakage of Electricity - Investigation by Engineers"

"Tests have been taken by the subcommittee appointed by the conference of engineers which is investigating the leakage of electricity, and the damage caused thereby to gas, water and telephone mains. The results will be considered this week by the conference, which will be attended by representatives of the Melbourne Electricity Supply, Tramway Board, Board of Works, Railways Department, and Postmaster-General's Department. The findings of the committee would appear to indicate that the leakage has been traced to the electric railways.

The conference of engineers chose for the tests the district between Glenhuntly Road and Sandringham, where there can be no leakage of current from the tramway systems. The results show that there is a considerable leakage current in the Brighton area. The damage done consists chiefly in the eating away of metal structure, whether gas pipe, water pipe or telephone cable"

At about the same time, the Board of Works and the Metropolitan Gas Company pooled resources to engage Wilfred W Kernot, Associate Professor of Engineering at the University of Melbourne as an Electrolysis Consultant.

However, little progress was to be made towards resolving the electrolysis problem, until on the 9th June 1922 a serious failure of the Board of Works 900 mm water main in Punt Road, Richmond, resulted in a cavity in Alexander Avenue exceeding 10 metres by 12 metres in area. This led to considerable and extended exchanges between the Board of Works and the Railway Department regarding liability for the damage and the repair cost. Two invoices [£27-14-9 and £118-7-4] covering two immediately prior faults were presented to the Railway Department on 22-June-1922 relating to these faults together with reports from Mr Kernot in support. The Department replied on 17-July-1922 that their engineers are investigating the liability of the Department for the damage. A letter similar to that sent to the Railways was sent to the Victorian Premier at the same time to increase the pressure.

A follow-up letter was sent on 21 September 1922, and the file copy is annotated on 24-October-1922 that no reply has been received, and again annotated on 14-June-1924.This was a period of 'informative' articles about Electrolysis in the newspapers.

6.3 Formation of the VEC

In July 1922 as a result of protracted disputes between the Board of Works and the Railways, the above incident was brought to the attention of the Premier, together with the placement of synchronised submissions from the water, gas and telephone companies being placed before the Government.

Parliamentary debate in November resulted in the Government directing the State Electricity Commission of Victoria to report on the electrolysis situation, and following further newspaper publicity in January 1923 (Headlines from "The Age" 5 January 1923 reading "Escaped Electricity - Damage to Water and Gas Mains - Serious Effects of Electrolysis - Need for Government Action"), an *Electrolysis Investigation Board* was formed in 1923. (Three years after the Commission was formed.)

This Board comprised Chief Engineers from the State Electricity Commission, Melbourne and Metropolitan Tramways Board and Victorian Railways Department.
The water, gas and telephone companies were not represented which brought the following response from the Board of Works after consultation with the Metropolitan Gas and Postal Department.

> "*We note that the Electrolysis Investigation Board of three members includes two representatives of the major offenders, viz., the railways Department and the Melbourne Tramways Board. It is, therefore, doubtful what will come out of their deliberations, and whether the results will be satisfactory to us as representing the three bodies who are suffering damage from electrolysis".*

Although the doubts of the various authorities may have been well founded, it appears that at least the Investigation Board took some positive action. Following instances of rapid perforation of water mains in Malvern and Coburg during 1922 and 1923, Mr. H.R . Harper, Chairman of the Melbourne and Metropolitan Tramways Board wrote:

> *"I am informed that the Melbourne and Metropolitan Tramways Board has been able to improve the conditions in the locality where trouble was reported in Malvern and Coburg, and I think you may, with confidence, anticipate a reduction in, or a total cessation of failures".*

Nevertheless during these years, the Board of Works and the Metropolitan Gas Company continued to employ the services of Mr Kernot and electrolysis problems continue to be approached in what appears, at best, to be a piecemeal technique.

By 1925, damage quoted at 20,000 pounds per annum was being attributed to stray current corrosion, and in 1926 the transport authorities agreed that a more effective approach was required, as it was highly evident that the preventative measures attempted to this time had been largely ineffective.

Consequently, in its final report in November 1926, the Electrolysis Investigation Board made a strong recommendation that a permanent Co-operative Committee**,** representing all interested authorities, be set up. This committee was formed on 30 August 1927, under the aegis of the State Electricity Commission of Victoria, and became known as the Melbourne Electrolysis Committee.

At the time of formation, the following authorities were represented on the Committee:

- The State Electricity Commission of Victoria
- The Melbourne and Metropolitan Tramways Board
- The Victorian Railways Department
- The Melbourne and Metropolitan Board of Works

- The Metropolitan Gas Company
- The Postmaster General's Department.
- The Melbourne City Council Electricity Department was included in October 1929

The Constitution of the Committee provided for a Main Committee, consisting of senior members of the authorities represented, and a Technical Sub-Committee, comprising suitably qualified technical representatives to direct the field investigations. Mr. F.W. Clements, a Commissioner of the State Electricity Commission was the Committee's first Chairman until his retirement in 1937 when Mr. G.G. Jobbins, Chairman of the Commission, succeeded him.

From its inception, the Victorian Electrolysis Committee acted in an advisory and consultative capacity. To quote from part of its Constitution:-

"The objectives of the Victorian Electrolysis Committee shall be as follows:

a) To receive and investigate complaints from anybody or person, or such complaints as may be referred to it by the State Electricity Commission, as to injury alleged to be caused by electrolytic action

b) where such injury appears established, or it is anticipated, to:
(1) Determine the cause of same, and the works responsible therefore.
(2) Together with the parties interested, consider and advise upon the most suitable methods for minimising or removing as far as possible, such causes as determined under (1).

(a) Electricity Supply Industry representing the five distribution companies in Victoria

(b) Public Transport Corporation representing the tramway and railway traction systems

(c) Water Industry representing the four Melbourne metropolitan water companies

(d) Gas industry representing the three gas distribution and one transmission gas company (plus Elgas)

(e) Telstra

(f) Australian Institute of Petroleum representing the private oil pipeline owners, and

(g) Other interested parties in the non-metropolitan water industry.

Although the Committee had no direct powers by Government legislation, it obtained a degree of indirect power under the State Electricity Commission Cathodic Protection Regulations, which were proclaimed in 1970 and most recently updated in December 2009. These current Regulations provide powers, through the Electricity Safety Act 1998, relating to the operation of cathodic protection systems, but exclude traction drainage bonds.

This exclusion has been removed in a revision of the Regulations and together with the legislation of the Electricity Safety Act 1998, which establishes the Victorian Electrolysis Committee as an advisory committee on electrolysis matters to the Government.

In both Victoria and New South Wales, the traction system uses DC current and will continue to do so into the foreseeable future, due to the huge cost of converting trains, trams and their respective power supply systems to AC operations.

Alternating current (AC) is used in many overseas railway systems and in Australia on the West Australian and Queensland railways system.

Alternating currents ordinarily cause only about 1 per cent of the damage resulting from the equivalent amount of direct current. However, when operating under high load this may account for some damage, perhaps due to the breakdown of the polarisation film.

Two papers presented at NACE conferences 1998 suggest that corrosion due to AC currents may be very severe on pipes with excellent coatings. The good coating concentrates the stray AC currents to very high current densities at the few holidays (coating defects) that occur on any practical coating. Beyond a threshold of current density, corrosion appears to proceed very rapidly.

A paraphrase of the notes, letters and minutes of the early meeting of the Electrolysis Investigation Board is included in section 9 of this manual.

The structure and constitution of the Victorian Electrolysis Committee has remained substantially unchanged since the time of its formation with the inclusion of a member nominated by the Australian Institute of Petroleum.

As required under the Electricity Safety Act 1998 the Committee is to be constituted by:

- *(a) A person nominated by Energy Safe Victoria*
- *(b) A person nominated by the Minister administering the Transport Act 1983*
- *(c) A person selected by the Minister from nominations given to the Minister by the (electricity) distribution companies*
- *(d) A person selected by the Minister administering the Water Industry Act 1994 from nominations given to the Minister by the water companies within the meaning of that Act*
- *(e) A person nominated by the Minister administering the Gas Safety Act 1997*
- *(f) A person selected by the Minister from nominations given to the Minister by the carriers under the Telecommunications Act 1997 of the Commonwealth*
- *(g) A person nominated by the Australian Institute of Petroleum Ltd.*

Under Section 92 of the Electricity Safety Act the functions of the VEC are to:

- *(a) Establish and maintain standards for systems for cathodic protection and for the mitigation of stray current corrosion*
- *(b) Provide advice to Energy Safe Victoria on any matter related to electrolysis and the regulations relating to the cathodic protection and to the mitigation of stray current corrosion, when requested to do so by Energy Safe Victoria*
- *(c) Encourage the development of new methods and technology to increase the efficiency of systems for the mitigation of stray current corrosion.*

The Technical Sub-Committee (TSC) and the Works Liaison Sub-Committee has been established under the VEC to deal with operational matters under the VEC's guidance.

Further details in relation to these committees and the Victorian Electrolysis Committee Operations Group are contained in the VEC Code of Practice.

6.4 History of the VEC – Infrastructure owners overview

Refer section 12 for each industries detailed history.

6.4.1 Water

In 1853 work commenced on the creation of Melbourne's first water reservoir at Yan Yean. Prior to the completion and connection of the Yan Yean reservoir to Melbourne, water had been pumped from the Yarra River to storage tanks which were gravity fed via pipes to standpipes around the city and the development of a water reticulation system.

The first water supply piped from Yan Yean Reservoir began to flow to Melbourne shortly after the reservoirs completion in 1857.

From 1862 Melbourne's water supply was administered by the Water Supply Branch of the Public Works Department.

6.4.2 Gas

Town gas had also become a well established energy supply within Melbourne and its suburbs. Town Gas was generated by the destructive distillation of coal producing gas and coke. Other substances of useful by product were coal tar and ammonia.

Melbourne's first gas company was the City of Melbourne Gas and Coke Company which was formed in 1850 with the first gas works established in 1852 with the first gas being supplied to shops and offices on New Years Day 1856. Reticulated gas supply to street lighting commenced in 1857.

The demand for gas grew quickly and many gas works spread across the suburbs of Melbourne.

Melbourne had a rapidly expanding underground metallic pipe reticulation system for both water and gas.

6.4.3 Early electric light

In 1863 three battery powered arc lamps were erected outside Parliament house, the post office and the telegraph Office to celebrate the marriage of the Edward, the Prince of Wales (later to be King Edward).

In the next decade various companies including Sands and McDougal (printers) and the Apollo Candle Company set up their own electric arc lighting systems.

In August 1879 the Melbourne Cricket Ground was illuminated to enable a (Australian Rules) football match to be played at night. On 5 August 1879 the Collingwood Rifles played East Melbourne Artillery under electric lighting. The next night match was on 13 August 1879 Melbourne played Carlton. The lights were arc lamps powered by steam driven generators. This event occurred a couple of months before Edison's first successful experiment with filament incandescent lights. It wasn't until December 1984 that lighting for football was returned to the Melbourne Cricket Ground.

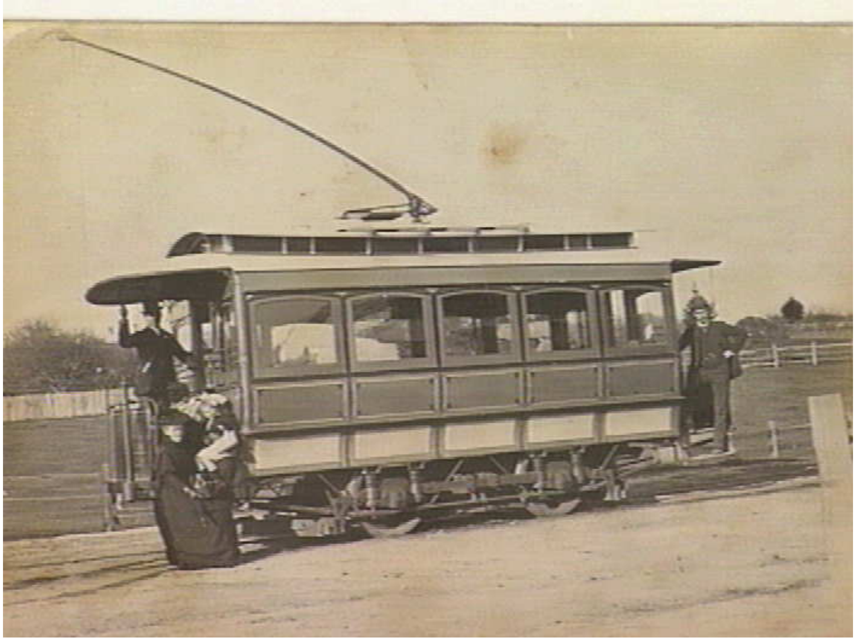
In 1881 electric arc street lights were erected by Mr A.U. Alcock outside his premises in Corrs lane in Melbourne where he made billiard tables. Mr Alcock had an important part to play in relation to electricity and tramways in Victoria.

In 1888 the Melbourne Exhibition Building was illuminated with electric light for the Melbourne Centennial International Exhibition. This international exhibition was the first to have night viewings, made possible by the electric lighting inside and outside the building. The electricity was supplied by approximately 100 kilometres of electric cable.

6.4.4 First permanent electric tramway

The next year, 1889, Melbourne's first electric tramway (and the first in the Southern Hemisphere) was formally opened on the 14 October 1889. This privately owned and operated tramway ran from Box Hill to Doncaster, distance of 3.6 kilometres. The tramway was initiated by a consortium of landowners who formed the Box Hill and Doncaster Tramway Company. Unfortunately this tramway ceased operation in 1896.

The Box Hill and Doncaster tramway went into service within one decade of the worlds first electric tramway in a suburb of Berlin, Germany which went into service in May 1881.



This tram was exhibited at the Melbourne Centennial International Exhibition by the electrical importer W.H. Masters and Company who operated it as a working tramway at the exhibition.

6.4.5 Electricity distribution commences

Melbourne was one of the first three places in the world to have electricity distribution.

Melbourne's first electricity distribution was supplied by a power station in Russell Place in 1882 owned by the Australian Electric Company (AEC). Earlier in that year, in April 1882, Edison's first public electricity supply scheme commenced in London at the Holborn Viaduct and his Pearl Street power in New York commenced suppling electricity in September 1882. (Note: The AEC was formally the Victorian Electricity Company that provided arc light to the Melbourne City Council's Eastern market using portable engine driven dynamos. The AEC formally wound up at the end of 1888 and the New Australian Electric Company (NAEC) started in early 1889.)

The Russell Place power station in Melbourne supplied electricity to Athenaeum Theatre and the Tivoli Theatre (known at the time as the Opera house) and other premises. The electricity supply from the power station was direct current. The original generation equipment was replaced by a rotary converter in 1929 supplied by an alternating current supply from a power station in Richmond. These rotary converters were subsequently replaced by a Mercury Arc Rectifier in 1950 and remained in service suppling DC to premises close to Russell Place until 2003, when the last of the DC electricity distribution within Melbourne was turned off.

Direct Current had advantages over Alternating current at this point in time as DC worked better with electric lights and effective AC motors and control had not been developed at that stage. Most electricity at the time was being used for lighting or for motors.

6.4.6 Electric Light and Power Act 1896

With the rapid growth in the number of electricity suppliers in Victoria the State Government created the Electric Light and Power Act in 1896. Section 5 of this Act required "***No council company or person shall use, lay, erect, construct, put up or place any electric line or supply electricity for public purposes or private purposes except under the authority of an order made in Council pursuant to this Act.***"

The requirement to obtain an order in council for electricity supply applied to local governments, companies and persons but not to the Victorian Railways. (Note: the Melbourne and Metropolitan Tramways Board did not come into existence until 1920.)

It is noted that there must have been serious concerns by the Gas Companies of the time about the impact of electricity supply to the profitability of suppling gas. Under Section 45 of the Act a gas undertaking that's demand for gas becomes unprofitable due to the supply of electricity can apply to be relieved of their obligation to supply gas to that area. Section 45 stated:

> *(1) Where a supply of electricity is authorized in any area by any order and a supply of gas by any gas undertakers or company is also authorized within such area or any part thereof by any Act under the provisions of which such gas undertakers or company are under any general or limited obligation to supply gas upon demand, the Minister may, upon the application of such gas undertakers or company, inquire into the circumstances of the case.*
> *(2) Such application shall not be considered by the Minister until after the expiration of one month from the publication of an advertisement in two newspapers published nearest to and circulating in the area affected by such application stating that such application is to be made and giving shortly the details and grounds thereof. Any council company or person prejudicially affected by such application shall be at liberty to oppose the same and on giving notice in writing of its or his intention to do so the Minister shall appoint a day to consider the case when either party shall be at liberty to produce such evidence as it or he may deem requisite.*
> *(3) If satisfied that any specified part of such area is sufficiently supplied with electric light and that the supply of gas in such specified part has ceased to be remunerative to the gas undertakers or company and that it is just that such gas undertakers or company should be relieved from the obligation to supply gas upon demand as aforesaid the Minister may recommend the Governor in Council accordingly.*
> *(4) Thereupon the Governor in Council may make an order relieving the gas undertakers or company from such obligation within such specified part of such area either wholly or in part and upon such terms and conditions as he may think proper.*

The first two Orders in Council for electricity supply were to Alcock's Electric Light and Motive Power Company and to the New Australian Electric Company.

In 1981 the Melbourne City Council resolved its own electricity supply department and was the first Council to be issued an Order in Council for Electricity Supply (Order number 3). Melbourne City Council held that Order until the merger of the Melbourne City Council Electricity Supply Department with the State Electricity Commissions prior to the privatization of electricity supply in Victoria the 1990's.

By the mid 1890's electric light was rapidly replacing the old gaslights with about 650 Arc lamps and 1200 incandescent lights installed in the streets of Melbourne.

By March 1894 the Melbourne City Council Electricity Supply Department had commissioned its own power station in Spencer Street in Melbourne.

The Electric Light and Power Act was remade a number of times, the last being the Electric Light and Power Act 1958 that was repealed on 1 July 1998 by section 167 of the Electricity Safety Act 1998.

6.4.7 Tramway expansion

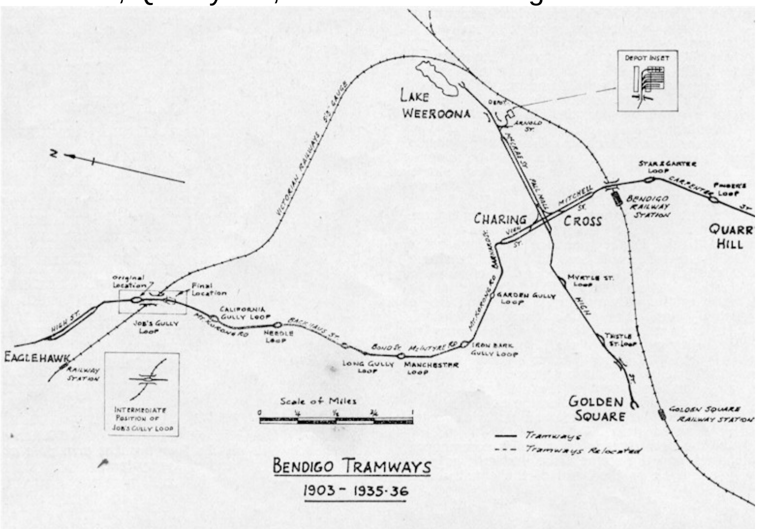
The Electricity Supply Company of Victoria opened their electric tramways in the rural centres of Bendigo (1903) and Ballarat (1905).

6.4.7.1 Bendigo

The old Bendigo Tramway was bought out by the Electricity Supply Company of Victoria in 1899. The previous tramway company had used electric battery and steam driven trams.

The Electricity Supply Company of Victoria converted the tramway to electric trams with an overhead catenary system.

The first of the new electric trams began operation in 1903 and linked Bendigo with Golden Square and Kangaroo Flat, Quarry Hill, White Hills and Eaglehawk.



Bendigo electric tramways 1903

6.4.7.2 Ballarat

The Electricity Supply Company of Victoria took over the existing horse drawn tramway in Ballarat in 1902 and converted it to electrically operated tramway which started operation in 1905.

Both the Ballarat and Bendigo tramways were taken over by the State Electricity Commission in 1934.

6.4.7.3 St. Kilda - Victorian Railways

Melbourne's next experience with electric tramways commenced on 5 May 1906 when the Victorian Railways opened the Electric Street Railway from St Kilda to Brighton. This tramway was originally powered by a steam driven DC generator at the Elwood Depot.

6.4.7.4 North Melbourne Electric Tramway and Lighting Company

The North Melbourne Electric Tramway and Lighting Company proposed an electric tramway to operate in the Municipal areas of Essendon and Flemington. Part of the proposal was supply of electricity for business and retail customers as well as council street lighting. Generating electricity for other customers provided a benefit to the tramway company as it enabled the generation station to earn income while the trams were not drawing energy and evens out the electricity demand on the power station (the trams draw full load when the tram is starting to move and no load when the tram is stationary or coasting).

There were objections from the Metropolitan Gas Company to this tramway proposal, mostly on the basis of the effect of electrolysis on the gas pipes due to stray current corrosion. It is also noted that the supply of electricity would also target the gas companies customers from the sale of "clean safe electric light".

An Order-in-Council was issued on 4 May 1904 authorizing the Councils of Essendon and Flemington to construct a tramway in their districts. The tramway was opened on 11 October 1906.

One of the lines ran from the terminus built at Flemington Bridge North Melbourne, along Mount Alexander Road to Essendon. The second route from the terminus ended at the Maribyrnong River (known as Saltwater River at that time).

The tramway was supplied electricity from three steam engines rated at 360 horsepower driving three generators each rated at 250 kilowatts providing a voltage of 550 volts DC to the traction system.

North Melbourne Electric Tramway and Lighting Company en route to Saltwater (Maribyrnong River).

Following on from the successful commencement of the North Melbourne Electric Tramway and Lighting Company tramway there was rapid development of tramways in Victoria.

6.4.7.5 Brighton extension Victorian Railways

On the 11 December 1907 the Victorian Railways electric tramway was extended from Middle Brighton to Brighton Beach.

6.4.7.6 Prahran and Malvern Tramways Trust

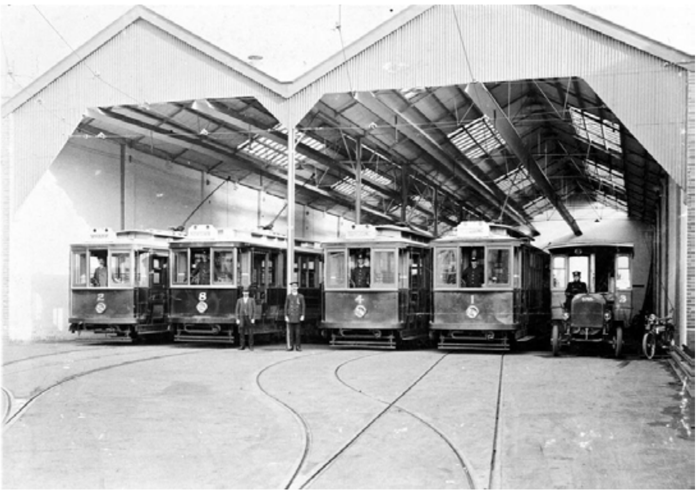
The Prahran and Malvern Tramways Trust created by the passing of the Prahran and Malvern Tramways Act 1907. Mr. Alex Cameron was elected as the first Chairman of the tramway on the 16 March 1908.

With Mr. Camerons guidance, the Prahran and Malvern Tramway Trust developed rapidly. From 1910 until 1918 the Prahran and Malvern Tramways not only electrified existing tramways but grew an extensive tramway system through St Kilda, Windsor, Prahran, South Yarra, Kew, Deepdene, Camberwell, Hawthorn and Caulfield.

In February 1920, when the Prahran and Malvern Tramway Trust was taken over by the Melbourne and Metropolitan Tramways Board, it was operating over 90 trams on 35 route miles of tramway.

6.4.7.7 Geelong Tramway

The Melbourne Electricity Supply Company opened the Geelong tramway in 1912.
The tramway was taken over by the State Electricity Commission of Victoria in 1930 and continued in operation until 1956.



Geelong tramway car depot 1915

6.4.7.8 Brunswick and Coburg Tramway

The Brunswick and Coburg municipalities, encouraged by the success of the Prahran and Malvern tramway, decided to create an electric railway from the cable tram terminus at the corner of Rathdowne Street and Park street Brunswick to the Nicholson and Bell Street intersection in Coburg. The Brunswick and Coburg Tramways Act was passed in February 1914. The concept of the tramway was extended to start at the corner of Swanston Street (formally Madeline Street) and Queensbury Street. The tramway would now include the City of Melbourne and a new Act, the Melbourne, Brunswick and Coburg Act was passed on the 26 October 1914.

The tramway trust was dissolved and taken over by the Melbourne and Metropolitan Tramways Board on the 2 February 1920

6.4.7.9 Hawthorn Tramways Trust

The Hawthorn Tramways Trust was established under the Melbourne to Burwood Tramways Act in 1914.

The Trusts main route was from Princes Bridge in the City of Melbourne out to Burwood.

The Tramway Trust was dissolved and taken over by the Melbourne and Metropolitan Tramways Board on the 2 February 1920

6.4.7.10 Fitzroy, Northcote and Preston Tramway Trust

Due to the success of other electric railways the municipalities of Fitzroy, Northcote and Preston put forward a proposal to construct and operate an electric tramway.

The proposed tramway was to run from North Fitzroy, near the cable tramway terminus as a municipal tramways trust, with routes commencing at the North Fitzroy cable tramway terminus and head to Miller Street in Preston where the tramway would have two branch lines, one heading to West Preston and the other to East Preston.

The Fitzroy, Northcote and Preston Tramways Act 1915 was proclaimed on the 3 August 1915 and the first tram ran on Tuesday 27 January 1920, just prior to being taken over by the Melbourne and Metropolitan Tramways Board.

6.4.7.11 Melbourne and Metropolitan Tramways Board (MMTB)

The Melbourne and Metropolitan Tramways Board was established on the 22 July 1918 under the provisions of the Melbourne and Metropolitan Tramways Act 1918.

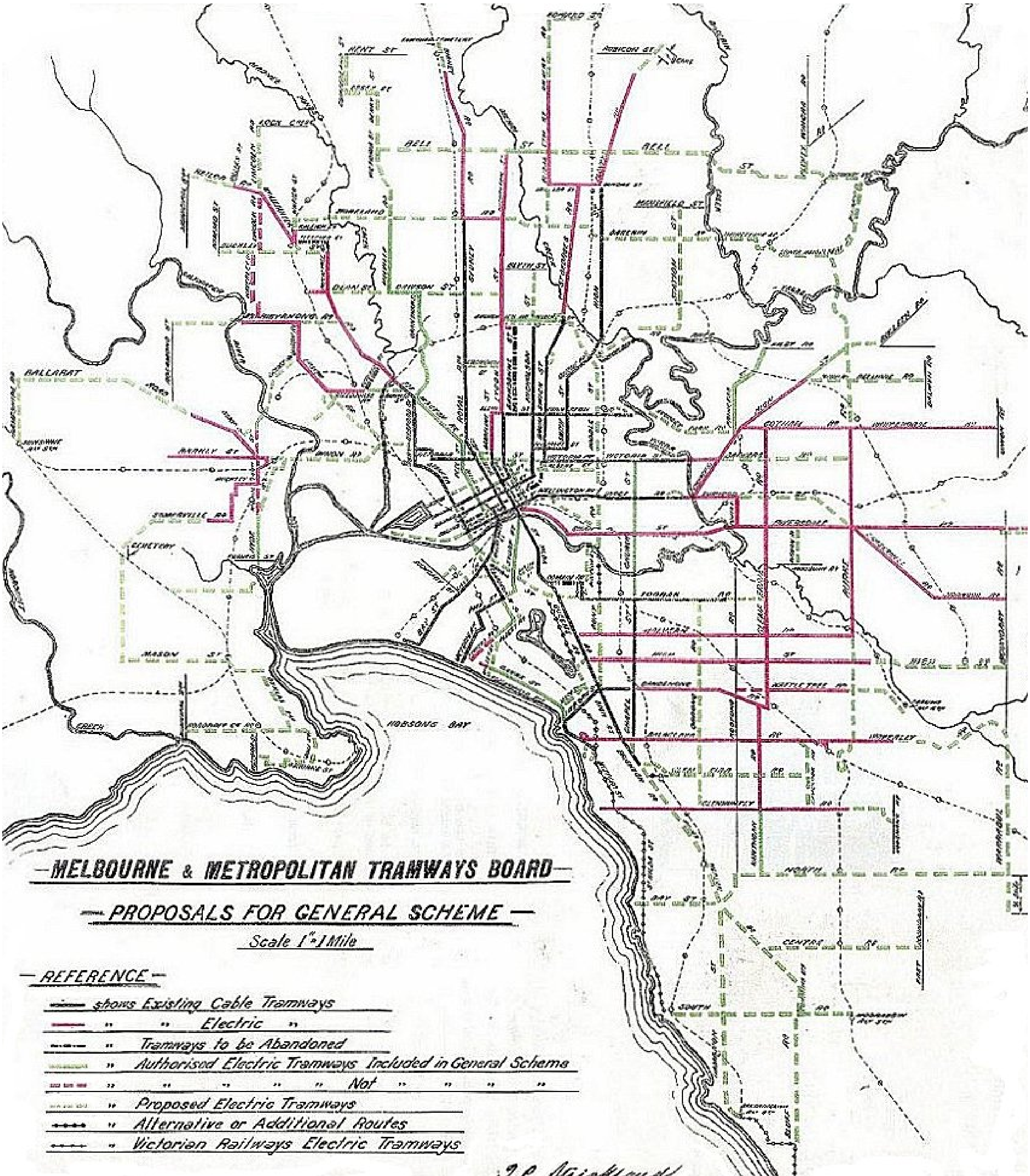
The MMTB was responsible for all tramways within 16 kilometres of the GPO (did not include Ballarat, Bendigo or Geelong).

Mr. Alex Cameron, Chairman of the Prahran and Malvern Tramways Trust was appointed as the chairman of the MMTB with the task to amalgamate the tramways and to electrify the existing cable and horse drawn tramways.

By the end of February 1920 the MMTB had control of the Melbourne tramways including the electric tramways of:

- Prahran and Malvern Tramways Trust
- Hawthorn Tramways Trust
- Melbourne, Brunswick and Coburg Tramways Trust
- Fitzroy, Northcote and Preston Tramways Trust
- Footscray Tramway Trust
- Northcote Municipality Cable Tramways.

The MMTB prepared a plan for the proposed upgrading and expansion of the Melbourne Tramway system in 1923.


MELBOURNE & METROPOLITAN TRAMWAYS BOARD
PROPOSALS FOR GENERAL SCHEME
Scale 1" = 1 Mile
REFERENCE
shows Existing Cable Tramways
" " Electric "
" Tramways to be Abandoned
" Authorised Electric Tramways Included in General Scheme
" " " " " " Not " " " "
" Proposed Electric Tramways
" Alternative or Additional Routes
" Victorian Railways Electric Tramways
HOBSONS BAY
BALLARAT
T.P. Strickland
Chief Engineer

6.4.8 Railway electrification

From 1852, the year after the colony of Victoria was established, railway companies started to be formed with the first steam train railway in Australia to operate from Flinders Street in Melbourne to Port Melbourne.

Over the next half century an extensive railway system was established across Victoria including the suburbs of Melbourne.

The Victorian Railways had its first experiences with electric traction with the St Kilda to Middle Brighton tram service which commenced service in 1906.

On the 13 May 1912 the electrification of the Melbourne suburban area railways was authorised.

The Victorian Railways power station to supply the electrified rail system was completed at Newport and operated until it closed in 1951.

The Newport power station was fuelled with black coal and the electricity was generated at a frequency of 25 hertz and distributed to substations around the network at 20,000 volts. The substations transformed the incoming AC supply to the DC traction supply. The traction supply was 1500 Volts DC. The transformation was initially done using a rotary converter which is basically an AC motor driving a DC generator.

On the 28 May 1919 the Victorian Railways first electric train service ran on the Sandringham - Essendon and Flemington Racecourse train line.

Electrification of major sections of the suburban network continued. By the end of 1920 the train system was electrified from Melbourne to:

- St. Kilda
- Port Melbourne
- North Carlton
- Reservoir
- Heidelberg
- Williamstown
- Fawkner.

By the end of 1925 the electrified system was further extended from Melbourne to:

- Broadmeadows
- St. Albans
- Frankston
- Dandenong
- Eltham
- Upper Ferntree Gully
- Ashburton
- Lilydale.

By this stage the electrified rail system covered a large portion of the Melbourne Metropolitan Area.

6.4.9 Electricity commissioners

Melbourne's electricity system had grown rapidly. Many local councils and private companies were supplying electricity.

Electric tramways had been well established

The three main power stations suppling Melbourne (one located in Spencer Street, Melbourne and two in Richmond). All three of these power stations burnt black coal to generate the electricity.

The Melbourne gas supply also relied on black coal to produce town gas. Black coal and coke from the gas works was also extensively used by industry and in homes.

Victoria was almost totally dependent on New South Wales for the supply of coal. The reliability of the coal supply was poor. The New South Wales coal strike in 1917 had a great effect on Melbourne. So much so that the Victorian Government appointed an advisory committee to "make certain investigations and report in regard to the commercial utilization of brown coal, and particularly for the purpose of generating electrical energy".

As a result of the report the Electricity Commissioners were commissioned in 1919 under the provision of the Electricity Commissioner Act 1918. Two years later the Board of Commissioners became the State Electricity Commission under the State Electricity Commission Act 1920.

The Commissions powers under the Act included:

- Construct, maintain and operate electrical undertakings
- Supply electricity developed from brown coal.

The SEC assumed the responsibility of the administration of the Electric Light and Power Act from the Department of Works until the Act was repealed.

By 1921 the brown coal open cut works had commenced. Electricity was being produced at the Yallourn Power Station by 1924.

The SEC also acquired the electrical undertaking of the North Melbourne Tramway and Lighting Company in 1922. The MMTB had acquired the tramway portion of the company.

In 1930 the SEC had acquired the Geelong Tramways followed by the Ballarat and Bendigo Tramways in 1934.

It is interesting to note that in 1930, the State Electricity Commission now owned an electric tramway that can create stray current (DC) corrosion and operates an electricity system that can spread the effect of stray current corrosion and who's underground assets can be effected by stray current corrosion. Unlike the tramway and electricity supply companies the SEC also has the charter to advise the government in relation to regulations for electricity safety.

6.4.10 The Code of Practice

The Victorian Electrolysis Committee - Code of Practice also provides guidance in relation to:

- Performance targets for Victorian Electrolysis Committee Operational Group (VECOG), traction operators and structure owners
- Cost sharing arrangements
- Registration of cathodic protection systems process
- Registration of mitigation systems process
- Health and Safety issues relevant to Committee activities
- Testing standards and criteria
- Dispute resolution.

The appendices to the Code provide:

- Guidelines for interference limits in cathodic protection design
- Specifications for data loggers used in area tests
- Flow diagrams for cathodic protection applications.

The Code of Practice also provides additional guidance on the functions and activities of the:

- Energy Safe Victoria
- Victorian Electrolysis Committee
- Technical Sub-Committee
- Victorian Electrolysis Committee Operations Group
- Works Liaison Sub-Committee.

In both Victoria and New South Wales, the traction system uses DC current and it is envisaged that it will continue to do so into the foreseeable future, due to the huge cost of and difficulty in converting trains, trams and their respective power supply systems, electrical protection and control equipment to AC operations.

6.4.11 AC traction

Alternating current (AC) is used in many overseas railway systems, and in Australia on the West Australian and Queensland railway systems.

Alternating currents ordinarily cause only about 1 per cent of the damage resulting from the equivalent amount of direct current. However, when operating under high load this may account for some damage.

Alternating current corrosion is being seen as an increasing problem worldwide.

Two papers presented at NACE conferences in 1998 suggest that corrosion due to AC currents may be very severe on pipes with excellent coatings. The good coating concentrates the stray AC currents to very high current densities at the few holidays that occur on any practical coating. Beyond a threshold of current density, corrosion appears to proceed very rapidly.

7 More recent history – The last 60(or so) years

7.1 Water

Melbourne's water is supplied from a number of large reservoirs mostly located to the north and the east of the Metropolitan area.

Melbourne Water is responsible for the water storages and transmission of the water to the metropolitan area, taking over from the Melbourne and Metropolitan Board of Works (MMBW) in 1991.

Recent additions to the transmission system include the North South pipeline to the Goulbourn River and the Wonthaggi Desalination Plant.

The distribution of water is undertaken by a number of distribution companies across Victoria. The companies that undertake the water distribution in the Melbourne Metropolitan area are:

- City West Water
- South East Water
- Yarra Valley Water.

7.2 Gas

The Gas and Fuel Corporation of Victoria was created in 1950 and in 1951 had taken over the gas supply of the Melbourne Gas Company and the Brighton gas Company. In 1971 the Gas and Fuel Corporation took over the Geelong Gas Company.

All of the gas companies still used black coal to produce town gas. Shortages of black coal from New South Wales still hampered the production of gas and coke and coal fuel in the Melbourne.

One of the initial tasks of the Gas and Fuel was to establish a brown coal to gas plant to produce Syngas using the Lurgi process. The Lurgi plant was commissioned in 1956 and a high pressure gas pipeline was constructed from the Lurgi plant located in Morwell in the Latrobe Valley to Melbourne.

The construction of the high pressure gas pipeline and the introduction of the electrification passenger rail service also from the Latrobe Valley to Melbourne were undertaken about the same time.

The discovery and tapping of natural gas in Bass Strait in the mid 1960's resulted in high pressure gas pipelines from the Bass Strait gas fields to Melbourne and the conversion of all of Melbourne's gas appliances to operate on natural gas.

The gas distribution and transmission network has continued to expand with the expansion of the Melbourne Metropolitan areas.

Along with the gas supply to Melbourne, gas has been transmitted to most major centres across Victoria. Gas transmission pipelines also connect to the Otway gas field and interconnect to South Australia, New South Wales and supply gas to Tasmania.

Similar to the Electricity network, the Gas and Fuel Corporation was split up and sold during the late 1990's.

7.3 Oil

The Westernport - Altona -Geelong (WAG) is a 135 kilometre pipeline that was constructed in the early 1970's.

The pipeline carries petroleum products from the Gippsland basin, including crude oil. The pipeline runs around Port Phillip through the Melbourne suburbs of Moorabbin, Brighton, Elwood, St Kilda and South Melbourne before continuing on to the Altona Refinery and Geelong.

The pipeline route crosses over numerous DC train and tramway systems as well as other structure.

The pipeline could be affected by stray current corrosion from traction systems and also affect the stray current corrosion protection of other structures.

The pipeline has a diameter of 600mm from Westernport to Altona and 400mm from Altona to Geelong.

Not being part of the Gas industry, the owner/operators were initially invited to attend the Victorian Electrolysis Committee meetings until the Act could be amended to appoint a new representative on the committee.

The Electricity Safety Act now requires a person nominated by the Australian Institute of Petroleum Ltd to be on the Victorian Electrolysis Committee. This person not only represents the interests of the WAG pipeline but also all affected petroleum pipeline owners.

7.4 Telecommunications

Telecommunications in Melbourne used to be solely with the Postmaster Generals Office. Telecom took over the telephone and communications system from the PMG until it was privatised into Telstra.

Telstra has been joined by a number of private telecommunication companies including Optus.

Telstra has a large number of lead covered cables still in operation with drainage bonds attached to and between these cables. As such Telstra, along with the other underground structures, being Water, Gas, Petroleum and Electricity continue to be subject to the effects of stray current corrosion and also interconnect the drainage system.

7.5 Tramways

The Tramway system continued to expand with the following route extensions having occurred:

- Bundoora (1987)/
- St Kilda and Port Melbourne (1988) Conversion from Railway to Tramway Light Rail Vehicles
- Burwood /East Burwood (1990)
- Airport West (1992)
- Mill Park (1995)
- Box Hill extension (2003)
- Melbourne Dockland extensions - progressively around 2010
- Vermont South (2005)

During this period, new tram rolling stock has been introduced:

W Class		single carriage introduced in 1935
Z Class		single carriage introduced in 1975
A Class		single carriage introduced in 1984
B Class		articulated 2 section introduced in 1984
C Class	Citadis	articulated 3 sections introduced in 2001
D Class	Combino	articulated 5 sections introduced in 2002
C2 Class	Bumblebee	articulated 5 sections introduced in 2008
E Class	Flexity Swift	articulated 3 sections introduced in 2013

The operation of the Tram system was transferred from the Melbourne and Metrolpolitan Tramways Board (MMTB) to the Public Transport Corporation (PTC) and then from the PTC to Yarra Trams and National Express. In 2004 Yarra Trams took over the operation of the entire tramways network.

The introduction of trams with regenerative braking has had a dramatic impact on the stray current mitigation systems and underground metal structures.

The regenerative braking changed substation loadings which resulted in reduced negative bus to earth voltages and therefore reduced effectiveness of the drainage systems.

When the tram is braking the tram generates electricity which feeds into the tram supply. The generation by the tram can introduce onto the underground structures, anodic potentials which do not correlate with the protection provided by existing straight drainage and thyristor drainage unit (TDU) systems.

Fortunately the regenerative breaking on the tramway system did not have as great an effect on structures as it did on the railway system. This can be attributed to the lower current drawn by the trams, the substations are closer together and there are usually more trams active within the same area as the braking tram.

E Class Tram.

7.6 Railways

Since 1925 the Victorian railways continued to electrify existing railway lines albeit at a much slower pace. These lines included:

- 1928 McLeod to Mont Park
- 1929 Reservoir to Thomastown and East Malvern to Glen Waverley
- 1934 Port Melbourne to Port Melbourne Pier.

In 1951 the State Electricity Commission took over the Victorian Railways Newport Power Station that was built in 1918.

The next major electrification project was to Warrigal which opened on the 22 July 1954 using an L Class Electric Locomotive. This was the first electrified main line in Australia.

The first electric passenger train ran to Traralgon on the 14 March 1956. This extended the electrified rail system to the Latrobe Valley where the State Electricity Commission brown coal mines, briquette factory and power stations were located. The electrification also enabled the SEC briquettes to be transported to Melbourne by the electricity generated by the SEC. Briquettes at that time were used extensively in industry, heating large commercial buildings and in domestic heaters and hot water units.

The first purpose built Harris (blue) steel bodied trains commenced operation on the 15 July 1956. These replaced the Tait Trains, known as “Red Rattlers”.

Over the next three years (from November 1956 to February 1958) the original Victorian Railways tramways from Sandringham to Black Rock, followed by Elwood to Park Street and then St Kilda to Elwood closed.

The existing tracks between East Camberwell and Box Hill were duplicated in 1971.

In December 1972 the first of the Hitachi (stainless steel) electric trains commenced service. This was the first of the trains for the modern era designed for use in the Melbourne Underground Rail Link (MURL).

The underground loop opened on the 24 January 1981.

The existing tracks between Ringwood and Bayswater line were duplicated in 1982 followed by the Ringwood to Croydon line in 1984 and the Croydon to Mooroolbark line in 1985.

The existing railway lines were electrified from Altona Junction to Laverton in 1984 and from Altona to Laverton in 1985.

The Williamstown to Williamstown Pier section was closed in 1985.

In 1987 saw the conversion of the existing electric railway line to light rail (tram) on the Melbourne to St Kilda and Melbourne to Port Melbourne railway line.

The existing tracks between Caulfield and Moorabbin were duplicated in 1987.

The last of the old trains were phased out with the last of the Tait trains running in November 1984 and the Harris trains in June 1988.

The existing Caulfield to Moorabbin track was duplicated on in 1987.

The next electrification was not until 25 March 1989 when the Dandenong to Cranbourne line was electrified.

On the 1 July 1983 the Victorian Railways became the State Transport Authority with V/Line and The Met as its operatives.

The Public Transport Corporation was formed on the 1 July 1989 from the Metropolitan Transport Authority "The Met" and the State Transport Authority.

Hillside, Bayside trains and V/Line were split off from the Public Transport Corporation on the 1 July 1998.

In October 1999 the operation of the metropolitan railway lines was franchised out with Connex taking over Hillside Trains and National Express taking over Bayside trains.

On the 27 October 2002 the St Albans to Sydenham electrified line commenced service.

In December 2002, National Express gave up their franchise for the trains in Victoria.

The X'Trapolis trains were the first of the regenerative braking trains and entered commercial service on the 27 December 2002 and were ordered and run on the Connex portion of the rail network. These trains initially created major stray traction current issues until limited at the request of the VEC.

The X'Trapolis trains, the first of the trains to have regenerative breaking, have created major problems created by stray traction current corrosion.

Seimens Nexas regenerative trains were the second of the regenerative trains to be introduced onto the Melbourne rail system and commenced operation 3 April 2003.

On the 18 April 2004 Connex took over the control of the entire metropolitan railway system.

On the 30 September 2007 the Broadmeadows to Craigieburn line was electrified.

The 30 November 2009 was the end of the Connex franchise. Metro trains now held the franchise for the entire metropolitan rail network.

The extension and electrification of the railway from Epping to South Morang went into service on the 22 April 2012.

The extension and electrification of the railway from Sydenham to Sunbury went into service on 18 November 2013.

X'Trapolis train

Siemens Nexas train

8 Tram and train electricity systems

8.1 Power distribution systems

Both the tramway and railway traction power distribution systems in Melbourne operate on direct current (DC), the operating voltages for each being 600 volts for tramways and 1500 volts for railways.

8.2 Railway Traction Systems

8.2.1 History

The initial railway traction power supply distribution system comprised the former Newport 'A' Power Station that was constructed, owned and operated by the Victorian Railways until 1951. The power was generated, transformed to 20,000 volts 25 Hertz and then transmitted to a number of large capacity substations located around the suburban railway network.

In the 1920’s, more substations were added to cater for the extension of the electrified system, with each substation being very much smaller than the original substations and automatically operated compared to the original manual operated substations.

The original substations and a number of those built in the 1920's achieved the transformation by means of large rotating machines known as rotary converters. The largest of these machines operated until the early 1970’s at the Jolimont Substation, located adjacent to the Melbourne Cricket Ground, and were each rated at 4500 kilowatts. The balance of these substations used mercury arc rectifying equipment.

In the late 1940's, the Victorian Railways decided to convert the AC part of the traction power supply system to 50 Hertz operation (this being the normal industrial power supply frequency throughout Australia) and prepared a conversion program planned for completion in 25 years.

The conversion work, performed by Victorian Railways staff, was completed on time when Jolimont Substation was de-commissioned in December of 1973.

The new substations used static rectifying equipment instead of rotary converters. Initially, steel tank mercury arc rectifiers were used with some glass bulb rectifiers being introduced midway through the program, and silicon diode rectifier units being used in all new substations built and/or rehabilitated since 1964.

One objective of the program was to develop a more even distribution of substations throughout the system than the rotary converter substations thus overcoming the voltage problems encountered by trains when remote from a rotary converter substation. The more even substation distribution improved the electrical protection for trains and overhead wiring.

A number of the old tie-stations were retained as tie-stations, others were converted into substations, whilst others were de-commissioned altogether. Some of the original substation buildings were converted for a 50 Hertz and rectifier operation, however most of the buildings were unsuitable for conversion.

All Mercury Arc rectifiers have been replaced with silicon diode rectifiers. The rectifiers are of a higher electrical capacity than that of the Mercury Arc in order to provide a system wide increase in capacity to ensure the availability of power for the most modern of the then PTC’s suburban train fleet.

The original substations were manually controlled, as stated earlier. In 1939, a supervisory system was installed to provide remote indication of the operating condition (i.e. on or off) of the equipment in manual substations, and to both provide remote control and indication of the operating condition of the substation in the adjoining substations. The supervisory system has since been replaced with a computerised system which provides more information on the substation performance than the previous system.

The distribution system is a major factor influencing stray current corrosion, with rail voltages dependent on the AC supply system, substation load capacity, rectifier equipment, substation location and track infrastructure.

For example, early distribution systems consisted of fewer substations with rotary converter rectifiers, greater distances apart and as a result, negative rail to earth voltages at the substations.

Diode rectifier substations installed today are closer together and share loading, with resultant positive to earth rail voltages at the substations.

8.2.2 High voltage transmission

The 25 Hertz railway traction power supply distribution system made extensive use of 20,000 volt transmission lines, both underground cable and bare overhead wires, to link Newport Power Station and the traction power substations. A standby supply from the Melbourne Electric Supply Company power station at Richmond (later taken over by the SECV) was linked into the system via Jolimont Substation.

Many of the aerial lines within the railway reserve were retained for 50 Hertz operation as part of the frequency conversion program, and many of them are still in service.

Of the underground cables, many were converted for use as 2200 volt signal power supply feeders, some were sold to the SECV and a small number were retained for 50 Hertz operation, while the remainder were abandoned.

Connection of existing and new substations to local high voltage supplies has had a major impact on electrolysis mitigation systems resulting from variation of AC supply voltage. For 22,000 volt supplies, a 2% (440V) variation can cause a substantial change in DC load current at adjoining substations, particularly for those lightly loaded, tending to either over drainage or loss of protection.

NOTE: This change of voltage is within the variation specified by the supply authority.

8.2.3 Overhead wiring systems

The railway system uses the catenary and contact wire method of overhead wiring construction. This is used because of the heavy currents drawn (in the order of 2500 amperes when a train is accelerating from stationary) and train operating speeds (the Werribee electrification extension was designed for train speeds up to 160 kilometres per hour, while speeds on other parts of the railway network are dependent of track layout and construction)

8.3 Tramway Traction System

Unlike the Railway system, the tramways never possessed its own generating system and has always operated on 50 Hertz power supplies from the local supply authority.

Power supplied to the tramway substations ranges from 6,600 volts to 22,000 volts.

Rotary converters from 500kW to 1000kW were installed in the 1920's to 1930's, followed by mercury arc rectifiers of differing capacities in the 1940's, 1950's and 1960's and silicon diode rectifiers from the late 1960's.

Although no rotary convertors are still in use, there is one mercury arc unit still in service, all others are silicon diode rectifiers.

As with the railway system, a supervisory system was installed to provide remote control and indication of substation equipment and has been replaced with a computerised system.

The tramway system (except the St Kilda and Port Melbourne light rail lines which use the railway system of overhead construction) uses the trolley wire system. This does not use a catenary wire, and is used for lower speeds than those on the railway system.

Pantographs are used exclusively on all electric trains and on the "A" and "B" class trams, while trolley poles were used on the "W" and "Z" class trams. The "W" and "Z" class trams have since been refitted with a pantograph at one end of the tram and the pole at that end of the tram has been removed.

It should be noted that many tram substations differ from railway substations by having remote track negative feeders installed. At these substations, a negative voltage is maintained at the negative busbar of the substation due to the resistor installed in the local track negative feeders. Positive feeders also supplement the overhead.

9 Précis of early documentation retrieved from SEC archives

9.1 The foundations of electrolysis mitigation

9.1.1 Electrolysis Investigation Board 15 November 1922 to 18 December 1923

The earliest document in our records is that of a legal opinion dated 25 September 1922 headed “Liability of Victorian Railway Commissioners to make good damage by electrolysis to the property of the Post Master General (PMG)and others through escape of electricity incidental to working of Suburban Railway Lines”.

It was written and signed by E.F. Mitchell of 463 Chancery Lane and made reference to Part VII of the Federal Post and Telegraph Act 1901 (Section 140) which in essence said that any electric authority including any State Government Railway authority cannot build, operate or do work on an electric line which causes damage to any Post Master General telegraph lines and that any authority doing so were liable to pay for any damage caused.

He also indicated that although other authorities had the legal right in legislation to lay pipes in public highways, there was no provision made for damage or injury due to the escape of electricity. He also indicated that the railways were within their rights to operate an electric line as per Sections 4 and 5 of the Victorian Electric Light and Power Act 1915 and the Railways Act of 1918 and had like powers conferred on them as per the Post Offices Act 1890.

He also made mention of court cases on this subject and gave some overseas examples such as the Eastern and South African Telegraph Company versus Cape Town Tramways Companies (1902), Midwood versus Manchester Corporation (1905) and Charing Cross Electricity Supply Company versus London Hydraulic Power Company (1913).

This document is referenced in a Victorian Railways memorandum of 26 October 1922 to the Railway Commissioners from the Crown Solicitors Office that appears to be in response to a demand by the Post Master General’s Department for the Railway Commissioners to pay for repairs to postal cables after an electrolysis survey indicated damage to the postal cables was more serious after electrification of the suburban railway system.

It appears that other instrumentalities had also submitted claims to the Solicitor General to repair damage that was attributed to the electrification of the suburban railway system but had not backed them up with electrolysis survey measurements.

The memorandum also details the response of the Crown Solicitor to this legal opinion from Sir Edward Mitchell KC onto whether the Railway Commissioners were legally liable. His considered position was that unless the Railway Commissioners could prove that they had taken all known and reasonable precautions, they would be liable for any damage to property and because they could not prove it they would have to pay the Post Master General’s claim considering that it had been well researched and documented and followed complaints from the Prime Minister to the Premier.

The memorandum also details the opinion of a Mr Merz in a letter dated 5 September that expresses the view that the railways should not be saddled with damage attributed to the tramway system and that any claim on the railways should be carefully analysed and liability disputed except where was unmistakable evidence that the damage has been caused by railway current.

The Chief Electrical Engineer accepted the PMG claim but directed that letters repudiating their responsibility be sent to the other instrumentalities which were the MMBW, Metropolitan Gas Company and the Melbourne City Council.

This action appears to have been the catalyst for the railways to create an “Electrolysis Investigation Board” with the inaugural meeting being held in 20 March 1923 between the Chief Engineers of the SECV, MMTB and VR.

The gentlemen representing these organizations were:

H.R. Harper Esq	Chief Engineer	SEC	22 William Street, Melbourne
T.P. Strickland Esq	Chief Engineer	MMTB	673 Bourke Street, Melbourne
H.P. Colwell Esq	Chief Electrical Engineer.	VR	Spencer Street, Melbourne

In future meetings Mr Harper is referred to as the “Chairman of the Electrolysis Investigation Board” with correspondence being processed via the SEC.

At this meeting they had a general discussion as to the substance of the Terms of Reference and made a number of decisions as follows:

- Accept that electrolysis in the metropolitan area did exist
- Send out invitations to other government departments and companies that also owned underground steel water mains and gas mains to provide them with records and evidence to join them for joint discussions
- Calculate leakage currents and rail voltages as an average over minimum and maximum traffic times for both tramway and railway systems
- Encourage other public services to take their own precautions against electrolysis especially at track crossing points.

Replies were received by the Board during April 1923 from various government departments with varying levels of support. There is no record of any meeting being held in this month with the next meeting on file being held on 8 May 1923.

At this meeting the Electrolysis Board was made aware that an Electrolysis Investigation Committee representing the Metropolitan Gas Company, the MMBW and the PMG was already actively collecting records of damage due to electrolysis. The members of this committee thought that they should be represented on the Electrolysis Board. The Electrolysis Board agreed that when an appropriate stage of deliberations of the Board had been reached the committee would be invited to attend.

At this meeting the business of protecting against electrolysis began in earnest with technical discussions between those present and with input from those bodies that replied to the invitations that were sent out in March.

Correspondence on file seems to indicate that the Board had to reassure some of the invitees that before any recommendations were made, that consultation was to be the way of controlling this problem and that their independence would not be threatened and their participation on this consultative basis would be encouraged.

Correspondence on file from the more enthusiastic invitees appeared to indicate their willingness to research and obtain all the information they could from overseas and local sources and clearly embrace the consultative process to benefit all.

To gather more information from the world stage on electrolysis, Mr Harper wrote to the Hon. R.W. Craig, Attorney General, Province of Manitoba in Winnipeg, Canada to obtain a copy of the Manitoba Electrolysis Act of 1918 and also to the Superintendent of Documents of the Government Printing Office in Washington, USA to obtain a copy of a report from the American Commission on Electrolysis and any rules issued by their Bureau of Standards.

Further meetings were held in quick succession on 5 June, 12 June, 26 June, 3 July, 10 July and 31 July 1923 where Mr Bennie of the Metropolitan Gas Company and Mr Ritchie of the MMBW submitted evidence of damage done to their gas and water mains that had been collated by Wilfred Kernot of the Melbourne University Engineering School located in Carlton, acting as an advisor on behalf of both organizations and R. Lawson Esq, State Engineer for the PMG in Melbourne also submitted information on electrolysis matters and in particular rail voltage potentials.

It appears that by August 1923 the Board had arrived at a point in their deliberations that even with all the engineering input they had sought they still had insufficient data to formulate effective regulations that could reliably control electrolysis and that what they really needed was a detailed railway and tramway rail potential map of the voltage gradients along the rails and through the soil.

The Board realized that to produce this data an extensive amount of testing would have to be conducted at considerable cost. Therefore, on the 8 August 1923 the Chairman wrote a letter to Sir John Monash requesting that sufficient funding be supplied.

Sir John Monash replied on the 14 August in an SECV departmental memo that he agreed that this request was within the terms of reference but clearly stated that the amount required and the cost sharing arrangements should be worked out before hand. He also laid out a strategic framework that in the first instance the three departments work through this with a view to inviting the remaining organizations to also participate and ultimately join the Board and formulate a joint recommendation that will be satisfactory to all parties.

The area chosen to conduct this survey was in the Geelong area adjacent to the Geelong electric tramway as the Board felt that as there had been very little evidence of electrolysis damage this would be the ideal location to collect the electrical rail voltage data that would be used to formulate the electrolysis regulations.

While this proposal was being worked on, much information was still being received from various sources outlining instances of electrolysis corrosion and a growing body of data.

One such example was received on 11 October, dated 5 September 1923 from the Agent-General for Victoria based in London who sent copies of two sets of British regulations made by the Minister of Transport and by the Board of Trade. This was closely followed by the receipt from the same source of a newspaper cutting on 23 October, dated 18 September 1923 from the Daily Telegraph published in London on 17 September 1923. The cutting entitled “Electro-Chemistry-Engineering Applications” contained a subsection “Corrosion of Underground Pipes”. Also from the same source received on 3 January 1924 was a copy of an extract from the Swiss Association of Electrical Engineers detailing the rules to be followed to protect metallic conduits and underground cables against corrosion due to electrolysis.

By the time meetings held on 16 October and 23 October, 1923 the Board were starting to assemble a good representative sample of corrosion faults with detailed electrical data and an appreciation of what overseas regulations were in place. Regulations governing tramways operation were then framed and after some discussion and amendment were submitted for consideration for the meeting of 30 October 1923. At this meeting it was agreed to send a copy of these proposed regulations to the Legal Officer to determine what penalty clauses would be appropriate to include. It was also agreed that these regulations would be a suitable basis to formulate regulations for railway operation.

In a letter from the Melbourne City Engineer to Wailes Dove Bitumastic Ltd in Newcastle-on-Tyne he mentions that it has been observed that corrosion effects are far less pronounced on mains that have a bitumen coating. A Mr C MacDonald from that company then wrote to the Australian representatives who sold Bitumastic Products who in turn wrote to the `SEC Chairman asking permission to have an interview with Mr Harper. The Australian agents were J Wilridge and Sinclair Limited, Refrigerating Engineers, of 590-592 Elizabeth Street, Melbourne and a Mr R.C. Pidgeon of that company wrote the Secretary of the SEC for the attention of Mr Harper on 16 November 1923 to discuss the merits of their products.

By November 1923 replies were being received from the initial enquiries made to overseas organizations. The Agent-General for Victoria in London had received information via His Majesty's representatives in many European countries that there were no electrolysis regulations in Italy, Greece and Bulgaria. Czechoslovakia and Norway, whilst no regulations were in place, the former was producing a pamphlet and the latter had already produced two pamphlets on the matter and that translation of those would be prepared. France and Germany had regulations in place but they were in respect to DC tramway systems and not for railway systems because of their more open track construction.

At the meetings held in November and December of 1923 considerable technical discussion about what sort of regulations were going to be adopted locally ensued. Concerns were raised that the use of tramway regulations on railway systems would set a precedent, not safeguard the Railways Department or public utilities and couldn't be applied to all lines. The alternative that was proposed was to have a body like the Board of Trade in England to satisfy itself that the railways were operating in such a way to minimize electrolysis as much as possible.

9.1.2 Electrolysis Investigation Board 19 March 1924 to 29 November 1926

By early March 1924, much overseas information was still being received. The Agent General for Victoria in London continued his ongoing look out for electrolysis information and supplied a copy of a paper by Mr S C Bartholomew entitled "Corrosion of Lead Covered Cables by Electrolytic Action and another set of regulations from the Colonial Office from His Majesty's Ambassador in Berlin entitled "Vorschriften und Norman des Verbandes Deutascher Elektrotechniker" detailing the German regulations as laid down by the Association of German Electrical Engineers. Also received were translations of the Swiss and French Electrolysis Regulations and from the Duke of Devonshire at the Colonial Office in Downing Street, London, a translation was received from the British Commercial Mission in Moscow from The People's Commissariat of Foreign Affairs of the Soviet Republic of Russia of regulations not legally sanctioned but adopted in that country by the 6th All Russian Electrotechnical Conference of 19 October1911.

Mr Colwell advised the Chairman of an intended visit from the 7 to the 12 of April 1924 by Mr Brain, the Chief Electrical Engineer of the NSW Government Railways and Tramways. The Chairman requested to have a meeting with him as it would be of mutual benefit, as it was believed that any electrolysis regulations formulated would probably apply to the Commonwealth due to interest by the PMG. The meeting appeared to open a strong and positive dialogue between the two gentlemen concerning railways and tramways track voltages with much communication ensuing.

Correspondence between Harold Clapp, Chairman of the Railways, Mr Harper, Chief Engineer of the SECV in his role as Chairman of the Electrolysis Investigation Board, and Charles Bright Esq, the Deputy Post Master General appeared to indicate that agreement had been reached on payment of the cable repair claim attributed to Railway current damage and clearly excluded that caused by tramway's current. In letters dated 26 and 28 April 1924, correspondence indicated a stated commitment to minimize the railway current leakage and that a great deal of work was being conducted to prevent this leakage thus satisfying the legal requirement to have taken all reasonable steps to prevent it from happening.

In a translated letter dated 8 April 1924 originating from a F. Espinosa de los Monteros in Madrid, to His Majesty's Representative in Spain and then via the Agent General in London to the Chairman of the SECV, he indicated that Spain had no definite regulations at that date but a Royal Order dated 14 July 1922 had directed that the Spanish Council of Public Works investigate the use of electric traction with the assistance of local railway engineers and technical experts.

In a letter dated 6 May 1924, the Victorian Agent General in London had sent a translated copy of the regulations of the methods adopted in Hungary to the Chairman of the SECV. They had been issued by a Dr Stettina on behalf of the Hungarian Minister of Commerce, and then sent by His Majesty's Representative in Budapest. They had been in operation since 11 May 1912 and were applicable to both the railway and tramway systems.

In the months following the collection of increasing amounts of electrolysis mitigation information from other countries, the Electrolysis Investigation Board completed their preparation of electrolysis regulations for the tramways and began to formulate regulations for the railways.

According to the correspondence on file, there appeared to be some lengthy delays in completing this task because of its complexity but all parties were being reassured that no hasty decisions would be made without thorough consultation between all parties, public and private, that may be effected by electrolytic action.

However, it also appeared that the Railways were very concerned that any regulations would offer them no protection against claims for damage. Following further correspondence and consultation, the VR representative made it quite clear in a letter dated 22 January 1925 to the Chairman of the Electrolysis Investigation Board that he was not going to be party to any regulations and clearly and emphatically gave four reasons for this stance and concluded that an independent body such as the SECV should act in a manner similar to the British Board of Trade to ensure that electrolysis matters are dealt with to safeguard other public and private interests.

Briefly, the four reasons as stated in this letter were:

(1) Impossible to fix regulations when there are so many variables affecting electrolysis
(2) That there was no legal protection as clearly stated by the Crown Solicitor
(3) The actual trouble by experience from Electrolysis was small as per the records
(4) Enquiry abroad shows that other countries have found fixing regulations difficult and deal with problems as special cases when they arise, as we presently do.

Ironically on the very next day, a letter from FW Clements, the Manager and Engineer from the Melbourne Electric Supply Company was received by Mr Harper, detailing a cable fault attributed to electrolysis on the cable sheath on the underground supply cables in New

Street, Brighton in the vicinity of the Middle Brighton Railway Substation. Mr Harper immediately directed the Electrical Engineer to conduct an investigation which resulted in values of railways track voltage potential drops being recorded and reported to the Board on 30 April, 1925. The values ranged from 1.5 volts to 2.2 volts and varied according to where the trains were located, the maximum being measured when they crossed at the Dendy Street level crossing. The damage necessitated 29 yards of 0.1 cable being replaced.

This was closely followed by the news from the Agent General for Victoria in London that the Netherlands had passed fixed Electrolysis Regulations for railways and tramways by decree on 5 February, 1925. In a translation from the "Staatsblad" (the Government Gazette) of the Kingdom of the Netherlands, Articles 1 through to 11 gave clear, legally binding technical requirements, enforceable with stated monetary penalties for infringements.

During the early part of 1925, Mr Colwell, the VR representative went on an overseas fact finding mission to study what was being done in other countries and in conjunction with input to the Board from the Victorian Agent General in London, it was hoped that some sort of finalization of regulations could be achieved.
In a letter from the Secretary of the PMG Department to the Chairman of the Electrolysis Investigation Board on 11 May 1925 reference was made as to what stage the investigations and deliberations of the Board were up to. In a reply dated 9 June 1925 the Chairman emphasized that more information should be collected from the overseas experience to make a fully informed decision on what binding regulations should be applied to the railway's return currents.

However, in a SECV departmental memo dated 12 August 1925, the Chairman details a phone conversation whereby a Mr Crawford, the Chief Electrical Engineer for the GPO has made an appointment to discuss electrolysis affecting the post office cables as their organisation now finds it "necessary to press matters to a conclusion". Over the next few weeks, informal meetings between the Board members took place which resulted in an Electrolysis Conference being convened on 29 September 1925 between the Electrolysis Investigation Board and Mr Crawford.

Because Mr Colwell was overseas, the VR were represented at this conference by Mr C McDonald in his absence.

The intent of this conference was to formally attempt to resolve the electrolysis problem as Mr Crawford told the meeting that the PMG's Department was spending £20,000 per annum and this was likely to rise to £25,000 for this year (1925) on just the cable repairs known to be caused by electrolysis. Apart from this financial loss, there was also the inconvenience to the public. He went on to tell the meeting that the SECV had allegedly promised that a PMG representative will be invited to sit on the Board to assist.

In the Chairman's reply, he said that the PMG's Mr Lawson, the State Engineer and Mr Kilpatrick from Central Staff had attended several Board meetings to assist in deliberations and that he was unaware of any promise to appoint a member but it was clearly understood that an invitation would be made once regulations had been framed.

On the matter of costs, Mr Crawford feared that if the preventative measures cost more than the repairs, there was a tendency to take no action. However, if the reverse was occurring there would be a tendency to take action to eliminate trouble. Both the VR and Tramways representative assured Mr Crawford this was definitely not the case.

The Tramways representative claimed that Sydney had minimal electrolysis problems because of its adequately designed distribution system. It was envisaged that when the Tramway distribution system in Melbourne was further advanced, electrolysis damage attributed to their present system would be eliminated and that the Tramways will then concentrate on trouble spots.

The VR representative said that they were very aware of the dangers accruing from stray current and to demonstrate this concern had installed a return feeder at Newmarket costing £5,000. He went on to allege that faulty cable laying contributed to the damage. In reply, the PMG representative said that cable laying practices were standardized throughout Australia.

Mr Crawford was asked to estimate what percentage of their repair costs could be attributed to damage caused by leakage currents below the value stipulated in their own regulations. He had no definite value but believed it could have been as much as 90%.

Mr Crawford also was of the opinion that the Regulations framed for the Tramways were also applicable to the Railways. This interpretation of the Tramway rules was questioned by the members as the two systems were different in several fundamental respects.

The Chairman said that the Tramway regulations drafted by the Board were now before the SEC for consideration and they had moved on to drafting the Railway regulations but had decided to hold off finalization until the VR representative had returned. It was felt that he may have information to add that would assist in this task.

Mr Crawford asked if he could informally have a copy of these draft Tramway regulations to gauge from their perspective any likely impact on the PMG Department.

In a letter dated 7 October 1925 from the Chairman to Mr Crawford, an informal copy was attached but the Chairman was at pains to inform Mr Crawford that they were draft regulations and were before the SEC and the copy was to be held in the strictest confidence.

The Members agreed to meet again on a date to be fixed and that a Mr Partington, the State Engineer of the PMG's Department would also be attending. Mr Crawford also promised to provide all the data available, and maps showing the areas in which damage has been done to the telephone cables by electrolysis.

In a letter dated 20 October 1925 from Mr Crawford to Mr Harper a list of about 12 special danger locations where cables had been damaged by electrolysis were provided.

In a letter dated 17 November 1925 again from Mr Crawford to Mr Harper, he requested, after perusal of the copy in confidence, that omissions in the new regulations with respect to PMG's regulations will need to be discussed, including the volt drops per mile of track. The PMG regulations require a maximum voltage drop of 3 ½ volts but a maximum of 5 volts was quoted in the new draft regulations.

On the 4th December, 1925 an SECV memo from the Test Engineer to the Electrical Engineer detailed the results of testing on a 4 inch water main at Yarraville Terminal Station where the main had corroded away directly above an earthing cable/bus buried 9 inches below. The DC millivolts measured between the two was 7 to 14mV positive. The problem was further exacerbated as the pipe was buried in moist ash/clay land fill and the hemp and tallow thread seal on the pipe joints created a high resistance, effectively a barrier to low voltage traction return currents. The current saw the return path from the pipe to the earth cable via the ground as the path of least resistance back to the railway. It was proposed that the incoming pipes be bonded and earthed at the entry from the street at the property boundary to divert the current away.

On the 10 June, 1926 the Chairman received a letter from Mr F Clements of the Melbourne Electric Supply Co, informing him of a extensive cable fault outside the tramway sheds at the corner of Barker's and Bowen Streets, Kew, which resulted in a section of cable between two joints being replaced. Attached was a sketch on parchment showing the relationship and distance between the cable, the track and the 6 inch water main under which the fault occurred. A sample of the cable sheath was also supplied for inspection. The fault was noted and it was to be discussed at the next forthcoming conference held by the Electrolysis Investigation Board held on 1 June 1926.

Summary of conference notes

The following gentlemen were in attendance.

- Mr H Harper	Chief Electrical Engineer-SECV	(Chairman, Electrolysis Investigation Board)
- Mr H Colwell	Chief Electrical Engineer, Victorian Railways
- Mr J Crawford	Post Master General's Department
- Mr J Kilpatrick	Post Master General's Department

Mr Strickland from the MMTB was unable to attend due to the pressure of work.

Mr Crawford tabled records covering cable faults to the 12 months to January 1926. He explained that the frequency was increasing and that it was costing the PMG about £33,000 to £34,000 in Melbourne (only £14.000 in Sydney) and that the total cost was much greater after taking into account the inconvenience to the public and loss of revenue. He was clearly of the opinion, because of the wide spread and increasing number of faults, that definite measures need to be undertaken and that the all concerned authorities should share costs and thus losses.

Mr Colwell said that VR had demonstrated the level of their commitment by taking such steps as attempting to maintain a relatively high track ballast resistance and providing, in at least one area, negative return cables at a cost of £5000. Mr Colwell asked Mr Crawford what protective measures he thought should be adopted. He replied that the installation of "drainage cables" was one such measure that could be considered and indicated that in America, "cable sheath drainage" had reduced electrolysis troubles and was considered almost essential for complete protection to be achieved.

The members discussed the current practice in England whereby they thought that in the absence of any regulations, the Board of Trade gave permission for railway work to proceed but in the event of any trouble, the company was held accountable. Mr Crawford disagreed with this belief and to back his claim tabled an extract from the "Standard Handbook for Electric Railways", Section 16, that gave precise values of rail voltage drops, track voltage gradients and current densities and allowable limits.

Mr Colwell questioned whether Commonwealth statutory rules applied to the Railways but Mr Crawford was of the opinion that they were. Mr Colwell was of the opinion that it was the Tramways causing the trouble. He based this claim on a conversation that he had with Mr Strickland, that the Tramway system was being remodelled and that as a result the troubles would be eliminated. Mr Kilpatrick, also from the PMG, stated that he had observed that the potential difference between any two points when the railway and tramway systems were taken collectively they were outside the limits, but individually they were not. Therefore, he said it was difficult to proportion responsibility.

Mr Colwell told the meeting that in America, meetings are held between representatives of the different authorities concerned who arrange for tests to be made. These tests were discussed and agreement reached as to which body should take action. He said that his department had a full time officer engaged on electrolysis investigation and analysis of faults.

Mr Crawford said that the practice in England was to keep a record of all faults and he thought that the same thing should be done locally. When asked as to what areas should be tested he suggested Caulfield, Carlton and South Yarra. He was also asked his thoughts when comparing the draft Tramway Regulations and the PMG’s regulations. He said that the former were not as stringent and their adoption should be postponed as he thought they were not sufficiently effective in preventing electrolysis. In the meantime, he thought that the Board and the PMG’s Department should conjointly investigate the problem.

After further discussion, Mr Harper suggested that a sub-committee should be appointed consisting of the members and a representative of the PMG’s Department to undertake close investigation of the Post Office problems, taking each affected area in turn. He went on to say that endeavour would be made to arrive at an agreement as to the most suitable and economic treatment to be adopted in each case and as to the distribution of cost thereof. The recommendations of this sub-committee would then be submitted to an Electrolysis Committee for their consideration and final decision. Meetings of the Sub-Committee would be frequent and regular, in order that the investigations progress at a satisfactory rate. In all probability there would be other bodies interested in these investigations, such as the Gas Company, MMBW and the Melbourne Electric Supply Company and at some future date it may be advisable to invite these bodies to each nominate a representative to assist in the investigations as and when they become interested.

Subsequent to the conclusion of the conference, Mr Crawford wrote to Mr Harper nominating a Mr Ridgway as the PMG’s sub-committee representative and requested this matter be pushed forward as quickly as possible so that the present rather unsatisfactory situation may be terminated.

In Mr Harper’s reply dated 19 June 1926 accepting this nomination, he advised Mr Crawford that the Electrolysis Investigation Board was meeting within the next week where the conference suggestions would be discussed and that he thought it most likely that it will be possible to call a meeting of this sub-committee immediately. Over the next couple of days notices were sent out advising that the date of the next Board meeting would be Wednesday 23 June 1926.

At this meeting, instead of proceeding with the business of finalising the Tramway Regulations as drafted by the Electrolysis Board some time ago, the proposal to set up a sub-committee was discussed. Mr Crawford put forward the proposal to use the Board of Trade Regulations as used in England for electric railways but said they had never been applied to tramways. Mr Harper put forward the proposal to organise the sub-committee along the lines of what was adopted by committees already operating in America such as “The Joint Committee for Protection of Underground Structures in East Bay Cities” (an area of San Francisco) or the “Detroit Committee on Electrolysis”.

At the conclusion of these discussions it was agreed to appoint a sub-committee consisting of approved representatives of interested bodies and a Chairman. This sub-committee would then make representations to the Electrolysis Board on what protective or alleviatory measures were to be considered and how the costs of testing were to be apportioned. The cost of investigatory work could be met by each party lending an officer and the necessary apparatus to conduct tests. It was suggested that the position of Chairman be occupied by an independent body and it was agreed that the State Electricity Commission of Victoria should appoint a representative to occupy this position.

Through the following weeks of June and July 1926 much correspondence passed between the members of the Electrolysis Board and other organisations that were thought to be interested in the proposal. This communication also canvassed various names from these organisations. In an SECV Departmental Memo dated 6 July 1926, Mr Harper asked the SECV's Electrical Engineer, Mr E Bate if he could spare the time to become the Chairman for the Technical Sub-Committee and that his fellow committee members were to be Mr Stookley from the Victorian Railways, Mr Robertson from the Tramways Board and Mr Ridgway from the PMG's Department.

In a follow up Memo dated 27 July 1926, Mr Harper requested Mr Bate to call together the Technical Sub-Committee to start work

In a letter dated 5 August 1926 from Mr Colwell to his fellow members in the Electrolysis Board, he expressed his opinion that the time had perhaps come for the Board to formally recommend to the Electricity Commission that a main committee be set up with the Technical Sub-Committee.

This would formally conclude the work of the Electrolysis Board and enable the future problems to be dealt with by an organisation permanently established and satisfactory to all interested parties.
He suggested that at the next Board meeting consideration be given to this so that a final report could be prepared.

At the meeting of the Electrolysis Board on 11 August 1926 much robust discussion was had in an effort to hammer out the details, if this proposal was in fact to become reality.

It was at this point that the Mr Crawford, the Chief Engineer from the PMG's Department wrote to Mr Harper in a letter dated 24 August 1926 very politely informing him of his concern of being omitted from these discussions as the Electrolysis Board had been set up by the Victorian State Government in response to electrolysis damage to their cables and to this end they had inadvertently overlooked the Commonwealth Government organisation. He went on to express his opinion that the sub-committee including their representative should start meeting without delay.

Mr Harper wrote a letter dated 31 August 1926 expressing his regret at this misunderstanding and assured Mr Crawford that it was the intention to involve all interested parties in the set up of the main committee.

Epilogue

No further minutes of meeting of the Electrolysis Investigation Board were filed which makes the meeting held on 11 August 1926 appear to be the last time it formally met.

The final 20 page report from the Board, including its recommendations, signed by HR Harper, representing the SECV, TP Strickland, representing MMTB and HP Colwell representing the Victorian Railways, was formally submitted to the Chairman of the SECV, Sir John Monash in a Departmental Memo dated 18 November 1926. At Sir John's direction, via an initialled note dated the next day, the report and recommendations were sent to the Secretary for forwarding onto the Commissioners for perusal before the next meeting of the Commission.

In a "Copy of Minute" from the SECV meeting dated Wednesday 24 November 1926, it was resolved to adopt the report and the whole of its recommendations and that a permanent Electrolysis Committee with representatives from VR, MMTB, MMBW, PMG, the Metropolitan Gas Co and the SECV, be set up immediately.

Over the closing months of 1926 and through early 1927, the report and its recommendations were distributed to these authorities and with the exception of the Metropolitan Gas Co which did not initially reply until requested with follow up letters and the MMBW which had some objections, they pledged their wholehearted support for such a body to be set up.

The MMBW's main objection was that it "considers that the responsibility for suggesting remedial measures should not be placed upon bodies which are suffering, but be accepted by those causing the damage".

In a "Copy of Minute" from the SECV meeting dated Wednesday 4 May 1927, it was resolved that a conference be set up immediately so that the SECV's objective be more fully explained. In the following months, much correspondence was exchanged between the parties thrashing out the finer points of concern which finally resulted in the conference being held on Tuesday 30 August 1927.

One query raised by Sir John was what legislation imposed the responsibility of electrolysis on the SEC. In a note from the Legal Officer, Section 17 of Act No 2996 (1918), gave the power to the Governor in Council to make regulations on the SECV's recommendation relating to electrolysis which also referred to Section 11 (e) of the above Act.

As a result of this conference, a resolution drafting a constitution and outlining the basic rules governing how a main committee, to be called the Electrolysis Committee, was to operate was made.

The first meeting of this committee occurred on 5 September 1927.

The members were:	Mr F Clements	Chairman (SECV)
	Mr J Crawford	PMG's Department
	Mr G McDonald	Victorian Railways
	Mr J Reeson	Metropolitan Gas Co
	Mr E Ritchie	MMBW
	Mr T Strickland	MMTB

In the following months and meetings the Constitution was ratified with amendments and the first meeting of the Electrolysis Committee held under the new constitution was held on 18November 1927 where the following members of the newly created Technical Sub-Committee (TSC) were invited to attend, so that their future activities could be discussed.

Chairman (TSC)	Mr W Potts	SECV
	Mr R Archer	PMG's Department
	Mr P Nicholas	Victorian Railways
	Mr R Bennie	Metropolitan Gas Co
Position being	Advertised	MMBW
	Mr Fairley	MMTB

From then on, both committees functioned with electrolysis corrosion complaints being received by the main committee to deliberate over, with the TSC being asked to assist in supplying technical information from field testing to enable the main committee to reach a decision in a consultative and advisory manner.

10 Articles relating to early Electrolysis as printed in The Argus

The following articles were printed in The Argus newspaper in relation to electrolysis prior to and during the formation of the Victorian Electrolysis Committee.

The Argus was a prominent Melbourne newspaper at the time of the formation of the Victorian Electrolysis Committee.

17 May 1921

LEAKAGE OF ELECTRICITY.

TELEPHONE CABLES CORRODED. Railways Department's Precautions.

Residents of South Yarra who have had constant cause for complaint at the interruption to telephone services caused by corrosion of the sheaths of underground cables by a leakage of electricity from electrified railway lines are not likely to suffer in this respect in future.

In testing the flow of earth currents, the area south of Glenhuntly Road, Elsternwick, was selected because of the absence of tram ways. A series of tests carried out by a committee of representatives of the Postal department, gas companies, Board of Works, tramway and railway authorities definitely indicated that electricity was escaping earthwards, and that the maximum flow was around the Middle Brighton sub-station.

Having proved that the Railways department, and not the Tramways Board, was responsible for the damage done to the underground wire, and pipes, the committee requested the Railways Commissioners to take steps to minimise the damage. The commissioners have now completed alterations to the ballasting of the Brighton-Sandringham and Brighton-St. Kilda lines and the tramway crossover at Elsternwick station, which are expected to prove effective in checking the flow of current from the rails, Mr. E. P. Grove, representative of Messrs. Merz and McLellan, consulting engineers to the Railways Commissioners on the suburban electrification, urged the commissioners to reballast the Brighton lines, as dirty ballast and ill-laid sleepers produced conditions which were favourable to leakages of electricity.

The installation of an automatic device has been completed at the Elsternwick station, where the Glenhuntly Road electric trams cross the railway line. The opening of gates now renders a section of railway line at the crossing dead, while the closing of the gates cuts the current off from the tramline section thus preventing the two currents of electricity from mingling. The Postal authorities have already noticed an improvement from the work carried out by the Railways department. While the damage done by electrolysis is spread throughout Melbourne and suburbs, it is particularly noticeable in parts of South Yarra, where the life of an underground cable was about nine months owing to the corroding of the sheath by stray electric currents. The Postal department had to maintain a special staff to repair the damage. The cost was recouped by the Railways department but the annoyance to subscribers was continuous. It is believed that the remedial steps will prove effective.

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16 July 1921

LEAKAGE OF CURRENT.

Further Electrolysis Tests.

The statement by the secretary of the Melbourne Electric Supply Company Limited (Mr. W. J.Mountain) that electric light failures in suburban areas served from the company's power-house at Richmond have presumably been due to electrolytic troubles, over which the company has no control, and which have not yet been traced, has reference to the leakages of current which are corroding electricity, gas and water mains, and telephone and telegraph cables, and which are the subject of tests now being made by the Railways and Postal authorities.

Experiments by the Postal department in the area south of Glenhuntly Road, Elsternwick (where the district is served only by electric railways without tramway competition), indicated that there was a definite leakage from the railway sub-stations. The Railways authorities have now completed the cleaning up of the track on the Brighton railway line and made improvements to sub-station connections. This, it is thought, will have the effect of minimising the damage caused by electrolytic corrosion. In a fortnight supplementary tests are to be made by the Postal department to see if any improvement has resulted. While there is every reason to believe that the leakage of current in the tested area flows from the railway system, it cannot be proved that the Melbourne Electric Supply Company's cables are not in some measure affected by stray currents from electric tramways, which serve most of the suburban areas supplied with light and power by the company. The object of the tests now being conducted is to discover the source of the leakages and to minimise them. It is recognised that the trouble cannot be entirely eliminated.

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16 June 1922
DAMAGE BY ELECTROLYSIS.
WATER MAIN AFFECTED.
Are Railways Commissioners Liable?
Last week the 36in. water main which crosses the River Yarra at the Punt Road bridge burst in the South Yarra side of the bridge and tore up the roadway over a large area in Alexandra Avenue. An excavation was made down to the main, almost 14ft. below the road level, and at the request of the Melbourne and Metropolitan Board of Works Mr. W. N. Kernot, lecturer in engineering at the Melbourne University, examined the pipe to determine whether he suspected the damage to the main was due to electrolysis or corrosion caused by stray currents of electricity.
The chief engineer of water supply for the board (Mr. E. G. Ritchie), who reported on the main the day before Mr. Kernot's visit, states that he found the rivets of the pipe everywhere in good order. As rivets are generally more vulnerable than the plating to the attack of acids or (text illegible) the soil, the fact that they were not affected was the more significant of (text illegible) as electrolysis, corroding the plate. This view has been en-
(text illegible) Mr. Kernot who in a report submitted yesterday arrived at the following conclusions:
Text illegible.

M. Kernot added that this trouble following on the effects recently observed on the north side of the river, where the pipe was completely eaten through, indicated the serious state of affairs existing in this neighbourhood and pointed to the possible complete destruction of the 36in. main in this place at no distant date if stray electric currents were allowed to flow in the way that they did at present. The water supply's committee of the Board of Works, in view of the report, has decided to recommend that a bill of costs for damages to the main be served on the Railway department, which is held responsible for the leakage of electricity.
The Railways Commissioners have never admitted their liability in respect to damage caused by electrolysis, but in view of the investigations of a special committee on electrolysis (appointed over two years ago) indicating that the corrosion was caused by railway current, the commissioners have made special efforts to check these leakages. By observing the area south of Glenhuntly Road, Elsternwick, for electrolysis tests, thus eliminating interference from the Tramway Board's electricity, the electrolysis committee claimed to have proved conclusively that there were constant flows of electricity from the Brighton sub-station. The electrical experts of the Railways department made readjustments to all the sub-stations in Melbourne, installed a special gate crossing at Elsternwick to prevent railway current leaking into the tram-way rails, and on the advice of Mr. E. P. Grove, Chief Superintending Engineer of Messrs. Merz and McLellan, consulting engineers to the railways, the whole of the Brighton line was reballasted. These improvements minimised the

leakages in Brighton, but the trouble is recognised to be still acute in South Yarra. The underground telegraph and telephone conduits there have been affected, and tests are still being made by the railway experts to find the source of the leakage.

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31 October 1922

DAMAGE BY ELECTROLYSIS.

CONCRETE BUILDINGS SUFFER City Engineer's Alarming Statement.

A new aspect of the damage caused by electrolysis or the corrosion of metals by stray electric currents was revealed yesterday by the city engineer (Mr. H. E. Morton). Hitherto the damage was thought to be confined to underground telegraph and telephone wires and to gas and water mains. The accompanying photograph shows what Mr Morton declares is the effect of electrolysis on the steel rods in reinforced concrete buildings. The corrosion of the rods is, in Mr Morton's opinion, most serious, as it points to the possibility of reinforced structures being weakened and undermined is the very feature that is their strength.

The rods shown in the illustration were on view of Mr. Mortons office, and were taken recently from a building which he refused to specify beyond stating that it was in the neighbourhood of the railway viaduct in Flinders Street. The rods were laid bare in the concrete above the basement line when the construction of an adjoining building was in progress. The damage cannot be estimated, nor is it possible to ascertain the extra stress and strain thrown on the concrete by the weakening of the steel rods.

Mr. Morton is of the opinion that considerable leakage of railway current occurs in the vicinity of the viaduct. He has been informed that tests taken on the viaduct itself showed positive reactions in a galvanometer. He has communicated with the chief electrical engineer (Mr. H. P. Colwell) who referred him to the secretary (Mr. G. H. Sutton), but nothing further has been heard from the department in the matter.

A very serious view of the trouble is taken by Mr. Morton, who considers it likely that every reinforced concrete building within the influence of railway electrification will suffer damage by the steady action of the stray electricity. The Railways department will not admit its liability in the matter but as the result of tests made by the Postal department, which definitely indicated leakages from railway sub-stations, certain alterations were made which it was thought would minimise the trouble.

The tests made by the chief engineer of the Postal department (Mr. R. Lawson) were undertaken in the area south of Glenhuntly Road, Elsternwick, and Brighton. In this area there is no tramway other than the line operated by the Railways department. This eliminated the possibility of the damage being caused by current leaking from the tramway rails. The tests showed positive reactions centring in the Middle Brighton sub-station. Within the last few years the Railways department, still admitting no liability, made extensive rearrangements in the sub-station equipment, and also re-ballasted the Brighton line to remove as far as possible the chance of current "earthing" from the rails. An important alteration was also made in the "crossover" of the railway line with the Glenhuntly Road tramline at Elsternwick. Recently Mr. Lawson stated that these improvements had considerably reduced the leakages. But damage is still caused to the underground telephone and telegraph wires, particularly at South Yarra, while three months ago the Board of Works had occasion to unearth a 60in. main in Alexandra Avenue and found that it was corroded with pits (some of which were ¾in. deep), as the result of electrolysis.

The rods in the illustration are of ¾in. mild steel. Where they have been eaten away they are slightly more than 1-16th of an inch in diameter. It is of interest to note that the new ferro-concrete building of the State Electricity Commissioners, which cost £85,000 to build, is in the area thought by Mr. Morton to be affected by currents from the viaduct.

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1 November 1922
DAMAGE BY ELECTROLYSIS.
PREMIER ASKED FOR REMEDY. Railway Engineers' Anxious.
That the city engineer (Mr. H. E. Morton) had not exaggerated the serious nature of the damage caused to ferro concrete buildings by the corrosion of the reinforcement rods in the concrete by the action of stray electric currents, believed to be leakages from the rail system, was the general opinion of experts who discussed the problem with interest yesterday. An official photograph of the ferro concrete in the foundations of a building near the Flinders Street viaduct shows clearly how electrolysis has whittled away the metal from one rod, and deposited it on the end of another rod like an electrode.
It is recognised that the leakage comes from the railways. This has been proved by the Electrolysis Committee which thoroughly investigated the problem. The Postmaster-General's department, through the Prime Minister's department, has made strong representations to the Premier (Mr. Lawson) on the subject of these railway leakages, while similar reports have been made direct by the Metropolitan Gas Co. and the Metropolitan Board of Works. No replies have yet been received either admitting the liability of the State department for the damage caused, or suggesting a remedy.
Negative "Feeders" Wanted
One of the electrical engineers who reviewed the position yesterday said that there was only one remedy for the trouble, and that way laying of negative "feeders" on the railways. In brief, these feeders were copper-wire cables, which enabled the current to flow freely back to the power station, whereas in their absence the high-tension current met with considerable resistance in its passage through the steel rails and strayed off to find other channels, such as gas pipes, water mains, and underground wires, to travel through.
Every tramway system in the world had the negative "feeders", according to statutory ordinances, based upon the requirements of the British Board of Trade and United States standard. There was room for grave criticism of the designers of the Victorian electrification project in that similar precaution against electrolysis had not been taken at the outset.
Railway authorities, while still refusing to admit any liability, point out that the problem of damage by stray currents has occupied the serious attention of the Railways Commissioners for months. As the result of certain adjustments (indicated in these columns yesterday), a marked degree of improvements had resulted, but still further experiments were in hand, and the advice of Mr. E. P. Grove, representative of Messrs. Merz and Maclellan, consulting engineers to the Railways Commissioners, was being sought.
Mr. R. Lawson, Chief State Engineer to the Postal department, said that while he did not know of any case in which a ferro concrete building had collapsed by the weakening of the steel reinforcements through electrolysis, a very grave danger existed, which increased daily as the corrosive action of the currents was continuous. A factor of safety was provided for in every concrete structure over and above the estimated maximum demand, but if the main source of the structural strength was attacked in essence, it was apparent that this factor would be reduced and might disappear entirely. Experiments had been made in America to see if there were any process, such as painting of insulating the steel rods, that would keep out the stray currents, but it had been determined that such precautions were practically useless.
Board of Works Troubles
Mr. W. J. Carre-Riddell, Chairman of the Board of Works, announced that in respect to the 60-inch water main which had been unearthed in Alexandra Avenue, and found to be seriously damaged by electrolysis, the board had sent a bill for damages to the Railways department. "Until recently," said the chairman, "we thought that these stray currents of electricity that travelled along our mains caused damage to the metal only at the point where it quitted the pipe for another short cut to its destination. But we are now inclined to believe that it is attacking the lead joints of all our mains, which is a much more serious problem. The theory is that the difference in the coefficient of resistance between the iron of the pipe and the lead in the joint causes corrosion of the joint, and if every joint is being weakened we are faced with an immense liability for maintenance.

Sir John Monash's Views
Sir John Monash, Chairman of the State Electricity Commission, is recognised as the leading authority on ferro concrete in Melbourne. When interviewed yesterday he said that the question of possible injury to reinforced concrete structures by electrolysis had been before scientists for the last thirty years. Numerous laboratory experiments had been made to indicate the possibility of serious injury to important structures, but so far as he was aware there was no single recorded instance of any such serious damage. The action of electrolysis was well known and well understood. Certain very specific conditions had to be present before any such action could take place. There would have to be a continuous and considerable leakage of electricity from some underground conductor, of a nature and an extent which could easily be detected and measured. In addition the environment in which the leakage toook place would have to be a wet environment, that was to say, waterlogged, before the electricity could travel any considerable distance. It was likely to attack such metal as water and gas pipes which lay exposed while buried under the ground, without any protecting medium such as concrete. But in order that the escaping electricity could attack the rods in a concrete building it would be necessary that the concrete itself should be in an imperfect condition and waterlogged.

In the case of the Electricity Commissioners' building, the foundations were in solid schiatose rock, and perfectly dry and every care had been taken in the construction to prevent the access of water. All the vital parts of the building, such us the columns and the girders, were entirely above ground, and exposed to the air on all sides, so that an environment suitable for the action of electrolysis simply did not exist. The whole of the machinery and appliances of the staff of electric inspectors were in the basement of this building, and if there should be any escape of electricity from any of the neighbouring tramways or main it would be very speedily detected. So far there had been no evidence of any such phenomena. In the circumstances the public need have no anxiety as to the safety of permanence of this building.

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1 November 1922

TO THE EDITOR OF THE ARGUS.
Sir,-The article to-day on the damage by electrolysis to concrete buildings sounds a note of timely warning. I carried out extensive tests on the effect of electric currents upon reinforced concrete at the Massachusetts Institute of Technology, Boston, in 1908, and a further series of tests extending over 12 months at the Melbourne University in 1910. The results of these tests showed that under certain conditions direct currents of electricity as small as 0.1 amp. would not only eat away steel reinforcements in concrete, but would also crack concrete, sandstone, basalt, or brickwork encasing steel bar. These results occurred only when the steel was the anode. The results of these tests were published in "Engineering News," vol. 64, no. 22. A similar destructive effect of foundations of steel-frame buildings. In view of this danger I have adopted special precautions in the design of the foundations of reinforced concrete or steel frame structure which are in a damp area thought to be affected by stray electric currents, as there is no doubt that the foundations of modern buildings of reinforced concrete or steel-frame construction can be seriously damaged, weakened, and undermined by the electrolytic action of stray currents. Strong representations should be made to the Railways Commissioners and Tramways Board to induce them to use every effort to prevent the escape of electric current from the rails.
Yours,
U. JAMES NICHOLAS, B.Sc.,
Oct. 31. Structural Engineer.

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2 November 1922
TO THE EDITOR OF THE ARGUS.
Sir, It has been found from experience with reinforced concrete buildings that the effect of electrolysis due to stray electric currents, on the stability of such structures is practically nil. I know of no case where serious, or even partial damage has occurred to the stability of a reinforced concrete building through electrolytic action, due to stray electric currents of the magnitude and voltage usually met with in practice. When a stray electric current passes through a steel reinforcing rod embedded in dry concrete a small quantity of heat is generated, but after passage of the current there is practically no change either in the physical or chemical condition of the steel rod or its surrounding concrete. Electrolysis then has not taken place and cannot take place under these conditions, because the concrete in contact with the steel is dry, which is usually the case throughout the greater part of the reinforced concrete building. Electrolysis can only occur during the passage of an electric current through an electrolyte. Electrolytes are liquids, and therefore it follows that concrete can only act as an electrolyte when it is either moist or saturated with water. The foundations are the only parts of a concrete building which are at all likely to be in a very moist or water saturated condition for any length of time, and so if electrolysis does occur at all, it will occur only in foundations which are waterlogged. All foundations to reinforced concrete building built in the Melbourne city area have to be designed in accordance with the by-laws of the Melbourne City Council, and these bylaws are so conservative, and specify such large sections of rich concrete that generally speaking they are more than amply sufficient for the loads, even if all the steel reinforcement is left out of them, or is absolutely destroyed by electrolytic or any other action. There would, therefore, be little or no danger to the stability of the majority of city buildings even in the extreme case of all the steel reinforcement in the foundations being put out of action by electrolysis. However, such an extreme case as all the foundation steel being destroyed by electrolytic action is practically unknown, because it is found that the greater portion of the reinforcing rods is usually surrounded by practically dry concrete, which effectively protects the steel from corrosion and serious electrolysis. It is only, as a rule, in portions of the foundations where parts of the concrete may be porous, due to unity spacing or placing, that the water is able to penetrate as far as the steel, and so set up local electrolytic action. This action is, in the majority of cases purely local, and has little or no effect on the stability of the building as a whole. Even local electrolysis can be greatly minimised by taking certain precautions well known to engineers during the construction of the foundations. The case of underground water mains/gas mains, if in damp ground, is however quite different, and there is no doubt whatever that these are seriously damaged by stray electric currents.-

Yours,
H. STANLEY HARRIS, BSc, inst, CE,

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18 May 1923
DAMAGE BY ELECTROLYSIS.
NEW DANGERS FEARED. Corrosion of Gas Mains.
Attention has again been focused through the bursting of water mains, on the danger of widespread damage to water and gas reticulations and telephone and telegraph services by electrolysis. Experts and engineers of the departments affected pointed out yesterday that even greater than the damage to these services was the possibility of public safety being menaced by the corrosion of gas main on a large scale. At the same time it is reassuring to learn that the whole matter of minimising the damage caused by electrolysis has been taken in hand by the electricity commissioners, and that within a few weeks it is hoped that a cooperative campaign will be undertaken, with the aid of the Railways department, to curb the vagaries of stray electric currents.

The Chief Engineer of the Metropolitan Gas Co. (Mr.E. N. Reeson) said yesterday that the unearthing of the two mains which had burst on Tuesday and Wednesday near the corner of Punt Road and Alexandra Avenue, South Yarra, could be watched with the greatest interest. The electrolysis committee of which the members are Mr. Reeson, the State Electrical Engineer of the Postmaster General's department (Mr. R. Lawson), and the Engineer of Water Supply of the Board of Works (Mr. E. T. Ritchie), had for several years been engaged in unravelling the mysteries of electrolysis, and endeavouring to discover the source of the stray currents. About a year ago the 36in. main in Alexandra Avenue burst, and plaster casts of the piping in possession of Mr. Reeson, show that large pits were corroded, the craters of which gave strong evidence of electrolytic action. Following upon this the Board of Works lodged a formal claim upon the Railways department as originator of the damage, but the department repudiated liability. "There is no doubt," said Mr. Reeson, "That the problem of electrolysis is a very serious one to the Board of Works, as day by day its reticulation is being slowly eaten away, necessitating constant repairs, but in the case of the Metropolitan Gas Co., the damage, though less pronounced, is more sinister. I must confess that to date the Gas Co. has evidence of only one instance which we claim can be definitely attributed to electrolysis, but at the same time I am convinced that stray electric currents are slowly corroding our mains. This may eventually be carried to a point when the walls of the pipe will fall away, and an enormous volume of gas liberated. In the case of a water main, the bursting of the pipe is immediately apparent, but this will not be so in the case of a gas main, and it is probable that a sufficient volume of gas would escape to create conditions favourable for a large explosion."
Referring to tests undertaken by his committee to ascertain the origin of the stray electric currents, Mr. Reeson said that in an area selected south of Glenhuntly Road, Elsternwick (so as to eliminate the possibility of leakages from the electric tramway services), it had been clearly proved that there was a constant escape of varying currents of electricity in the vicinity of Middle Brighton sub-station. The calculations of Mr. Reeson's staff had been checked by the electrical engineers of the Railways department, and as a result the Brighton line was reballasted and special locking apparatus installed at the Elsternwick level crossing. While the Railways department, without admitting liability, had made considerable improvements, the leakage persisted.

Lead Joints Endangered.
The chairman of the Board of Works (Mr. W. J. Carre Riddell) mentioned a new aspect of the problem. Hitherto, he said, it had been thought that the corrosive action of the electric current was confined to the point at which it entered and left the water main. Recent evidence, however, tended to show that not only did this action occur but the current had a corrosive action on the lead joints along the section of main through which the current chanced to flow. "If this should be so," said Mr. Carre Riddell, "it opens up possibilities which I view with the gravest apprehension. It remains to be proved whether the recent bursting of our mains in South Yarra is due to electrolytic or chemical action. We have already communicated with the Railways Commissioners concerning their liability in a previous case, in which we claim that electrolytic corrosion was due to stray currents from the railways, but the department, of course, will not admit liability.
Some measure of relief must be discovered; that is imperative. If there is no other method than the installation of what is known as negative 'boosters' on the railways, then the question arises: Is it cheaper for the public to bear the cost of constant repairs to our mains or the expenditure upon the installation of these negative cables."

Remedies Being Investigated.
"We do not admit to any liability whatever in respect to any damage caused by electrolysis," said the railways commissioner in charge of electrification (Mr. W. M. Shannon) yesterday. "At the same time the commissioners are fully seized with the gravity of the problem, and are endeavouring to devise means of checking the loss of current from the railways. We know

that stray currents exit, as they do in every other large city which has a high tension electric service, and it is our care to guard against any damage to public property through this cause. The question of negative 'boosters' is one which, among others, is now receiving the attention of the commissioners. It would cost a very large sum to install these negative cables, and the commissioners would have to be assured that they would be a certain cure for the evil before they undertook the expenditure."

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28 January 1926
MAINS AND RETICULATIONS - COPPER SERVICE PIPES.

Damage Done by Stray Currents.
Owing to the great inconvenience of having to tear up and replace costly pavements whenever it is necessary to renew worn out service pipes that connect with the water mains, the Sydney City Council has passed a bylaw that all such pipes in future must be of copper. The "life" of a copper pipe is very much longer than that of an iron one, and though copper is considerably more expensive, its greater durability would make it cheaper in the end. It is stated that in some American cities it has even been decided to substitute copper or brass mains for those of iron owing to the great expense incurred in renewing or repairing mains when these are laid beneath the heavy concrete roads which are becoming standard in the larger cities of the United States and elsewhere.

Damage by Current Leakage.
The life of mains and reticulations depends in part upon the nature of the soil in which they are laid, and on the amount of moisture that is in the soil. But during the last 30 years or so another destructive factor has had to be reckoned with the electrolytic effect due to leakage of current. This causes severe pitting of the metal, and the pitting, in its turn, accelerates the rate of corrosion. This would attack copper pipes as well as those of iron, though its effect on copper would he less destructive. Electric railways and tramways are almost solely responsible for the damage done not only to water and gas mains and their reticulations, but to all metal structures that these stray currents make use of as the easiest, though, perhaps not the shortest path to get back to the source at which they were generated. This they will always do. Steel-frame and reinforced concrete structures, such as buildings or bridges, may offer such a path, but now that the danger is understood, it is possible to guard against it by means of insulation. But it is said that it would not be practicable to insulate mains and service pipes, so there is a tendency now to attack the trouble itself rather than to discover palliatives for it.
At present both in the case of electric railways and electric tramways the rails used "return" the current. Steel, however, offers considerable electric resistance, and it is certain, therefore, that some of the current will escape in its endeavour to find an easier path home. The railways leakage takes place chiefly where the rail is in contact with the sleepers, for even in dry weather there will probably be some moisture imprisoned between the rail and sleeper, as well as in the sleeper itself, and water is an excellent conductor. This leakage is something that can be guarded against, and as it may do a great deal of harm, and put municipal authorities and private individuals to great expense, it should not be tolerated. All engineers (except, perhaps, those interested in electric tramways and railways) agree to that. It has been indicated that current escapes in an endeavour to find a better conductor than the rails offer. If the rail is not a sufficiently good conductor to prevent leakage, of course a better should be found, and the best possible conductor can be provided by returning the current not along the rail, but along a moderately heavy continuous strip of copper by the side of the rail. This has been done in a few instances recently where leakage has occurred in tramway systems, and the trouble has at once eased.

The bursting of mains in Melbourne has become increasingly frequent during recent years. That may be due in part to the ageing of the mains, but it is certain that in some instances mains that have failed have been weakened by electrolytic action. It would be interesting to know whether this is true of the Swanston Street main which, during the last two months, has burst 22 times.

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27 August 1926

DAMAGE FROM ELECTROLYSIS.

Committee to Report.

After an inquiry into the cause and extent of electrolysis in the metropolitan area and into means for minimising trouble from this source, the Electrolysis Board which was appointed several years ago has decided to prepare a final report. The report will contain recommendations for dealing with electrolysis, and it is likely that the appointment of a permanent organisation will be suggested.

Trouble due to electrolysis has been increasing steadily for some time, and after the opening of the electric railways the Board was appointed. The Board consisted of representatives of the Railways department, the Tramways Board, the Post Office, and the State Electricity Commission. One of the chief difficulties in dealing with electrolysis has been that of ascertaining the source of the current leakage. Electrolysis is caused by the stray electric currents passing through the earth encountering under- ground conductors, such as the lead sheathing of telephone cables and water and gas pipes, along which it is carried for considerable distances. At the point where it leaves the underground conductor, corrosion of the material of the conductor is set up and serious damage is caused. One of the chief sources of the trouble is the leakage of current from the rails of electric railways and tramway systems. Much has been done recently to overcome the trouble by improving the conductivity of the return circuit. The Railways Commissioners have "bonded" the rail joints throughout the metropolitan area with welded copper bands to reduce resistance at joints, and the rails have been lifted above the track.

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1 May 1936

ELECTROLYSIS IS THE VILLAIN OF SCIENCE

PROBLEMS FOR RESEARCH Early Discovery, Late Remedy

Electricity has changed the whole of the modern industrial system, and has brought to the aid of the engineer one of the most useful and versatile agents man has ever devised, but electricity, like fire, is a good servant and a bad master.

The havoc it can cause when it breaks the boundaries to which it should be confined is spectacularly demonstrated when a "blow out" occurs through a short circuit on a giant switchboard in a power station, perhaps demolishing the entire contents of a large room, or when lightning razes a stately tree or a giant chimney stack.

Perhaps though, the greatest damage of which electricity is capable is that which is never seen and seldom suspected until it is irreparable, except by complete reconstruction, the insidious, steady disintegration of underground metal structures by the quiet process of electrolysis.

Early Effects

The problem of combating electrolysis is essentially one of the last 30 years, but curiously enough the basis of the problem was one of the first of the physical effects of the influences of electric currents to be observed in the laboratory. The process of electroplating, by which the silverware of the modern table or the bright fittings of the modern motor car receive their encasing film of silver or chromium, is well known. If a copper spoon and a plate of silver are suspended in an appropriate chemical, and a current is passed between them, the copper

spoon becomes silver- plated, the silver for the plating process being dissolved from the silver plate. An identical process proceeds beneath the surface of the ground when electric currents escape from the conductors which are supposed to carry them and escape away into the ground. Usually railways and tramways are the chief source of electrolysis. The current from the powerhouse is sent out through the overhead conductor and, after operating the traction motors it is supposed to return to the powerhouse through the rails. Steel, however, has an electrical resistance which is relatively high. The resistance of the earth, on the contrary, is low, especially when it is moist. Electric currents tend always to seek the path of lowest resistance. Thus the return current from a train, miles from its powerhouse, instead of following the rails back, may branch "across country" and follow a lower resistance path through the earth. On the way it may encounter a water main, a telephone cable, or the subterranean frame of a steel building or bridge. So long as it can do so, it follows this metal structure, but ultimately it branches away again through the earth.
And at every point where it leaves such a buried conductor the leaking current begins to decompose it. The decay of the metal structure proceeds steadily so long as the current flows. Ultimately, the water bursts through a main and demolishes the road surface above, rain seeps into a telephone cable and damages the delicate conductors within it, or the foundations of a great structure are weakened to the point of danger. These are the factors which the electrical and structural engineer has to face in combating electrolysis.

The problem of preventing electrolysis has been attacked from two angles so effectively that it is rapidly ceasing to be a serious problem in modern engineering practice. In the first place, the leakage of current away from transport service rails can be greatly minimised if the electrical resistance of the rails can be reduced. Here modern welding practice has helped immensely. Most of the resistance of the rails occurs at the joints. This resistance disappears if the joints, instead of being bolted, are welded. Welding technique has recently been so simplified and cheapened that the welding of the thousands of rail joints in a modern city is no longer a costly or formidable business, and the wholesale welding of rails in the suburban railways which has proceeded in the last few years has been undertaken mainly as a means of combating electrolysis.
The other main avenue by which the problem of electrolysis has been attacked by modern engineering practice has been to prevent the escape of stray currents from pipes, cables, and building structures back into the ground. Much progress has been made in preventing stray currents from entering underground structures by effectively insulating those structures. Water pipes and gas mains are heavily coated with non-conducting compounds and fabrics before being placed underground. The increasing use of concrete and other non-metal pipes has been a further important contribution to the problem. Finally, it has been clearly established that a current will not escape from an underground metal structure back into the earth if a lower resistance metal path is provided for it. Hence it has become possible by "banding" or interconnecting with metal links all extensive underground pipe systems in such a way that these structures are made a permanent and continuous part of the return current, so that the currents that leak into them need never leave again for a further journey through the earth.

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29 August 1940
PROOF AGAINST TIME
Industry Which Has Stood Rigorous Tests
At the beginning of this century an Austrian engineer by the name of Hatschek evolved a new process for manufacturing roofing tiles with water, cement, and asbestos. The ingenuity of the process lay in the skilful combination of two such permanent materials - the asbestos reinforcement being indestructible and of very high tensile strength.
It was found that by manufacturing under this process in certain proportions of cement and asbestos of selected grades the product attained, within a month of manufacture, approximately 12 times the strength of ordinary cement slabs, and thereafter continued to increase high strength until petrification became complete.
The asbestos industry rapidly grew, and factories operating the Hatschek process were put into operation in all the chief countries of the world, including Australia
It was the remarkable resistance to destructive agents, combined with low initial costs, which prompted Commendatore Mazza to seek a new and greater scope for the asbestos industry. He realised that if an asbestos cement tile less than 3/16in. thick could withstand the atmospheric agents and the elements of corrosion in industrial areas the life of an asbestos cement pipe of greater thickness, and spun under pressure, would possess practically unlimited durability.
No Deterioration
The study of the problem of asbestos cement pipe manufacture was immediately taken up, and in 1913 the first experimental pipes were made. The process evolved was so successful that in 1916 an almost perfect asbestos cement pipe was produced, and these pipes remain to-day entirely unaltered after 22 years of service. The report of engineers on a pipe taken from a main laid down in 1916 is of special interest as demonstrating the tendency of asbestos cement pipes to Increase in strength with the passing of time.
It is generally accepted that the supply of water is the most important of public utility services. Asbestos cement pressure pipes fulfil the requirements of an age demanding safe and permanent transport for water as well as other liquids used in industry and agriculture.
Water pipes buried in the ground are subject to the attack of three destructive agencies - tuberculation from the interior and soil corrosion and electrolysis on the exterior. To endure permanently under these conditions the material of which a pipe is composed must be inherently resistant to all three of these agencies.
Many Uses
Of the problems involved in water transportation tuberculation is the most prevalent, the most troublesome, and the most expensive. Tuberculation usually results from a chemical reaction between the water in the pipe line and the metallic elements of the pipe itself. Regardless, however, of the exact cause of tuberculatlon in any particular case, the result is the same - a gradual filling of the interior of the pipe and progressive reduction in its carrying capacity.
Being non-metallic, asbestos cement pipe cannot tuberculate. Its exceptional corrosion resistance has also led to its use for mine drainage and for industrial process liquor lines.
Many of the earlier European installations of asbestos cement pipe were used to carry sea water. After many years of this severe service the pipe still shows no evidence of deterioration, either inside or outside.
The enormous toll exacted each year in Australia by soil corrosion is well known. Oxygen and water, two principal causes of destruction to ordinary pipe material, cannot harm asbestos cement. In fact, they are actually the curing agents of asbestos cement pipe.
Stray electric currents from high voltage lines or from street railway systems set up a highly destructive action at the point where they leave the pipe line. Investigation has shown that one ampere a year corrodes 20 pounds of Iron and 74 pounds of lead. Not only does electrolysis due to direct current cause serious damage to pipe lines, but evidence indicates that in many instances alternating current is responsible for odours, tastes, and colour in drinking water.

Since it is a non-conductor of electricity, asbestos cement provides assurance against danger of electrolysis.

Successful Trials

In 1924 the chief engineers of the Sydney Metropolitan Water, Sewerage, and Drainage Board and the Melbourne and Metropolitan Board of Works visited Europe and investigated the suitability of asbestos cement pipes for water mains. So impressed were they with the reports furnished by various European users regarding the efficiency of the pipes, that both engineers, on their return to Australia, recommended to their Boards that trial lines of asbestos cement pipes be laid. As a result the pipes were ordered, and arrived in Australia in 1925. Most of the pipes for the Sydney Board were laid in the Bankstown district, and when one of the pipes was uncovered at Lugarno Point in 1934 it was found to be in excellent condition.

The manufacture of asbestos cement pipe in Australia was commenced in 1927, and already over 1,400 miles of locally manufactured pipes have been supplied to various water authorities; Government departments, railways, shire and municipal councils, dairy, mining, and industrial concerns throughout Australia for pumping, gravitation, and reticulation mains.

11 Members of the VEC Electrolysis history

11.1 The gas industry

Gas pipelines were first laid in Melbourne in the late 1800s. These were low pressure cast iron pipes fed from a number of coal gas plants around Melbourne.

In 1951, the Victorian government took over two of the three main gas utilities in Melbourne, the Metropolitan Gas Company and the Brighton Gas Company. By 1974 the government had acquired the remaining non government gas utilities and the Gas and Fuel Corporation was the government owned monopoly supplier of household gas in Victoria.
Until the late 1990's, the Gas and Fuel Corporation (GFCV) continued to be the sole distributor of reticulated gas in Victoria supplying over one million consumers through a network of 20,000 km of pipelines and distribution mains.

Victorian HP steel system introduced in 1955
Prior to 1955, the reticulation of Melbourne gas was carried at low or medium pressures in large diameter cast iron pipes. The introduction of smaller diameter high-pressure (up to 65psi) steel pipe represented large efficiencies in costs of laying and materials.
High-pressure gas mains were first laid in Oak Park and Broadmeadows in 1955. During 1960, three corrosion-related gas escapes were reported to the corrosion mitigation division of the GFCV. In 1963, there were 86 corrosion-related gas escapes (1).
Potential surveys carried out during this period indicated that one of the causes for the rapid corrosion rate was due to stray current corrosion. The fact that the new delivery system was failing shortly after being introduced was treated very seriously and attempts to rectify the problem began.

Electrolysis drainage ongoing from 1963
In Melbourne, where the effects of stray current on underground steel structures are very evident, mitigation of these effects is achieved by the use of a citywide electrolysis drainage system. Some smaller systems are also installed in country areas.

Although stray current drainage appeared to reduce the rate of increase of corrosion faults, the projected number would still have been in the vicinity of 10,000 in 1985. This was estimated to be at a cost of 5 million dollars in 1985 (4). So it was important that an additional means of reducing the corrosion had to be introduced.

GFCV introduces 10 year protection program in 1972
Cathodic protection for steel pipelines has been around for approximately 70 years, with the first installations appearing on oil pipelines in the United States and the Middle East in the 1930's. The first impressed current unit in Australia was installed by the Metropolitan Board of Works in Northcote in 1935 (5). Cathodic Protection was introduced on gas transmission pipelines in Australia in the early 1960's in order to provide a higher level of safety and reliability.

The leak rate on the new steel high-pressure reticulation was not considered particularly significant until the leak frequency curve begun to rise exponentially.

In 1971, the GFCV decided to install cathodic protection on the high-pressure system. At over 10,000 km in length, and growing, this was a large project and at the time it was estimated it would take ten years, but for various reasons it was to take 50% longer that this before nominal cathodic protection of the steel network was completed.

Cathodic protection is achieved by the application of a direct current to the pipeline, the source of which may be from sacrificial galvanic anodes, or by impressed current with an external current power supply.

Removal of foreign structure contacts begins
Effective cathodic protective of a gas reticulation system or pipeline not only requires that they be coated, they also need to be electrically isolated from other metallic structures.

The normal method of electricity supply reticulation in Melbourne is the multiple earthed neutral (MEN) system that supplies power to the consumer via an active conductor and allows return of current to the supply point via a neutral conductor. Each neutral conductor is earthed at the consumer's supply point to an electrode or metallic water pipe.

As nearly all premises have the MEN connection, and unless insulated from the gas system are joined together by the metallic water mains and services, it can be seen that a short circuit would connect a large earth (mainly copper) to the steel gas system.
This introduced galvanic corrosion and greatly increased the task of installing the amount of cathodic protection required to reach the protection level. For these reasons leaving those earth contacts connected to the coated steel gas system was not an option.

The most common types of foreign structure contacts found were faulty meter insulators allowing a connection to the MEN earth through appliances with electrical equipment (fans) or where the gas and water connection come together. Of course the same problem occurs if the two utilities are in contact in the street.

It is estimated that the GFCV identified, removed and or repaired in excess of 11,000 contacts to foreign metallic structures and faulty or missing meter insulators (6). In the original estimate of (ten years) the extent of contacts to foreign structures had not been anticipated. As a result, the corrosion mitigation group of the GFCV had to nearly double its staff through the ten years to identify these contacts and continue work associated with installation of cathodic protection.

Full nominal protection achieved on HP in 1986 To divide the system into reasonable sizes for cathodic protection purposes the HP metropolitan reticulation system was divided into more than 130 separate electrically isolated areas. Areas were isolated by the use of insulating joints and flanges with test points on both sides, so that if necessary, protection current could be interchanged across areas.

Initially, in the design phase a current density of 0.6 to 1.0 milliamps per square meter was used as it was thought this would be suitable for reasonably well-coated coal tar enamel system (7). However, in practice it was found to be higher than this in most areas. The cause of this was established as to be mainly coating damage and deterioration.

At the beginning of this project, it was estimated it would take ten years, but because of the number of short circuits that had to be removed and the number of cathodic protection units to be installed, it took until after 1986 before nominal cathodic protection of the steel network was completed.

It can be shown that since the installation of cathodic protection, together with the earlier introduced stray current drainage system, the combination has proved to be a very effective method of mitigating corrosion. The results of these undertakings are revealed quite clearly on the attached graph (Figure 1).

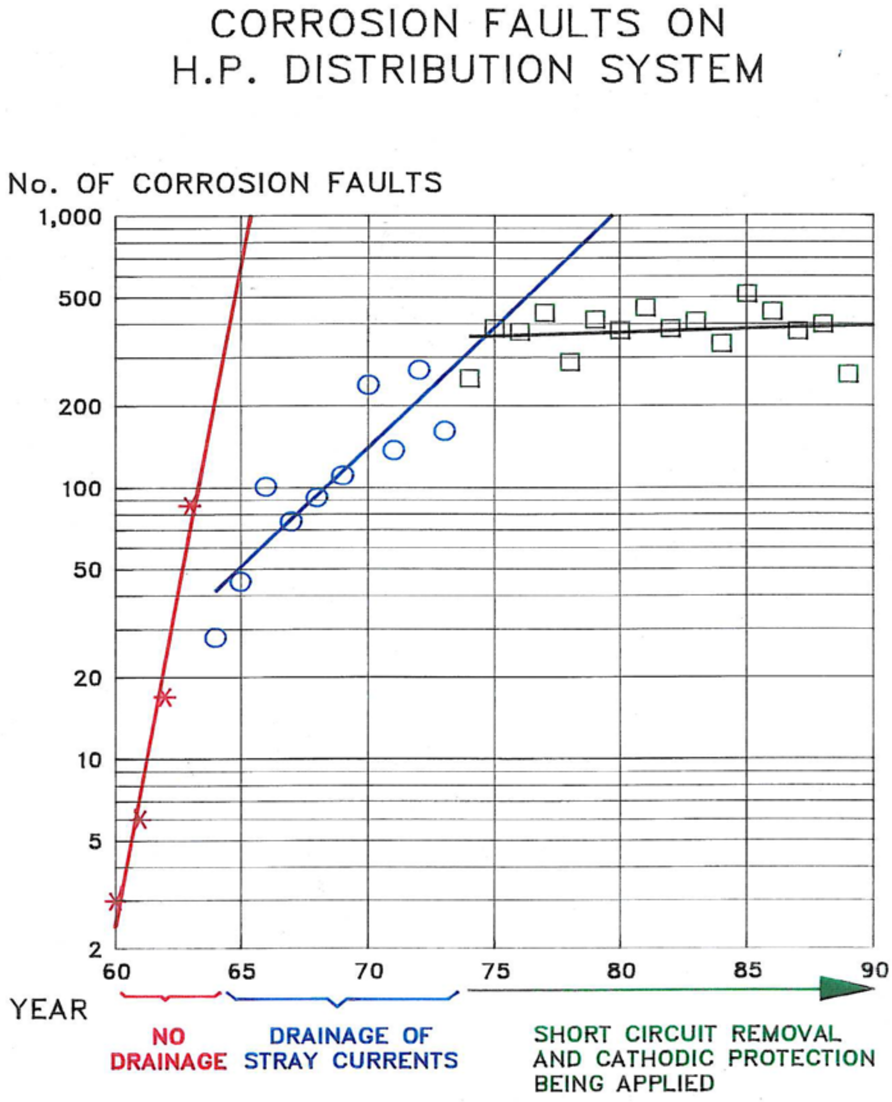

CORROSION FAULTS ON
H.P. DISTRIBUTION SYSTEM
No. OF CORROSION FAULTS
1,000
500
200
100
50
20
10
5
2
60
65
70
75
80
85
90
YEAR
NO
DRAINAGE
DRAINAGE OF
STRAY CURRENTS
SHORT CIRCUIT REMOVAL
AND CATHODIC PROTECTION
BEING APPLIED

Figure 1

Following the success of significantly reducing corrosion on the high pressure system in the mid 1980's after completion of the cathodic protection system for the high pressure distribution a program commenced to retrofit cathodic protection to the coated steel medium pressure system. This program was completed in the early 1990's.

Monitoring and maintenance phase begins
After completing the ten plus year program in the late 1980's to retrofit cathodic protection to its steel high-pressure gas network, monitoring and maintaining the system became the GFCV's Corrosion Mitigation Division's major focus.

All buried steel gas pipelines and distribution networks were required to be monitored to ensure that adequate levels of corrosion protection levels were achieved and maintained in accordance with the relevant criteria. Cathodic protection and stray current equipment also are required to be checked at regular intervals to ensure that these systems are operating normally.

During this time the GFC invested considerable effort in developing electronic data logging systems to replace electro–mechanical chart recorders. This improved reliability of recording and most importantly allowed for electronic processing and storage of data. Much of the development undertaken by the GFC was adopted by other pipeline operators.

Privatization of Gas and Fuel
In 1992 the government-owned Gas and Fuel Corporation of Victoria began the process that was to lead to full privatisation in the late 1990's. The GFCV was divided into one gas transmission pipeline company and three gas reticulation companies. Those companies were then subsequently privatised.

1994 - Gas and Fuel was corporatized setting a number of financially independent businesses,

1. Gas Services Business (comprising of special services such as CPS,
Engineering, Technical services)
2. Western, Northern, Southern Regions
3. Gas Supply Group
4. Gas Transmission Company

In other words, 1994 GFC was corporatized into Gascor and a separate transmission business.

1 July 1997 Gascor was split into 3 retail businesses and 3 distribution businesses. The distributions were Stratus Networks, Multinet Gas, and Westar.

1. TPA - Transmission Pipelines Australia
2. Westar
3. Multinet
4. Stratus

In 1999 these businesses were then sold

1. TPA to GPU becoming GPU GasNet to now APA
2. Westar to TXU to SP AusNet

3. Multinet to Agility to Jemena
4. Stratus to Boral to Origin to APA

Gas Transmission System

APA

By 2010 the Victorian natural gas transmission system was wholly owned and operated by APA Group (formerly GasNet Australia). It consists of over 2000 km of transmission pipelines operating at pressures between 2800 kPa and 8800 kPa. It is protected from corrosion by a combination of primarily impressed current cathodic protection units and stray current drainage.

Gas Distribution

SP AusNet Gas

SP AusNet owns, operates and maintains gas transmission pipelines (including mainline valves, associated city gates, and field regulators) and an extensive gas distribution network across its geographic footprint.In addition, SP AusNet owns and operates a small LP gas reticulation network at the alpine resort of Mt Baw Baw.

The SP AusNet network includes 183 km of transmission pipeline (20 Gas transmission pipelines) and about 9,500 km of distribution mains. At present, approximately 74% of the distribution mains operate at high pressure (515kPa, 700kPa or 900kpa), 8% operate at medium pressure (80 kPa), 16% at low pressure (3 kPa) and 2% operate at transmission pressure (>1,050 kPa).
The cathdic protection system for SP AusNet consists of a combination of impressed current and sacrificial anode system along with stray current drainage.

SP AusNet's geographic coverage is illustrated in below figure.

Source: SP AusNet

APA

1 April 1999 Stratus Networks was sold - the asset management to Boral and the pipeline assets to Vic Gas Distribution which is a subsidiary of Envestra. Boral demerged into Boral Building Products and Boral Energy which was rebranded to Origin Energy in February 2000 and 3 July 2007 Origin Energy Asset Management sold to APA Group.

APA Networks in Victoria has 245km of gas transmission pipelines and approximately 3000km of distribution network in metropolitan and country areas nominally cathodically protected. Protection methods are similar to other Victorian gas businesses with Impressed Cathodic Protection Units, sacrificial anodes, and stray current drainage.

Multinet Gas

Multinet Gas distribution business was created when the Victorian Government owned Gas and Fuel Corporation was corporatised in the 1990's. Multinet was subsequently privatised in 1999 and a consortium of AMP Capital Investors and Aquila acquired the business. In early 2003 Multinet Gas ownership was restructured and DUET in partnership with Jemena Ltd purchased the business. Jemena Asset Management manages and operates Multinet Gas Network on their behalf.
The Multinet Gas Network consists of 290km of high-pressure transmission steel pipelines, with a distribution network including 2,900km of steel pipes. These steel pipelines are cathodically protected by means of 198 impressed current cathodic protection units, sacrificial galvanic anodes and stray traction current drainage.

11.2 The water industry

Structure Corrosion effects - MMBW Water mains

Because of the early onset of problems following the electrification of tram and train systems, the MMBW collected perforation data on its Mild Steel and Wrought Iron mains. Stray traction currents generally have little effect on the cast iron mains used in smaller sizes for local distribution and delivery to the householder. Consequently the analysis omits fault analysis of the cast iron mains entirely. The data builds from 1903 until the disaggregation of the MMBW into a water wholesaler and 3 water distribution companies in the mid 1990s. Data from the individual companies has not been re-aggregated to show comparable current data.

In the simple terms of perforations per annum, the data show three well defined phases:

1. The initial rise to approximately 80 p.p.a by 1925, which is basically the period drawing public attention to the problem, and leading to the establishment of the VEC. A projection of this rate forward suggests that it would have risen to about 400 p.p.a by 1940. A very expensive maintenance problem.
2. A slower rise period to about 200 p.p.a. by 1965 which covers the period of experimentation and learning how to control the problem. Be aware also that the water main length exposed to the stray currents increased by 4 times over this period.
3. A dramatic decrease from 1965 onwards due largely to the conversion to output controlled drains and later to the addition of cathodic protection to locations where drainage could not be provided economically. Up to 1995, the length of main exposed to the stray currents again doubled.

This is shown on the Figure1.1 – Perforation rate per annum.

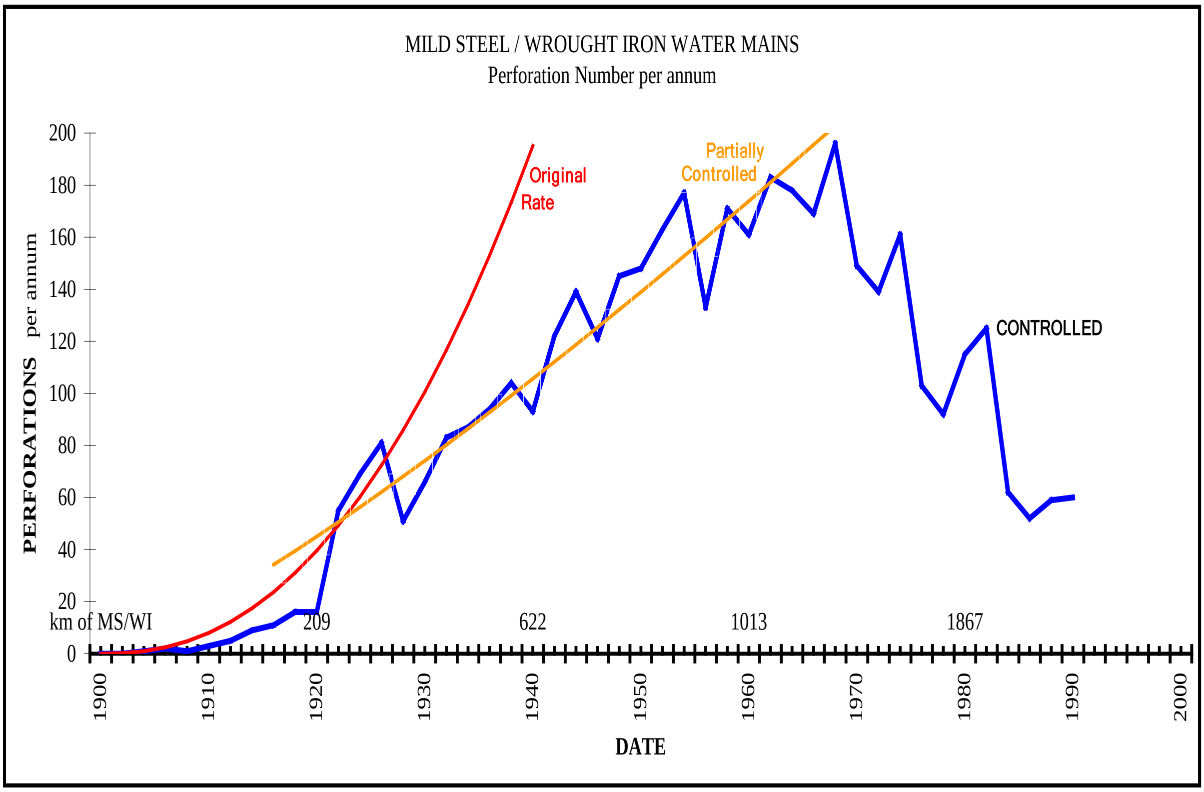


Fig. 1.1 **Perforation Rate per Annum**

A more realistic analysis must take account of the accumulated 'exposure time' of the pipes to the stray traction currents, i.e., how long have they been in that environment. When the data is modified to include the pipe exposure factor, the perforations per annum per 100km.year show the same 3 phases but with some useful variations, see Figure 1.2

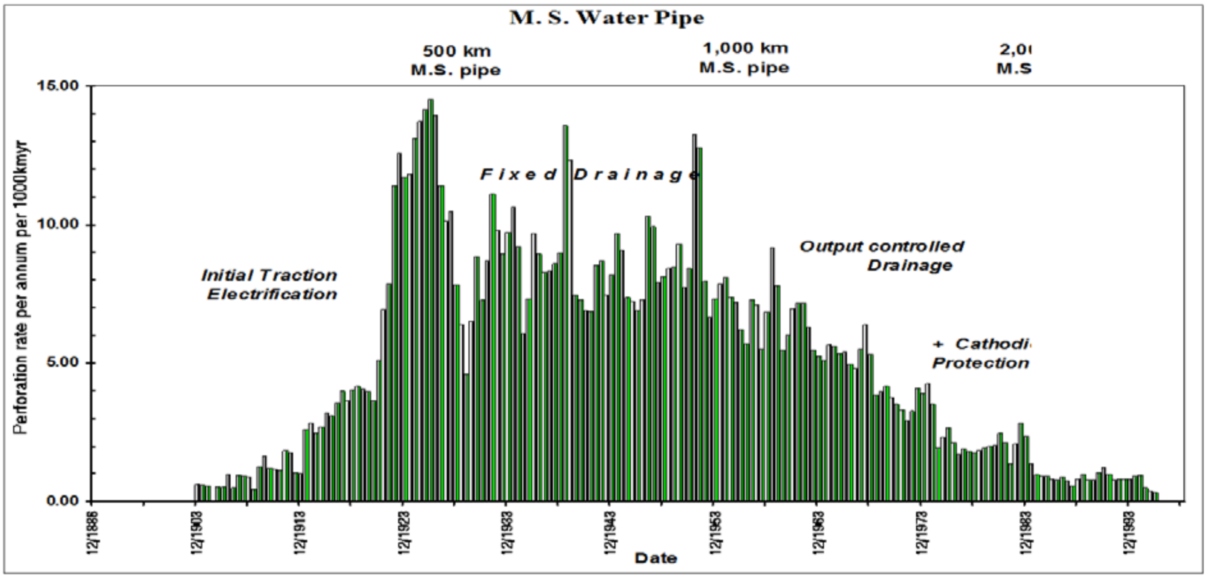


Fig. 1.2. **Perforation Rates per Annum per km/year**

1. The initial period to 1925/26 is still very strong, and is followed by a steep reduction until 1929. This arose because the location of the early perforations was concentrated around the traction substations and therefore easily drained by short cables from the pipe to the substation negative bus. The boom and bust process tends to repeat as the easiest problem areas are progressively fixed.
2. The second period shows basically that the corrosion rate was held approximately constant despite the considerable increase in pipe exposure, and was actually falling from about 1953. In general terms, the high spikes correspond to drought years when drying of the clay soils cause movement of lead jointed pipes, and water leaks become much more visible to the public and to maintenance men.
   The end of this period corresponds with the conversion to the present feeder drainage system and the disconnection of the power boosted drainage bonds about 1965. A significant number of the boosted drains had actually increased the corrosion rate of some water mains as proved by later perforation data.
3. The final period shows the effective adjustment of the controlled drainage systems plus the addition of cathodic protection to control corrosion not attributable to stray traction currents from 1973.

The current corrosion problem on the MS water mains is now quite low, giving a very long and economical life to the current water mains.

11.3 Telstra

Telstra's Victorian Electrolysis experience

As far back as Federation (1901) the problems of stray traction current from D.C Tramway and Railway systems were recognised by Telephone administrations. Whilst data is now scarce on activities of the time, the (then newly formed) Post Masters General (P.M.G) Department carried out tests to discover how to stop the electrolytic corrosion of lead sheathed telephone cables. Somewhat incredibly, local records dated 1908, are existing and they detail the fact that Engineering staff of the day were more than aware of Faraday's laws on the subject.

In March 1923, an Electrolysis Investigation Board was formed to report on the submissions tabled to the State Government on serious failures on gas, water and telephone structures attributed to electrolysis. This board comprised of Chief Engineers from the State Electricity Commission, Melbourne and Metropolitan Tramways Board, and the Victorian Railways Department. Curiously no representatives from the Board of Works, Metropolitan Gas or Postal Department were represented. The final report from this Board in November 1926, strongly recommended the formation of a Co-operative Committee, representing all interested parties. This committee was formed on 30 August 1927, under the auspices of the State Electricity Commission, and became known as the Melbourne Electrolysis Committee. At the time of formation, authorities represented on the Committee were: The State Electricity Commission; The Melbourne and Metropolitan Tramways Board; The Victorian Railways Department; The Melbourne and Metropolitan Board of Works; The Metropolitan Gas Company; and The Postmaster General's Department (PMG).

By 1925, it was stated that £20,000 worth of damage per annum was being done to telephone cables.

The effectiveness of the Electrolysis Committee was soon evident to the PMG. In the early 1930's, telephone cable faults were occurring at the rate of approximately one per week, in the Carlton area. Application of drainage resulted in a reduction to less than three per annum. At Camberwell, seventeen cable faults occurred in 1930. Installation of two drainage bonds in 1931 reduced the incidence immediately to less than one per annum.

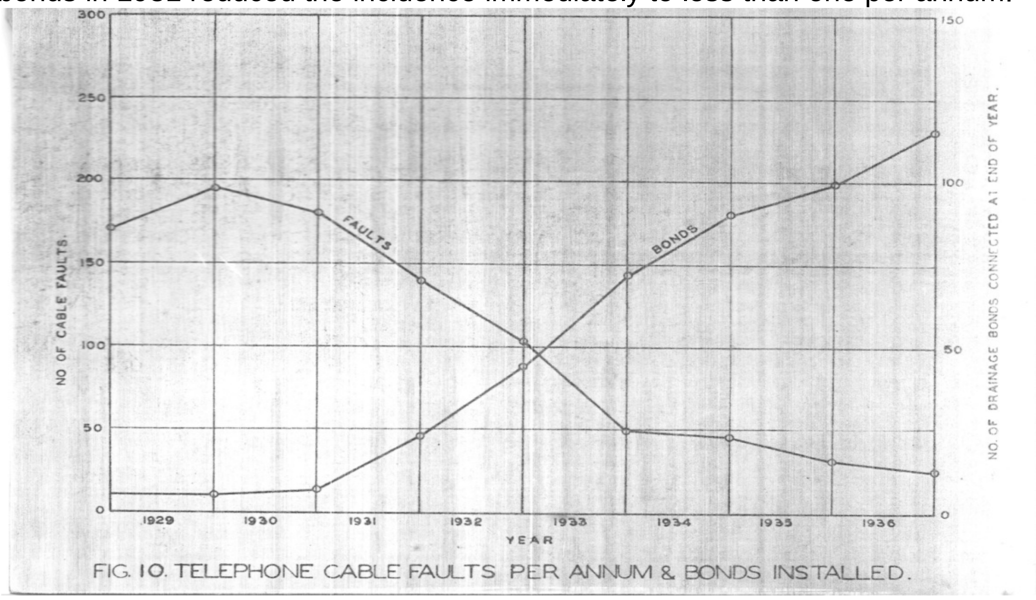


Figure 1 - Telephone cable faults per annum and bonds installed

In the mean time Statutory Rule 1920, number 246 was gazetted. This placed, for the first time, operating limits on the electrical and traction industry insofar as their effect on the telephone system was concerned. This was amended in 1921, number 151, and later in 1934, number 130 was produced. This further set in concrete the extent to which interference with the works of the Postmaster General was tolerated. Several conditions pertaining to tram track conductivity, potential difference to soil at different points of a track (e.g. 0.8 Volts max, cable to rail) and insulation of feeders, etc, were made compulsory. It was incumbent on the Traction Authority to install and maintain measures that will adequately safeguard underground cables, and the PMG was charged with effecting supervision of these provisions of the Post and Telegraph Act. A variety of physical and mechanical constraints such as the negative terminal of the generator shall not be earthed (the opposite of the British Board of Trade) as well as harmonic ("leakage or inductive condition") interference were also applied. Clause 19 (2) read:

> (2) "Where damage does result from such uninsulated return or where electrical tests indicate that it is likely to occur owing to the operation of the electric tramway or railway, such steps shall be taken as are agreed by the parties to remove, with the least possible delay, the cause of such damage."

These rules are unique in regard that that for the first time, electric drainage is permitted and limitations as regard to rail drops are not advanced as an engineering solution. In other words, it was recognised that circumstances alter cases and co-operation is definitely encouraged.

It was usual for Postmaster General's Department to claim damages under the Act, the extent being the actual cost of replacing the damaged cable or of restoring service. No other public or private body had statutory powers of this nature.
To determine if a fault on a telephone cable could be attributed to stray current corrosion, a number of tests would take place. Firstly, the appearance of the fault was assessed. Secondly, a potential reading is made between the cable sheath and a local earth plate. The location of the fault with respect to the electric traction system is also taken into account. Finally, an examination of the duct water is made. About this time, engineers from the PMG started conducting chemical analysis on soil samples near faults in an effort to distinguish between Electrolysis and Chemical attack. An analysis is also made of the corrosion product, the duct water around the cable, and a microscopic examination of the cable sheathing. The test showed that corrosion attributed to Electrolysis had the following characteristics: Steep sided pits and long corroded furrows in the metal; Visible fissures between crystal grains sometimes making it possible to isolate individual crystals – inter-crystalline attack; transparent watery crystals in the end products strong in chlorides and sulphates, often lead peroxide present; clean duct water substantially free from organic matter and containing normal amounts of salts such as chlorides, carbonates, sulphates, etc. Should each of the tests be consistent with the contention that traction currents caused the corrosion, it is considered that a prima facie case has been established and the fault is reported to the Committee.

The incidence of stray current corrosion upon telephone cables in several Australian cities is indicated in Table 1, which has been compiled based on the tests methods above. The effectiveness of the methods of investigation adopted in Australia under the Cooperative Committee system is reflected in Table 1. Although some efforts to relieve the electrolysis situation were made prior to the date shown in the table, the years shown can be regarded as the starting point of effective control. Generally speaking, this meant the year after the formation of Cooperative Committees.

STRAY CURRENT CORROSION REPORTED AS OCCURRING ON LEAD COVERED TELEPHONE CABLES.

Calendar Year	Number of faults reported during year								
	Adelaide	Ballarat	Bendigo	Brisbane	Geelong	Melbourne	Newcastle	Perth & Fremantle	Sydney
1929		16 *	4		3	195 *			
1930	11	7	4 *	8	15 *	180		4	36
1931	9	5	1	12	1	140	7	2	53
1932	2 *	3	2	7	0	103	20	3	97
1933	2	9	2	6	0	50	29	1	106
1934	1	2	2	7	0	46	19	2	138
1935	0	1	0	7	0	32	33	2	150*
1936	1	0	0	4	0	25	28	5	114

* Note - Mitigative measures instituted in this year.

Blank spaces indicate no reliable data available.

Figures for Sydney and Newcastle prior to 1932 may be inaccurate.

Table 1 - Stray current corrosion on lead sheathed telephone cables

By the beginning of the Second World War, the various states had tackled the corrosion problem with varying degrees of success, based on the authority of Rule 130. The oddly titled position of Engineer, Electrolytic Survey, in the PMG Department was established in the eastern states.

Telephone cable sheath types

Telstra's network of telecommunications cables is made up of bare lead (Pb), Plastic Jacketed (PJ) lead, and plastic sheathed.

Lead cables were laid from the 1900's to the 1960's. PJ cables from the 1960's to the 1980's, and plastic cables from the 1980's on. It is possible that a single cable from end to end can change from bare lead to PJ then plastic and back to bare lead. This leads to problems with continuity of the metallic sheath, particularly with regards to Cathodic Protection (CP) and Electrolysis Drainage Bonds (DB).

Amphorteric metals

Both lead and aluminium are amphoteric metals, meaning they can corrode in acidic or alkaline environments. When lead is driven to a too negative potential (-1400mV to $CuCuSO_4$) a local alkaline environment is established, and if the excessive negative potentials are then removed or reduced rapid corrosion will occur. It is therefore necessary to ensure that lead is protected in the range of -650mV to -1400mV to $CuCuSO_4$.

Cable pressure alarm system

Water ingress into air-cored cables (both paper and to a lesser extent polyethylene insulated cables) can result in the complete failure of the cables through a decrease in the electrical properties of the cable. Water can infiltrate into the cable through any hole in the cable sheath that is subjected to a head of water. The main causes of holes in the cable sheath are corrosion and mechanical damage. To prevent the ingress of moisture air-cored cables are pressurised with dry air. The air pressure in the cable will generally prevent the entry of moisture in the event of minor sheath failure.

Pressurised dry air is fed into the cables from either electric compressors or compressed dry air cylinders. Both types of air sources are normally located in telephone exchanges, and are alarmed so as to monitor the condition of the air source.
When a sheath failure occurs, the drop in pressure operates an alarm which is displayed at a central location.

Variable Conductance Drainage Bond (VCDB)
During the late 1980's Telecom Australia (now Telstra) started work to develop an intelligent resistor that could replace the conventional resistance wire in drainage bonds. The result was the Variable Conductance Drainage Bond (VCDB). The VCDB is basically a feedback element which reacts to shifts in structure potential, and feeds it back to the drainage bond as a conductance change, thus maintaining the structure potential to a preset level. This resistance or conductance varies infinitely from open circuit to near short circuit. The advantages of this are that both cathodic and anodic excursions are reduced at the location. After some early problems, ironically on Telecom cables, relating to induced noise being generated, these devices are being used on more widespread basis. The VCDB is particularly useful in combating the effects from Regenerative Braking trains and trams.

Cable recovery project
In 2002 Telstra embarked on a project to recover/rationalise junction cables (those connected between telephone exchanges). Many cables had low usage rates, and were often duplicated by other junction cables and optical fibre cables. This resulted in a large number of lead cables being removed from the network. Subsequently, continuity from existing drainage bonds and cathodic protection units was lost at many locations. Where this was identified the installation of continuity feeders, consisting of 7/1.70 or 19/1.53 plastic insulated copper cable was installed to bridge the gaps in continuity of the metallic sheath. At this time a number of DB's and CP's were no longer required and were decommissioned. Also around this time most Coaxial cables (once the most important telephone cables due to the larger bandwidth available) were also decommissioned.

National Broadband Network (NBN)
As of 2012 the future for lead sheathed cables in Telstra is questionable, due to the government of the day installing the "National Broadband Network (NBN)". This network will consist of optical fibre cables running to most houses in Australia, with the remaining being serviced by satellite communications. As part of this project all "copper cables" (being copper conductors with either lead or plastic sheaths) are to be decommissioned once the NBN has been established. Lead sheathed cables have serviced the Australian population well, with most of the current cables being installed in the years following World War II, and having a service life of only 25-30 years. Thanks to the efforts of Telstra's corrosion group, along with the Victorian Electrolysis Committee, the service life of these cables has been extended so that they still give a reliable service.

11.4 Australian Institute of Petroleum

The Australian Institute of Petroleum (AIP) has had a representative on the TSC since 1980. However up until 1987 the AIP was represented on the VEC by the DITR representative. The DITR ceased representing the AIP late 1987. From 1987 to December 1988 the VEC informed the AIP members of activities on an ad-hoc basis.

In December 1988 the then, Secretary of the VEC, Mr. W. Attard, wrote to the AIP extolling the advantages of the AIP being members of the VEC. Extract of letter dated 20th December 1988.

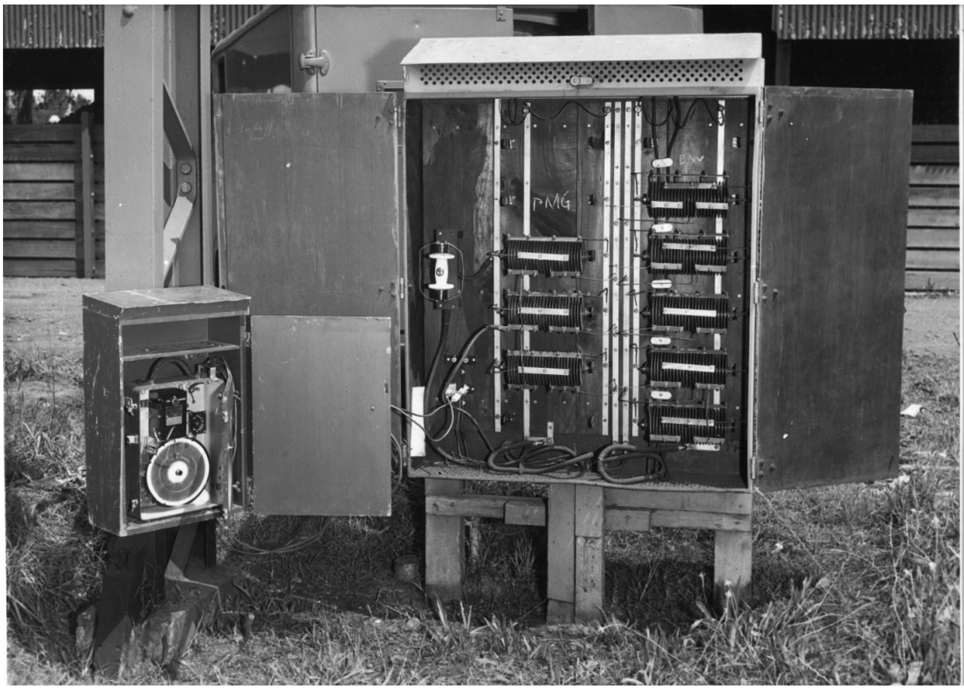
"Therefore, the advantages of being a member are:

- *Participation in the formulation of policies and the implementation of these policies for stray current corrosion and cathodic protection.*
- *Representation on the Committee will enable closer scrutiny of area tests involving oil pipelines.*
- *Representation will ensure that adequate and effective interference testing is being conducted during commissioning test of cathodic protection installations.*
- *Representation will give greater weight to any changes required to the benefit of oil pipelines.*
- *Representation will enable participation of the oil companies in "State of the Art" corrosion control, as authorities are carrying out R&D into corrosion control.*
- *Cathodic Protection applications for oil pipelines may have less resistance through the Committee by having representation at Technical Subcommittee level.*
- *Cost sharing of new drainage systems*
- *Representation will give the oil companies an influential voice on corrosion control."*

Interestingly the Victorian membership of the Petroleum Marketing Engineers Advisory Committee had meet on the 14th December to consider whether AIP should apply for membership. The recommendation was to apply for membership.

A number of follow up meetings were conducted during 1989 with AIP member companies to review and endorse the application for membership, with the only point of dissension being the proposed fee structure. Negotiations with the VEC resulted in an agreed outcome with the AIP assuming full membership of the VEC on January 1990. Since then, the AIP has continued to support the work of the VEC with a representative from member companies sitting on the VEC in an active role.

12 APPENDIX 1 – Historical Photographs



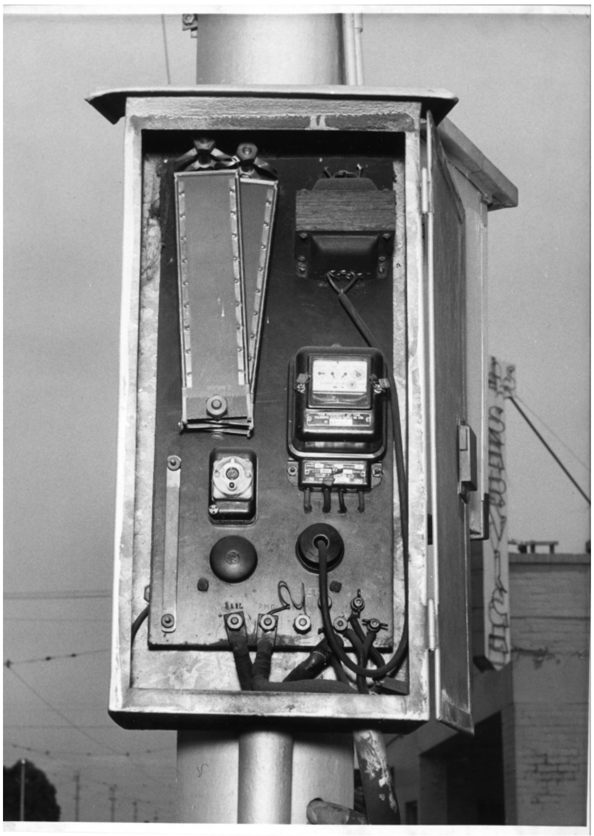
12.1 Boosted Drainage Bond

12.2 Drainage Bond in Glenhuntly

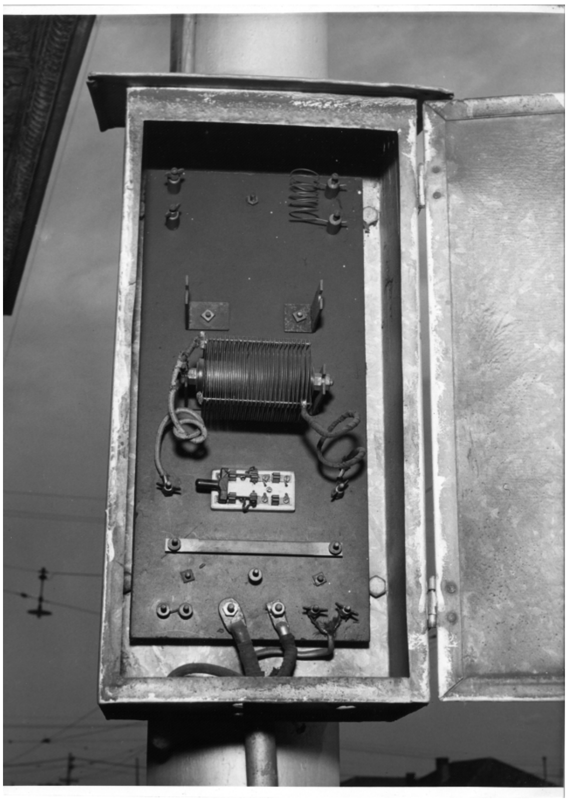
12.3 Drainage Bond Opposite Glenhuntly Tram Depot

12.4 Guardian Voltmeter, Pb/PbCl Electrode

12.5 P Stevens & D Hunt at Lilydale Substation

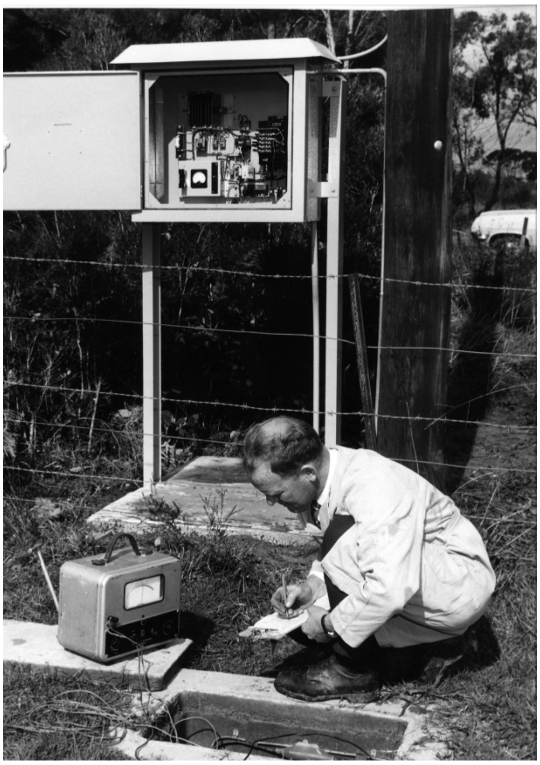


12.6 MMTB Boosted Drainage Bond



12.7 MMTB Unboosted Drainage Bond

12.8 Pakenham CPU – Rex Waters & J Mc Pherson



12.9 Pakenham TP with VTVM

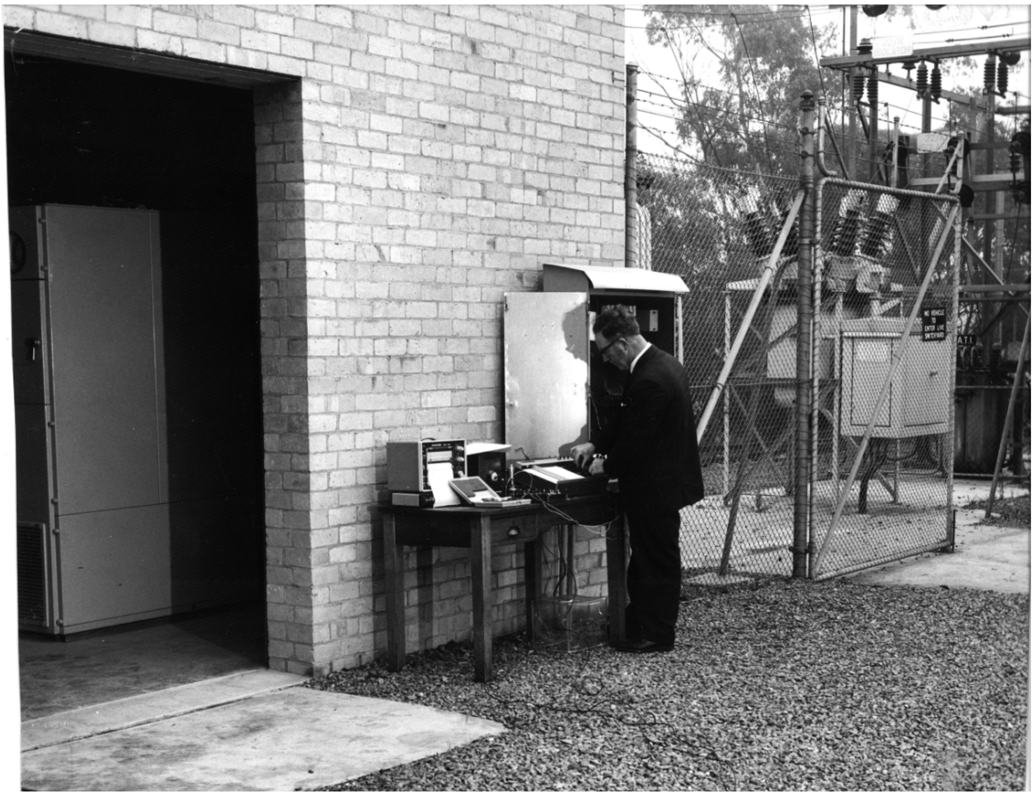
12.10 PMG CPU – Geelong Road at Werribee Bridge

12.11 John Mulvaney Taking Potential Measurements

12.12 Carrying Out Temporary CP Testing

12.13 VR Drainage Bond, Spotswood

12.14 VR Drainage Bond – Bristol Recorder



12.15 N Water testing with an X-Y Recorder

12.16 Electrolysis Surveyor

12.17 Electrolysis Field Staff, Bell Street Coburg, 1932

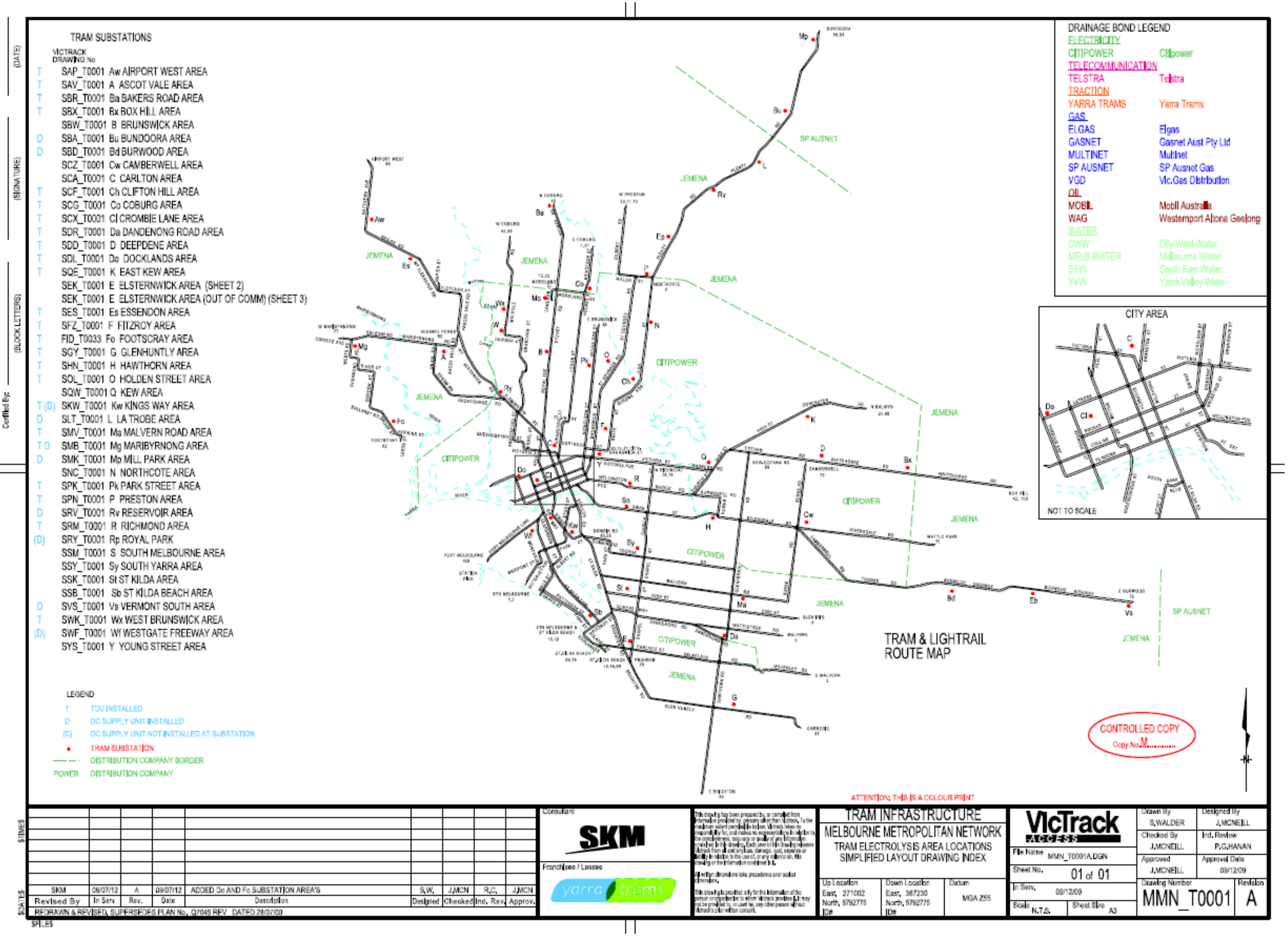
13 APPENDIX 2 – Traction Substations (As of May 2014)

TRACTION SUBSTATIONS - ELECTROLYSIS INVESTIGATIONS						
	LOCATION	S/STN	TRACTION	TRACTION	TDU	REMARKS
		ABBREV	OWNER	TYPE	INSTALLED	
1	Werribee	WR	MTM	**Siemens**		
2	Hoppers Crossing	HC	MTM	**Siemens**		
3	Aircraft	AC	MTM	**Siemens**		
4	Paisley	PA	MTM	**Siemens**	Yes	
5	Newport	NP	MTM	**Siemens**	DC Supply	Tie S/Stn/VCDB drainage system
6	Williamstown	WL	MTM	**Siemens**	Yes	
7	Yarraville	YV	MTM	**Siemens**	Yes	
8	Sunbury	SUY	MTM	**Siemens**		
9	Jackson's Hill	JHL	MTM	**Siemens**		
10	Diggers Rest	DIT	MTM	**Siemens**		
11	Holden Road		MTM	**Siemens**		
12	Calder Park		MTM	**Siemens**		
13	Sydenham	SDM	MTM	**Siemens**		
14	St Albans	SA	MTM	**Siemens**	Yes	
15	Albion	AL	MTM	**Siemens**		DC Supply/VCDB/Talmage St
16	Tottenham	TO	MTM	**Siemens**	Yes	
17	North Melbourne	NM	MTM	**Siemens**		
18	Docklands	Do	Yarra	Tramway	Yes	
19	Royal Park	Rp	Yarra	Tramway		DC Supply/VCDB/Wellington St
20	Ascot Vale	A	Yarra	Tramway	Yes	
21	Maribyrnong	Mg	Yarra	Tramway	Yes	DC Supply/VCDB drainage system
22	Footscray	Fo	Yarra	Tramway		
23	Essendon	Es	Yarra	Tramway	Yes	DC Supply/VCDB/ Rachelle Rd
24	Airport West	Aw	Yarra	Tramway	Yes	
25	Essendon	EN	MTM	**Siemens**	Yes	
26	Pascoe Vale	PV	MTM	**Siemens**	Yes	
27	Glenroy	GL	MTM	**Siemens**	Yes	
28	Coolaroo	CLO	MTM	**Siemens**	Yes	
29	Roxburgh Park	RXP	MTM	**Siemens**	Yes	
30	Craigieburn	CGB	MTM	**Siemens**	Yes	
31	Campbellfield	CF	MTM	**Siemens**	Yes	
32	Coburg	CG	MTM	**Siemens**	Yes	
33	Coburg	Co	Yarra	Tramway	Yes	
34	Moreland	Mo	Yarra	Tramway		
35	Bakers Road	Ba	Yarra	Tramway	Yes	
36	Brunswick Road	B	Yarra	Tramway		
37	West Brunswick	Wx	Yarra	Tramway	Yes	
38	Carlton	C	Yarra	Tramway	Yes	
39	Crombie Lane	Cl	Yarra	Tramway	Yes	
40	Young Street	Y	Yarra	Tramway		
41	Fitzroy	F	Yarra	Tramway	Yes	
42	Victoria Park	VP	MTM	**X'Trapolis**	Yes	
43	Clifton Hill	Ch	Yarra	Tramway	Yes	
44	Holden Street	O	Yarra	Tramway	Yes	
45	Park St	Pk	Yarra	Tramway	Yes	
46	Northcote	N	Yarra	Tramway		
47	Croxton	CR	MTM	**X'Trapolis**		
48	Preston	P	Yarra	Tramway	Yes	
49	East Preston	Ep	Yarra	Tramway		
50	Reservoir	Rv	Yarra	Tramway	DC Supply	VCDB drainage system
51	LaTrobe	L	Yarra	Tramway	DC Supply	VCDB drainage system
52	Bundoora	Bu	Yarra	Tramway	DC Supply	VCDB drainage system

	LOCATION	S/STN	TRACTION	TRACTION	TDU	REMARKS
		ABBREV	**OWNER**	**TYPE**	**INSTALLED**	
53	Mill Park	Mp	Yarra	Tramway	DC Supply	VCDB drainage system
54	Reservoir	RE	MTM	**X'Trapolis**	Yes	
55	Thomastown	TH	MTM	**X'Trapolis**	Yes	
56	Epping	EG	MTM	**X'Trapolis**	Yes	
57	Hurstbridge	HB	MTM	**X'Trapolis**		
58	Wattle Glen	WG	MTM	**X'Trapolis**	Yes	
59	Eltham Nth	ELN	MTM	**X'Trapolis**	Yes	
60	Eltham	EL	MTM	**X'Trapolis**	Yes	
61	Montmorency	MMY	MTM	**X'Trapolis**		
62	Greensborough	GR	MTM	**X'Trapolis**	Yes	
63	Rosanna	RO	MTM	**X'Trapolis**	Yes	
64	Alphington	AT	MTM	**X'Trapolis**	Yes	
65	Richmond	R	Yarra	Tramway	Yes	
66	Swan Street	Sn	Yarra	Tramway		
67	Hawthorn	H	Yarra	Tramway	Yes	
68	Burnley	BN	MTM	**X'Trapolis**		
69	Kew	Q	Yarra	Tramway		
70	East Kew	K	Yarra	Tramway	Yes	
71	Deepdene	D	Yarra	Tramway	Yes	
72	East Camberwell	EC	MTM	**X'Trapolis**	Yes	
73	Camberwell	Cw	Yarra	Tramway		
74	Box Hill	Bx	Yarra	Tramway	Yes	
75	Box Hill	BH	MTM	**X'Trapolis**	Yes	
76	Blackburn	BL	MTM	**X'Trapolis**	Yes	
77	Mitcham	MT	MTM	**X'Trapolis**	Yes	
78	Ringwood	RW	MTM	**X'Trapolis**	Yes	
79	Croydon	CN	MTM	**X'Trapolis**	Yes	
80	Mooroolbark	MK	MTM	**X'Trapolis**	Yes	
81	Lilydale	LD	MTM	**X'Trapolis**		
82	Ferntree Gully	FG	MTM	**X'Trapolis**	Yes	
83	Upwey	UP	MTM	**X'Trapolis**	Yes	
84	Glen Waverley	GW	MTM	**X'Trapolis**	Yes	
85	Mount Waverley	MW	MTM	**X'Trapolis**	Yes	
86	East Burwood	Eb	Yarra	Tramway		
87	Vermont South	Vs	Yarra	Tramway	DC supply	VCDB drainage system
88	Burwood	Bd	Yarra	Tramway	DC supply	VCDB drainage system
89	Holmesglen TDU	HG	MTM	**X'Trapolis**	Yes	
90	Ashburton	AS	MTM	**X'Trapolis**	Yes	
91	Gardiner	GA	MTM	**X'Trapolis**	Yes	
92	Malvern Rd	Ma	Yarra	Tramway	Yes	
93	Dandenong Rd	Da	Yarra	Tramway	Yes	VCDB's/Inkerman Rd/Dandenong Rd
94	Caulfield	CA	MTM	**Siemens**		
95	Glenhuntly	G	Yarra	Tramway	Yes	
96	Oakleigh	OA	MTM	**Siemens**	Yes	
97	Westall	WE	MTM	**Siemens**	Yes	
92	Springvale	SPG	MTM	**Siemens**		
93	Noble Park	NO	MTM	**Siemens**	Yes	
94	East Dandenong	ED	MTM	**Siemens**	Yes	
95	Lyndhurst	LHT	MTM	**Siemens**		
96	Merinda Park	MEP	MTM	**Siemens**	Yes	
97	Cranbourne	CB	MTM	**Siemens**	Yes	DC Supply/VCDB/Grassmere Rd

	LOCATION	S/STN	TRACTION	TRACTION	TDU	REMARKS
		ABBREV	**OWNER**	**TYPE**	**INSTALLED**	
98	Hallam TDU	HM	MTM	**Siemens**	Yes	Hallam Rd Rail Crossing
99	Narre Warren	NW	MTM	**Siemens**	Yes	Clyde St Rail Crossing
100	Beaconsfield TDU	BC	MTM	**Siemens**	Yes	Kenilworth Ave east of Station St
101	Officer	OF	MTM	**Siemens**	Yes	
101	Pakenham	PKM	MTM	**Siemens**		
102	East Pakenham	EP	MTM	**Siemens**	Yes	
103	Bentleigh	BE	MTM	**Siemens**	Yes	
104	Highett	HT	MTM	**Siemens**	Yes	
105	Mentone	ME	MTM	**Siemens**	Yes	
106	Mordialloc	MD	MTM	**Siemens**	Yes	
107	Chelsea	CS	MTM	**Siemens**	Yes	
108	Seaford	SE	MTM	**Siemens**	Yes	
109	Frankston	FR	MTM	**Siemens**	Yes	
110	Hampton	HN	MTM	**Siemens**		
111	Middle Brighton	MB	MTM	**Siemens**	Yes	
112	Sub E Chapel St.	E	Yarra	Tramway	Yes	
113	South Yarra	Sy	Yarra	Tramway	Yes	
114	St Kilda	St	Yarra	Tramway		
115	South Melbourne	S	Yarra	Tramway		
116	Kingsway	Kw	Yarra	Tramway	Yes	
117	Westgate Fwy	Wf	Yarra	Tramway		DC Supply/VCDB/Montague St
118	St Kilda Beach	Sb	Yarra	Tramway		
119	Bendigo	Ben	BTT	Tramway	Yes	

14 APPENDIX 3 – Plan of Tramways Traction Area



15 APPENDIX 4 – Plan of Railways Traction Area