Independent Technical Analysis of the Wellington Trolleybus Electrical Infrastructure

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1. Introduction

An independent technical analysis has been carried out since April this year to reach an informed view of the current state of the Wellington trolleybus infrastructure. Archival and historical information on the system from the days of Wellington City Council (WCC) ownership has been reviewed and all trolleybus route overhead line routes have been recently surveyed by physical inspection to check configuration, power feeding connections and to verify general condition.

This document is focused at providing independent and objective information for further debate and assessment, and has been purposely carried out independently of vested parties. It is not offered as professional advice to any of the stakeholders.

2. Executive Summary

An analysis of the trolleybus infrastructure system has been carried out which shows that the life extension of the existing system is possible at significantly reduced costs compared to the 2014 Transport Plan indicative costs. It identifies key elements that should be considered for upgrade to life extend the system after mid 2017 for another 10-12 years to coincide with utilisation of the trolleybus vehicles for an expected 20 year operating life.

The analysis of the WELL traction power supply system indicates that the estimated replacement cost of about $4.5M is all that should be necessary to life extend the existing traction power supply system. An engineering testing programme of all feeder cables should be carried out to confirm the condition of each feeder cable to verify that the $2M allowed for these is adequate. The replacement of the substation DC high speed circuit breakers is considered unlikely to be necessary in line with experience with other DC traction systems, but a specialist engineering survey should be carried out to confirm this.

Indicative costs to carry out the partial or major renewal overhead line work is estimated at $7.2M and expenditure can be spread out over a number of years. In addition the installation of the remaining lineside protection boxes (known as TBOP’s) is estimated to cost $2.2M.

A minimum of a 10-12 year life extension horizon from 2017 is envisaged for the trolleybus electrical infrastructure to allow the trolleybus vehicles to maximise an anticipated operating life of 20 years.

All costs specified are broad estimates only and will be of the order plus or minus 25%.

There are a number of DC traction systems around the world with old legacy and ageing equipment that continue to operate safely and reliably with minor enhancements, and there is no reason technically why the Wellington Trolleybus system cannot also continue to be one.

3. Background

There has been a certain amount of information divulged by Greater Wellington Regional Council (GWRC) on the state of the trolleybus system and the reasons used for the planned closure in 2017. The information publicly available and reports from consultants engaged by GWRC indicate that considerable investment would be required to keep the system running notwithstanding that the trolleybus overhead lines are acknowledged as being in the best condition they have been for many years.

The trolleybus DC power supply substation equipment and cabling was contentious with the Transport Plan claiming that total replacement was required at costs estimated up to about $52M if the system was to continue operating in the medium term. A reduced figure of $16.5M (understood to be for the replacement of the substation equipment only) was subsequently identified publicly during decision deliberations by GWRC councillors in 2014. The GWRC currently plans for the termination of trolleybus operations in mid-2017.

In order to ascertain the likely true state and condition of the direct current (DC) power supply cabling information from various sources, including available archival information from the days of public ownership, was obtained and analysed in some detail. Considerable research was carried out to practically determine the overall status of cabling types installed over the years, and how the cabling network evolved from the previous tramway cabling network installation.

Some research was also carried out to compare the Wellington trolleybus traction system against other traction systems with similar types of old equipment still in use.

4. Trolleybus system elements and ownership

The Wellington trolleybus system consists of three major elements as follows;

a) <u>Traction power supply system</u>

This consists of substation equipment and cabling that supplies the 550 volts DC traction power to the trolleybus wires. The traction power supply system is currently owned by Wellington Electricity Lines Ltd (WELL).

b) <u>Trolleybus overhead wires (owned by Wellington Cable Car Ltd)</u>

These are strung above the roadway and allow the trolleybuses to collect power through the roof mounted trolley poles. Two wires are provided, one each for positive and negative DC power. The trolleybus overhead lines are owned by Wellington Cable Car Ltd (WCCL) which is a subsidiary of the Wellington City Council (WCC).

c) <u>Trolleybuses</u>

Trolleybuses are electric road vehicles that normally take power from the overhead wires. It is understood they are owned by Wellington City Transport Ltd, (the Wellington subsidiary of NZ Bus which is owned by Infratil Ltd) which operates the bulk of the Wellington city bus services. When fitted with traction batteries they have limited capability to operate under battery power (refer to 9.2 below).

The system elements are discussed in greater detail in the following sections.

WCC effectively owned the Traction power supply system and the trolleybuses through subsidiary entities up to the 1990's at which time they were sold off to private entities.

5. Traction power supply system

5.1 System elements

The traction power supply consists of the following primary elements;

5.1.1 Substation based equipment:

a) 11kV stepdown traction transformers which provide about 410 volts AC (6 or 12 pulse) power to the DC rectifier sets
b) DC rectifier sets that convert the 6 or 12 pulse AC power to DC traction power at a nominal voltage of 550 volts DC.
c) DC traction high speed breakers (HSB's) that provide overload electrical protection and an isolation (disconnection) function for the DC traction power leaving the substation. (Note that these HSB's are normally operated by remote control from the WELL power network control room).
d) DC switches that provide a manual means of isolating equipment and the outgoing cables.

5.1.2 DC traction cabling network:

The DC cable distribution network links the traction substations with supply point pillar boxes adjacent to the overhead trolleybus wires. These convey the DC power from the substation to the overhead line distribution points.

Also provided between a number of the more important substations are tie cables, which were originally intended to supply DC traction power between adjacent substations in the event that one substation lost its 11kV or DC traction power supply.

5.1.3 Lineside protection boxes (TBOP's):

Lineside protection boxes (known as TBOP's)[1] have been installed by WCCL to provide additional electrical protection at a number of locations in place of the supply point pillar boxes. These TBOP's combined with the traction substation DC HSB's (see 5.1.1 above) effectively provide a modern standard[2] of electrical protection to the overhead trolleybus lines, and can be regarded as a necessary safety enhancement.

5.2 Development history

The origins of the DC traction supply system extend back to the introduction of electric tramways in Wellington in 1904 when a single power station at Jevois Quay and a feeder cable network radiating

1 "Trolley Bus Overhead Protection" system – refer paper Wellington's Trolleybus Overhead Electrical Network – Introduction of Electrical Fault Protection System presented at the EEA Conference 18-20 June 2014

2 TBOP compliments basic overload protection provided by the connecting feeder substation HSB

from this point were installed[3]. As the tramways grew more traction substations were added and the feeder cable system enhanced and extended. About 1939, two new “rectifier substations”[4] were added, (Brooklyn Rd and Duncan Terrace Kilbirnie) to reinforce the power supply system for the expected Centennial Exhibition traffic increases. This brought the number of tramway feeder substations to seven[5], the remaining five being of the earlier technology “rotary converter” type[6].

In the late 1940’s, conversion to trolleybuses commenced. This work continued through the 1950’s to the early 1960’s and included a programme of the following;

a) Addition of 12 new traction substations.
b) Conversion of 2 of the old “rotary converter” substations (Newtown and Chaytor St, Karori) to new “rectifier substations”
c) Decommissioning of three old “rotary converter” substations (Jevois Quay, Thorndon and Evans Bay).
d) Extensive new DC traction feeder cabling primarily to cater for the new substations, and to provide a new positive tie cable link between substations where required.
e) Rearrangement of existing feeder cabling and also tie cabling between substations.

The trams last ran in Wellington in 1964 and by 1966 all connectivity to the old tramway system had been removed and the above works completed. A new Traction Diagram dated 1966[7] showing schematic details of the trolleybus traction substation and cabling arrangements was issued. The system with some additions, changes and route deletions remains largely the same today.

5.3 Traction Substation Equipment

5.3.1 Equipment currently installed

The traction substation equipment for the conversion to trolleybuses was sourced from reputable British manufacturers of the time, and the same or similar equipment was extensively used around the world.

The DC rectifier sets installed were the air cooled steel tank mercury arc rectifiers supplied by GEC (these were the same types as first installed at Duncan Terrace and Brooklyn Rd in about 1939). They were coupled to purposely designed 11kV stepdown traction transformers. Some of these rectifier sets have now been replaced by solid state rectifier units, but most are still in service.

Virtually all of the DC high speed circuit breakers were sourced from Bertram Thomas who were regarded at the time as a leading British maker of DC switchgear with a world-wide reputation for quality equipment.

3 City of Wellington, General Conditions, Specification and Form of Tender for the Erection and Maintenance of Materials, etc., for the Overhead Equipment & Feeders - For the City Electrical Tramways. Dated July 1902.

4 Considered to be modern technology at the time
5 WCC Tramways Dept drawing No 1606 “Tramway Feeder System Diagram Diagram (as amended 14/4/1943)
6 A motor driving a special rotary machine that converted the AC power to DC power
7 Copy of drawing showing network operative in 1966 held by author

5.3.2 Equipment load ratings

The traction substation average load ratings are currently relatively light[8] compared to the continuous full load rating of the supply equipment (i.e. they are not overloaded). In common with other traction substation equipment the short time overload ratings[9,10] will be typically 150% for 2 hours and 300% for 1 minute. The 1 minute ratings allows short bursts of overload power but in some cases will trip the substation circuit breakers if too many buses pull maximum power at the same time when, for instance, starting from a stationary position.

The original substation network was designed to support the operation of a maximum of 119 trolleybuses whereas it now supports the operation of only 60 trolleybuses. This load reduction will have the biggest reduced load impact on the CBD traction substations, and to a lesser extent on the Newtown and Kilbirnie traction substations.

5.4 Traction cabling network

5.4.1 Tramway feeder system

The original tramway feeder system installed at the commencement of the 1900's utilised vulcanised insulated rubber (VIR) types of cable laid on bridges (spacing blocks) in wooden boxing and covered with "genuine Trinidad Bitumen". This form of cable laying was referred to as "boxing" and utilised bitumen with known quality sealing properties at the time.

Around the early 1920's, paper insulated lead sheathed cables (PILC) without armouring were introduced, which were also laid in wooden boxing for protection, or alternatively "Sykes"earthenware pipes when laid in parts of the city area. This was promptly followed by the adoption of armoured PILC cables in the mid 1920's[11] which had the advantage that it did not need the direct protection of wooden boxing.

From the mid 1920's the Wellington City Electricity Department commenced installing 11kV PILC cabling for the new city AC power reticulation system and in many cases it shared a common trench or cable route with the tramway feeder cabling system as well as some low voltage reticulation cables (see Appendix 1 for examples). When new 11kV PILC cables were laid it was often common practice to upgrade and install new tramway feeder cabling in the same (or directly adjacent) cabling trench. Some of these original 11kV cables may be still in use.[12]

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8 Sighted figures range from about 25% to 35% load factor with respect to continuous full load substation rating
9 Electric Traction, Dover 1962 Pages 414 and 421 – typical parameters applicable for mercury arc rectifier sets
10 IEC 60146 - specifies ratings for various classes of rectifier equipment.
11 Sighted evidence from field notes of use of PILC tape armoured cables (noted as PLTA on the WCC Electricity Department cable plans and field books) used in Riddiford Street as early as 1924 with the commissioning of the Newtown original DC tramway traction substation equipment.
12 Refer to WELL 2015-2025 AMP Fig 6.25 "Age Profile of Distribution Cables" on Page 118.

5.4.2 Trolleybus conversion

When WCC embarked on a trolleybus conversion programme in the late 1940's the WCC Electricity Department started upgrading and re-arranging the DC traction power cabling system, while it continued to feed the tramway system. As the tramway routes were dis-established, new feeder cabling to the trolleybus overhead lines was installed, and some existing cabling re-used. Existing tramway cable feeders in "boxing" were either abandoned or where in good condition re-allocated to less important service, and in many cases consigned to use as the negative leg of "tie" cables between substations. All new cabling installed during this period was PILC steel wire armoured.[13] By 1966 the traction cable feeder system had been re-configured for full trolleybus system use and all connections for tramway purposes to the overhead and rails severed. The new Traction Diagram plan dated 1966 shows the re-configured network[14], including substation switching arrangements and the schematic feeder and tie cable details.

5.4.3 Cable types installed

The evidence sighted through review of the available archival information suggests that the following applies;

a) The majority of the current traction cabling used as direct feeders to the overhead lines is of the later "PILC" type with armouring.
b) The small amount of new cabling installed since the mid 1980's is of modern plastic types.
c) A minor amount of the very old "boxing" cabling may still be in use as direct feeders (and in general is installed as the negative leg).
d) Tie cables between substations may partly consist of "boxing" cable mainly with un-armoured PILC cables installed.
e) A considerable amount of jointing between cable types may exist, especially in the vicinity of substations and distribution pillars where 2 core cables may be split out into singles for ease of entry and termination onto equipment.

Thus the vast majority of the direct feeder cable network consists of PILC armoured cable types.

It is understood that all power and tramway feeder cabling was obtained from reputable British manufacturers of the day (eg. BICC) from the 1920's and comprehensive records kept of installation, so that any cabling found defective could be traced to the relevant drum number and supplier.

5.4.4 Cable plans and records

The cabling layouts were historically shown on the WCC Electricity Department scale drawings which combined their 11kV, pilot control and 400v AC distribution cabling with the DC traction 500v and rail return (or negative DC) cables (refer Appendix 1). Cable protection cover type is often shown with extensive use of tram rail in earlier days. Extensive cross-referencing is made to serial

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13 Known in the electrical industry as type "PILC SWA" (but noted as PLA on the WCC Electricity Department cable layout plans and cable installation field books).

14 Copy of the plan showing the network as it existed in 1966 held by Author.

numbered field books which showed specific site details. These field books came in 2 series; old field books (OFB) commencing in 1904, and new field books (NFB) from about 1924 onwards, probably to coincide with the commencement of the 11kv cabling reticulation rollout. It is understood that the cabling records were transcribed into a computer mapping system in the late 1980's and the 1990's, and these details (where still applicable) should now be recorded in the WELL asset management system.

6. Other DC traction systems

6.1 General

DC Traction systems for heavy rail, light rail, trams and trolleybuses generically use the same or similar power supply equipment with the voltage, power ratings and size of equipment being the main differences.

Traction systems by their nature tend to have a long service life, and experience around the world indicates that in fact a very long service life can be obtained from most components. Some items may need selective replacement and by way of example it has been common practice to replace mercury arc rectifier sets in DC traction systems after a service life of about 30 to 40 years with solid state rectifier units, utilising the existing rectifier transformer when in good condition, and where necessary reconditioning them.

Some examples of practices in other traction systems are outlined in 6.2, 6.3 and 6.4 below.

6.2 Network Rail, UK

Network Rail operate the 650/750V DC third rail traction system principally in the south-east of England which is the most heavily loaded DC traction system in the world. They have over 300 DC traction substations and continue to operate in daily service a large number of old generation Bertram Thomas and RJR DC high speed circuit breakers. The last of their mercury arc rectifier sets including the GEC air cooled steel tank types were replaced by the mid 1990's but they retained many of the original rectifier traction transformers in current service.

6.3 Melbourne metropolitan area

The Melbourne metropolitan area has one of the largest installed DC traction equipment clusters in the world, consisting of the 600v Yarra Trams network and the Metro Trains 1500v suburban electrified rail systems serving the city and outlying areas.

Yarra Trams have replaced virtually all of their older traction substations due to the need to upgrade to cater for the very significant traction load capacity increases resulting from the introduction of modern trams. However they retain a legacy feeder cable network, a large portion which pre-dates 1950 with the oldest cables installed in the 1920's. PILC cable types are extensively used and make up a large portion of their cable network. It is understood that these cables are very reliable in service and are coping well with the system traction loads imposed.

Metro Trains have been successfully life-extending old substation equipment where a power capacity upgrade is not necessary. The mercury arc rectifier sets installed in the 1950's and early 1960's have all now been replaced with solid state rectifier retrofit units but they continue to use the original rectifier traction transformers. These transformers are overhauled as required when condition monitoring dictates.

Metro Trains continue to operate in daily service a considerable number of old generation GE type JR DC high speed circuit breakers (HSB's) including a number installed when the system commenced operations in 1919. Some of these old generation DC HSB's are being overhauled for further service. These HSB's are proving to be more reliable in service than a later type installed in the 1980's. The JR type HSB's are an earlier shelf mounted version and almost identical to the trolley mounted RJR type HSB's used in the UK and NZ.

6.4 Wellington suburban 1500V DC traction system

There are currently seven substations on the Wellington suburban 1500v DC network originally installed in the 1950's and fitted with old generation Bertram Thomas DC HSB's. Old generation RJR type HSB's sourced second hand from the UK are also installed in four of the substations built between the early 1970's and mid 1980's.

I understand that the last steel tank mercury arc rectifier in service will be eliminated when the Petone substation is replaced. When this work is completed, about 40 HSB's representing 35% of the total installed numbers of DC HSB's on the 1500v DC traction system will be old generation DC HSB's.

From experience when working for KiwiRail, these old generation circuit breakers can be expected to provide reliable service for at least another 10 to 20 years provided they are properly maintained, and provided there is no need to upgrade the substation capacity due to substantial traction load increases, or a need to completely replace the substation for other reasons.

7. Condition Analysis of Trolleybus Traction Power Supply System

7.1 General

Condition analysis of the various components of the trolleybus traction power supply system are discussed below. Comparisons are made to accepted traction power supply system industry practices and WELL's current asset management plan to align condition and any priorities for replacement.

7.2 Asset Management Plan

An asset management plan (AMP) is a tactical plan for managing an organisation's infrastructure and other assets to deliver an agreed standard of service. Typically, an asset management plan will cover more than a single asset, taking a system approach - especially where a number of assets are co-dependent and are required to work together to deliver an agreed standard of service[15].

15 Definition derived from on-line Wikipedia. https://en.wikipedia.org/wiki/Asset_Management_Plan 9/10/2015

WELL are required to provide an AMP in accordance with the Commerce Commission's Information Disclosure Determination, October 2012. WELL's current AMP which is publically available on the web[16] describes Wellington Electricity's long-term investment plans for the planning period from 1 April 2015 to 31 March 2025, covering their sub-transmission and distribution network but excludes the Wellington trolleybus traction power supply system. In line with other organisations they specify strategies for the replacement or life extension of their key assets and assess options by formal condition assessment and risk review techniques accordingly.

No AMP or equivalent document for the trolleybus traction power supply system appears to be available, so condition analysis is compared to relevant methodologies in the current WELL AMP where appropriate, as well as accepted DC traction power supply system industry practices.

WELL have successfully life extended significant elements of their power distribution system, and this is has also been successfully practised by asset managers responsible for old established DC traction systems around the world. AMP requirements for a power distribution system may not always align to that of a traction power system, and differences are noted accordingly.

7. 3 Mercury Arc rectifier Sets

The GEC steel tank mercury arc rectifier sets were extensively used in the UK and other parts of the world. Experience with other traction systems indicate that these items suffered reliability problems with age and were often replaced with solid state rectifier sets as a separate component after about 30-40 years of service. The fact that they have lasted so long in Wellington trolleybus service is probably attributable in part to the relatively light average traction loads compared to their nominal full load rating.

Conclusion - It is reasonable to expect that they will now be showing age symptoms, and thus these units should be considered for replacement.

No equivalent item can be referenced in the current WELL AMP.

7.3 Traction Transformers

The rectifier traction transformers originally matched to the mercury arc rectifier sets were sourced from the UK. Traction transformers supplied by British manufacturers at the time were conservatively designed and well built (this applied from the 1930's right up to the 1980's). Many ageing units supplied in this era are still in service in the UK and other parts of the world.

Traction transformers are by design provided with additional bracing to withstand periodic short circuits expected in traction systems. A short circuit event could occur many times in one year on a traction transformer whereas on a distribution transformer it is unlikely to be more than a few events per year at worst. It is not uncommon for traction transformers to be overhauled to give a considerable life extension well past the original design life expectation when manufactured. It is

16 http://www.welectricity.co.nz/disclosures/2015-asset-management-plan/ (9/10/2015)

also not inconceivable that a conservatively designed and moderately loaded traction transformer should be able to achieve an in-service life expectancy exceeding 80 years providing it is well maintained and there is no external damage.

Metro Trains Melbourne have been successfully life extending by refurbishment their old rectifier traction transformers originally installed with the mercury arc rectifier sets in the 1950's and early 1960's.

For comparison, WELL utilised two general types of power transformer within its power distribution network as follows;

- 33kV to 11kV stepdown (sub-transmission) transformers which are normally located at Zone substations (these substations are regarded as important as they feed the 11kV high voltage distribution network)
- 11kV to 400 volt three phase stepdown (distribution) transformers (these feed low voltage power lines which in turn feed local consumers).

Referring to the current WELL AMP (page 253), sub-transmission transformers are subject to oil testing to provide an estimated Degree of Polymerisation (DP) value for the paper insulation, which provides an initial overview of the transformer condition. Quoting from their document;

> "*Fig 10-10 shows the estimated remaining life of Wellington Electricity's power transformer fleet as given by DP results, plotted against the nominal 60-year life of the assets. This clearly shows that, as long as corrosion and other mechanical issues can be managed, all of the transformers except one are expected to last beyond their nominal 60-year life.*"

The document follows on to discuss renewal or refurbishment options that they apply to these transformers.

Referring to the current WELL AMP section 10.4.5 "Distribution Substations and transformers" (page 279), the routine maintenance procedures are listed and no particular reference is made to oil testing. On page 282 under the heading "Distribution Transformers", the document quotes;

> "*If a distribution transformer is found to be in an unsatisfactory condition during its regular inspection, it is programmed for corrective maintenance or replacement. An in-service transformer failure is rare and, if it occurs, it is investigated to determine the cause. This assessment determines if the unit is repaired, refurbished, or scrapped[17] depending on cost and residual life of the unit. Typical condition issues include rust, heavy oil leaks, integrity and security of the unit. Some minor issues such as paint, spot rust and small leaks are repaired and the unit will be returned to service on the network. The refurbishment and replacement of transformers is an ongoing programme, which is provided for in the asset maintenance and replacement forecast, however it is undertaken on an as-needed basis (condition, loading, etc) arising from inspection rather than by age.* "

17 Suggested correct spelling is "scrapped"

Conclusion – The traction transformers should (if not already done so) be subject to individual assessment including full oil testing to determine condition. As all the transformers are housed indoors they should not be subject to external weathering issues that often dictate replacement regardless of electrical condition. In line with WELL's experience with their sub-transmission and distribution transformers, and that experienced in other traction systems, it is expected that most, if not all, of the traction transformers should have some remaining lifetime of at least 10 to 20 years, especially since they are moderately loaded. Strategies to manage this including the overhaul, repair and holding of spares could be readily implemented, if not already in place.

7.4 Circuit Breakers

The Bertram Thomas (BT) DC high speed breakers (HSB's) with big arc chutes were installed in all traction substation except Hania St. These BT circuit breakers in common with some other types (e.g. the BTH type RJR) were extensively used in the UK and in British influenced traction systems world-wide and many are still in service. They are well built and have readily maintainable mechanisms. Both the BT and RJR types been proven to be more reliable than some later types installed. These BT and RJR HSB's have a virtual infinite life providing that that the fault clearance and thermal ratings are not exceeded, and that they are adequately maintained. As the trolleybus traction system is moderately loaded and the DC fault current levels are relatively low, there should be no rating issues with the installed DC HSB's.

The DC traction HSB's operate in air and cannot be readily compared to distribution oil filled circuit breakers which have different technical attributes to be considered for AMP purposes.

It appears that most of the tie cable network may be out of use, so there should be a few spare circuit BT breakers able to be used as a source of spares as required. Worn contacts can be readily re-manufactured by SBA Melbourne.

Conclusion - There should be no need to replace the BT HSB's at this stage with the traction supply in its current configuration. However modern electronic protection relays could be fitted to the feeder HSB's where the feeding cable circuit termination point is currently not fitted with TBOP's (refer 5.1.3), or alternatively TBOP's installed on the remaining unprotected feeders in place of the conventional lineside pillar manual switch boxes. The TBOP's is probably the better solution but it would be prudent to review the options before any more are installed. The BT HSB's should also be subject to an engineering survey by a traction engineer with specialist DC circuit breaker experience to determine condition and any maintenance or remedial work required.

7.5 Switches

The substation switches installed are of a substantial knife type, and electrically and mechanically should present no issues. However they may need suitable shrouding if not already installed, and for electrical safety reasons should be operated only when the attached circuits are proven de-energised.

Referring to the current WELL AMP Page 282 under the heading "Low Voltage Distribution Switchgear (Substation)", the AMP notes that;

"The Wellington City area has a large number of open LV distribution boards in substations and a safety programme to cover these with clear Perspex covers has been completed. A small annual provision is made to capture any sites missed in the original programme. Smaller substations have a higher level of shielding on many of the installations. The overall performance of LV distribution switchgear and fusing is good and there are no programmes underway to replace this equipment."

Conclusion – The switches are all assumed to be covered by Perspex covers, and with appropriate operating precautions should be suitable for continued service on the existing switchboards.

7.6 Feeder cable installation

Referring to 5.4.3, the vast majority of the DC traction direct feeder cable network consists of PILC armoured cable types which essentially are the same construction as the distribution PILC cables, and generally laid in the same cable routes (refer 5.4.4). In line with industry experience world-wide, PILC cables have proven to be very reliable particularly if they are left undisturbed. This is also backed up by WELL in their current AMP (see extracts below).

WELL have a significant amount of power distribution PILC cabling installed. The following extracts from the current WELL AMP are reproduced below:

Page 118 - Section 6.2.4 "Distribution and LV cables"

Approximately 91% of the underground 11kV cables are PILC and PIAS[18] *and the remaining 9% are newer XLPE insulated cables. PILC cables use a mature technology but are in good condition and have proven to be very reliable.*

The majority of low voltage cables are PILC or PVC insulated and a much smaller number are newer XLPE insulated cables. In general, the low voltage cables are in good condition. An age profile of distribution cables of both voltages is shown below in Figure 6-25.

Pages 278 & 279 - section 10.4.4 "Distribution and LV Cables"

Maintenance of the underground distribution cable network is limited to visual inspection and thermal imaging of cable terminations. Cables are operated to failure and then either repaired or sections replaced. A proactive maintenance regime is not cost effective, given the network is generally designed so that supply can be maintained while cable repairs are undertaken. Cables are replaced when their condition has deteriorated to the point where repair is not considered economic.

The decision to replace rather than repair a cable is based on a combination of fault history and frequency, together with the results of tests undertaken after earlier cable fault repairs. An annual budget allowance is made for cable replacement, targeted at cables exhibiting high fault rates, or showing poor test results following a repair. Recent issues highlight the

18 Paper Insulated aluminium sheathed (an alternative type of cable used)

effect of fault stresses on older joints and the need to overlay sections of cables due to repeat joint failures. The small numbers of natural polyurethane insulated cables show high failure rates and this type of cable is therefore more likely to be replaced following a cable fault. An allowance is made each year in the CAPEX programme for cable replacement based upon historic trends and known defects. The need for a capacity upgrade is also considered.

In 2014, there were 28 cable, cable joint and termination failures at 11kV and above. Underground cables usually have a long life and high reliability as they are not subjected to environmental hazards, however as these cables age and reach their end of life, performance is seen to decrease. External influences such as third party strikes, inadvertent overloading, or even unusual high loading within normal conditions can reduce the service life of a cable. Some instances of failure are due to workmanship on newer joints (which can be addressed through training and education), whilst others are due to age or environment, which is less controllable.

By reference to the current WELL AMP Figure 6.25 on page 118, it can be seen that there is a portion of cabling installed between 1923 and 1950 still operative (all assumed to be PILC type). Some of these cables would have been installed in conjunction with DC traction PILC cables, illustrating that a very long service life can be demonstrated in many cases.

Referring to the above extracts from the WELL AMP, it is most probable that WELL apply the same maintenance standards to the DC traction cabling network apply as they do to the 11KV HV and 400v LV cable network, in that they do not carry out routine cable testing to determine condition, or to predict deterioration. This may be appropriate for a large distribution cable network with large numbers of cables where failure statistics can be established with certainty for AMP planning purposes, but introduces some uncertainty when a relatively small number of specialist ageing assets are considered. It does not facilitate a proper asset condition listing for each of the traction feeder or tie cables, nor provide a credible position especially when public funding may have to be budgeted for defined replacement works.

Yarra Trams test their cabling every 2 years for insulation integrity and can in many cases take action to prevent cable failure by planning early repairs and/or replacement.

I have been informed that there were very few faults in the Wellington trolleybus DC feeder and tie cable system right up to the late 1990's, and that any fault found was promptly rectified. Since then there have been a small number of events that have come to public attention through the media.

Conclusion – The actual electrical insulation condition of the full DC traction feeder cable network may not be fully documented. A proper engineering testing programme would establish the condition of each feeder cable and thus allow for sectionalised repairs or full replacement of identified feeder cables (where justified) to be identified formally.
Based on other evidence presented there should not be any undue concern for the majority of the cable network, but this should be verified accordingly by a formal testing processes being applied to all cables, so that any investment decisions utilising public funds can withstand proper scrutiny.

7.7 Tie cable installation

Referring to 5.4.3, a portion of the DC traction tie cable network linking important substations may consist of some older cable types, and thus be more susceptible to failure.

It is understood that portions of the tie cable network may now not be operative, but this may now not be a significant operating issue as the current trolley bus fleet (with a few exceptions) are fitted with batteries which allows the trolleybuses to get past sections of dead trolleybus overhead in the occasional event of a substation outage. However it would be wise to carry out a formal risk assessment to determine what tie cable functionality should be retained.

7.8 Network Configuration

As noted in 5.4.2, the network configuration of the DC traction feeder system is largely as installed for the original completion of the trolleybus network in the early 1960's. Some minor improvements and changes would benefit the system (eg better voltage support on the Lyall Bay route). It is appropriate to note that even though the existing DC traction system is by today's standards a legacy design, it can be safety life-extended technically to support the existing trolleybus operations.

The introduction of a modern light rail system would trigger new requirements for substantial traction system capacity upgrades. Integration with newer 750v DC traction systems is possible by applying appropriate electric segregation measures, and where necessary adopting the use of multi-tap transformers to peg the DC line voltage back to 600v for common operation.

7.9 Indicative potential replacement costs

Indicative costs to replace or upgrade essential elements of the WELL traction power supply system listed above are estimated as follows:

a) Replacement of remaining mercury arc rectifier units[19] – say 14 @ $120k each – allow $1.68M
b) Allowance for capitalised overhaul of traction transformers (provisional sum) - $0.5M
c) Feeder cable testing survey – allow $200k
d) Allowance for feeder cable capitalised repairs and replacements (provisional sum) - $2M

Total – $4.38M **(Allow $4.5M)**

The feeder cable testing survey (Item b)) should be carried out promptly and any work for item c) (and expenditure timeframes) will depend on the results of this survey. No allowance has been made for the replacement of any traction transformers but the indicative budget could cover a small number once any firm costs are established.

The fitting of additional TBOP's is covered under section 8.3.

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19 Suitable retrofit units should be available for $80k to $100K each

8. Trolleybus Overhead Lines System

8.1 General Engineering assessment

A general engineering assessment has been carried out to determine the current condition of the trolleybus overhead wire network. Each route was surveyed by visual inspection and line segments categorised into one of 4 categories. The indicative results which have been tabulated on a separate spreadsheet (refer to Appendix 2) show that;

a) **39%** of the network (17.2km) has been renewed in the last 5-7 years and should have a lifespan of 15-20 years without any major renewals
b) **28%** of the network (12.2km) is in good order and should last for at least 10-12 years without any major renewals
c) **19%** of the network (8.4m) may need some renewal within 10-12 years
d) **14%** of the network (5.9km) will probably need major renewal within 10-12 years.

A specific methodology has been applied to this assessment which will provide a reasonably accurate indicative summary in the absence of access to maintenance records, and in particular contact wire wear measurements.

Thus the current operative trolleybus network can be broadly be classified into two blocks as follows;

e) **67%** of the network has been renewed in the last 5-7 years or is in good order [combines a) and b) from above]
f) **33%** of the network may need some partial or major renewal within 10-12 years [combines c) and d) from above].

8.2 Overhead renewal costs

The capitalised cost of renewing a kilometre section of trolleybus overhead is estimated at about $700k. The contact wire alone accounts for a significant portion of the costs. This cost per kilometre is indicative and may vary depending on the work carried out (including pole replacement) and the complexity of the overhead line arrangements. Costs to run new contact wire only is obviously cheaper in cases where the span wires and fittings can be re-used. Certain sections may only need partial renewals to life extend the overhead lines.

Capitalised costs for major renewals for 8.1 c) and 8.1 d) above are assessed broadly as follows:

a) Major renewals (5.85km at $800k per km) – allow $4.68M
b) Partial renewals (8.38km at $300k per km) – allow $2.51M

Total –$7.2M **(Allow $7M)**

These costs can be spread out over a number of years, with timeframes depending on a detailed assessment of acceptable remaining operating lifetime for the identified sections.

8.3 TBOP's

TBOP's are currently installed at approximately 11 sites. A preliminary analysis indicates that about 22 sites need to be equipped if this safety enhancement programme is to be completed. Completion of this programme would ensure that a modern standard of electrical protection encompassing earth fault trip-out can be provided to the complete trolleybus overhead network without any upgrades required to the DC feeder electrical protection in the WELL traction substations.

The installed cost of these TBOP units is estimated to be of the order $100k each, so the total cost to complete this programme is about $2.2M.

8.4 Poles

As a part of the overhead lines assessment, the general condition of poles supporting the trolleybus overhead was noted. Although there are a relatively small number of old hardwood poles still installed, there is clear evidence of an active ongoing pole replacement management plan in place.

A specific survey of the Lyall Bay route from the bus storage sheds to Hungerford Road terminus in May 2015 shows that there were 14 old hardwood poles installed representing less than 10% of the poles installed to support the trolleybus overhead on that route section, and this is generally indicative on the older original trolleybus routes in the suburbs except for the Hataitai loop. Practically all old hardwood poles have been eliminated in the CBD area and on the upgraded routes.

9. Trolleybus Vehicles

9.1 Life expectancy

The current batch of 57 twin rear axle trolleybus vehicles were supplied between 2007 and 2009 and in 2017 will be 8 to 10years old. Internationally trolleybuses typically are expected to have a service life of 25 years.

The first generation of trolleybuses for the post second world war conversion programme were supplied between 1949 and 1964. These first generation trolleybuses achieved typically 20 to 30 years of service until fully superseded by the Volvo trolleybuses between 1981 and 1986. The Volvos in turn were superseded between 2007 and 2009 by the current fleet of trolleybuses, thus typically achieving a service life of 25 years.

The current trolleybuses should be able to achieve a minimum economic service life of at least 15 years, and potentially 20 years which would see them in operation until 2027 to 2029.

The NZ Bus chief executive (Zane Fulljames) was publicly quoted in 2014 as stating that the current trolleybuses have at least 10 years life left which equates to a minimum service life of 15 years.

9.2 Battery capacity

Almost all trolleybuses are fitted with batteries that allow a limited amount of running without power being drawn from the overhead wires. This feature allows the trolleybuses to travel past sections of dead overhead, or to do short trips away from the overhead wires. This flexibility, combined with relatively short overhead electrical sections particularly in the CBD has significantly reduced the instances of stranded trolleybuses due to any local loss of overhead power.

10 Discussion and analysis

10.1 WELL asset management plans

WELL are required to provide an AMP for their power distribution network in accordance with the Commerce Commission's Information Disclosure Determination, October 2012 (see 7.2) as they are a natural monopoly for the supply of electricity lines services to consumers so that electricity energy can be supplied by other parties. This ensures that the natural monopoly abides by a clear set of rules designed to ensure that they do not exert any undue influence on pricing or their supply services position.

The WELL 2015 AMP is quite a substantial document and it covers all asset elements in some detail. No equivalent document for the traction power supply system appears to exist.

10.2 WELL traction system renewal costs

WELL costs to replace the complete traction system including cabling were originally stated as $52Mthen reduced to a proposed alternative option of $16.5M (see 3 above).

WELL's chief executive (Greg Skelton) is on public record as promoting electric buses without wires in his article "Electric buses without wires are not in the future – they're here now" in his article published in the Dominion Post on the 12 May 2014 (see page A9), and notes that a refurbished trolleybus system would be particularly expensive.

The analysis presented by this paper shows that practical options exist to significantly reduce any investment to life extend the WELL trolleybus traction power supply system. As public funding has been provided to support trolleybus operations by way of finance to renew some elements of the WELL traction power supply system (as well as the trolleybus overhead lines owned by WCCL), it is important that these costs and the supporting analysis are fully transparent in line with Commerce Commission guidelines applying for the distribution lines assets.

10.3 GWRC funding to date

Significant public funding has already been provided by GWRC to upgrade the trolleybus overhead network in the last 5-7 years, and these costs are broadly assessed as follows;

a) 17.3km of overhead rebuilt by WCCL at $0.8M per kilometre, or $13.84M (about $14M)
b) Installation of the TBOP's to date by WCCL at $100k each, or about $1.2M
c) Some additional funding to WELL for some minor capitalised replacement of the DC traction power supply equipment (conservatively estimated at $1M[20]).

Aggregated cost - $16M

20 Amount likely to be in the range $1M to $2M

10.4 Life extension costs

The capital improvement costs that would be necessary to life extend the infrastructure assets trolleybus operations for 10-12 years past mid 2017 are broadly assessed as follows;

d) Upgrade of essential elements of the DC traction feeder system - $4.52M
e) Major and partial renewal of the trolleybus overhead lines - $7.2M
f) Installation of the remaining TBOP's - $2.2M

Aggregated cost - $14.9M (say $15M)

10.5 Costs of abandoning the trolleybus system

The cost of abandonment of the trolleybus system has the following financial implications to the various parties;

g) Write-off of the non-depreciated portion of the assessed $16M from recently replaced assets by WCCL and WELL funded by GWRC (say $10M)
h) Costs to remove the trolleybus overhead (anticipated to be in the order of $10M taking into account scrap recovery credits)
i) Write-off of the non-depreciated portion of the trolleybus vehicles by the vehicle owner (actual value unknown but expected to be a figure of the order of $14M if 50% of the purchase price is used and straight line depreciation applies)

Aggregated costs – approximately $34M (of which $20M is a charge to public entities).

10.6 Summary

The life extension costs from 10.4 above compare favourably with the costs of abandonment in 10.5 above.

11. Conclusions

An analysis of the trolleybus infrastructure system shows that life extension is possible at significantly reduced costs compared to published estimates.

It identifies key elements that should be considered for upgrade to life extend the system after mid 2017 for another 10-12 years to coincide with utilisation of the trolleybus vehicles for an expected 20 year operating life.

The analysis of the WELL traction power supply system indicates that the estimated replacement cost of about $4.5M is all that should be necessary to life extend the existing traction power supply system. An engineering testing programme of all feeder cables should be carried out to confirm the condition of each feeder cable and thus allow costs for sectionalised repairs or full replacement to be properly established to verify that the $2M allowed is adequate. The replacement of the substation DC HSB's is considered unlikely to be necessary in line with experience with other traction systems, but a specialist survey should be carried out to confirm this.

Indicative costs to carry out the partial or major renewal overhead line work is estimated at about $7.2M spread out over a number of years. In addition the installation of the remaining TBOP's is estimated to cost $2.2M.

Appendices

Appendix 1: Examples of WCC Electricity Department cable installation details (2 pages)

Appendix 2: Wellington Trolleybus Overhead Assessment dated 12 October 2015 (7 pages)

About the Author

Allan Neilson is a chartered professional engineer, a Fellow of the Institute of Professional Engineers NZ (FIPENZ) and has other professional engineering affiliations. Allan has over 40 years electrical engineering experience primarily encompassing rail infrastructure signalling and electrical installations, and including traction systems.

He was KiwiRail's "Manager Traction and Electrical" from 2007 until retirement from full time work in April 2015. This position carried nationwide technical management responsibility for the infrastructure traction and electrical assets including engineering standards and design, and also for electricity supply. He provided technical oversight for the implementation of Wellington Electrified Area (WEA) traction extensions to Waikanae and substation power enhancements to support the introduction of the new Matangi electric passenger trains, and the implementation and commissioning of the overhead and traction substation power supplies for the new Auckland 25kV AC electrification, which extended from Britomart Station south to Papakura and west to Swanson.

He also has considerable experience working alongside a number of specialist international consultants familiar with traction overhead and power systems, and is also familiar with tramway and trolleybus types of equipment through over 30 years of extensive involvement with tramway heritage engineering activities.