DOCKETED	
Docket Number:	19-ERDD-01
Project Title:	Research Idea Exchange
TN #:	226467
Document Title:	Amo kraftkabel AB, Sweden Comments Covered conductor system solution to minimize risk of fire ignition
Description:	N/A
Filer:	System
Organization:	Amo kraftkabel AB, Sweden
Submitter Role:	Applicant
Submission Date:	2/6/2019 4:02:14 AM
Docketed Date:	2/6/2019

Comment Received From: Amo kraftkabel AB, Sweden
Submitted On: 2/6/2019
Docket Number: 19-ERDD-01

Covered conductor system solution to minimize risk of fire ignition

1) Existing technologies:

We have run a similar project in Victoria, Australia, since 2015 to minimize the risk of fire ignition. As an introduction we have attached the public report from the research program performed together with the Victorian Powerline Bushfire Safety Program, PBSP.
The project in Australia was run together with our local partner Groundline Engineering. We have 25 yearsâ€™ experience of designing and producing covered conductors according to European Norm, EN50397-1. We designed a customized covered conductor solution (conductors and accessories) for the Australian climate and ambient conditions. The product was tested, risk assessed, installed and monitored within the scope of the program.
For further information please contact us and we will add more info then hopefully a meeting can be arranged.

Additional submitted attachment is included below.

Market Ready Covered Conductor Research and Development Project

September 2017

Final Report

for

Department of Environment, Land, Water and Planning (DELWP)

Document Reference	GR7272-ER-05-P
Date	28th September 2017
Revision	1.1

Groundline ENGINEERING

Document Control

Rev.	Description	Author/Editor	Reviewer	Approver
1.0 (28/09/2017)	Non-Confidential Release	D Ellis	I Flatley	I Flatley
1.1 (25/09/2018)	Fixed spelling issues	D Ellis	I Flatley	I Flatley

Non-Disclosure Notice

Acknowledgements

Groundline Australia would like to acknowledge the important contribution to the success of this project by the following people and organisations:

- Dr Joseph Brian Wareing (Ret.)
- Jesper Svensson (Amokabel)
- Fredrik Warme (Amokabel)
- Christer Ohls (Amokabel)
- Topi Virtanen (Ensto)
- Michael Meraklis (United Energy)
- Peter Livingston (United Energy)
- Dave Denny (United Energy)
- Professor Emad Gad (Swinburne University)
- Kia Rasekhi (Swinburne University)
- Dr Baraneedaran Sriskantharajah (Groundline Limited)
- Ian Flatley (Groundline Limited)
- Damian Ellis (Groundline Limited)
- Brian Hinneberg (Advice Plus)
- Jack Roughan (Fluid Limit)
- Dr Peter Haberecht

Special acknowledgment and thanks to Dr Brian Wareing who retired on the 30th September 2017 following completion of this report after over 50 years of contributions to the international electrical industry. Brian imparted considerable experience and expertise in the application of covered conductor technology of which we are particularly appreciative of and has made important contributions to the success of this project. The project group and the organisations above wish Brian all the best for his well deserved retirement.

Executive Summary

On 19th October 2016, Groundline, in conjunction with a consortia of Participating Organisations, received a Grant of $291,375 to undertake testing and trials of Covered Conductor replacement options for three existing bare wire overhead conductors. The conductors tested are nominated in the Performance Specifications of the Powerline Bushfire Safety Program (PBSP) - Research & Development (R&D) Fund, Covered Conductor Grant Program - Guidelines document. This testing and trialling is being undertaken with investment from the PBSP - R&D Fund.

Figure 1: Powerline through bushland

The objective of this project was to research and develop market ready covered conductor technology and associated hardware, accessories and installation techniques with the view to specific requirements for the Victorian Operating Environment. The Victorian Operating Environment was determined to be as follows:

- High summer temperatures (approximately 45°C maximum),
- Low overnight winter temperatures (approximately -5°C minimum),
- Very high UV exposure during summer and parts of autumn and spring months (Extreme UV exposure when considering Australian Operating Environment),
- High levels of salt spray in coastal areas,
- High contaminant levels in some built up areas,
- Conditions conducive to severe conductor vibration in some locations,
- Potential of conductor coming into contact with trees of very high hardness level for extended periods (10+ Janka hardness rating for many Victorian/Australian native species, proposed conductors have been tested against up to 4 Janka hardness species in Europe),

- High fault currents on some assets that will potentially be replaced with covered conductor,
- Need for installation and maintenance in very remote locations (minimise need for very specialised tools, equipment and skills).

In relation to the above, the objective was to prove suitability of the proposed Amokabel Covered Conductor products for use in the above described Victorian Operating Environment. This was with consideration to the intent of Australian Standards, rather than meeting all prescriptive elements of some Australian Standards. These standards may not be considered relevant or are considered outdated, in addition, conductors was assessed against other international standards that were deemed relevant to the required objective of the project. Further, the overall objective of the project was to meet Recommendation 27 of the Final Report from the 2009 Victorian Bushfires Royal Commission which states:

> *The State amend the Regulations under Victoria's Electricity Safety Act 1998 and otherwise take such steps as may be required to give effect to the following:*
>
> - *the progressive replacement of all SWER (single-wire earth return) power lines in Victoria with aerial bundled cable, underground cabling or other technology that delivers greatly reduced bushfire risk. The replacement program should be completed in the areas of highest bushfire risk within 10 years and should continue in areas of lower bushfire risk as the lines reach the end of their engineering lives*
> - *the progressive replacement of all 22-kilovolt distribution feeders with aerial bundled cable, underground ca-*

Figure 2: Covered conductor product

bling or other technology that delivers greatly reduced bushfire risk as the feeders reach the end of their engineering lives. Priority should be given to distribution feeders in the areas of highest bushfire risk.

To meet the requirements of recommendation 27, this project sought to present a viable set of Covered Conductor types and associated hardware, accessories and installation techniques for bare conductor replacement for the Victorian Operating Environment.

- Suitable mechanical, electrical and environmental testing against relevant Australian and international standard to determine suitability of proposed Amokabel Covered Conductor products,
- Install lengths of a number of Amokabel Covered Conductor types on the Victorian Electrical Network to trial Amokabel Covered Conductor products and to develop installation methods, familiarise installation crews with product and determine required hardware and accessories required for installation in the Victorian Operating Environment.
- Determine applicable retrofit options for lines currently comprising bare overhead conductor based on the three Amokabel Covered Conductor products assessed.

Figure 3: Work crew covered conductor & hardware demonstration

Following commencement of the project, the project consortia met in Melbourne to finalise the makeup of the proposed Covered Conductor products and agree on a detailed schedule of testing and trials. The consortia settled on a set of proposed Covered Conductor products which are a customisation of off the shelf products to best meet the requirements of the Victorian operating environment.

The primary outcome of this project was to prove the three Amokabel Covered Conductor products proposed as part of this project as suitable for the Victorian Operating Environment being;

- 25mm^2 Aluminium Clad Steel (ACS) Conductor (Product newly developed by Amokabel specifically for Victoria)
- 59mm^2 Aluminium Conductor Steel Reinforced Conductor (ACSR) (Amokabel off the shelf product)
- 159mm^2 All Aluminium Alloy Conductor (AAAC) (Amokabel off the shelf product)

Following on from the above outcome, to make available to the Victorian distribution industry a viable, cost effective and proven set of Amokabel Covered Conductor products for use in retrofitting to existing high risk bare overhead lines within bushfire risk areas in Victoria.

The success of the intended outcomes of this project can only be measured by the level of acceptance of the proposed Amokabel Covered Conductor products by the wider Victorian distribution industry and further measured on installed kilometres of the three proposed Amokabel Covered Conductor products and other similar covered conductor products following project completion.

This report provides results of comprehensive tests primarily undertaken in Victoria. The comprehensive schedule of testing was undertaken to relevant International and Australian/New Zealand standards to determine suitability of market ready covered conductor types nominated as replacement options for existing bare wire conductor currently being used in Victoria.

Figure 4: Amokabel covered conductor drums on stringing trailer

The testing encompassed:

- Electrical (voltage, current, resistance, current leakage, surge, and lightning strike),
- Mechanical (tension, vibration, abrasion, water penetration, and thermal),
- Exposure (UV exposure, flame and radiant heat exposure, and flora exposure).

The tests were conducted under the auspices of Professor Emad Gad, Dean of Engineering, School of Engineering at Swinburne University of Technology with support from Dr Baraneedaran Sriskantharajah firstly to relevant Australian standards. Where Australian standards were not available or were not deemed relevant to the conductor type being tested, suitable and applicable international standards were sought and applied. Where a relevant standard did not exist, an appropriate test was designed in consultation between Swinburne University and the other participating organisations to determine the suitability of the proposed covered conductor products for Victorian operating conditions.

Results from testing indicated generally that the proposed Covered Conductor products met or exceeded the requirements of applicable Australian/New Zealand and International standards. This project has focussed on the performance aspects of the proposed Covered Conductor products rather than on necessarily meeting

Figure 5: Stringing ACS covered conductor on SWER

the prescriptive and in some cases restrictive design requirements of Australian standards.

Following testing, two sites were selected for installation of trial sections of two of the proposed Covered Conductor replacement options. These sites have been selected to ensure a range of circuit types are trialled (SWER, single or three phase circuits) and considering a typical span for each conductor and circuit type within Victoria. In addition to the covered conductor products themselves, a range of covered conductor accessories were required for the design and construction of the distribution system. The construction included non-standard materials for United Energy that were assessed and in some cases tested to measure performance against Australian and International standards. The test results were vital for United Energy to assess the level of risk present when trialling the materials on a live distribution network.

These trial sites have remained energized for more than six months without fault or concern. All required clearances and power quality metrics are being maintained with no deterioration to the equipment being trialled. The sites are being monitored on an ongoing basis through analytics applied to the smart meter analytics and a more frequent inspection program.

Following completion of the trial phase of the project a final report was submitted to the Department of Environment, Land, Water and Planning for review and with a view to wider implementation of this technology within the Victorian Electrical Supply Industry.

Figure 6: Installed ACS covered conductor on SWER asset

This project has delivered a viable set of covered conductor products for the Victorian Operating Environment that far exceeds the performance and cost effectivness of any conductor that can be delivered in compliance with the current set of relevant Australian Standards.

Little has been done in the last twenty years or so to realistically improve the safety in design, installation and maintenance practices within the Victorian distribution (and wider transmission) industries despite the high risks associated with asset degradation and failure as a result of poor design, installation and maintenance practices. The result of this increases the risk of fire start from electrical assets and extended electrical supply outages. This project has demonstrated that for a relatively insignificant additional cost (long term there is expected to be a real cost saving) the use of high quality conductor, hardware and accessories and implementation of a rigorous design process and installation process to current standards and best practices, significant improvements to electrical network safety and reliability can be achieved. This project has demonstrated a viable cost efficient and rapidly deployable option to vastly improve safety of overhead lines in bushfire risk areas and is based on a three prong approach;

- Implementing sound engineering practices based on AS/NZS 7000 and other relevant international standards as part of a rigorous design process
- Use of high quality and proven (through testing and overseas experience) covered conductor products and associated hardware and accessories
- Implementation of improved installation practices through development of those processes through collaboration with conductor and hardware/accessory manufacturers, asset owners, design consultants and installation services providers.

Further improvements to the safety of electrical assets will be realised as part of this project in relation to improved inspection and maintenance practices which have been implemented as part of the wider implications of trialling the proposed Amokabel Covered Conductor products on the Victorian electricity network.

This project has demonstrated that the Amokabel Covered Conductor products offer significant cost advantages and installation efficiencies. Through the use of the Amokabel Covered Conductor products there is the opportunity to cover lengths of the existing bare distribution network many multiples over what is achievable using underground cable or other covered conductor technologies.

This project has further identified that there is a need to revise and update AS/NZS 3675 to incorporate realistic and achievable covered conductor performance requirements and to bring the standard in line with equivalent international standards. This will further assist with wider industry acceptance of the proposed Amokabel Covered Conductor products investigated as part of this project and other similar covered conductor products in general.

Figure 7: Installation crew- Cape Schanck

Groundline ENGINEERING

CONTENTS

List Of Figures

LIST OF TABLES

1 Project Background

1.1 Project Organisational Chart

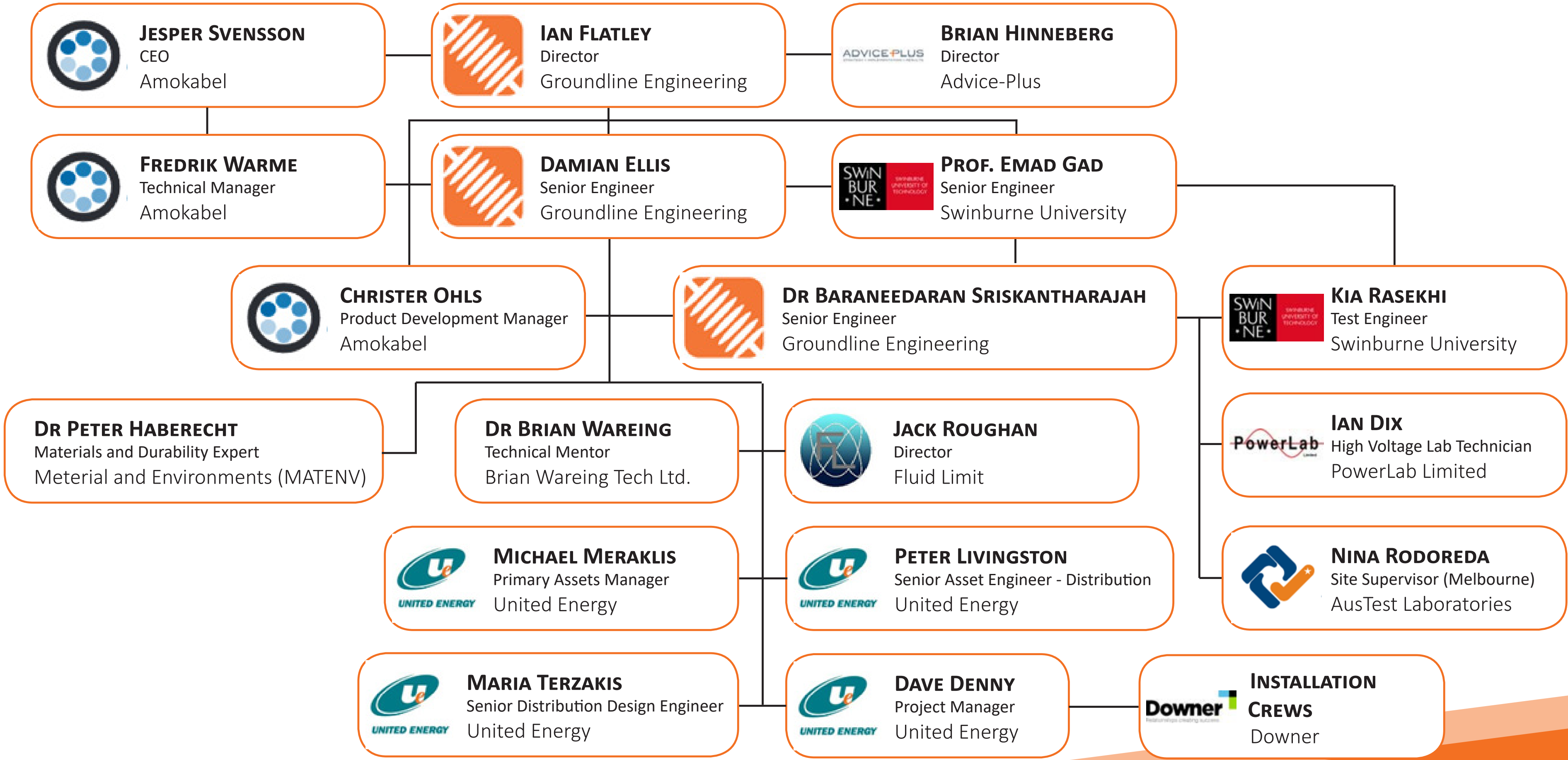

Figure 8: Project Organisational Chart

1.2 PROJECT KEY PERSONNEL

Table 1: Project Key Personnel

Organisation	Name	Role	Position
Groundline Engineering	Ian Flatley	Project Proponent / Oversight	Director
	Robert Lake	Project Oversight / Technical Advisor	Principal Lines Engineer (to end July 2017)
	Damian Ellis	Project Lead	Lead Senior Lines Engineer
	Dr Baraneedaran Sriskantharajah	Project Testing Lead	Senior Engineer (Seconded to Swinburne Uni.)
	Kellie White	Design Engineer	Lines Engineer
Advice Plus	Brian Hinneberg	Independent Project Governance	Director
amokabel	Jesper Svensson	Project Proponent	CEO
	Christer Ohls	Technical Advisor / Conductor Supplier	Product Development Manager
	Fredrik Warme	Technical Advisor	Technical Manager
Swinburne University of Technology	Professor Emad Gad	Project Proponent	Dean of School of Engineering
	Kia Rasekhi	Mechanical Testing	Test Engineer
Ensto	Topi Virtanen	Hardware/Fittings Technical Advisor	Product Manager
	Dr Joseph Brian Wareing	Technical Mentor	CEO

Table 1: Project Key Personnel

Organisation	Name	Role	Position
	Jack Roughan	Technical Advisor	Director
United Energy	Michael Meraklis	Installation and Monitoring Service Provider	Distribution Team Leader
	Peter Livingston	Technical & Installation Advisor	Senior Asset Engineer - Distribution
	Craig Savage	Project Proponent	General Manager Asset Management
	Maria Terzakis	Distribution Design Engineer	Senior Distribution Design Engineer
	Dave Denny	Installation Manager	Project Manager
	Dr Peter Haberecht	Materials Expert	

1.3 Project Collaborations

Groundline and Amokabel hold a Heads of Agreement and mutual Non Disclosure Document in which the collaborative effort of the parties is agreed and confirmed. Letters of support to Groundline from Amokabel, Swinburne University and United Energy have also been received and form the project collaboration links as described in the diagram below.

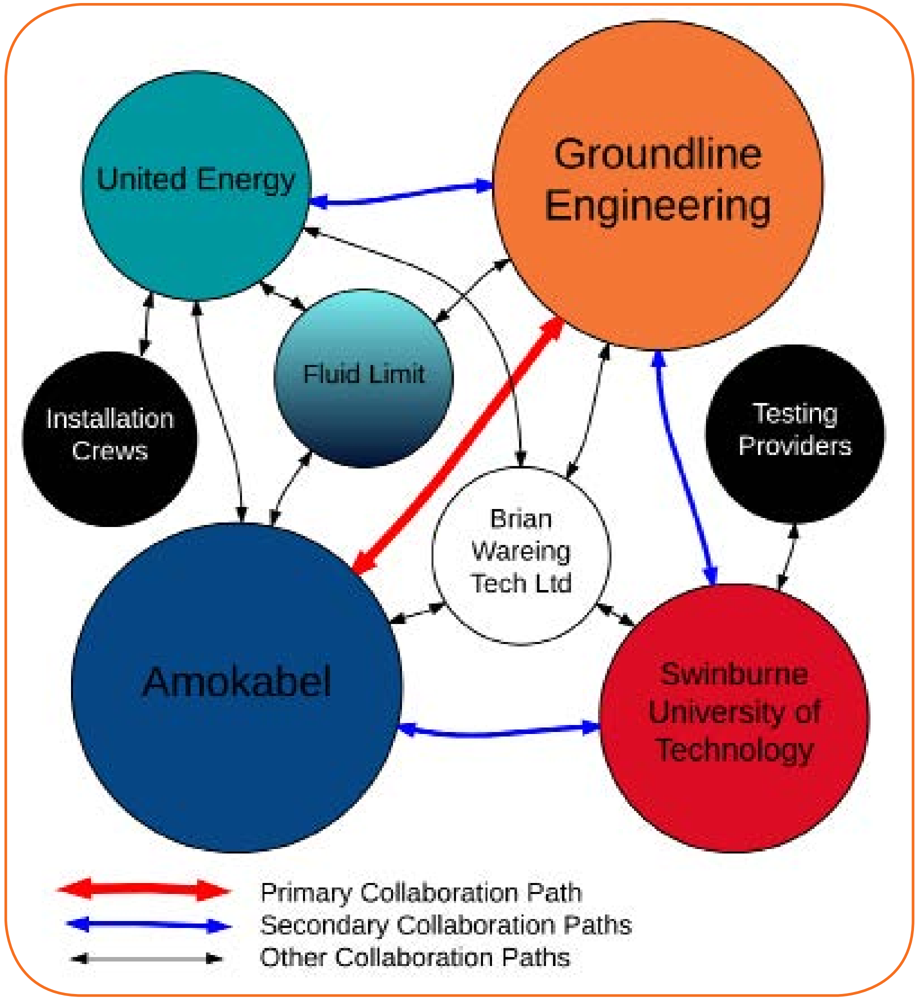

Figure 9: Collaboration Links Diagram

1.4 Amokabel Covered Conductor Technology

Amokabel has manufactured covered conductors for use, predominantly in Europe, since 1997. The main two types produced are CCSX and CCST according to European standard, EN50397-1. CCSX is an XLPE, triple layer covered conductor with a semi-conductive inner screen. The CCST is the thermoplastic version of the same type of conductor, which is 100% recyclable.

All production lines are equipped with hermetic gravimetric dosing units (airtight mass controlled polymer dosing process), to ensure that the highest quality plastic materials are blended to the highest accuracy and regularity. Both the CCST and the CCSX are triple extruded, which means that the semi-conductive, insulation and the jacketing materials are extruded in the same process to ensure 100% bonding between the layers and to prevent impurities (like dust, air, etc.) in between the layers.

The covered conductors, specially designed for Victoria utilize the best from both CCSX and CCST. The insulation is XLPE, to enable high service temperature. The outer jacket is a UV and track resistant HDPE, which has very high abrasion resistance in case a branch or other foreign object scratch the jacket. The three different conductors that are intended to be used in Victoria are of different types, the largest is a 159mm² AAAC (All Aluminium Alloy Conductor). The mid-size alternative is a 62mm² ACSR (aluminium conductor steel reinforced). Both these are intended to be used in a conventional three phase system. The smallest and most specialized conductor is a 25mm² ACS (aluminium clad steel conductor) with excellent mechanical properties. This conductor can be used in either a three phase system or as a SWER (Single Wire Earth Return) conductor.

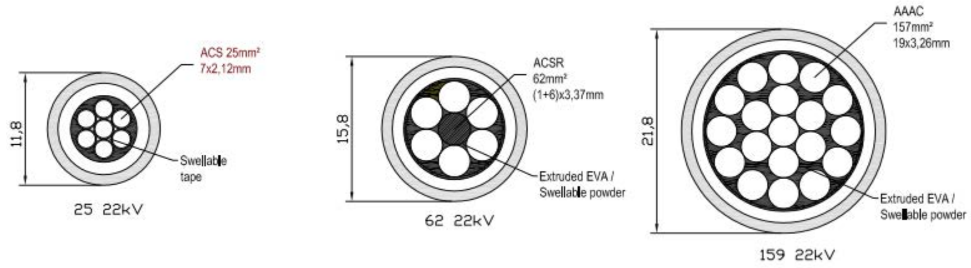

Figure 11: Amokabel Covered Conductor Cross-Section Diagrams

The design idea for the conductors proposed for Victoria has from the start been to combine well-known conductor alternatives used internationally and having a proven track record, with the design expertise of Amokabel to produce a viable set of covered conductor products for use in the Victorian environment. In particular the specially developed covered conductor option for replacing small bare steel conductor SWER and three phase circuits with a covered conductor design is unique in its design including the requisite conductor covering, improved conductivity and is very high in tensile strength, while still being based on traditional bare conductor technologies that Victorian lines crews are familiar with.

In this way the products being investigated present a user friendly, safe and more cost effective product in comparison to other recently developed overhead conductor technologies and underground cable products.

Figure 10: Amokabel Factory in Alstermo, Sweden

2 Project Commencement

2.1 Start-up Meeting (Scope Definition and Planning)

Figure 12: Project Team Photo, 9th November 2016

Following project award on the 19th October 2016 arrangements were made for representatives from all the project participants to meet in Melbourne to define the project scope and assign task responsibilities for undertaking the work required to deliver the project. This meeting occurred within three weeks of project award and involved a panel of experts from five different countries (Finland, Sweden, United Kingdom, New Zealand and Australia.) The meeting took place over two days starting 8th November 2016. The agenda for the meeting included a morning at Swinburne University Hawthorn Campus to inspect the laboratories where the testing would be undertaken, then a site visit to one of the earlier proposed trial sites near Frankston. Following this a meeting was held at United Energy's offices in Glen Waverley involving additional personnel from United Energy. For the following day further meetings were held at Swinburne University to agree on the conductor testing requirements.

3 Testing Preparations

Early test preparations commenced immediately after grant award, with the seeking of commercial test facilities for electrical and environmental testing that could not be undertaken with the equipment and expertise available at Swinburne University. Planning also commenced as to how Swinburne University would undertake the mechanical testing component of the project. Below is a description of the planning and intent of each form of testing undertaken on the three covered conductor types.

3.1 Electrical Testing

Initially the consortia approached suitably accredited electrical testing labs both in Victoria (including a small lab in Bendigo), and interstate. However due to limited capabilities to complete the testing in the required time to meet project time-lines, or due to a lack of interest in completing the testing, the Project Management Team were forced to look outside of Victoria to find an interested lab with suitable capabilities to complete the schedule of testing required.

The Project Management Team approached PowerLab in Christchurch, New Zealand, where Groundline has an office. PowerLab confirmed that they had the technical expertise and capability to meet the project requirements and time-frames. Electrical testing was therefore undertaken at PowerLab Limited (http://www.powerlab.co.nz/).

Electrical testing was undertaken to Australian/New Zealand Standard AS/NZS 3675-2002 - Conductors - Covered Overhead - For working voltages 6.35/11 (12) kV up to and including 19/33 (36) kV. It is noted that a number of requirements of this standard are either outdated or excessively stringent based on comparable international standards and test methods. These matters are detailed below under the relevant test descriptions.

3.1.1 Resistivity Testing

Resistivity testing was undertaken on the three conductive strand types that make up the three Covered Conductor products being investigated by this project. Testing was based on that as specified in AS 1531-1991 - Conductors - Bare overhead - Aluminium and alu-

TABLE 3.1

TESTS ON COVERED CONDUCTORS—PASS CRITERIA, CATEGORY AND REFERENCE

Test	Pass criteria	Category	Reference for test method
1 Tests on wire before stranding (a) Wire diameter (b) Ultimate tensile stress test (c) Wrapping test (d) Resistivity test	As specified in AS 1531		
2 Tests on covering material			
2.1 Tests on X-90 All appropriate tests on covering taken from or measured on a completed covered conductor	As specified in AS/NZS 3808		
2.2 Tests on HDPE (a) All appropriate tests on covering taken from or measured on a completed covered conductor	As specified in AS/NZS 3808		
(b) Carbon black dispersion	<5	Type	AS/NZS 1660.2.4
3 Tests on completed covered conductor			
(a) Interstrand conductivity test			
(i) Resistance when connected to outer layer	Not more than 1.02 times the calculated conductor resistance in AS 1531	Routine	Appendix C
(ii) Resistance when connected to a single wire	Not more than 1.02 times 3(a)(i)	Routine	Appendix C
(b) Thickness of covering		Sample	AS/NZS 1660.2.1
(not measured at location of embossing) Minimum average (mm) Minimum at any point (mm) Maximum at any point (mm)	See Table 2.1 or 2.2 as appropriate		
(c) Static water blocking test	Water penetration <2.0 mm	Sample	Appendix D
(d) Dynamic water blocking test	Water penetration <2.0 mm	Type	Appendix E
(e) Stripping test	No water blocking compound left on the contact surface of conductor	Sample	Appendix F
(f) Adhesion test	No failures listed in Paragraph G6(a), (b), (c) or (d) shall occur	Type	Appendix G
(g) Spark test	No breakdown	Routine	AS/NZS 1660.3
(h) UV weathering test	V ≥0.8	Type	Appendix H
(i) Dripping test	No dripping of blocking compound into tray	Type	Appendix I
(j) High voltage a.c. test for 4h	No breakdown (CC shall be tested at 22 kV)	Type	AS/NZS 1660.3

Figure 13: Excerpt from AS/NZS 3675-2002- Testing Requirements

minium alloy. This is referenced in Table 3.1 of AS/NZS 3675-2002.

3.1.2 Inter-strand Conductivity Testing

Inter-strand conductivity testing was undertaken on the three covered conductor products being investigated as part of this project. Testing was based on that specified in AS/NZS 3675-2002 Appendix C.

3.1.3 Static And Dynamic Water Blocking Testing

Static Water Blocking testing was undertaken on the 7/2.12 ACS and 19/3.26 AAAC covered conductors (smallest and largest cross section) based on AS/NZS 3675-2002 Appendix D requirements. It was decided that testing the largest and smallest cross section of conductor would provide an indicative performance for all covered conductor sizes and limit the time required to complete the testing.

It is considered that the pass criteria in AS/NZS 3675-2002 for both static and dynamic water blocking testing is overly stringent and well beyond the requirements of similar international standards. It is commonly acknowledged that it is very difficult to produce a conductor that is capable of meeting this requirement, and attempting to do so introduces other integrity issues with the conductor which are of a greater concern than the water blocking performance. This is noted in a 2006 paper by Sebire and Souprounovich for the Australian Strategic Technology Programme entitled, "Covered Conductors System for Distribution - Stage 2: High Voltage Covered Conductor from an Australian Perspective". The authors stated that "the onerous water blocking requirement in AS/NZS 3675 produces a conductor covering which is eccentric. The standard also has no test for covering hardness. These result in a conductor that is difficult to use. This standard needs revision."

Issues were experienced by PowerLab in preparing for this test due in part to the misleading apparatus listing in AS/NZS 3675-2002 Appendix D, specifically the requirement for the source of UV light to be at a wavelength of 254 nanometres. Operation of this form of light source presents a number of safety concerns particularly around use as an inspection light source. Through researching the specific requirements for the fluorescein sodium salt solution called for in the standard, it was concluded that a basic black-light was all that was required as a UV light source for this testing.

Further issues with the availability of the fluorescein sodium salt solution delayed preparations for this testing. The chemical was not available anywhere in New Zealand and needed to be imported into the country. The chemical was received by the lab on the 7th April and testing immediately commenced.

Dynamic Water Blocking testing was not completed. In consultation with Swinburne University and PowerLab it was decided to not progress with the Dynamic Water Blocking testing, on the basis that the conductors were already expected to fail the static water blocking test based on AS/NZS 3675-2002 requirements. There was therefore little additional knowledge to be gained from the more severe Dynamic Water Blocking test.

3.1.4 Spark Testing

Spark testing was undertaken on the smallest of the three covered conductor products being investigated as part of this project. Testing was performed on one size of conductor as the test is intended to determine conductor covering performance only. Given all three covered conductor products have the same covering, results from one type of conductor is considered reflective of the performance of all conductors being investigated. Testing was based on that specified in AS 1660.3-1998 - Test methods for electric cables, cords and conductors - Method 3: Electrical tests. Which is referenced in Table 3.1 of AS/NZS 3675-2002.

3.1.5 Four-Hour High Voltage Testing

Four-Hour High Voltage testing was undertaken on the smallest of the three covered conductor products being investigated as part of this project. Testing was based on that specified in AS 1660.3-1998 - Test methods for electric cables, cords and conductors - Method 3: Electrical tests. Which is referenced in Table 3.1 of AS/NZS 3675-2002.

3.1.6 Insulation Resistance Testing

Insulation Resistance testing was undertaken on the smallest of the three covered conductor products being investigated as part of this project. Testing was based on that specified in AS/NZS 3808-2000 - Insulating and sheathing materials for electric cables, which is referenced in Table 3.1

of AS/NZS 3675-2002.

3.1.7 Leakage Current Testing

Leakage Current testing was undertaken as an additional important test of the conductor covering performance not included in the nominated tests within AS/NZS 3675-2002. Testing was completed based on EN 50397-1-2006 - Covered conductors for overhead lines and the related accessories for rated voltages above 1 kV a.c. and not exceeding 36 kV a.c. - Part 1: Covered Conductors. Leakage currents pose a risk to both objects and people coming in contact with the covered conductor and to a less extent risk of fire start from contact with flammable objects.

3.2 Mechanical Testing

Mechanical testing was predominantly undertaken at the Hawthorn campus of Swinburne University of Technology in Melbourne. Due to the length of the area required by the test bed for the vibration testing, this testing was instead facilitated at Swinburne's Croydon campus.

Mechanical testing was based on Australian/New Zealand Standard AS/NZS 3675-2002 - Conductors - Covered Overhead - For working voltages 6.35/11 (12) kV up to and including 19/33 (36) kV. It was noted that a number of requirements of this standard are either outdated or excessively stringent based on comparable international standards and test methods. These matters are detailed below under the relevant test descriptions.

3.2.1 Adhesion Testing

Adhesion testing was undertaken on the 7/2.12 ACS and 19/3.26 AAAC covered conductor products being investigated as part of this project. It was decided that testing the largest and smallest cross sections of conductor would provide indicative performance for all covered conductor sizes and limit the time required to complete testing. Testing was based on the requirements specified in Appendix G of AS/NZS 3675-2002.

3.2.2 Dripping Testing

Dripping testing was undertaken on all three of the covered conductor products being investigated as part of this project. Testing was based on the requirements specified in Appendix I of AS/NZS 3675-2002.

3.2.3 Conductor Strand Testing

Conductor Strand testing was undertaken on all three of the covered conductor products being investigated as part of this project. Note that individual tests were undertaken on both the aluminium and steel stranding found within the ACSR 62mm2 covered conductor specimen. Wire diameter testing was based on section 4.2 in AS 1531-1991 - Conductors - Bare overhead - Aluminium and aluminium alloy. Ultimate Tensile Stress testing was based on the method provided in AS 1391-2007 - Metallic materials - Tensile testing at ambient temperature, where the results were analysed against the results provided in Tables 2.2, 2.3, and 2.4. Percentage Elongation testing was based on the method provided in AS 1391-2007 where results were analysed against the values provided in Table 4.2. Wrapping testing was based on AS 2505.5-2002 - Metallic materials - Wire - Simple torsion test, where the results were analysed against the acceptance criteria in Table 4.3.

3.2.4 Stripping Testing

Stripping testing was undertaken on all three of the covered conductor products being investigated as part of this project. Testing was based on the requirements specified in Appendix F of AS/NZS 3675-2002.

3.2.5 Vibration Testing

Vibration testing was undertaken on the 7/2.12 ACS and 19/3.26 AAAC covered conductor products being investigated as part of this project. It was decided that testing the largest and smallest cross sections of conductor would provide indicative performance for all covered conductor sizes and limit the time required to complete testing. Testing was based on AS 1154.1-2009 - Insulator and conductor fittings for overhead power lines - Performance, material, general requirements and dimensions and EN 62567-2013 - Overhead lines - Methods for testing self-damping characteristics of conductors.

Issues were experienced in preparing for this test due to the minimum span length required for this test. The Hawthorn campus of Swinburne University could not provide for the desired 30m span length, as such alternative locations were sought and their Croydon campus was selected.

In addition to determining exact test requirements from applicable standards, the rigging machine and test beds needed to be assembled before testing could commence.

Vibration testing was conducted to evaluate the conductor self-damping physical characteristic. The self-damping characteristic defines the conductor's capacity to dissipate energy internally when subjected to vibration. For conventional stranded conductors, energy dissipation can be attributed partly to inelastic effects within the body of the wires but mostly to frictional damping, due to small relative movements between overlapping individual wires, as the conductor flexes with the vibration wave shape.

The following standards and documents are used to find the non-dimensional viscous damping coefficient of a conductor:

- AS 1154.1-2009 Insulator and conductor fittings for overhead power lines - Performance, material, general requirements and dimensions
- EN62567 Overhead Lines - Methods for testing self-damping characteristics of conductors
- CIGRE: TF22.11.2 - Guide to vibration measurements on overhead lines
- There are three prescribed ways to determine the self-damping characteristics of conductors. These are:
  - » Power method: Determines the dissipation characteristics of a conductor by the measurement of the force and the vibration level imparted to the test span at the point of attachment to the shaker.
  - » ISWR method: Determines the power dissipation characteristics of a conductor by measurement of nodal and anti-nodal amplitudes on the span at each tunable harmonic.
  - » Decay method: Determines the power dissipation characteristics of a conductor by the measurement of the decay rate of the

amplitude of motion of a span following a period of forced vibration at a natural frequency and fixed amplitude.

The Power Method was adopted to evaluate the self-damping characteristic due to the anticipated cable properties, available time for testing the cable samples and simple data collection and processing function.

3.2.6 Bending Testing At Low Temperature

Bending testing was undertaken on the 7/2.12 ACS type covered conductor only. As per AS/NZS 3675-2002 this is the only conductor that required testing based on a maximum diameter of 12.5mm for this type of testing. Testing was based on the requirements specified in Section 2.3 of AS/NZS 3675-2002.

A suitable testing rig was required to be fabricated in order to undertake this testing. The test rig was fabricated based on the requirements and diagrams provided in the above referenced standard.

3.3 Environmental Testing

3.3.1 Abrasion Testing

A specific test setup had to be created for this test. In this setup, representative timber segments were attached to an actuator which moved them in a linear manner (back and forth) while they are in contact with the covered conductors. This creates rubbing effects which could result from tree branches bearing against conductors. The test apparatus is shown below.

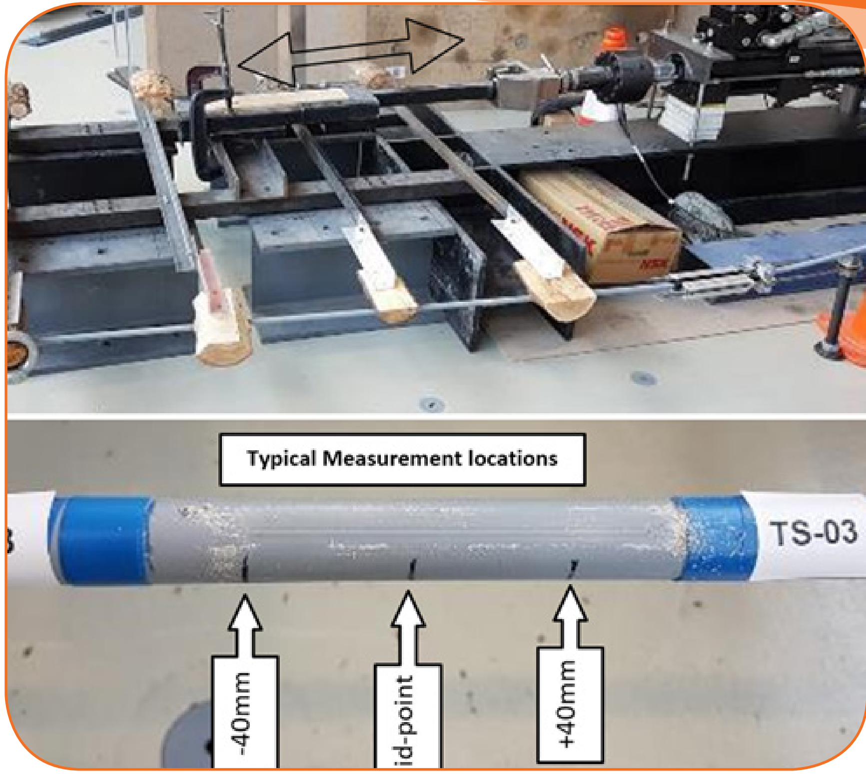

Figure 14: Abrasion test setup showing typical test specimen with locations of measurement of diameters during testing

3.3.2 UV/Weathering Testing

UV/Weathering testing was undertaken based on an alternative method to that specified in AS/NZS 3675-2002 Appendix H. Analysis of the testing method specified in AS/NZS 3765, which refers to ASTM G155-Cycle 1 method and the associated intent of this testing method revealed that it was not an appropriate test when considering the deterioration of the mechanical properties of the cover is the primary intent of this testing. ASTM G155 is primarily aimed at determining the aesthetic deterioration of paint, coating materials and plastic objects that will be exposed to sunlight. It was decided that a more appropriate testing method would be used based on ASTM G154-Cycle 4. This test method exposes objects under test to a very close approximation of sunlight across wavelengths that are most damaging to polyethylene based plastics at an intensity of approximately twice that of direct sunlight under worst case conditions. The test also requires exposure cycling of objects under test based on eight

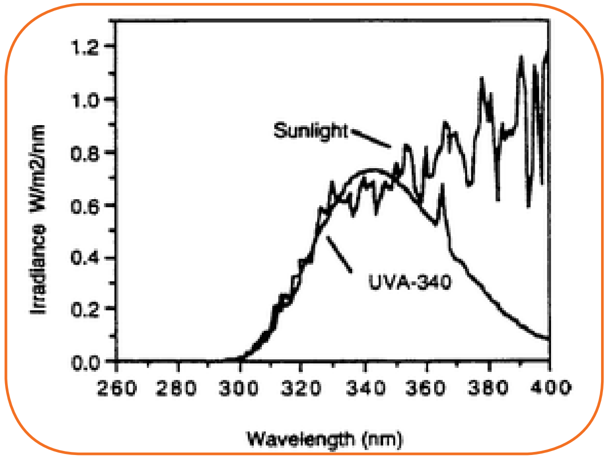

Figure 15: Spectral power distribution of UVA-340 lamp and sunlight

hours of UV exposure at 70°C then four hours of exposure to condensation (without UV exposure) at 50°C.

Testing to ASTM G154 is typically undertaken with an exposure time of 1000 hours, although 500 hours and 2000 hours are also common. Given conductor coverings are designed to perform extremely well under UV/weathering exposure, it was decided to undertake testing over a period of 2000 hours. Samples were taken after exposure periods of 100, 200, 500, 700, 1000, 1500, and 2000 hours to determine deterioration trends of the materials under test.

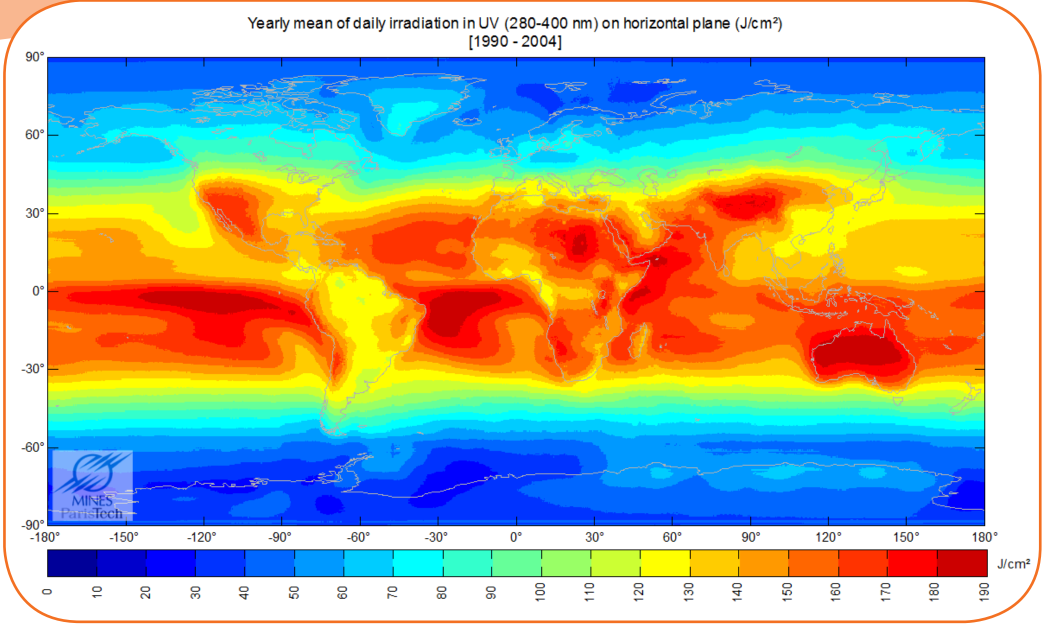

Figure 16: Yearly mean of daily UV irradiation

In addition to the HDPE/XLPE hybrid conductor covering under investigation, samples of XLPE/XLPE covering, the covering material used in High Voltage Aerial Bundled Cable, and samples of basic non-UV stabilised ABS material. The two additional conductor covering materials are intended for comparison with the HDPE/XLPE hybrid conductor covering material under test and the non-UV stabilised ABS material is intended for a comparison with material that is not UV stabilised and expected to deteriorate rapidly under the above specified test conditions.

Figure 17: UV Testing Specimen Plate

4 Testing Results

4.1 Electrical Testing

This consisted of a relevant range of tests as per the Australian Standard requirements.

4.1.1 Resistivity Testing

Resistivity testing was undertaken on all three covered conductor types to determine resistivity of each covered conductor. Based on these resistivity results, the three covered conductor types have calculated resistances of:

- 7/2.12 ACS - 3.1 Ω/km,
- 1/6/3.37 ACSR - 0.45 Ω/km, and
- 19/3.26 AAAC - 0.19 Ω/km.

These resistances are comparable to similar sized and construction bare conductor types.

Table 2: Resistivity Testing Summary Results

Sample	Result	Comment
7/2.12 ACS	0.0769 μΩ.m	No relevant limit
1/6/3.37 ACSR	0.0285 μΩ.m	No relevant limit
19/3.26 AAAC	0.0295 μΩ.m	No relevant limit

4.1.2 Inter-strand Conductivity Testing

Inter-strand conductivity testing was undertaken using two test methods. The first test measured inter-strand conductivity when connected to the outer layer of conductor strands. Pass requirement for this test was a resistance reading not more than 1.02 times the calculated conductor resistance. Results are as follows:

The second test measured inter-strand conductivity when connected to a single strand. Pass requirement for this test was a resistance reading not more than 1.02 times the result of the first test. Results are as follows:

These same conductors readily pass the individual strand tests when tested using the European method.

Subsequent discussions on this testing noted that the test setup was not as per typical European testing. However, as the full conductor test was a pass, the fail for the individual strands is less significant.

The requirement for this form of testing is as a direct result of the stringent water blocking requirement of AS/NZS 3675, which are far in excess of any other equivalent international standard. This conductor does not conform to the stringent water blocking requirements of AS/NZS 3675 (see below) and conductor strands are not pressed together in an attempt to meet the inter-strand conductivity requirements, as this results in other detrimental effects to the finished conductor. Refer to paper “Covered Conductor Systems for Distribution” by Sebire and Souprounovich (2006) for further background information.

Table 3: Interstrand Conductivity Testing Summary Results (Outer Strands)

Sample	Result
7/2.12 ACS	Pass
1/6/3.37 ACSR	Pass
19/3.26 AAAC	Pass

Table 4: Interstrand Conductivity Testing Summary Results (One Strand)

Sample	Result
7/2.12 ACS	Fail (22% above minimum)
1/6/3.37 ACSR	Fail (22% above minimum)
19/3.26 AAAC	Fail (41% above minimum)

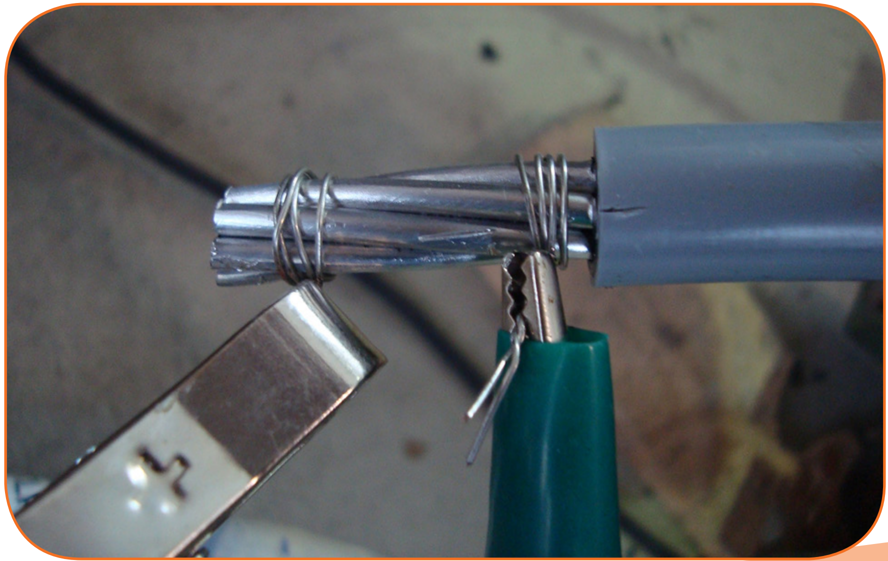

Figure 18: Interstrand Conductivity Test Setup

4.1.3 Static And Dynamic Water Blocking Testing

Static water blocking testing was undertaken as per the requirements of AS/NZS 3675-2002 Appendix D on both the 7/2.12 ACS and 19/3.26 AAAC conductors. As expected and briefly discussed above, both conductor types failed to meet the requirements of AS/NZS 3675-2002. It was decided to not progress with Dynamic Water Blocking Testing as per that specified in AS/NZS 3675-2002 as it was deemed that no additional information would be obtained from such a test over the Static Water Blocking Testing as performed.

Table 5: Static Water Blocking Testing Results Summary

Sample	Result (Limit)
7/2.12 ACS	Fail
19/3.26 AAAC	Fail

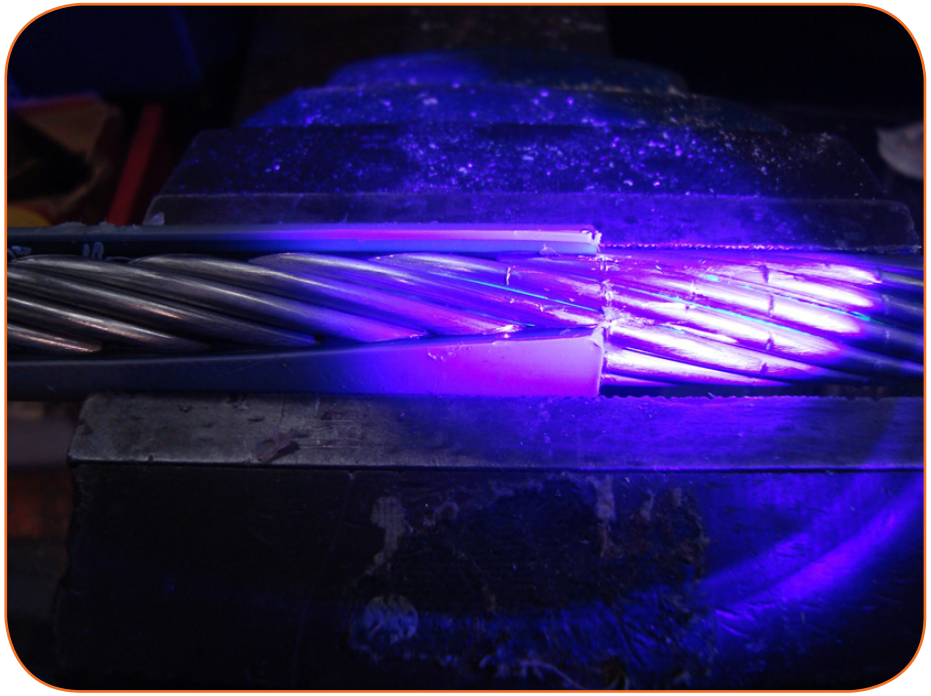

Figure 19: Typical View During Water Blocking Testing

The stringent water blocking requirement of AS/NZS 3675, which are far in excess of any other equivalent international standard, make it impractical to produce a conductor that meets this requirement as adding the excess of water blocking material required to meet this requirement has other detrimental effects on the conductor. These conductors pass the water blocking requirements of equivalent European standards which specify a maximum water penetration of one metre (compared to the AS/NZS 3675 requirement of 2mm). Refer to paper “Covered Conductor Systems for Distribution” by Sebire and Souprounovich (2006) for further background information.

AS/NZS 3675 was developed at a time when it was common practice to strip the outer layers of conductor off to make mechanical and electrical connections. The use of more recently developed water tight Insulation Piercing Connectors (IPCs) effectively negates the need for such stringent water blocking requirements.

4.1.4 Spark Testing

Spark testing was undertaken to a DC voltage of 38 kV as per AS/NZS 1660.3 requirements. This voltage was applied to a 10m length of the 7/2.12 ACS conductor. As this test is a test of the performance of the conductor covering materials only one conductor required testing, as the covering material is the same for all covered conductors under investigation.

Table 6: Spark Testing Result

Sample	Result
7/2.12 ACS	Pass - No breakdown of covering material

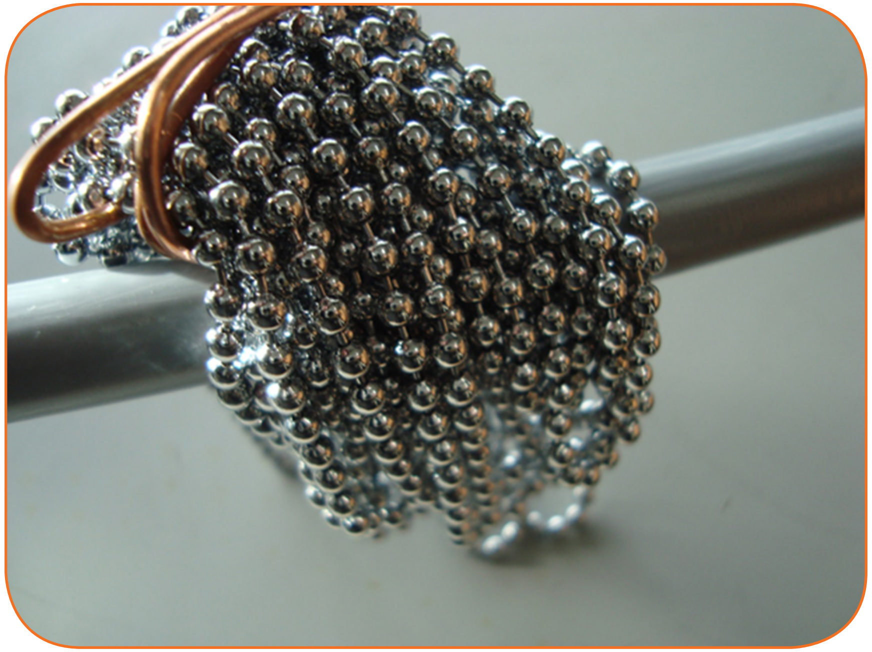

Figure 20: Spark Test Typical Setup

4.1.5 Four-Hour High Voltage Testing

Four-Hour high voltage testing was undertaken based on the requirements of AS/NZS 1660.3 for cables rated between 0.6/1 kV and 19/33 kV. A five meter length of 7/2.12 ACS conductor was immersed in water at ambient temperature for twelve hours. A voltage was then applied between the conductor and water and gradually increased to 22 kV and held at that voltage for four hours. As this test is a test of the performance of the conductor covering materials only one conductor required testing, as the covering material is the same for all covered conductors under investigation.

Table 7: Four-Hour High Voltage Testing Result

Sample	Result
7/2.12 ACS	Pass - No breakdown of covering material

Insulation Resistance Testing

Insulation resistance testing was undertaken based on limits specified in AS/NZS 3808 Table 9 under the two conditions specified in the standard. One being the insulation resistance at 20 °C and the other being the insulation resistance at 90 °C. Both tests were performed on the 7/2.12 ACS type conductor. Results are as follows:

Table 8: Insulation Resistance Testing Results Summary

Test Temperature	Result (Limit)
20 °C	Pass
90 °C	Pass

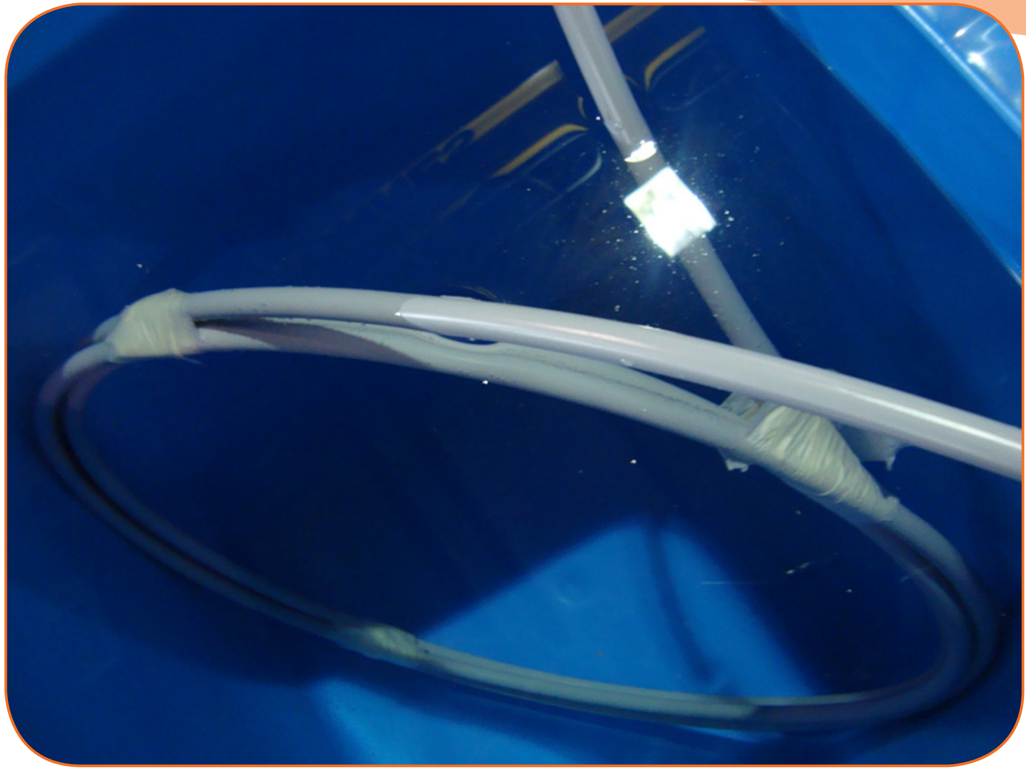

Figure 21: Four-Hour High Voltage Testing Typical Setup

4.1.6 Leakage Current Testing

Leakage current testing was undertaken to EN 50397-1 for all three conductor types. The test involved wrapping a copper wire (the electrode) around each conductor type for a width of 100mm, applying a voltage of 15.4kV to the conductor and measuring the current leaking to ground through the electrode. Results are as follows:

Table 9: Leakage Current Testing Results Summary

Sample	Result
7/2.12 ACS	Pass
1/6/3.37 ACSR	Pass
19/3.26 AAAC	Pass

4.2 Mechanical Testing

This consisted of a relevant range of tests as per the Australian Standard requirements. Where no Australian Standard was applicable, tests as part of relevant International standards or internationally recognised test methods were used.

4.2.1 Adhesion Testing

The tension was applied steadily increasing it over a period of one minute up to 21% of the calculated breaking load of the conductor and maintaining this tension for a further 10 minutes as per the requirements of AS/NZS 3675-2002 Appendix G. The change in distance between various reference marks were then measured to determine changes and recorded as per the above referenced standard.

Table 10: Adhesion Testing Summary Results

Sample	Result
7/2.12 ACS	Fail (Reached >90% of test load)
19/3.26 AAAC	Pass

The 'Fail' result of the 7/2.12 ACS conductor type is predominantly due to the very high tensile strength of the ACS material in comparison to the covering material and the prescriptive requirements for a pass result within AS/NZS 3675-2002 Appendix G. As a result of this test fail, only compression dead ends (tags/lugs) will be used for the 7/2.12 ACS conductor option.

4.2.2 Dripping Testing

In accordance with AS/NZS 3675-2002 Appendix I, the temperature inside an oven was held at 100°C and two samples each of all three conductor types were prepared and placed in the oven with a metal tray positioned under the samples in such a way that any dripping or oozing water blocking compound is caught in the tray. The samples were left in the oven for a period of 24 hours, at the end of this period the samples were removed and the samples and tray were inspected for the presence of any water blocking compound drips or oozing.

Table 11: Dripping Testing

Sample	Comment
7/2.12 ACS	Pass
1/6/3.37 ACSR	Pass
19/3.26 AAAC	Pass

4.2.3 Conductor Strand Testing

Testing below was based on the requirements of AS 1531-1991 Section 4.2.

4.2.3.1 Wire Diameter

The diameter of the wire was measured and recorded.

4.2.3.2 Ultimate Tensile Stress Test

The ultimate tensile stress was calculated on the basis of the original cross-sectional area of the wire before testing.

Figure 22: Dripping Test Setup

Table 12: Wire Diameter Results Summary

Sample	Result
7/2.12 ACS	Pass
1/6/3.37 ACSR	Pass
19/3.26 AAAC	Pass

Table 13: Ultimate Tensile Stress Summary

Sample	Result
7/2.12 ACS	Pass
1/6/3.37 ACSR (Steel)	Pass
1/6/3.37 ACSR (Al)	Pass
19/3.26 AAAC	Pass

4.2.3.3 Percentage Elongation Test

The elongation of each sample for a gauge length of 250 mm, was not less than the appropriate values given in the standards.

Figure 23: Typical Strand Tensile Testing Setup

Table 14: Percentage Elongation Test Summary

Sample	Average Result
7/2.12 ACS	No test requirement in AS/NZS 3675
1/6/3.37 ACSR (Steel)	No test requirement in AS/NZS 3675
1/6/3.37 ACSR (Al)	Pass > 1.2%
19/3.26 AAAC	Pass > 1.2%

4.2.3.4 Wrapping Test

Each test specimen was wrapped around a wire of its own diameter to form a close helix of eight turns. Following this, the strands are inspected for any surface fractures. Strands also may not break during testing.

Table 15: Wrapping Test Summary

Sample	Comment
7/2.12 ACS	Pass
1/6/3.37 ACSR (Steel)	Pass
1/6/3.37 ACSR (Al)	Pass
19/3.26 AAAC	Pass

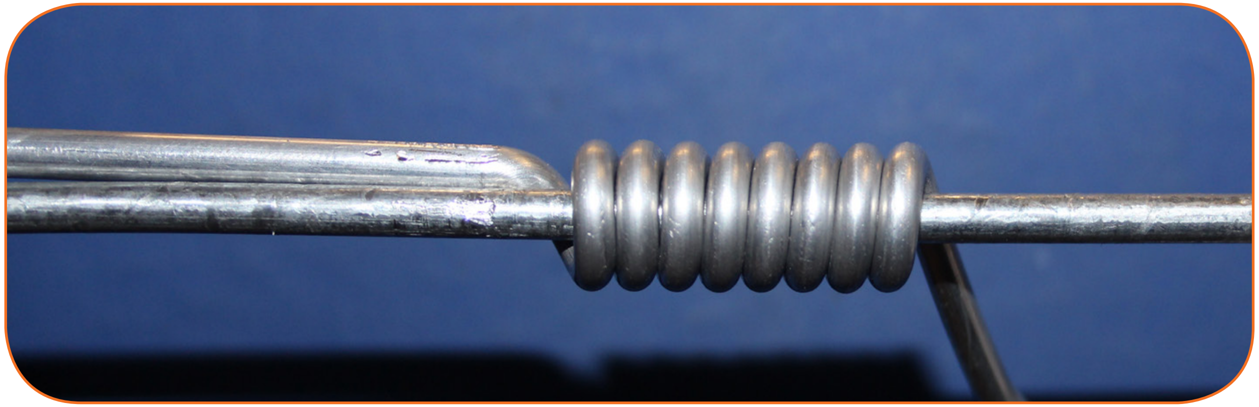

Figure 24: Strand Wrapping Test Example

4.2.4 Stripping Testing

As per the requirements of AS/NZS 3675-2002 Appendix F, at the completion of the removal of the covering, the surface of the exposed conductor was examined and noted for any water blocking material remaining within or on the wires of the conductor.

Table 16: Stripping Test Result Summary

Sample	Comment
7/2.12 ACS	Pass
1/6/3.37 ACSR	Pass
19/3.26 AAAC	Pass

Figure 25: Stripping Test Example

4.2.5 Vibration Testing

A schematic diagram of the test bed is shown below, as well as the actual test setup, in the following figures. The supports, fixtures and instruments are chosen to meet the requirements of the standards.

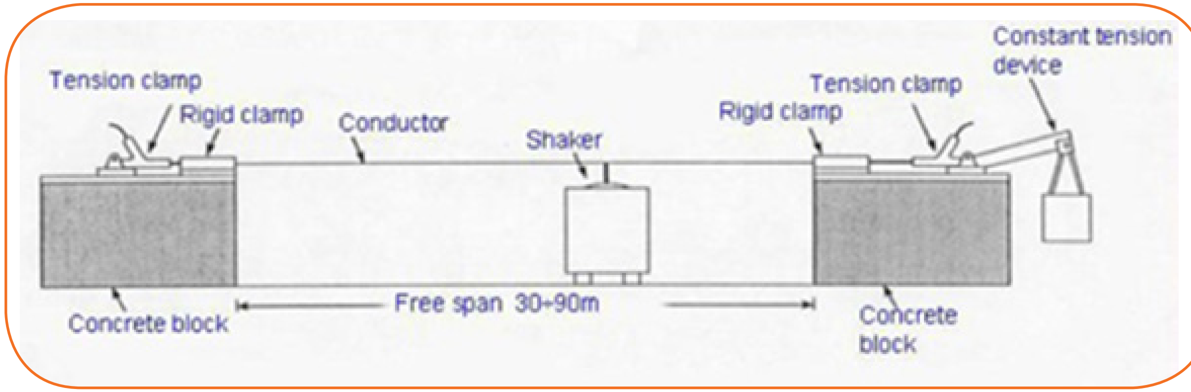

Figure 26: Test span for conductor self-damping measurement

Figure 27: Test Span for Conductor Self-damping Testing

The test procedure used to evaluate the conductor self-damping coefficient (power method) is as follows:

1. Establish span resonance beginning at the first tunable harmonic within the prescribed frequency range (minimum of ten loops).
2. Measure and record the vibration frequency.
3. Locate a mid-span anti-node.
4. Adjust the anti-nodal amplitude to the prescribed level and record this value.
5. Record the input force and displacement and their phase angle differential at the driving point.
6. Measure and record the free loop length.
7. Proceed to the next tunable harmonic frequency.
8. Continue this procedure until the upper end of the required frequency range are reached.

Following capture of all required data, an analysis is undertaken to determine the self-dampening characteristics of the conductors under test. From this analysis the following results were obtained:

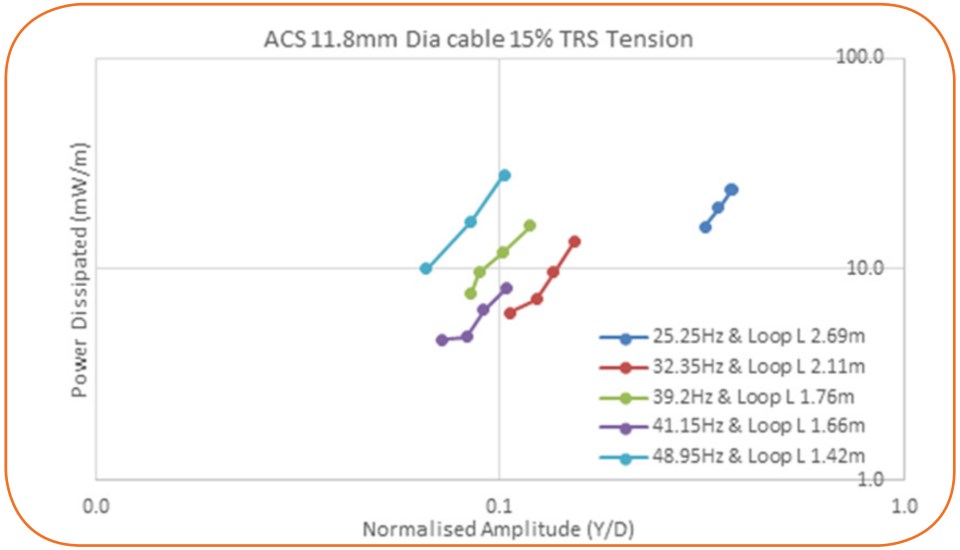

Figure 28: 7/2.12 ACS Vibration Testing Result at 15% UTS Tension

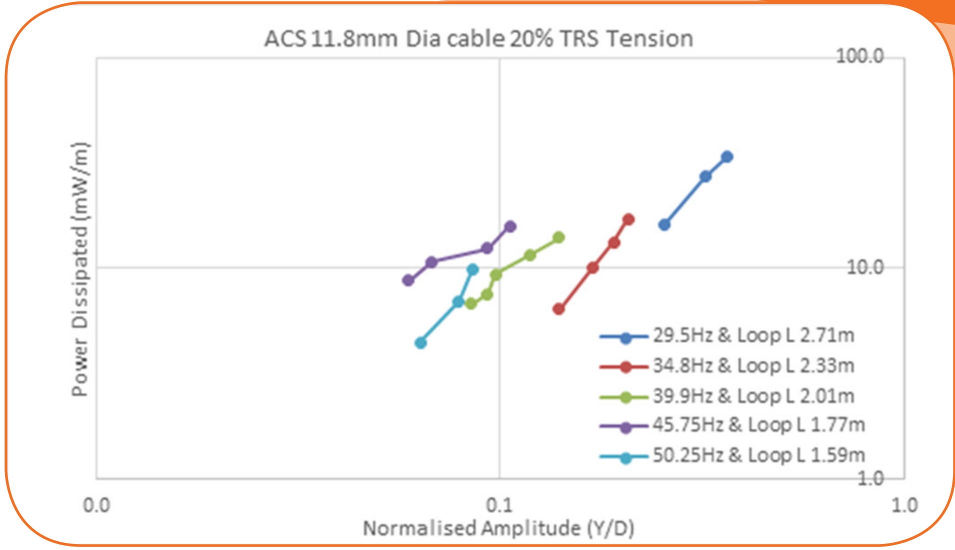

Figure 29: 7/2.12 ACS Vibration Testing Result at 20% UTS Tension

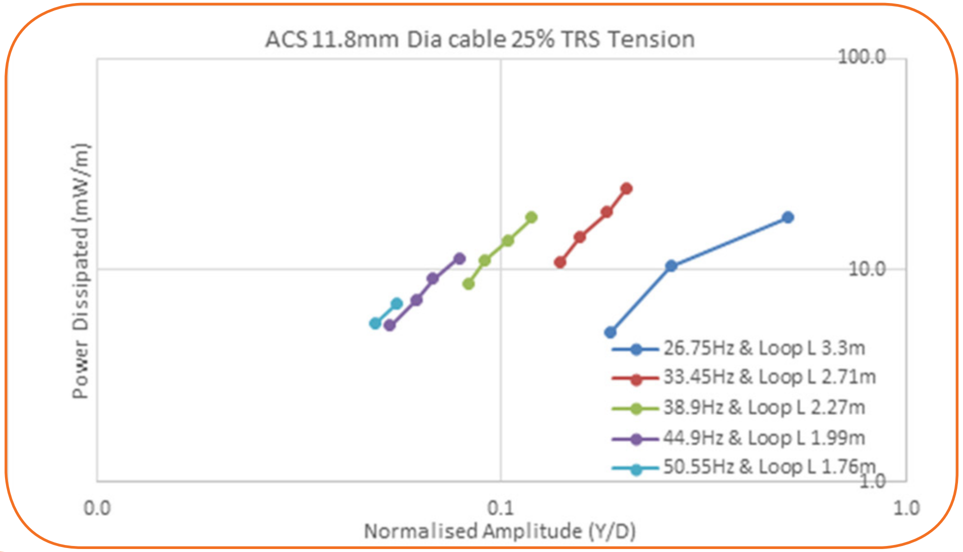

Figure 30: 7/2.12 ACS Vibration Testing Result at 25% UTS Tension

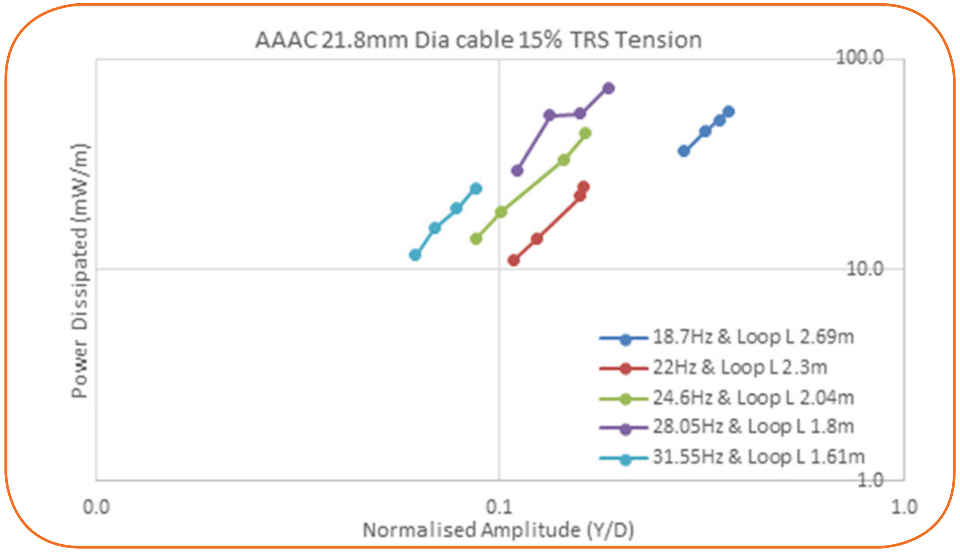

Figure 31: 19/3.37 AAAC Vibration Testing Result at 15% UTS Tension

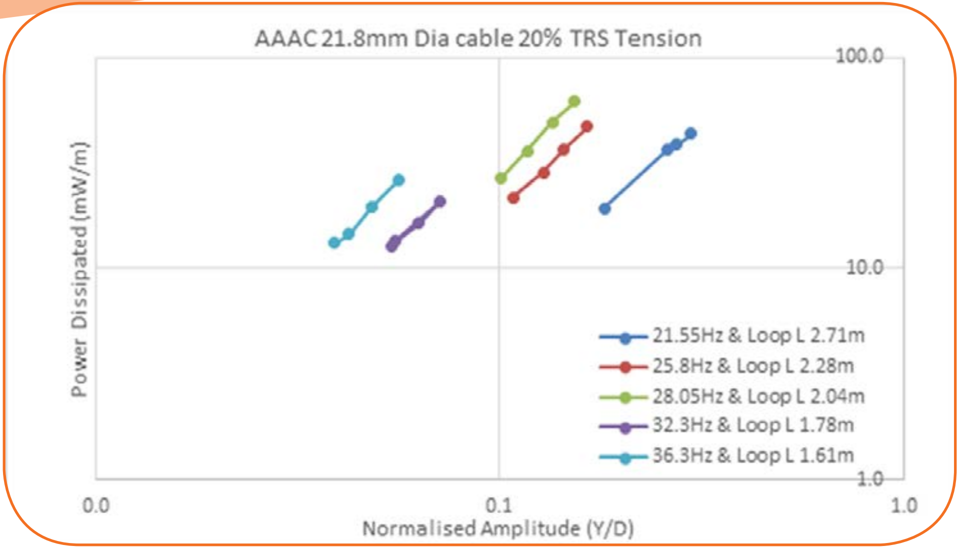

Figure 32: 19/3.37 AAAC Vibration Testing Result at 20% UTS Tension

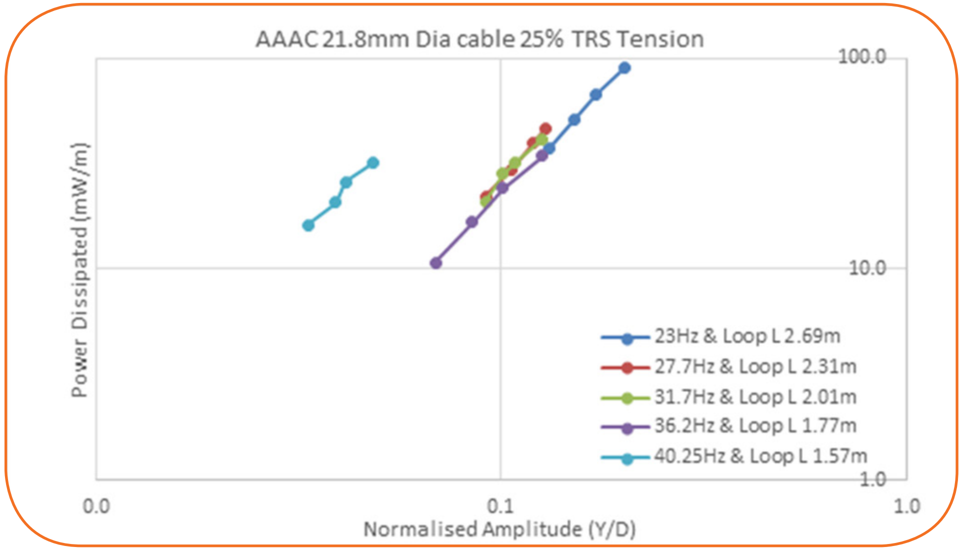

Figure 33: 19/3.37 AAAC Vibration Testing Result at 25% UTS Tension

4.2.6 Bending Test At Low Temperature

Following the requirements of AS/NZS 3675-2002 Section 2.3 the sample of 7/2.12 ACS covered conductor was bent around a mandrel of approximately 55mm diameter (4.7x conductor diameter), after the conductor and apparatus were cooled in a Refrigerator (at approx. 4°C) for a period of 16 hours. Following this, the sample was inspected for cracks in the covering material.

Table 17: Bending Test at Low Temperature Result Summary

Sample	Result
7/2.12 ACS	Pass - No breakdown of covering material

Figure 34: Bending Test at Low Temperature Example

4.3 Environmental Testing

Environmental Testing includes Abrasion Resistance Performance and UV Exposure Testing.

4.3.1 Abrasion Testing

The abrasion testing rig was set up to be similar to a previous test method identified in the United Kingdom, Four different timber species were used to get the results of natural tree abrasion effects. The species are Eucalyptus, Lophostemon, Pinus and Allocasuarina which were supplied by United Energy as typical species encountered in the field. The test rig was setup to have a stroke length of 100mm and a cycle rate of one per second. The reaction at the cable from the timber is set to have 2kg (approx. 20N).

Results for the Abrasion testing are as follows:

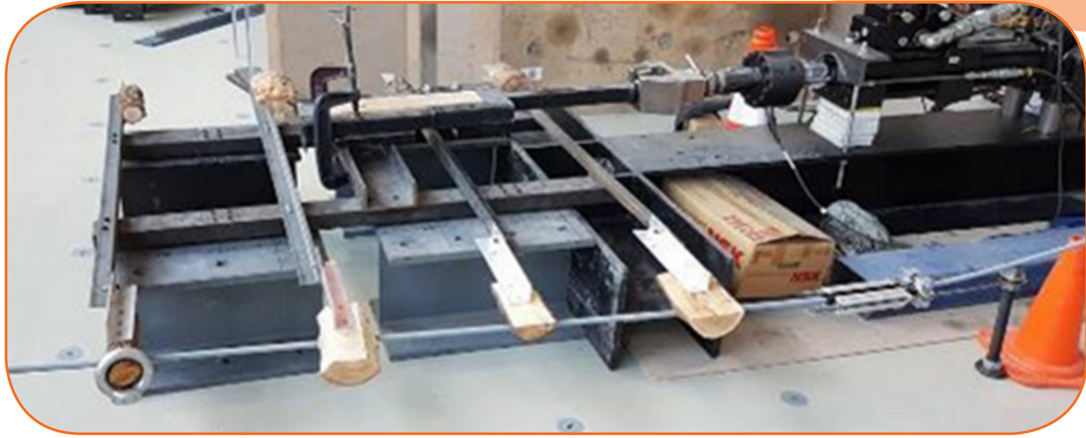

Figure 35: Abrasion Testing Rig

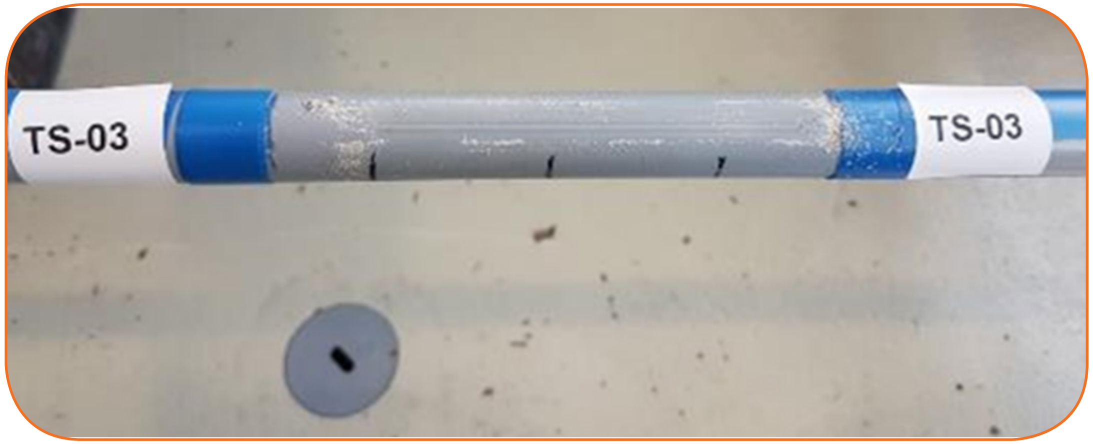

Figure 36: Abrasion Testing Example Test Specimen

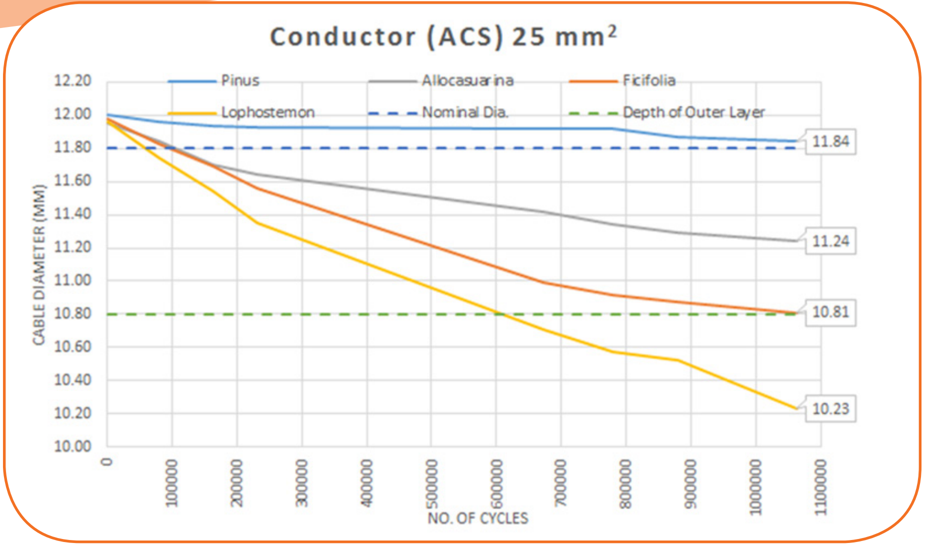

Figure 37: 7/2.12 ACS Abrasion Testing Results

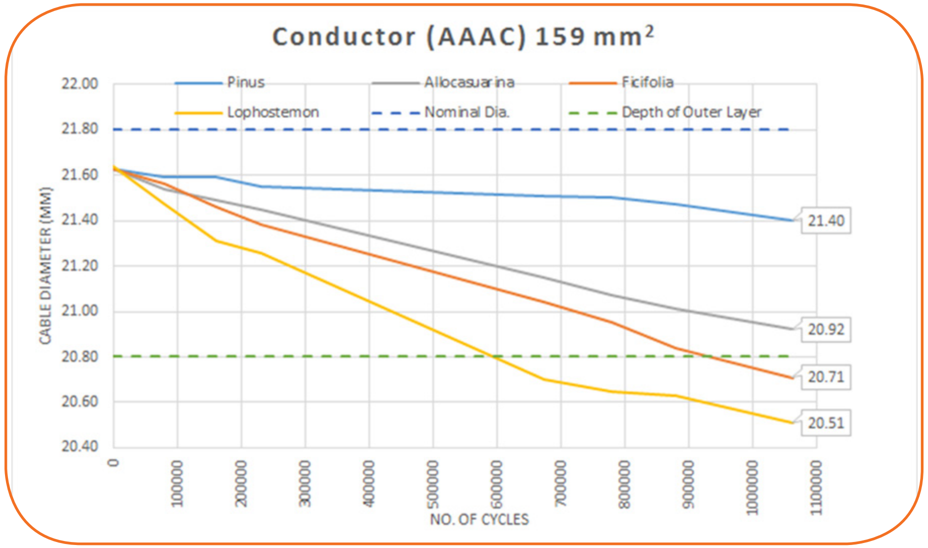

Figure 38: 19/3.37 AAAC Abrasion Testing Result

The timber species adopted for the Abrasion testing are quite dense and hard, and are significantly harder than the earlier tests undertaken in the UK. However, it is concluded that the covered conductors performed well with the samples showing material loss to below the outer covering layer after over 1,000,000 cycles.

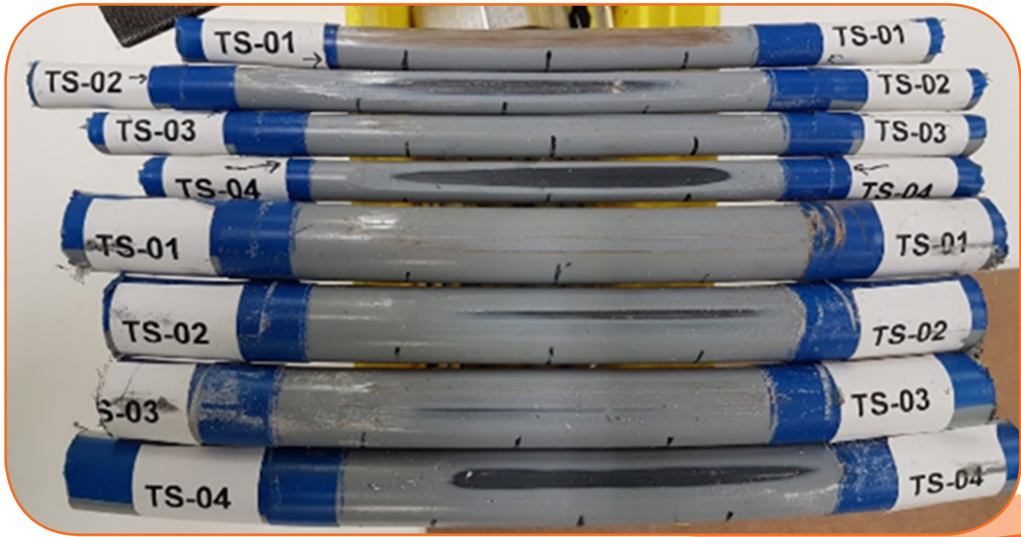

Figure 39: Abrasion Test Specimens Post Test

4.3.2 UV/Weathering Testing

Four different materials were tested for mechanical properties for intact (as new condition) and UV exposed conditions. The samples tested are as follows:

A. HDPE/XLPE Hybrid conductor covering material

B. XLPE/XLPE conductor covering material

C. United Energy Covering Sample

D. Non-UV Treat Sample

The UV testing was conducted as described in the ASTM G154 – Cycle 4. Accelerated test of UV-A radiation for 2000 hours (84 days) using UVA-340 lamps with 1.55W/m2/nm irradiance based on a cycle of 8 hours UV exposure at 70C black panel temp and 4 hours condensation at 50C black panel temperature. This was agreed through consultation with the project group and an external materials testing expert considering the time limitations on completing this testing.

Figure 43: Non-UV treated ABS Material*- Photo order: Intact sample, 100hrs UV, 200hrs UV & 500hr

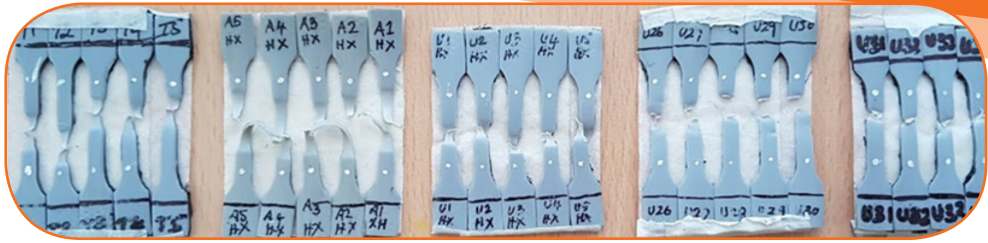

Figure 40: HDPE/XLPE Covered Conductor sample- Photo order: Intact sample, 336hrs aging test, 100hrs UV, 200hrs UV & 500hrs UV

Figure 41: XLPE/XLPE Covered Conductor sample- Photo order: Intact sample, 100hrs UV, 200hrs UV & 500hrs UV

Figure 42: United Energy Cable sample- Photo order: Intact sample, 100hrs UV, 200hrs UV & 500hrs UV

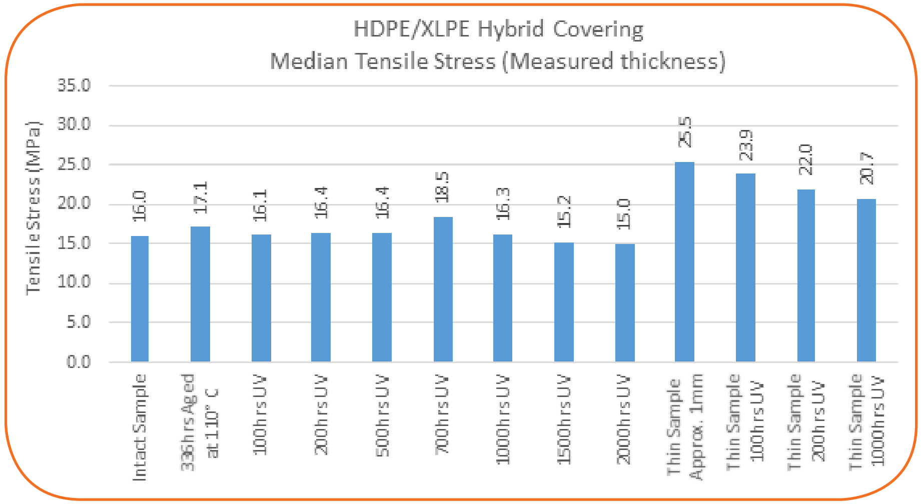

Figure 45: HDPE/XLPE Hybrid Covering Median Tensile Stress (Measured thickness)

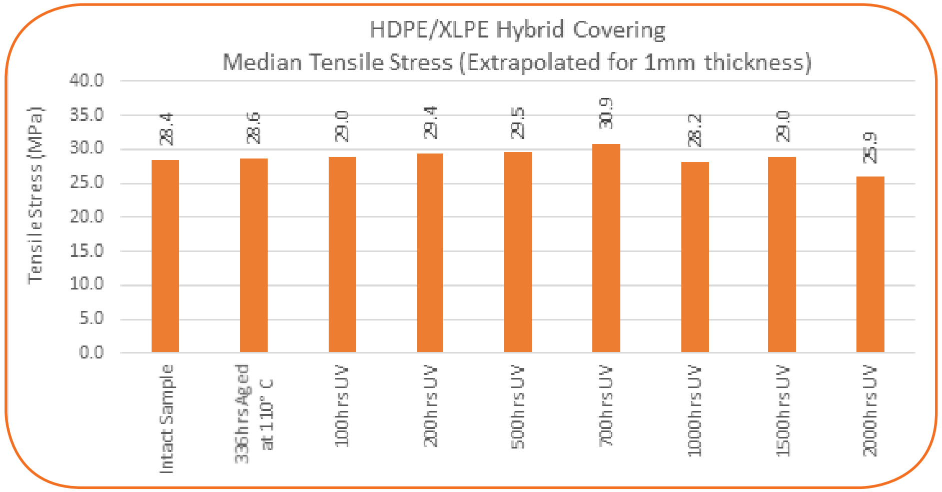

Figure 44: HDPE/XLPE Hybrid Covering Median Tensile Stress (Extrapolated for 1mm thickness)

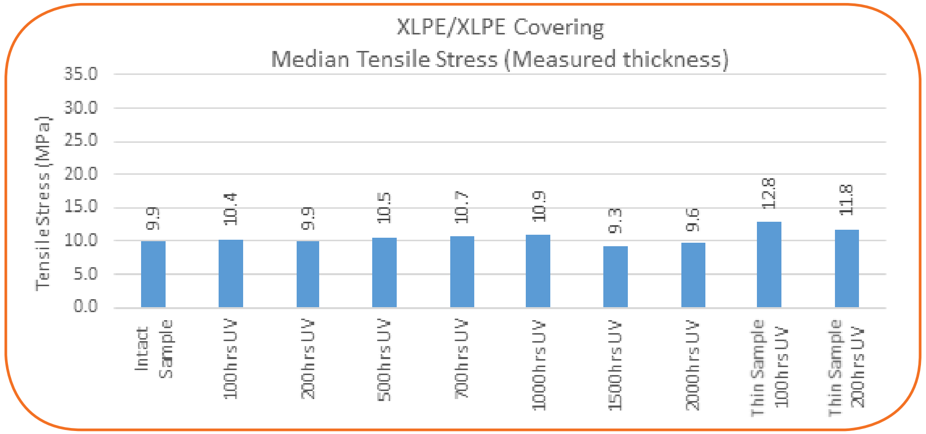

Figure 47: XLPE/XLPE Covering Median Tensile Stress (Measured thickness)

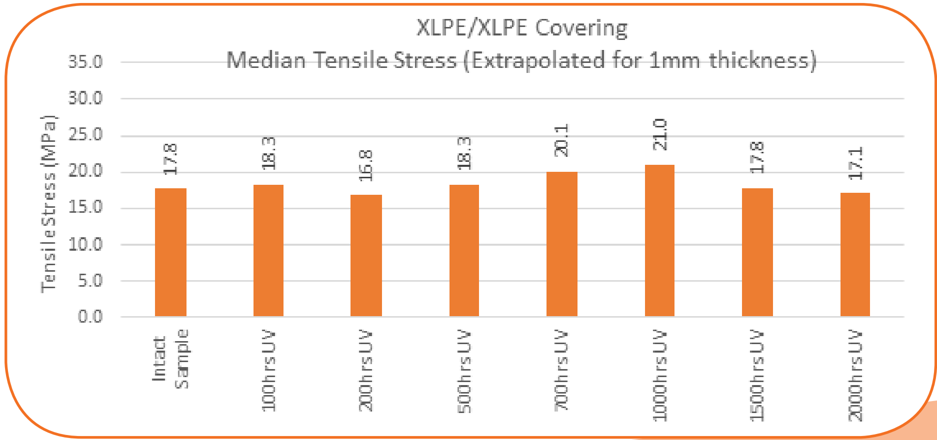

Figure 46: XLPE/XLPE Covering Median Tensile Stress (Extrapolated for 1mm thickness)

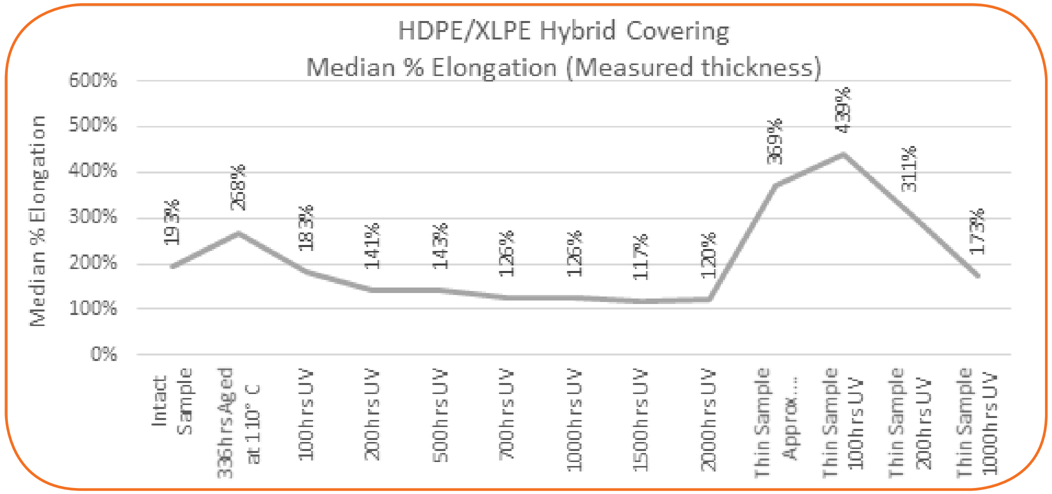

Figure 48: HDPE/XLPE Hybrid Covering Median % Elongation (Measured thickness)

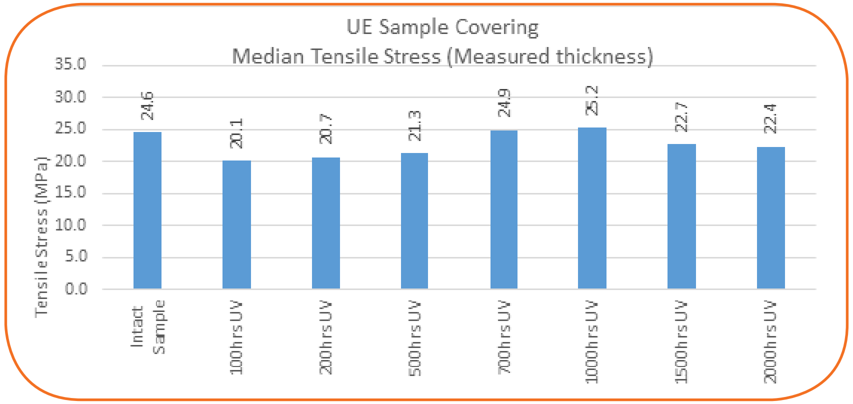

Figure 50: UE Sample Covering Median Tensile Stress (Measured thickness)

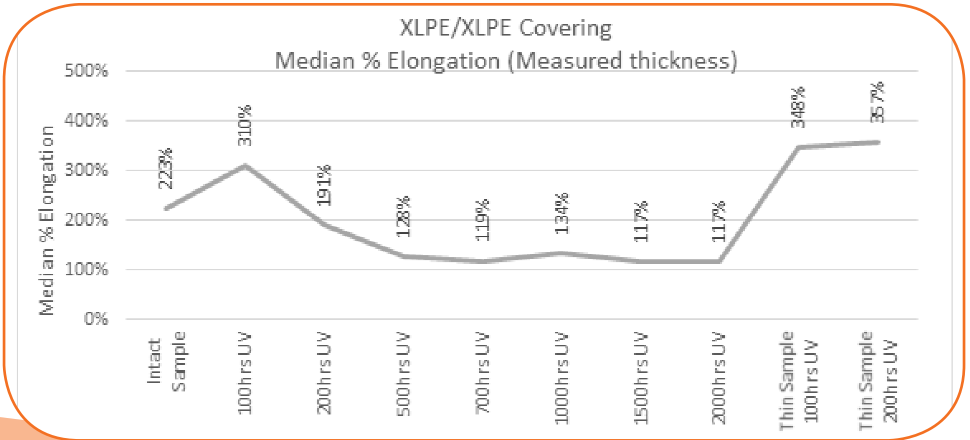

Figure 49: XLPE/XLPE Covering Median % Elongation (Measured thickness)

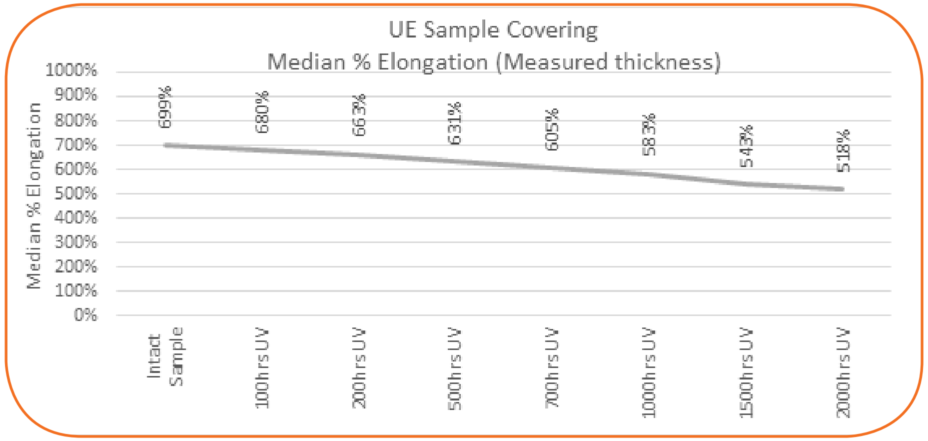

Figure 51: UE Sample Covering Median % Elongation (Measured thickness)

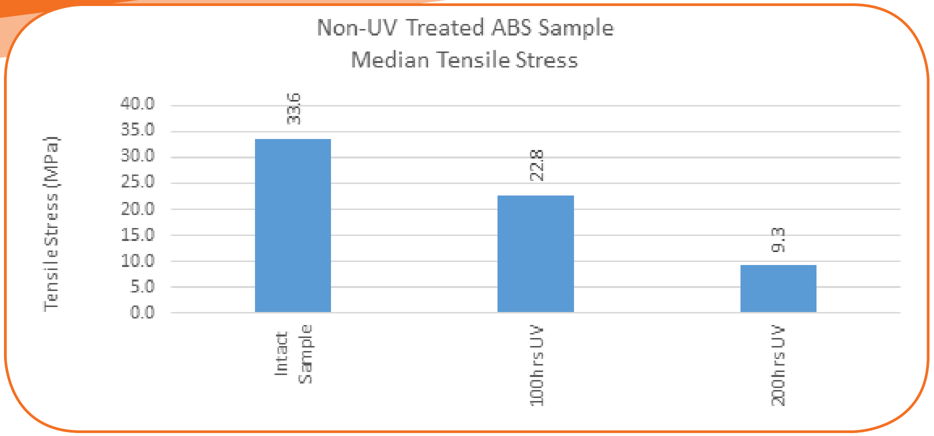

Figure 53: Non-UV Treated ABS Sample Median Tensile Stress

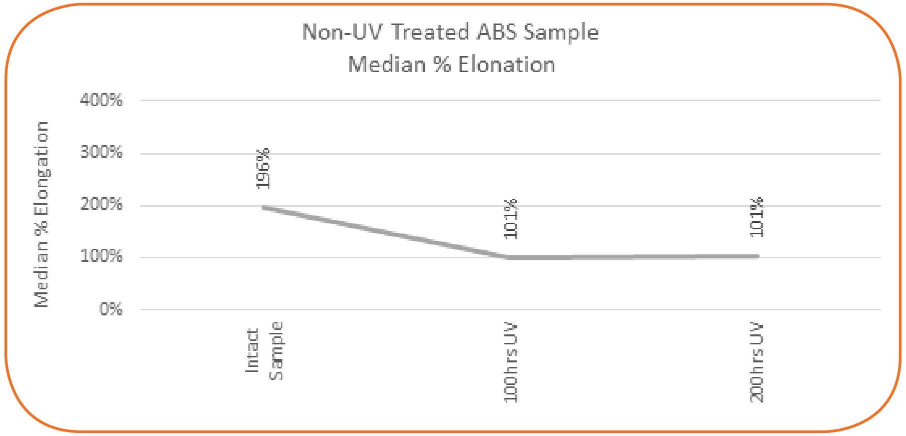

Figure 52: Non-UV Treated ABS Sample Median % Elongation

*Note: The non-UV treated samples could not be tested beyond 200 hours. At 500 hours and beyond, the non-UV treated samples were very brittle and disintegrated before they were removed from the test plates. The UV testing of these samples was performed for illustration purposes only.

NOTE: The listed exposure hours for the UV samples are the nominal hours (±24 hours).

The performance of the HDPE/XLPE Hybrid conductor covering material under UV exposure was shown to be better than a covering material tested in conjunction with the HDPE/XLPE material that is approved for use in Victoria (High Voltage Aerial Bundled Cable) achieving a variation of material properties in comparison with HV-ABC of 1.002 (AS/NZS3675-2002 minimum pass requirement is 0.80).

5 Trial Preparation

5.1 Trial Site Selection

The Business Case for the installation of the covered conductor at two trial sites on the United Energy (UE) network was approved by UE management in March 2017.

The trial provided the opportunity to evaluate a predominantly “off-the-shelf” solution with a comprehensive international in-service history. The trial locations were selected to demonstrate the capability within the Australian environment of the tested covered conductor technologies, some of which were specifically adapted for the Victorian industry.

Two locations were been identified for the trial, being:

Cape Schanck – this is a section of SWER network (feeder RBD21) in an environmentally exposed rural area with dense coastal vegetation that is susceptible to strong winds and salt spray. This installation uses a combination of readily available covered conductor products and items specifically adapted for the Victorian industry.

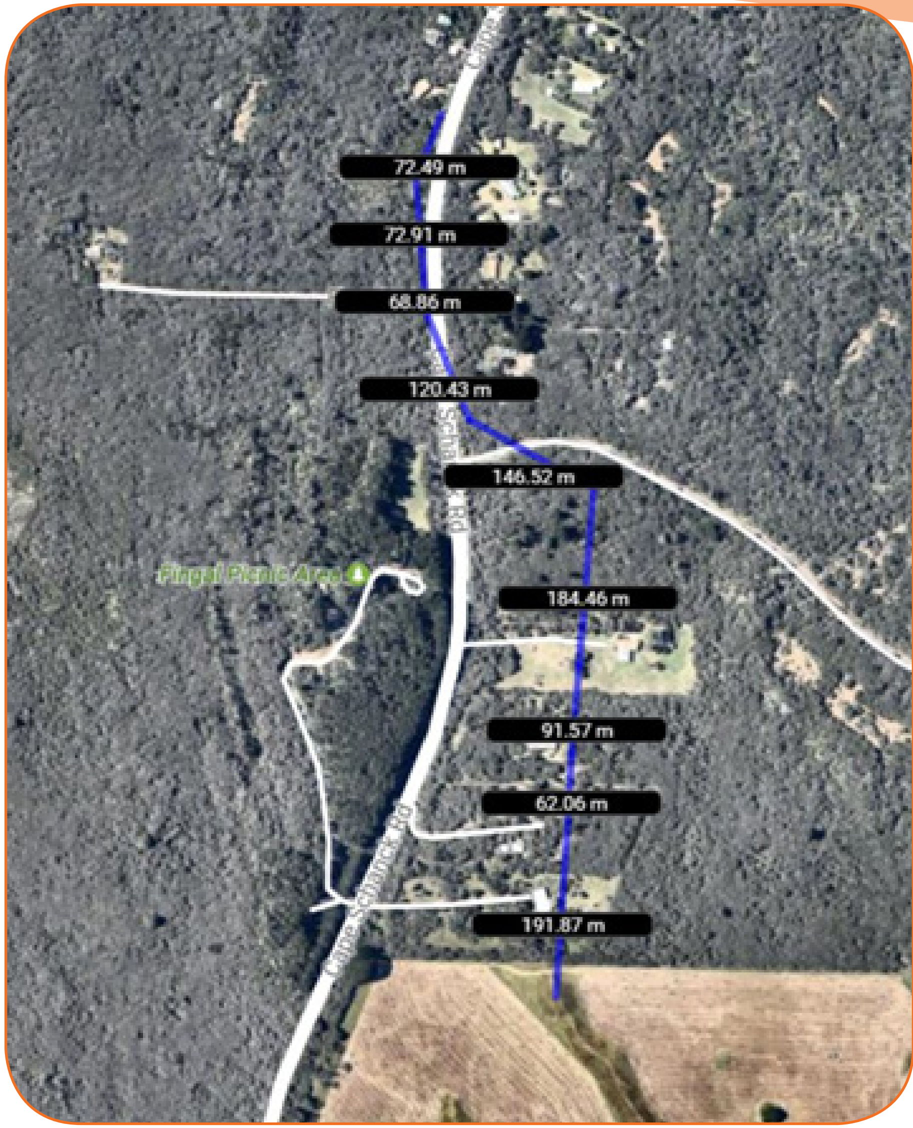

Figure 54: Cape Schanck Trial Section Route

Figure 55: Mordialloc Trial Section Route

Mordialloc – this section is a bay-side location (feeder MC01) also susceptible to salt spray and has been chosen to allow for evaluation of the safety impacts of covered conductor in an exposed urban environment using a fully proven, in service covered conductor system. This is also an area with a high fault frequency and high fault current, and will allow for evaluation of the covered conductor system under electrical stress conditions.

5.2 Design

5.2.1 Preparation

The trial sites were surveyed to capture existing installation data as an input into the construction design and to provide a benchmark for validation of the design post installation. To assess the likely cost to retrofit this solution to existing network infrastructure the decision was made to string the covered conductor on the existing infrastructure with the same sag and clearances as that of the existing bare conductors. This was especially important as the covering on the conductor results in a heavier overall conductor that sags more that its equivalent bare conductor at a given tension. Retrofitting this material to existing infrastructure will result in additional mechanical load on poles and/or reduced clearance to land. Providing a sample to estimate the cost implications of this consideration assists in identifying the design configuration that results in the lowest life-cycle cost for a system retrofit to existing infrastructure.

A required input to the design process is sag charts describing the sag/tension performance of covered conductors for various installed conditions. As these charts were not available for the required span length and tension characteristics for the Covered Conductors being considered as part of this project, Groundline Engineering set about developing these charts from engineering first principles. An example of the sag charts produced is provided below:

Groundline Engineering produced a total of six sag charts for this project which are designed to match existing bare conductor sag charts. Groundline Engineering are further capable of producing additional covered conductor sag charts to any reasonable existing bare conductor sag chart.

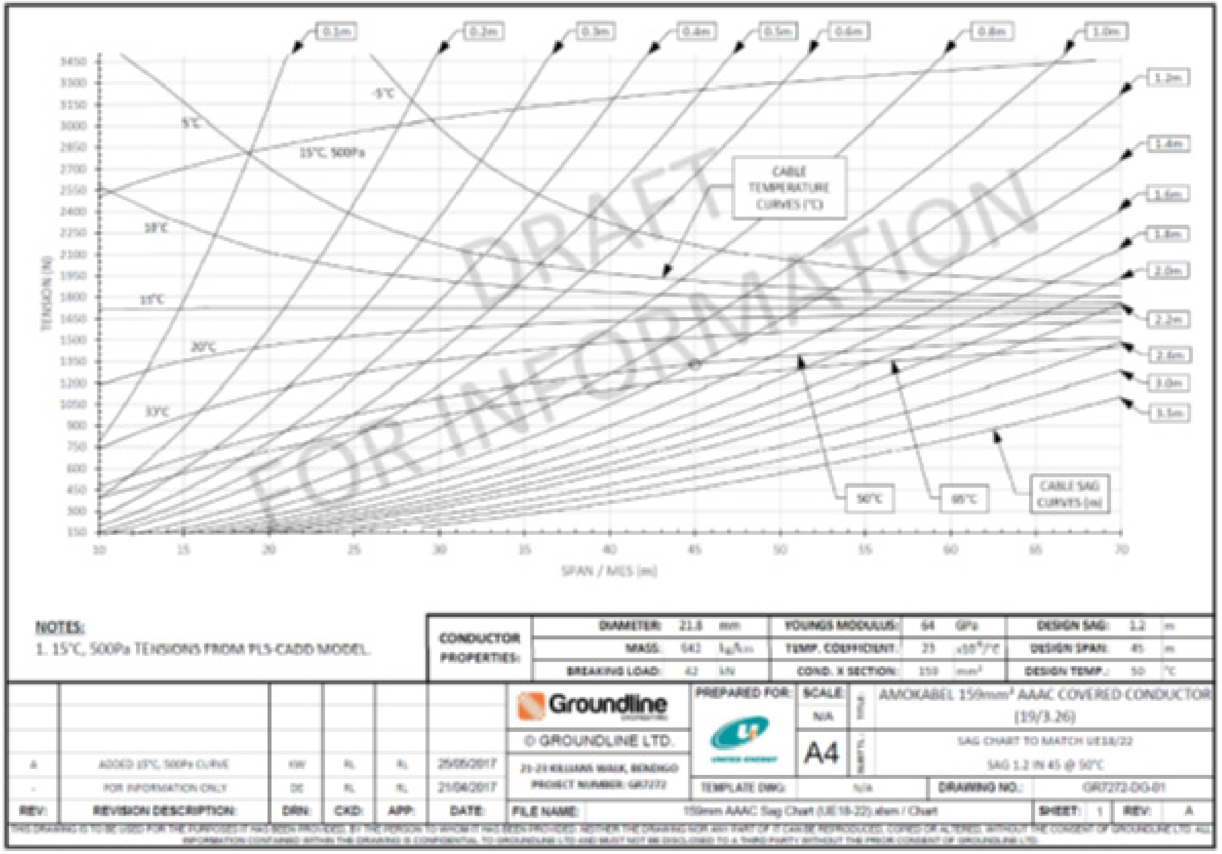

Figure 56: Example Sag Chart Produced for Amokabel Covered Conductor

5.2.2 Construction Design

The survey information was used in-conjunction with existing United Energy asset data, the covered conductor material specifications and Groundline Engineering's Sag and Tension charts to develop the final construction design. United Energy used nPoles overhead line design software to validate the Sag and Tension charts and bring together all these elements to calculate all applicable clearances and the new pole and footing loads with the new covered conductor system.

The application of the covered conductor on the existing network infrastructure did increase the load on the poles and footings, however all serviceable poles were still within acceptable limits and the conductor installation itself did not result in any assets being overloaded or requiring replacement.

The Tension charts were used to string the covered conductor and post installation surveys performed to validate the Sag calculations and accuracy of the Sag charts. Following successful validation of the new stringing charts future installations will revert back to the standard practice of stringing by sag.

In parallel with United Energy design works, Groundline Engineering produced a PLS-CADD 3D line model for both the Cape Schanck and Mordialloc trial sites. The models have been developed with information from United Energy's internal databases and information obtained from site surveys of both trial sites. This includes, but is not limited to, structure orientation, structure type, span lengths, conductor type, and sagging specifications. The intent of the PLS-CADD model was to verify both the sag charts produced based on engineering first principles and the line design produced by United Energy using nPoles.

5.2.3 Product Evaluation And Risk Assessment

United Energy have defined processes within their safety management scheme for the adoption of new technology on the electricity network. These include product technical evaluation to confirm that the proposed product has been manufactured and conforms to approved industry standards, and a risk based assessment of the impact of the new equipment on operation and management of the electricity network.

Any new product must be technically assessed to determine the effect on the network and existing network assets, changes to existing work practices, and financial viability of the product. This evaluation is supported by a range of manufacturer's information that includes: application of recognised international standards throughout the life-cycle of the product evolution, certified recommendation of intended use, life-cycle testing, and installation, inspection and maintenance instructions. Evaluation of in service experience of the product in similar environments also forms part of the technical evaluation.

As such United Energy have been working closely with the covered conductor system manufacturers, obtaining and reviewing technical data of the various components against the existing

United Energy design and construction standards. This has identified a number of deviations from the current standards, particularly where components of the covered conductor system are manufactured to comply with European standards that differ from Australian or international standards. The United Energy technical evaluation has also included reviews of the testing of the various components and understanding the impact of these results on the electricity network.

The outcome of technical evaluation was a key input into the risk analysis of the covered conductor system components, where the use of the new equipment is evaluated based on the corporate United Energy risk assessment procedure. The risk assessment assesses known and potential failure modes identifying possible causes and determining appropriate controls and actions required to address the inherent risks. For the covered conductor material trialled here its deviations from existing Australian standards is addressed in the United Energy risk assessment.

Figure 57 below provides an overview of product evaluation risk assessment:

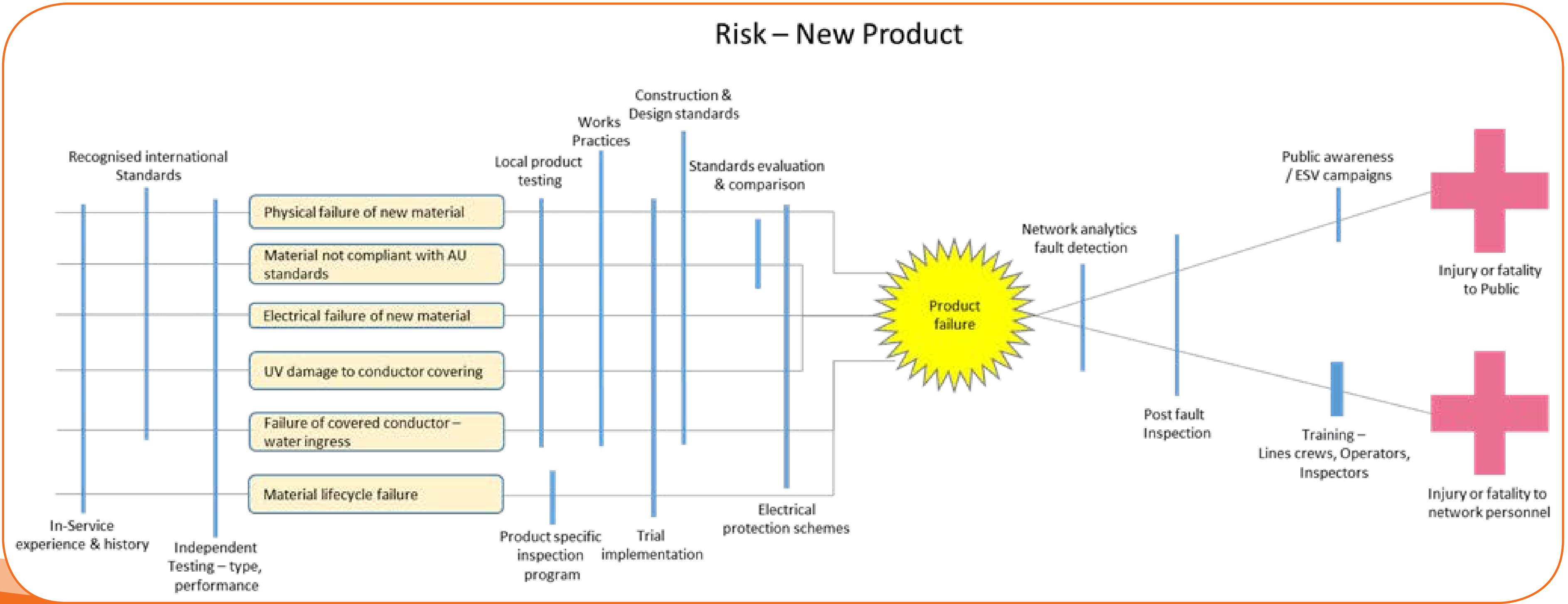

Figure 57: New Product Assessment- Threat Barrier Diagram

Table 18 below discusses the top 5 risks as assessed:

Table 18: Summary of top 5 risks

Risk	Existing Rating	Cause	Control	Residual Risk
Failure of new material - all - leading to injury to personnel/public	Likely / Major - Extreme	Standard methods for appraisal of material suitability for use are compromised; scope of Australian standards is narrow (no Aust. Standard for covered conductor fittings) performance criteria in existing Australian standard is internationally recognized as onerous UE does not have technical specifications for materials design schedules and construction standards have not been developed	Conduct a field trial of construction with the materials including the following; assess available test reports and material specs against Aust. and international standards develop design schedules for material and validate following construction construction to bare construction standards with noted variations	Rare / Major - High
Wire down - Fatality/Serious Injury with member of public, UE staff or contractor	Possible / Major - Very High	Live conductor not directly grounded due to insulation due to conductor/connector failure or assisted failure (vegetation, third party contact)	Covered conductor HDPE outer coating provide strong mechanical protection and XLPE insulating layer provide electrical insulation against intermittent contact. The lower sensitivity of protection to wire down scenario is offset by increased resilience of system	Rare / Major - High
Failure of new material - Covered Conductor CCSX 159 AAAC 22kV W and CCSX 25 ACS 22kV W - leading to injury to personnel/ public	Possible / Major - Very High	Damage to conductor covering/insulation due to water ingress	Avoid stripping where possible, use of insulation piercing connectors, cap cable ends, heat shrink over compression lug for CCSX 25 ACS W 22kV	Rare / Major - High
Failure of new material - HV Insulation Piercing Connectors (IPC) - leading to injury to personnel/ public	Possible / Moderate - Medium	Electrical failure of materials SEW20.7, SLW26 or SLW27 when used as a branch (non-tension) connector under fault (abnormal load) conditions	Material Complies with the testing requirements of Covered conductors for overhead lines and the related accessories for rated voltages above 1 kV AC and not exceeding 36 kV AC – Part 2: Accessories for covered conductors – Tests and acceptance criteria for testing in combination with Amokabel BLL-T 157 AlMgSi covered conductor. Sample testing for UE of short-circuit withstand to 16kA for 1 sec was performed Increased visual inspection and thermal survey frequency for trial sites	Unlikely / Moderate - Medium

Table 18: Summary of top 5 risks

Risk	Existing Rating	Cause	Control	Residual Risk
Failure of new material – LV IPC used on 12.7kV network – leading to injury to personnel/public	Possible / Moderate - Medium	Electrical failure of materials SLIW57 when used as a branch (non-tension) connector under normal load conditions	Material Complies with the testing requirements of EN 50483-4, Connector Class A1, for testing in combination with LV ABC conductor. Sample testing for UE - SLIW57 insulation piercing test at ambient temperature and short-circuit testing with CCSX 25 ACS W 22kV Increased visual inspection and thermal survey frequency for trial sites	Unlikely / Moderate - Medium

A specific risk assessment was performed as part of the material selection process looking at the impact of a "wire down" scenario. This risk assessment focussed on the differences between bare wire and covered conductor systems where a failure resulted in the live conductor falling to ground. Key risks identified were the likelihood of the downed conductor causing serious injury and death to a member of the public and the ability to detect the conductor on the ground.

The risk assessment determined that the likelihood of a covered conductor failure resulting in a live wire on the ground was reduced by a combination of characteristics of the materials / system and the application of controls that lower the likelihood of network faults stressing of aging the assets. Bare live elements of an electrical system are exposed to environmental degradation and susceptible to contact from animals. Reducing the exposed bare elements by using a covered conductor and applying the control of using Insulation Piercing Connectors (IPCs) reduces the likelihood of network faults.

The covering on the conductor is capable of withstanding intermittent contact removing the susceptibility of the conductor to damage from clashing between conductors of different phases. The mechanical strength of the covering also provides an improved resistance to mechanical damage or failure from external forces and contact – from vegetation or third party contact – further lowering the likelihood of network faults.

The risk assessment recognised that a live covered conductor on the ground will be more difficult to detect than a bare conductor. Existing protection techniques and settings were determined to be consistent with other utility companies employing different versions of insulated/covered conductors.

The reduced protection sensitivity was determined to be offset by the increased resilience of the system and subsequently the wire down risk was assessed as no worse when using covered conductor than is currently accepted with the use of bare conductor. Statistics on in-service experience in Europe have demonstrated an increased resilience of covered conductor systems. UE is confident that experience gained in Australian conditions will demonstrate the increased resilience of this system and support an assessment that the risk in a wire down scenario is reduced.

Figure 58 below provides an overview of the wire down risk assessment.

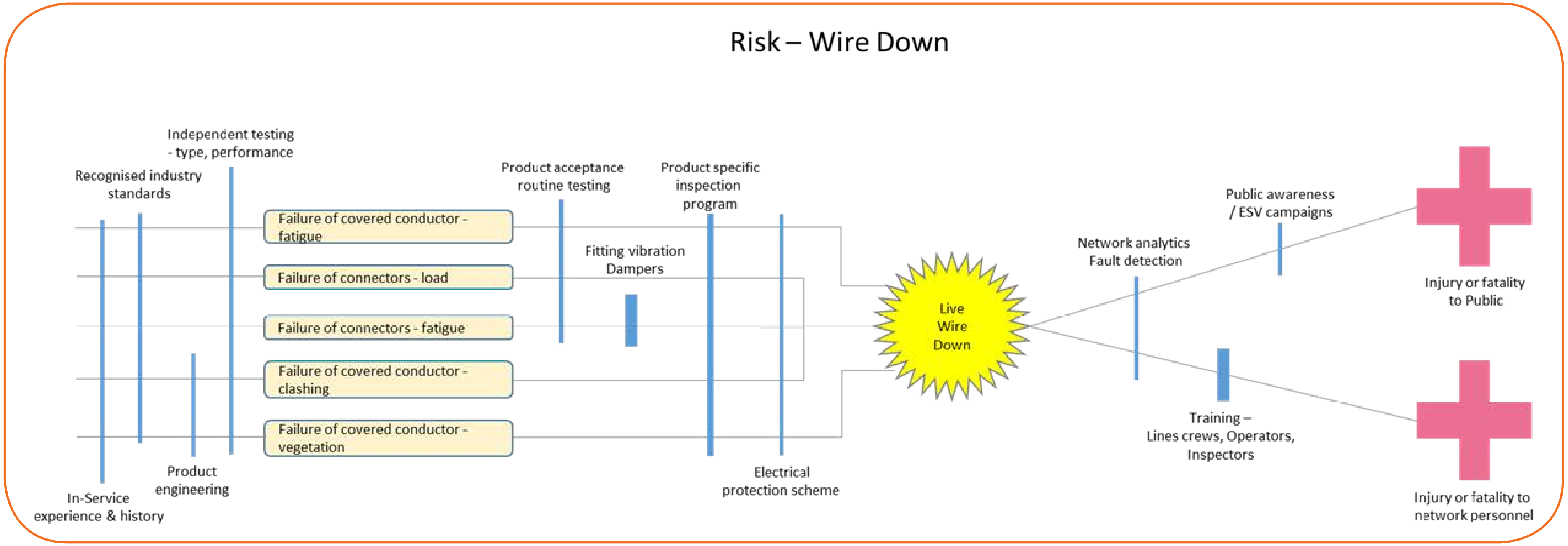

Figure 58: Wire Down- Threat Barrier Diagram

United Energy also performed an installation specific risk assessment that is designed to capture the issues related to the installation of the new conductor on the network. This assessment identified risks and control measures related to conductor stringing, field crew training, and ongoing maintenance and monitoring of the installation at the trial locations. Various controls were implemented to address the identified risks and updated throughout the installation process to ensure any learnings were captured and implemented as appropriate.

5.3 Trial Installation And Post Installation

5.3.1 Construction Experience

In general, the construction of the covered conductor is very similar to bare conductor. The use of Insulation Piercing Connectors (IPC), helical terminations and tie top insulators are all standard works practices on the United Energy network.

The covered conductor did however, introduce a small number of new accessories that required new construction practices. United Energy worked closely with the material suppliers and installation contractors to review the non-standard equipment and determine the appropriate works practices. The implementation of depot based training provided an opportunity for the installation crews to evaluate and familiarise themselves with the accessories and conductor for this trial.

The depot based training was supported with both United Energy subject matter experts and representatives from the international suppliers (Amokabel and Ensto) present on site during the training. This provided opportunities for the installation crews to ask questions directly to the engineering and manufacturing representatives.

There were few issues experienced during the installation and the feedback from the installation teams was very positive. The installation teams appeared comfortable with the works practices for stringing and connecting the covered conductor and rarely relied on the United Energy subject matter experts who were available on site during the installation works to support the in-

Figure 59: Covered Conductor Installation

stallation teams.

A Post Implementation Review (PIR) was performed following the installation works. The PIR considered the design and installation phases of the covered conductor trial and allowed for the collation of feedback from the various stakeholders. Actions generated from the PIR learnings included the development of construction standards and updating training material prior to the broader adoption of the covered conductor on the network as well as implementation of increased in-service monitoring of the covered conductor at the trial locations.

5.3.2 Inspection And Maintenance

Evaluation of the in-service performance of the covered conductor will be facilitated by frequent site inspection and proactive monitoring using data and network analytics.

The covered conductor installations will be physically inspected every 6 months. This will include visual inspection – looking for connector or termination degradation, and signs of damage or bulging on the conductor covering. The covered conductor inspection will also include thermal assessment of the connectors and terminations looking for signs of overheating that could indicate degradation or failure of the connector.

The covered conductor sections will be patrolled following faults on the feeders they are installed on specifically to confirm the integrity of the system and look for signs of secondary damage such as clashing and connector, termination or tie failures.

The risk assessment identified that wire down faults may be more difficult to detect on a covered conductor system. As such UE have implemented proactive monitoring of the network connected downstream of the covered conductor installations. This monitoring includes utilising AMI data for premises supplied from different substations to identify coincidental supply

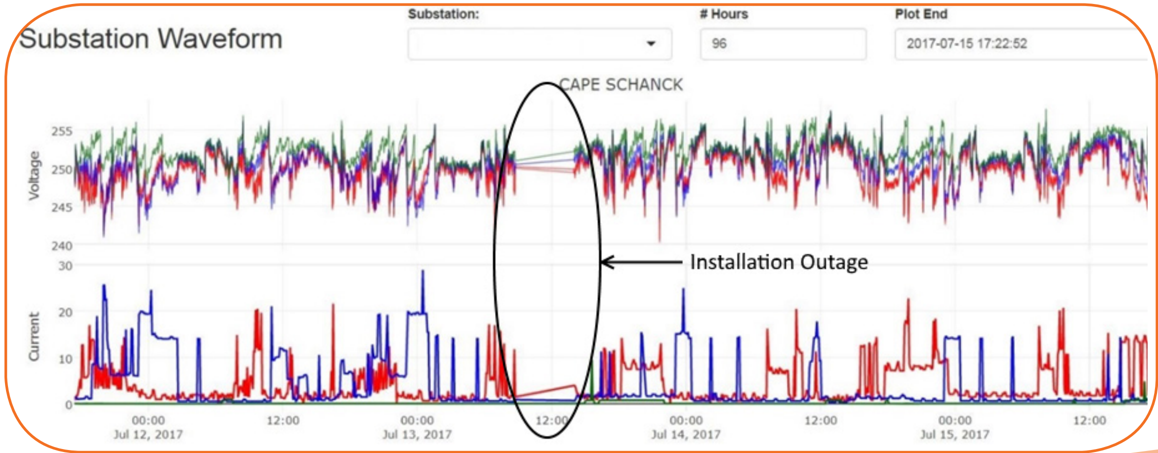

Figure 60: Voltage and Current Profile Pre and Post Covered Conductor Installation

failures that may indicate the loss of a conductor. The monitoring will initiate a notification that will trigger a patrol of the network to determine the nature of the failures. This has been implemented on both the SWER and 22kV network supplied by the covered conductor.

Network analytics data was also utilised post installation to validate that the IPC connections were applied correctly. As can be seen from Figure 60 the voltage profile for this particular substation was consistent both before and after the outage to install the covered conductor.

5.3.3 Recommendations For Acceptance

To date, United Energy have focussed on evaluation of the covered conductor for its suitability to be trialled on the network. The performance of the covered conductor during the trial on the network forms part of the formal approval of the conductor for further operational use.

Additional to the evaluation of the trial locations, United Energy will need to consider the following prior to being able to formally approve the covered conductor for use:

- During the testing of the covered conductor it was determined that the water blocking did not meet the prescriptive requirements of AS/NZS3675-2002 however testing indicated that it will meet the equivalent European Standard requirement. The dynamic water blocking test needs to be revisited for the 25mm^2 conductor and the performance of the conductor assessed against the current European Standards.
- Independent test results for the water blocked 25mm^2 ACS conductor, validating the internal testing and confirming its performance against the European Standard.
- Following failure of adhesion test on the 25mm^2 conductor, the conductor was stripped and crimped to enable it to be installed to the appropriate tension and sag. During installation, it was determined that the stringing method for the smaller 25mm^2 conductor needed to be revisited to enable the conductor to be strung to the tensions required for the maximum design spans. A new compression lug will need to be designed to provide a connection for temporary stringing equipment separate to the permanent termination

connection.

- Improved markings on the conductor covering to facilitate positive identification of the composition of the covering.
- Engineering confirmation of the current rating of the covered conductor when compared with a similar bare conductor.
- Availability of local, ongoing support for the covered conductor product.
- Confirmation and comparison of the pricing for the covered conductor system against currently approved materials.
- Validation of in service application and history for other covered conductor installations.

6 Project Conclusion

6.1 The Objectives

The objective of this project was to research and develop market ready covered conductor technology and associated hardware, accessories and installation techniques with the view to specific requirements for the Victorian Operating Environment. The Victorian Operating Environment was determined to be as follows:

- High summer temperatures (approximately 45°C maximum),
- Low overnight winter temperatures (approximately -5°C minimum),
- Very high UV exposure during summer and parts of autumn and spring months (Extreme UV exposure when considering Australian Operating Environment),
- High levels of salt spray in coastal areas,
- High contaminant levels in some built up areas,
- Conditions conducive to severe conductor vibration in some locations,
- Potential of conductor coming into contact with trees of very high hardness level for extended periods (10+ Janka hardness rating for many Victorian/Australian native species, proposed conductors have been tested against up to 4 Janka hardness species in Europe),
- High fault currents on some assets that will potentially be replaced with covered conductor,
- Need for installation and maintenance in very remote locations (minimise need for very specialised tools, equipment and skills).

In relation to the above, the objective was to prove suitability of the proposed Amokabel Covered Conductor products for use in the above described Victorian Operating Environment. This was with consideration to the intent of Australian Standards, rather than meeting all prescriptive elements of some Australian Standards. These standards may not be considered relevant or are considered outdated, in addition, conductors was assessed against other international standards that were deemed relevant to the required objective of the project.

6.2 The Deliverables

Recommendation 27 of the Final Report from the 2009 Victorian Bushfires Royal Commission stated:

> *The State amend the Regulations under Victoria's Electricity Safety Act 1998 and otherwise take such steps as may be required to give effect to the following:*
>
> - *the progressive replacement of all SWER (single-wire earth return) power lines in Victoria with aerial bundled cable, underground cabling or other technology that delivers greatly reduced bushfire risk. The replacement program should be completed in the areas of highest bushfire risk within 10 years and should continue in areas of lower bushfire risk as the lines reach the end of their engineering lives*
> - *the progressive replacement of all 22-kilovolt distribution feeders with aerial bundled cable, underground cabling or other technology that delivers greatly reduced bushfire risk as the feeders reach the end of their engineering lives. Priority should be given to distribution feeders in the areas of highest bushfire risk.*

To meet the requirements of recommendation 27, this project sought to present a viable set of Covered Conductor types and associated hardware, accessories and installation techniques for bare conductor replacement for the Victorian Operating Environment.

- Suitable mechanical, electrical and environmental testing against relevant Australian and international standard to determine suitability of proposed Amokabel Covered Conductor products,
- Install lengths of a number of Amokabel Covered Conductor types on the Victorian Electrical Network to trial Amokabel Covered Conductor products and to develop installation methods, familiarise installation crews with product and determine required hardware and accessories required for installation in the Victorian Operating Environment.
- Determine applicable retrofit options for lines currently comprising bare overhead conductor based on the three Amokabel Covered Conductor products assessed.

6.3 The Intended Outcomes

The primary outcome of this project is to prove the three Amokabel Covered Conductor products proposed as part of this project as suitable for the Victorian Operating Environment being;

- 25mm² Aluminium Clad Steel (ACS) Conductor (Product newly developed by Amokabel specifically for Victoria)
- 62mm² Aluminium Conductor Steel Reinforced Conductor (ACSR) (Amokabel off the shelf product)
- 159mm² All Aluminium Alloy Conductor (AAAC) (Amokabel off the shelf product)

Following on from the above outcome, to make available to the Victorian distribution industry a viable, cost effective and proven set of Amokabel Covered Conductor products for use in retrofitting to existing high risk bare overhead lines within bushfire risk areas in Victoria.

This project has delivered a viable set of covered conductor products for the Victorian Operating Environment that far exceeds the performance and cost effectiveness of any conductor that can be delivered in compliance with the current set of relevant Australian Standards.

6.4 Future Outlook

6.4.1 Industry Acceptance

A key criterion for wider distribution industry acceptance will be through acceptance of the process undertaken as part of this project to prove viability of the proposed Amokabel Covered Conductor products and associated hardware, accessories and installation methods in the Victorian Operating Environment. This will be a contingent factor in the wider acceptance of the proposed Amokabel Covered Conductor products and associated hardware and accessories by the other distribution asset owners within Victoria.

6.4.2 Safety, Installation And Maintenance Improvements

Little has been done in the last twenty years or so to realistically improve the safety in design, installation and maintenance practices within the Victorian distribution (and wider transmission) industries despite the high risks associated with asset degradation and failure as a result of poor design, installation and maintenance practices. The result of this increases the risk of fire start from electrical assets and extended electrical supply outages. This project has demonstrated that for a relatively insignificant additional cost (long term there is expected to be a real cost saving) the use of high quality conductor, hardware and accessories and implementation of a rigorous design process and installation process to current standards and best practices, significant improvements to electrical network safety and reliability can be achieved. This project has demonstrated a viable cost efficient option to vastly improve safety of overhead lines in bushfire risk areas and is based on a three prong approach;

- Implementing sound engineering practices based on AS/NZS 7000 and other relevant international standards as part of a rigorous design process
- Use of high quality and proven (through testing and overseas experience) covered conductor products and associated hardware and accessories
- Implementation of improved installation practices through development of those processes through collaboration with conductor and hardware/accessory manufacturers, asset owners, design consultants and installation services providers.

Further improvements to the safety of electrical assets will be realised as part of this project in relation to improved inspection and maintenance practices which have been implemented as part of the wider implications of trialling the proposed Amokabel Covered Conductor products on the Victorian electricity network.

This project has demonstrated that the Amokabel Covered Conductor products offer significant cost advantages and installation efficiencies. Through the use of the Amokabel Covered Conductor products there is the opportunity to cover lengths of the existing bare distribution network many multiples over what is achievable using underground cable or other covered conductor technologies.

6.4.3 Improvement/Updating Of Relevant Australian Standards

This project has further identified that there is a need to revise and update AS/NZS 3675 to incorporate realistic and achievable covered conductor performance requirements and to bring the standard in line with equivalent international standards. This will further assist with wider industry acceptance of the proposed Amokabel Covered Conductor products investigated as part of this project and other similar covered conductor products in general.