Report

Covered Conductor Systems for Distribution

Author: J B Wareing

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Covered Conductor Systems for Distribution

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Covered Conductor Systems for Distribution

by

J B Wareing

Summary

The ASTP have requested a detailed review of international experience focusing on reliability and cost issues, with a view to subsequently developing a performance system specification for covered conductor (CC) use in Australia. This report represents Stage 1 of this review. It details the international experience with covered conductors and explores the reasons why widespread application has not occurred in Australia. It covers international practices and standards relating to covered conductors as well as identifying the problems and issues encountered. The report concludes with identifying specific issues, which if addressed may result in more widespread adoption of covered conductors in Australia. Recommendations to achieve this are given.

In summary, the report covers the various issues that restricted the spread of CC in Australia after the initial installations in the early 1990s. It then details the substantial and significant research and development in all areas of CC use that have been carried out in Europe over the last 15-20 years and how this is applicable to the Australian environment with significant advantages in terms of safety, reliability and security to the Australian Power network. The economics of CC use depends on the inspection and maintenance procedures of the utility and the cost benefit put on safety, reliability and fault reduction. Some utilities state that the lifetime costs are lower due to greater reliability and reduction in fault levels. Others state that their line patrols etc still need to be carried out and so no reduction in lifetime costs is apparent. CC is, however, accepted world-wide as having a major impact on safety levels for both human and wildlife though some utilities state that this alone does not justify the higher initial capital cost. The problem of detecting a downed conductor is still the subject of research but most utilities consider that the use of SEF and recloser strategies is sufficient to meet safety requirements and that the performance of downed CC detection is very little different than that of detection of a downed bare wire conductor.

It is recommended that presentations be made to relevant Australian utilities concerning this report and that these utilities be given the opportunity to explain their particular
environmental and other issues that have restricted their use of CC. These presentations should be made by relevant experts in the CC field.

It is also recommended that a CC conference or seminar/workshop be held where experts in areas related to CC use in Australia and the rest of the world be invited to share expertise and resolve outstanding issues i.e. the holding of a seminar or workshop on CC use in the Australian environment. This may provide a route for a way forward for improving the Australian power network in a reliable and cost-effective manner.
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1 Introduction

1.1 General

The Australian Strategic Technology Program (ASTP) provides funding for technology development issues which fall into the non-competitive technical areas of utility business, thus opening up new areas of member co-operation.

The ASTP recently conducted a half-day workshop titled “WHERE DO WE GO WITH COVERED CONDUCTORS?” held at Energy Australia’s offices in Sydney[1]. A total of six speakers from the industry and consultants/manufacturers addressed issues pertaining to the greater take-up of medium voltage covered conductors (CC) in Australia. Overseas experience was discussed. As a result of the workshop the ASTP decided to arrange for a detailed review of international experience focusing on reliability and cost issues, with a view to subsequently developing a performance system specification. In this paper ‘medium voltage’ is taken to refer to network voltages of 6-33kV.

EA Technology Ltd (EATL) submitted a proposal to examine the international experience with covered conductors and explore the reasons why widespread application has not occurred in Australia. This was submitted for consideration by the ASTP who approved Stage 1 of the proposal. This report covers this work.

1.2 Scope and tasks

The scope of the project is to examine international experience relating to CC, identifying any specific issues that are acting as a barrier to its introduction into Australia. The main tasks are:

1. Document international practices and standards relating to covered conductors

2. Document international experience of installation and operation, including references.

3. Identify any problems and issues encountered

4. Identify specific issues, which if addressed may result in more widespread adoption of covered conductors in Australia.

1.3 Definition

The current European CENELEC draft standard[2] for covered conductors defines CC as:

Covered conductors consist of a conductor surrounded by a covering made of insulating material as protection against accidental contacts with other covered conductors and with grounded parts such as tree branches, etc. In comparison with insulated conductors, this covering has reduced properties, but is sufficient to withstand the phase-to-earth voltage temporarily.
In line with this definition, the single phase conductor with one or more layers of covering material in common use in networks up to 132kV\textsuperscript{3} will be considered in this report. In addition, the use of span supports for three single CC as commonly used in the USA will also be included. This is commonly referred to as ‘Spacer Cable’ and is in use at up to 69kV. Finally, a covered but fully insulated three phase conductor commonly used in Sweden and increasingly now in the UK will also be included. The particular type covered is the Axces/Excel overhead cable in use up to 24kV.

1.4 Report layout

Before dealing with the agreed tasks, the report describes the various types of covered conductor available throughout the world, including insulated overhead ‘aerial’ cable. It then deals with the current standards from a historical viewpoint showing how they were developed in terms of the continuing research and development in the covered conductor (CC) field over the last 15-20 years. Then, in line with task 2 in §1.2, a brief history of the development of CC use in Europe, North and South America and Japan is included followed by details of international experience of installation and operation. The problems seen as restricting more widespread use of CC in Australia are identified and then it is shown how these have been approached and dealt with world-wide. This section includes the wide range of research into CC by EA Technology for UK, Scandinavian and American companies and which has formed the basis for many standards. This provides a focus for Task 4, dealing with problems specific to Australia and how recent developments may encourage more widespread adoption of CC.

2 Types of CC currently available

2.1 Basic Types

This section looks briefly at the various types of covered and insulated conductors on the market. Aspects such as current carrying capacity, weather loads and line design are covered elsewhere in this report.

There are three basic types of CC overhead line systems in use at distribution voltages:

- XLPE/HDPE Covered Conductors (single or multiple sheathed)
- Aerial cable systems
- Spacer Cable concept

XLPE (Cross-Linked Polyethylene) and HDPE (High Density Polyethylene) are the most common sheath materials.

The conductor material can be a high conductivity copper or aluminium or a conductor designed to give a balance between strength and conductivity (steel cored aluminium types such as ACSR).

Bare wire is normally the cheapest and easiest system to build but covered conductors have a higher reliability because clashing and accidental contact is not a problem. Spacer cable is essentially the three CC phases held in a cradle and supported by a steel or alumoweld cable
(see later in this section). The fact that the conductors are not self-supporting means that vibration risks are reduced and reliability increased. Aerial cable is essentially a fully\textsuperscript{[5]} insulated 3-core cable with an earth screen used for overhead applications. Its low susceptibility to lightning and the inherent reliability of the cable design means that this system is the most expensive, but also the most reliable. In very general terms, the reliability of bare wire distribution systems and the three basic types of CC described here is shown schematically in Figure 2.1.

![Figure 2.1](image)

**Figure 2.1** Schematic reliability of various distribution systems

### 2.2 Single sheath CC

Single sheath CC commonly use aluminium alloy conductors (Figure 2.2) with an XLPE or HDPE sheath of 2.3mm thickness. The conductor is also produced, however, with 1.6 and 1.8 mm thick sheaths for steel reinforced aluminium (ACSR) or aluminium alloy (AACSR) conductor and copper conductor. The thinner sheaths reduce the overall diameter and so the wind resistance leading to lower vibration levels and lower snow loads. Copper is used in highly salt-polluted environments. To improve long-term phase-to-phase contact performance at 33 kV, sheath thicknesses of up to 3.3 mm can be used.

The characteristics of single sheath CCs are:

- Single layer
- Typically Low Density Polyethylene (XLPE)
- Covering thickness ranges from 2.3 to 3.3 mm
- Lower impulse strength than two and three layer designs
- Provides some resistance to outages caused by tree and wildlife contact

The impulse strength of a single layer of XLPE sheathed CC is around 115kV\textsuperscript{[4]}. However, the electrical stresses caused by trees on the line or conductors on the cross-arm can erode the sheath in periods from months to minutes depending on the system voltage. Surface voltage stresses are greater with porcelain insulators rather than polymeric insulators due to the greater difference in the dielectric constants of the porcelain (three times that of polymeric
insulators) and the XLPE sheath. The use of ‘floating’ helical fittings can also cause surface tracking of XLPE sheathed conductor in coastal environments, especially if the carbon black content is around 3% (which is in many CCs). This effect can be reduced by the use of polymeric insulators or switching to an HDPE sheathed conductor that contains substantially less carbon black.

There are several types of single sheath covered conductor available in the UK.

2.2.1 SAX

This cable is of Finnish manufacture (Pirelli Cables & Systems Oy) and was the earliest covered conductor to be widely employed at 20 kV in Scandinavia. Substantial lengths (over 20,000 km) have been erected in the UK. It is available in 35 to 240 mm² sizes, although 50 and 120mm² are the most common. The aluminium alloy conductor is fully compacted, covered with a 2.3 or 3.3mm thickness of XLPE normally with 2.5 to 3% carbon content and is available ungreased or with powder, tape and grease water blocking. A typical specification for SAX is given in Appendix I.

2.2.2 PAS/BLX

These conductors are similar to the SAX system and are manufactured in Norway and Sweden (ABB Norsk Kabel and Rekka amongst others). The aluminium alloy conductor is normally supplied in compacted form from 35 mm² to 241 mm². BLX is also available with copper conductor for use in highly saline areas. It is used on the Southern Baltic Norwegian coast. The XLPE is available in nominal thicknesses of 2 to 3 mm. Rather confusingly, BLX is also a trade name for a triple extruded conductor made in Sweden (Figure 2.2) which is discussed in §2.3.

2.2.3 CC/CCT

Covered Conductor (CC) and Covered Conductor with increased insulation thickness (CCT) were installed extensively in Australia and the Far East in the late 1980’s and early 1990’s (manufacturer: Midland Metals Overseas PTE Ltd, Singapore). They can have a grey XLPE coating compared with the black XLPE of SAX conductor. The lighter CC (2 mm insulation) has tended to be used for rural, long span situations, whilst the CCT (originally 2.3 mm insulation) is used for forested terrain. Apart from the UV stabilisation (carbon black in the BLX, titanium oxide in the CC and CCT) the other major difference from the PAS/BLX/SAX system is that the conductor is uncompacted and is not greased. It has a water-blocking compound between it and the XLPE layer (ethylene vinyl acetate - EVA). A similar product is made in Sweden

![Figure 2.2 Single sheath CC (Courtesy Pirelli Cables & Systems Oy)](image-url)
2.3 Multiple sheath CC (Medium Voltage)

CC can have one, two or three sheath layers at medium voltage (6.6-33kV) whilst at 66-132 kV the conductor may have up to 5 layers\textsuperscript{[3]}. Examples of three-sheathed CC are BLX and BLX-T, a triple extrusion system, manufactured in Sweden by Amo Kraft AB (see Appendix II)\textsuperscript{[6, 7]}. It is available in low (0.5%) or zero carbon content sheath material to reduce tracking problems. Generally uncompacted, it has a larger overall diameter than the equivalent compacted versions. A mastic EVA compound provides moisture penetration resistance. It is also available in partially compacted form. The three layers (Figures 2.3 and 2.4) are basically a semi-conducting sheath (A) close to the metal conductor to equalize out the electric field, an insulating polyethylene sheath (B) and finally a hard abrasion-resistant outside layer of HDPE (C).

![Figure 2.3 Basic triple extruded design](image)

![Figure 2.4 Cross-section of Swedish manufactured triple extruded BLX\textsuperscript{[5]} (Courtesy Amo Kraft AB)](image)

The semi-conducting sheath is particularly useful on an uncompacted conductor as it equalises out the electric field and reduces the local voltage stress across the sheath when in contact with another object (tree, crossarm etc) (Figure 2.5). This allows the conductor to last for considerable lengths of time when, for instance, it is brought into contact with an earthed object.
Figure 2.5  Effect of using semi-conducting layer or shield on metal conductor of CC

EATL has carried out tests on the effectiveness of this technique and this is reported in §6.3.

Ericsson Network Technologies of Sweden also produce some CC (known as BLL) according to the latest BSEN standard\(^2\). The design today is an ACSR non-compacted line sealed with extruded thermal adhesive, inner conductive layer, polyethylene (PE)-insulation and HDPE outer layer (see Appendix III). The reason for applying the outer HDPE layer is that there is a demand for hardness in the standard.

2.4  Spacer cable

Spacer cable systems are essentially three CC phases in a polymeric support cradle supported by a ‘messenger’ cable. Figure 2.6 shows the support system at a pole and Figure 2.7 shows the cable strung at an EATL test site in the UK. The system, as manufactured by Hendrix Inc (USA), is detailed in Appendix IV but basically, the system has:

- A messenger-supported three layer cable construction in a close triangular configuration
- The mechanical strength to weather severe storms
- The electrical strength to prevent faults due to phase to phase or phase to ground contact, tree contact or animal contact
- A complete coordinated system including cable, messenger, spacers, insulators and hardware

The conductor is the triple sheathed CC version discussed in the previous section. The system is used widely in the USA, South America and parts of Canada and is being marketed in Europe. Overall it is used in 60 countries world-wide. It has been tested in the UK\(^8\) but at the time of publication no network installations have been made.
Figure 2.6  Triple sheathed version of the Spacer Cable (Courtesy Hendrix Inc, USA)

Figure 2.7  Spacer cable strung at a UK test site along with other CC and bare wire systems\textsuperscript{[8]}
2.5 Aerial cable

Aerial cable, also known as ‘overhead’ or Universal cable, is basically a cable that can be strung overhead and run underground and underwater. It obviates the need for OHL/cable junctions and has a very low susceptibility to lightning\(^4\). Since cable has a lower impedance than bare or CC, the voltage drop is lower for an aerial cable than for other types of CC line and it is possible to increase the network length between substations by 40-50% using aerial cable instead of bare or CC line. Some typical values are given in Table 2.1\(^{22}\).

Table 2.1 Voltage drops/km for Axces aerial cable and standard covered conductors

<table>
<thead>
<tr>
<th>Conductor</th>
<th>Size</th>
<th>Resistance Ω/km</th>
<th>Impedance Ω/km</th>
<th>∆V/V per km 10kV ph-ph 100A</th>
<th>∆V/V per km 20kV ph-ph 100A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aerial Cable</td>
<td>Axces 3x95mm(^2)</td>
<td>0.32</td>
<td>0.33</td>
<td>0.59%</td>
<td>0.29%</td>
</tr>
<tr>
<td>CC</td>
<td>CC 99mm(^2)</td>
<td>0.35</td>
<td>0.53</td>
<td>0.95%</td>
<td>0.47%</td>
</tr>
<tr>
<td>CC</td>
<td>CC 157mm(^2)</td>
<td>0.22</td>
<td>0.46</td>
<td>0.83%</td>
<td>0.42%</td>
</tr>
<tr>
<td>CC</td>
<td>CC 241mm(^2)</td>
<td>0.14</td>
<td>0.42</td>
<td>0.76%</td>
<td>0.38%</td>
</tr>
</tbody>
</table>

The features of aerial cable are:

- Fully shielded three core power cables
- Excellent contact resistance
- Go overhead, underground, underwater
- No crossarms
- No OHL/underground cable junction
- Made in USA, Sweden and Finland

Figure 2.8 shows the structure of the Swedish version (Axces Universal cable made by Ericssons Network Technologies, Sweden) now used in many parts of the UK. The cable is totally self-supporting. It has a high impulse strength, 400kV, and uses an earthed screen.

![Figure 2.8 Schematic of Axces ‘Universal’ overhead cable (Courtesy Ericssons Network Technologies)](image-url)
Figure 2.9 compares the smaller copper (EXCEL) and larger aluminium conductor versions. The conductor is held on the wood poles by hooks in a similar fashion to LV aerial bundled conductor (ABC). Cable systems are more complicated to joint than single-phase OHL conductors and so aerial cable is more suitable for long runs where there are few transformers and spurs lines. It is commonly strung together with LV cable on the same poles.

![Figure 2.9 Excel (copper) and Axces (aluminium) Universal Overhead cable](image)

As a result of a major storm in Sweden in January, 2005, the big utilities (E.on and Vatenfal) have changed their priority on CC build. The first choice is underground cable, the second is cable in the air (Universal cable) and the third covered conductors or bare wires. Further north in Sweden bare wires operate satisfactorily as there are fewer and smaller trees.

One of the problems in Australia is bush fires. These can be ignited by branches blown onto bare wires and then falling down and starting the fire. CC or aerial cable would solve that problem. Recent experience with falling trees or high lightning activity indicates that aerial cable performs better than CC in Sweden.

Universal cables are currently used in UK, Germany, Sweden, Norway, Finland, Estonia, Poland, Hungary, Ireland, Slovenia, Croatia and Bosnia. Slovenia and Croatia are the main established markets for Universal cable after Sweden. The main drivers are the same as in Sweden, bad weather with falling trees, as well as aesthetic appearance. A short training line has also been erected in New Zealand. Weak links are used to avoid pole failure when trees fall onto the line. These are commercially available and are used for suspension or tension clamps to drop the conductor in the case of fallen trees. Being fully insulated with an earthed screen, this conductor is generally safe on the ground unless severely damaged. With the weak link technique the cable and pole are normally undamaged and the cable just needs to be lifted back in position again. The link failure levels are set at 4kN for Excel and 13kN for Axces cable.

2.6 High Voltage CC (HVCC) for 66-132kV networks

Single sheath CC used in medium voltage applications is commonly covered with a 2.3-3.3 mm layer of black weather resistant XLPE. If this method were used at higher voltages, problems with dendritic tree growth in the polyethylene could occur due to the higher electrical stresses. This means that when operating above medium voltage levels the partial discharge phenomena inside the covering has to be considered, especially in situations where fallen trees lies on the line or phase conductors are touching each other. Therefore a new
covered conductor type was developed which has a thin layer of extruded semi-conducting XLPE compound controlling the electric field at the conductor surface.

The main part of the HVCC covering consists of extruded water-tree retardant XLPE insulation compound. Unfortunately its ability to withstand ultra-violet light (from solar radiation), is not very good. So an extra layer has to be applied that protects the main insulation against UV degradation. This outmost layer consists of weather and track resistant black XLPE insulation compound.

All three layers, conductor screen, main covering and outer weather resistant coating are extruded simultaneously in a highly controlled, completely dry, curing and cooling process.

High voltage covered conductor (named HVCC SAX and manufactured by Pirelli Cables & Systems Oy, Finland) consists of watertight, stranded and compacted all-aluminium alloy conductor covered by a triple-extruded XLPE layer.

A schematic picture of HVCC SAX for voltages from 66 kV to 132 kV is shown in Figure 2.10 where the numbered items are:

1. Watertight, stranded and compacted aluminium alloy conductor, cross-sectional areas available from 120 mm$^2$ to 355 mm$^2$

2. Extruded semi-conducting XLPE screen

3. Extruded water-tree retardant XLPE insulation compound, thickness 2.5…5.5 mm

4. Extruded layer of weather and track resistant black XLPE insulation compound, thickness 1 mm

![Figure 2.10 HVCC SAX conductor made in Finland (Courtesy Pirelli Cables & Systems Oy)](image)

Line designs for 66/132kV HVCC systems are available$^{[38]}$ as is a comparison of cost/km for various 132kV alternatives$^{[27]}$. 
3 International standards and practices relating to CC

3.1 Europe

The first installations of CC in Europe were in Finland and that country was the first to produce a CC standard, quickly followed by Sweden and Norway.

3.1.1 UK

In the UK all utilities use the three UK standards ENATS 43-120, 121 and 122 but will use prEN50397 when it is finalised. In §4.1 the development of two early UK standards is described. These were combined into one set of UK standards which were effectively in use from 1998 but have been issued as:

- ENATS 43-120 Covered Conductor 1 to 33kV March 2002
- ENATS 43-121 Compact CC construction for single circuit wood pole lines January 2004 (draft)
- ENATS 43-122 Fittings for CC lines 1 to 33kV March 2002

These three standards are the most comprehensive standards for CC use that have been published world-wide to date. Together with the Austrian and Scandinavian standards they have been used to produce the current European CENELEC draft prEN50397. This relates to the conductor only. A second CENELEC standard will relate to CC fittings but this standard has progressed very little to date. The three UK standards were based initially on the Swedish and Finnish standards but progressed these to include a series of tests and informative sections. The Swedish standard included AAAC and ACSR and stated a minimum carbon black content of 2% in an XLPE sheath. However, Sweden now uses CC with 0 or 0.5% carbon black in an HDPE sheath[7]. It was the first standard to include a method of measuring the adhesion strength of the sheath and conductor. This was developed further in the UK standards.

The UK standards ENATS 43-122 and 120 were produced during a period of rapid change and developments in both the conductor and fittings. Most of these developments were due to tests carried out by EA Technology and also at the ABB Drammen works in Norway and Ensto Oy in Finland. ENATS 43-121 is the only CC standard world-wide to provide a detailed line design method which includes a software spreadsheet based programme for line design. Historically overhead line specifications in the UK generally provided information to the design engineer which eliminated the need for complicated calculations. This had been achieved by providing lookup tables which covered most situations encountered in the field. Each structure's capabilities were determined in relation to the conductor type and basic span. In addition to this, fixed wind and ice values were applied and traditional factors of safety used. Applying these factors, the maximum allowable wind spans, angles of deviation, gradients and strut loadings imposed on each structure could be compiled and tabulated.

ENATS 43-40 introduced a new approach which allowed the design engineer to consider various loading requirements and allow each structure or component on the overhead line to be stressed if necessary without the traditional factors of safety. ENATS 43-40 was produced to specifically address the requirements of the 1988 Electricity Supply Regulations. EATS 43-121 was compiled along the same basic lines as ENATS 43-40 to allow for the design of XLPE Covered Conductor overhead lines. The approach taken by the design committee was
to allow both the earlier deterministic and the more recent semi-probabilistic methods to be made available for the user. A description of the way the data is used is given in Appendix V.

A computer program was developed, in Microsoft Excel, which allowed the user the flexibility in design approach, and choice of conductor specific to the system requirements. A User Guide provides a description of the Microsoft Excel workbook spreadsheets and a worked example is provided in the standard with tabulated results.

**ENATS 43-122**
This standard covers compacted and uncompacted AAAC conductors up to 185mm² for networks from 1 to 33kV. It includes the safety and longitudinal water tightness tests from the Finnish standard, as well as stripping and slippage tests and calculations on current carrying capacity. The use of a stripping tool is specified. Specifications for UV stability are included and a carbon black content of 2.5%±0.5% is specified if an XLPE sheath is used. Routine and sample tests as well as electrical and bend tests are specified. The slippage tests specify loads and clamp design. The standard has 30 pages.

**ENATS 43-120**
This standard covers fittings for the conductors specified in ENATS 43-122. These include helical and compression fittings, insulation piercing connectors and arc protection devices. Tension and non-tension joints, Stockbridge and spiral vibration dampers are also included as are protection against corrosion and UV. A comprehensive series of routine and sample tests is provided for all types of fittings with particular emphasis on insulation piercing connectors (IPC). The use of IPCs for the attachment of earth leads and tests to confirm their integrity are covered in detail. Tests are provided for aeolian vibration measurement and also for tracking resistance. Appendices cover the tests in detail with drawings of the apparatus required. The standard has 36 pages.

**ENATS 43-121**
This standard covers installation and line design of CC systems on wood poles up to 33kV. The standard has 70 pages and comes with the design software on CD. The 2004 version has been amended to include various changes required by the BSEN50341 (2001) and BSEN50432 (2004) which cover overhead lines above and below 45kV respectively and also changes to bring it in line with the CENELEC draft prEN50397-1 (2003). It covers design data, materials and technical requirements (span lengths, failure containment, poles, crossarms, foundations etc) as well as lightning protection. It also includes a section on conductor erection guidance including pre-tensioning and over-tensioning and allowance for creep. For the latter a temperature shift of -10°C for 50mm² CC and -15°C for 120-185mm² CC. General assembly drawings and material lists are also provided for single and H-poles. A user guide for the Excel spreadsheet software is included as is a full description and a worked example.

**prEN 50397-1. (June 2003)**
This draft standard took the Scandinavian, Austrian and UK CC standards, as current in 2001, to produce a common European CC standard for lines between 1 and 36kV. As stated above, the current UK standard ENATS 43-121 (2004) already conforms to this draft standard. The standard is to be in two parts covering the conductor and fittings but the fittings section (prEN50397-2) has been subject to considerable delays. The current part 1 specifies a new designation for CC where typically:
**CX 66-Al3 WK 20kV**

is a compacted XLPE covered conductor of nominal 66mm² cross-section of aluminium alloy type Al3 with longitudinal water blocking and operating at 20kV.

The standard covers AAAC and ACSR compacted and uncompacted conductor up to 240mm² nominal conductor cross-section. Rather than designating the sheath material it sets target requirements which should be met. It therefore covers thermoplastics as well as XLPE. If carbon black is used it is specified as 2.5±0.5% content and the sheath thickness is to be a minimum of 0.11x(rated voltage in kV) with a minimum thickness of 2.3mm. This thickness does not include any semi-conductive screen which must be in addition to the sheath thickness.

The standard also includes an appendix on ‘special’ conductors which covers all currently available covered conductors on the market apart from those with copper conductors. The section on measurement of leakage current is from the Scandinavian and UK standards as is the slippage test section. Measurements of tracking resistance are specified and this is essentially based on IEC60587. The apparatus and technique are fully described.

### 3.1.2 Finland

**Standards**

- SFS 5792  Construction and arc protection for XLPE covered conductors
- SFS 4385  Insulator pins, line materials
- SFS-EN 10025  Structural steels
- SFS 2593  Aluminium alloy
- SFS 2663  Connector tests
- SFS 2765  Metallic coatings
- SFS 5791  12/20 kV XLPE covered conductors
- SFS-EN 10002-1  Tensile tests
- SFS-IEC 811-1-1  Sheath tests
- SFS-IEC 811-1-2  Sheath tests
- SFS-IEC 811-1-3  Sheath tests
- SFS-IEC 811-2-1  Sheath tests
- SFS-IEC 811-4-1  Sheath tests
- IEC 228  Conductors of insulated cables

**Conductor**

Normally, fully compacted aluminium alloy to Al2 (IEC 104 type A) covered with a black XLPE sheath. Voltage operation up to 24 kV. SFS 5791 covers details of the conductor material and sheath properties.

**Vibration**

The 1994 standard specified a maximum EDS tension of 35 N/mm² to avoid vibration problems. However, a later version reduces this to 30 N/mm². At levels above this, the use of vibration dampers is recommended.

**Arc Protection Devices (APDs)**
Finnish utilities have regulations covering APDs in their publication KL 134-89. The aim of APDs is to move the origin of any lightning-generated arc from the conductor to the consumable electrodes of the APD. The operation of this device requires moderate fault currents and narrow (< 700 mm) phase spacing\cite{5} (Figure 3.1). When this specification is modified for other countries the Ensto PAD (Power Arc Device – see §4.2) is more reliable.

![Finnish APD design showing direction of current flow](image1)

**Figure 3.1** Finnish APD design showing direction of current flow

**Construction**

The standard phase spacing for horizontal configuration is 450 mm with an insulator height of 260 mm. The vertical dual circuit configuration (Figure 3.2) has 550 mm spacing. The angle support structure for the horizontal allows a larger phase spacing of 900-1200 mm. The comparative EATS 43-121 specification (see below) is narrower than this. The Finnish angle vertical configuration, however, maintains the 550 mm phase spacing at the intermediate in-line pole (Figure 3.3).

![Vertical configuration of twin circuit poles](image2)

**Figure 3.2** Vertical configuration of twin circuit poles
The dead-end structure turns to the narrower phase spacing of 450 mm, increasing to 515 mm for an offset central pin. The cross-arms are steel or aluminium of 100 x 100 x 4 mm section. The standard sets a safety test method for measuring the leakage current and sets a limit of 1mA. This was developed further in the UK standard ENATS 43-122. The carbon black content of the sheath is set at 2-3%. This standard was the first to include installation methods including clamps, tensioning and jointing. The tension limits of 35 and 30N/mm² EDS were specified but this was later modified to 28N/mm² in the UK after problems in operation. It also included basic instructions that arc protection devices and vibration dampers should be used but with no specific details.

### 3.1.3 Sweden

The CC construction used in Sweden and Norway is based on the Swedish standards:

- SS 414 14 63 SLPE covered stranded aluminium alloy conductors
- SS 401 03 02 Cables
- SS 424 08 12 AlmgSi conductors
- SS 424 08 14 Al59
- SS 424 14 17 Tests for XLPE power cables
- SS 424 17 02 Type marking
- SS 436 01 02 Specifications for HV overhead lines
- SS 436 01 08 XLPE covered HV aluminium alloy conductors
- SS IEC 540 Tests for insulation

**Conductor**

The conductor is an uncompacted aluminium alloy, normally type Al2 (IEC 104 type A) designed to operate at 12-24 kV. Type Al59 is also used. The conductor is specified in the range 62 to 241 mm². The XLPE sheath has a nominal thickness of 2 mm. The carbon black must not be less than 2%.
**Mechanical Construction**

The standard inter-phase distance is 500 mm for horizontal configuration cross-arms. The cross-arms are often constructed of square section box aluminium and are 1.2 m wide for intermediate poles. This construction is similar to the Japanese standard, although galvanised steel is also used in Japan. The insulators are commonly porcelain (without the semi-conductive layer that is present on all UK insulators) or composite, with the future trend being to use composites throughout.

Vertical configuration is also used – often in twin circuit construction. In this construction, the insulators are mounted directly off a vertical cross-arm bolted to the pole (see Figure 3.2). The insulators may be angled upwards or downwards. This construction is narrower than the horizontal configuration but is more expensive for single circuit lines. Lightning protection is based on heavy bosses on the insulator fitting, allowing arcs between adjacent vertical phases. On the horizontal construction, lightning protection is based on the APD (see §4.2) principle (used initially also in the UK but later superseded by the power arc device (PAD) described in §6.3).

### 3.1.4 Norway

Norway produced a NEK 610 (1997) standard for CC up to 24kV. In common with many other standards it states that the sheath should be 2.3mm thick black XLPE with 2-3% carbon black content. The water blocking test is taken from the Finnish Standard.

### 3.1.5 Spain

Spain has published Iberdrola Standard NI 56.41.01 (2000) for CC lines up to 24kV. It specifically refers to CC use in forested and wildlife areas. The standard is very short and deals with AAAC and ACSR conductor sizes and sheath material and dimensions. It does not cover installation.

### 3.1.6 France

The company Cableries de Lens manufactures a wide range of bare, PVC and XLPE covered conductors to:

- **HN 33-S-23** 10 kV overhead line conductors

At the present time there is no consensus on line construction. France produced the CLC/TC20 (Manier-Pinet) standard in October, 2000 for CC lines up to 22kV and is based on IEC 61089 for the conductor and IEC 60502-2 for the sheath and the complete conductor. It does not cover installation. It covers AAAC conductor material only. The material is specified in accordance with IEC 60104. Compacted conductors are not included. The water blocking system is not defined and the sheath is stated as black XLPE. Certain routine and sample tests are defined, the water penetration test being taken from the Finnish standard. A specific UV test is described which is similar to that in the UK standard.
3.1.7 Other European countries

Most other CC users in Europe (Sweden, Finland, Norway, Serbia, Montenegro, Ireland) use the prEN 50397 (2005) standard. Austria produced a CLC/TC20(AT)40 in October, 1999. It relates to CC use up to 30kV with material according to EN50182. It states that the sheath should be black XLPE with a minimum carbon black content of 2%. A safety test is included which is taken from the Finnish standard SFS 5791. In Eastern Europe (Poland, Hungary, Estonia, etc.) use the simple PAS type conductor and so the Swedish standard. Israel uses the prEN 50397 standard. Other users within Europe currently use their national standards but will switch to the prEN 50397 when it is finalised.

3.2 USA

The CC types manufactured in the USA are to the following specifications:

- ASTM B 231, “Concentric Lay Stranded, Aluminium 1350 Conductors”.
- ASTM B 400, “Compact Round Concentric Lay Stranded Aluminium 1350 Conductors”.
- ASTM B 416, “Concentric Lay Stranded Aluminium Clad Steel Conductors”.
- ASTM B 502, “Aluminium Clad Steel Core Wire for Aluminium Conductors, Aluminium Clad Steel Reinforced”.
- ASTM B 549, “Concentric Lay Stranded Aluminium Conductors, Aluminium Clad Steel Reinforced”.
- ASTM D 1248, “Polyethylene Plastics Moulding and Extrusion Materials”.
- ICEA S-61-402, “Thermoplastic Insulated Wire and Cable for the Transmission and Distribution of Electrical Energy”.
- ICEA S-70-547, “Weather Resistant Polyolefin Covered Wire & Cable”.

The conductor shield (if present) shall be an extruded black semi conducting polymer meeting the physical requirements of ICEA S-61-402. The nominal thickness varies from 0.4 to 0.5mm depending on system voltage.

3.3 Brazil

Brazil basically follows the American method of spacer supports (Hendrix) for 8.7/15 kV XLPE covered conductor. The standards are:

- AB-2173 XLPE covered conductors to 25 kV
- IEC-587 Tracking tests
- ASTM D 2132 Tracking tests
- ASTM G26 Weathering tests.
Australia/New Zealand

The Australian/New Zealand standard AS/NZS 3675:2002 differs from the current European standards in several aspects:

1. The minimum CC sheath thickness is 2mm (1.7mm actually allowed) instead of 2.3mm
2. This minimum thickness is allowed at 33kV whereas prEN50397 states a thickness of 0.11xU mm where U is the network voltage in kV.
3. Conductor material restricted to AAAC whereas prEN50397 has wider range
4. The CCT thickness relates to single sheath and is considerably larger than in prEN50397.
5. No construction details
7. The water penetration test is less severe than UK and Finnish standards but more severe than prEN50397
8. The adhesion clamp specified has smoother jaws than that in UK Standard.
9. The dripping test is not present in European standards
10. The technical characteristics tables are more comprehensive than in European standards.
11. No fittings or line design details are included.

4 International experience of installation and operation

4.1 UK

In 1994 the Norwegian BLX conductor and line design was introduced into the UK by the NORWEB (now United Utilities) utility (Figure 4.1). Tests and trials of various CC types were carried out also for several other utilities including the then Southern Electric (now Scottish & Southern). These two companies developed their own design standards and started to install major quantities of the SAX conductor. Eventually these two designs were used in the generation of a single UK design standard EATS 43-121, conductor standard EATS 43-122, and fittings standard EATS 43-120. There is currently over 15,000km route length of CC installed in the UK.
Figure 4.1 The typical close spacing and compact construction of Norwegian CC lines which prompted the first use of CC in the UK.

Despite the knowledge of the Scandinavian experiences with CC, the UK tended to make the same mistakes in terms of tension levels, lightning protection and sheath problems. However, a substantial amount of work in looking at the CC failures, identifying and solving the problems led to the UK becoming one of the foremost countries in the world for successful use and knowledge of CC. This series of development is covered under the appropriate headings in §6.

Scottish Power was the first operator in the UK to use the EXCEL/AXCES system. After several trial projects Scottish Power have published a report\cite{79} that recommends the use of this cable system in their network.

4.2 Finland

The large area of forested terrain in Finland led to an early interest in the use of covered conductors, although this was initially concentrated on LV ABC. The interest in CC in Australia led to Finnish research in the late 1970s into covered conductors with the main impetus being the reduction of forest fires caused by trees falling onto bare overhead lines. The result of this work was the introduction of BLX or SAX into the Finnish 20 kV network. By 1989, Norway and Sweden followed this idea with research on a 22kV line at Flesberg showing that such conductors could withstand prolonged (6-9 months) contact with fallen trees with minimal mechanical problems. There were, however, discharges between the phases and between a phase conductor and the lying trees. At 24 kV this led to an earth fault in one case within 3 months. This sort of incident could lie undetected until damage had occurred to the line. However, this ability to maintain supplies under tree problems would allow maintenance and repair to be carried out more on a planned rather than an emergency basis.

Initially, a reduction of arcing due to clashing on bare wire lines was tried by introducing CC as the centre phase conductor only. However, problems with vibration fatigue led to research into tension levels for CC. Problems still occurred with downed conductors in lightning storms. This led to research in Sweden and Finland (Ensto Ltd) into a more reliable system
of arc protection devices (APD) called Power Arc Devices (PAD). These were successful in protecting the lines from lightning damage and significantly reduced outages compared with lines using the older APDs. This system has been taken up by most utilities in the UK. Currently Finland has 5000km of CC on 11/12kV and 22/24kV lines and Norway and Sweden around 4000km each. Although these represent only around 8% of the total of the 12 and 24kV OHL network in Scandinavia, the CC share of new construction and refurbishment schemes is around 60% generally and over 70% in Southern Norway\[46\].

4.3 Sweden

4.3.1 CC use

CC construction methods in Sweden have changed a lot since it first was introduced in 1984. This development has been done in cooperation with technical expertise from Swedish utilities and influence from other countries’ experience from CC. In 1984 no one in Sweden had any experience from CC systems. Finland had already used this system for many years and it was natural to start with their PAS system. One of the first areas in Sweden\[6\] where it was used was on the highlands in Småland, south east of Sweden. This was an area with a lot of snow and often windy and CC was installed to reduce faults due to snow-laden branches resting on the line (Figure 4.2) and clashing.

![Figure 4.2](image)

**Figure 4.2** Snow laden branches resting on a double circuit CC line in Sweden with no interruption to supply\[7\]

This PAS was a compacted XLPE covered conductor but, as normal Finnish practice, was not water blocked. Four years later in 1988, after a number of test installations had been made, the first Swedish Standard was released based on experience from these test installations. Two main changes were made when introducing the Swedish BLX.

One was the decision to use a non-compacted conductor construction. The reason for this was a belief that a compacted construction would cause vibration problems due to the lower self damping construction and the reduction of elongation to break in compacted construction. These beliefs were later confirmed by tests at EA Technology in the 1990’s which showed the low elongation values of compacted strands\[9\] and the improved vibration performance of
non-compacted conductor\[10\]. The other change was to make the conductor longitudinal water protected by filling the air gap inside with grease.

In beginning of the 1990’s, a large programme of building 20kV CC line was started in some areas in the south of Sweden by Forskraft. After a few years they started to have a number of broken lines due to fallen trees on the lines. Forskraft then made a series of tests on the BLX they used at this time. They also made many voltage tests on samples from different suppliers. From all these tests it was quite clear that the then BLX construction was very good on 10kV lines but could not withstand long-term phase-to-phase contact on lines operating at 20kV. The typical value for the standard voltage test in water was 17kV-18kV. At 24kV test voltage the conductor broke down in a few hours when the preferred time was to be at least 14 days. To get a better performance the standard was changed from 2.0mm wall thickness to 2.3mm. This gave some improvement but did not satisfy the entire customer’s requirement. Based on the experience from the Forskraft tests a new version of BLX was produced by AMO Kraft AB which had a semi conductive layer and a water-blocking compound instead of grease.

The method for water blocking had been developed in Australia and gave a major advantage of a dry conductor in combination with a non-compacted conductor and a non-slip covering. By extruding a semi-conductive layer over the conductor this construction could easily reach 24 kV for 48 hours in the voltage test in water. The old grease filled types currently employed were replaced by the new version over a period of a few years.

Carbon black filled XLPE also sets a limit for voltage capacity due to tracking problems. In order to improve the electrical performance a new type of CC was launched in 1997. This type has an insulating layer of pure XLPE with a reduction in carbon black and used AAAC or ACSR conductor. This increased the capacity up to 30kV for 2.3mm wall thickness.

Finally there was a move from cross-linked PE with maximum temperature of 80°C to a thermoplastic PE suitable for 60°C mainly for environmental purposes (easier to recycle than XLPE). The new BLL CC was a thermoplastic covered conductor with good electrical performance. This is now very popular in Sweden due to the greatly improved withstand time for phase-to-phase contact (now weeks rather than hours), improved vibration performance and better tracking resistance. CC in coastal areas must be tracking resistant to prevent breakdown due to leakage current on the surface of the covered conductor. This was tested in a salt fog chamber to ASTM 2303 by Amo Kraft AB\[6\] and to IEC 6071 by EATL\[11\].

### 4.3.2 Experience with aerial cable

A major storm in Sweden on 23 February, 1992 caused 154 line failures with 4500 trees falling onto overhead lines. Although 8% of the network at that time was BLX, none of these lines failed compared with 430 phase wire breaks and 127 pole failures on the bare wire network. Similar experience occurred in New Year storms in the UK in 2000 and 2001.

However, another major Swedish storm in January, 2005, saw many pole failures on CC lines. This was because of the strength of the narrow spaced CC line design which resulted in few conductor breaks but more stress on the poles. Lines using Axces and Excel cable (see §2.4) however had no cable failures or pole breaks (Figure 4.3). This was put down to the higher flexibility of this ‘Universal’ cable. Fortum, on the west cost of Sweden, have installed a lot of Universal cables and many of them were hit by the storm. None of the
AXCES installations were interrupted and most of the lighter EXCEL cable also maintained supplies. The few problems seen were related to the suspension clamps. A couple of clamps for EXCEL of ABC-type (Ensto SO99) lost their rubber insets when the cable slid in them and the cable was damaged from contact with the steel parts in the clamp. Apart from this problem, the Universal cables worked very well. Although the poles did not break, there is a limit for the poles and there is increasing use of suitable ‘weak links’ which effectively drop the conductor on the ground totally intact. If the cable comes down due to trees falling, the pole is saved and also the cable is fully insulated and so there are unlikely to be safety or fire problems. Weak links are used more widely in Central Europe and currently available from several sources (Pfisterer of Germany, among others, has links in use in Slovenia and Croatia on CC lines).

![Figure 4.3 The January, 2005, storm in Sweden with trees on an Axces line.](image)

### 4.4 Development of HVCC in Europe

At voltages above 45kV, the single sheath CC is not suitable and the multi-layer HVCC cable is used. Research by the (then) Nokia Cables and IVO Power Engineering in the late 1980’s and early 1990’s led to the construction of the first 110kV line in 1993. After some initial problems the first commercial 110kV line was installed on a steel tower line by Tuusulanjärven Energia near Helsinki airport in 1996. Further developments by IVO and Nokia Cables (now Pirelli Cables & Systems Oy) has led to a wood pole 110kV line installed near Tuuka in Finland (Figure 4.4) and a 110kV line in Silesia in southern Poland[^52].
4.5 Other European countries

France started to install CC in the early 1990’s but the market is quite small compared with Eastern Europe, the UK and Scandinavia. The main supplier is Câbleries de Lens. This is a single sheath compacted AAAC conductor. Spain and Italy are also moderate users of CC but the biggest current growth areas in Europe are Slovenia, Poland\(^{[81]}\) and Russia with Estonia also starting to install significant quantities. In Poland the installation rate of CC on 11kV networks has been exponential.

4.6 USA and South America

The north east USA is extensively forested and the driving force for installation of CC was resistance to outages and avoidance of fires. Initial CC use resulted in many tracking problems. Although some CC is installed in horizontal and triangular formation, more problems with vibration fatigue led to the extensive use of the Hendrix Spacer Cable (see §2.4 and Appendix IV) initially at 15kV and later at network voltages up to 69kV. Its use spread to the Caribbean islands and it is now extensively used in Brazil. The main drivers here are safety and avoidance of fires. Initially tree abrasion, UV instability, pollution and tracking caused problems. The early CC had 2.5 to 3mm thick XLPE sheath thickness but the Hendrix spacer cable began to be installed widely in the late 1980’s with few problems.

Problems that arose in some South American countries – conductor burn-down – were traced to the use of alternatively sourced non-standard manufacture of the spacers and the use of 600V rated CC on 11kV networks. This sort of inferior manufacture led to severe tracking and resultant fires.

In the North East part of the USA there has been extensive use of the Hendrix spacer cable for nearly 50 years – almost exclusively at 15 and 35kV – with no reported major problems.
4.7 Japan

Prior to 1972 there were many accidents with bare wire OHLs in Japan, due in part to the use of multiple voltages on the same pole and the extensive use of OHLs within cities (due to earthquake problems less than 1% of lines were undergrounded). Public access to OHLs was thus widespread. Line protectors (slide-on sheaths) were used where trees were a problem. Consideration was given in 1965 to switching over to CC use to remedy this problem and also to improve reliability and reduce customer minutes lost (CML). Perhaps the greatest amount of CC installed by one utility was in Kyushu Island in Japan where KEPCO changed its entire 74km 6.6kV overhead bare wire network to XLPE CC over a period of 10 years[13]. The main drivers were unreliability of the previous network and unacceptably high fatalities in employees and the general public. Increased safety levels (a reduction by a factor of 50 in accidents/year) and significant reductions in outages (total CML down to 3 minutes/year) were attained within the first few years of this change (Figure 4.5).

Figure 4.5 Effect of CC installation on accident rate in Kyushu island (Annual Report KEPCO)[13]

NGK are the major CC manufacturer in Japan. Lightning is a major concern here and the use solely of arc gap devices led to some initial line failures. Lightning protection was therefore changed to the Current Limiting Arcing Horn (CLAH – Figure 4.6) which is essentially an arrester mounted beneath the tension insulators (and occasionally parallel to pin/post insulators). There is a small gap at the live terminal of the arrester which keeps it isolated from other network overvoltages.

As the spans are relatively short, often less than 50m, vibration is not a problem in Japan.
Salt pollution was also a concern in Japan, however, as this could lead to tracking. After initial problems using helical fittings (tracking occurred due to the high electric field at the end of the fitting), the network was then switched to the use of compression fittings with plastic covers to avoid moisture ingress. This system works because of the high rainfall which washes off the salt pollution. It is unlikely to be as effective in areas of low rainfall. Copper conductor is used in some of the smaller islands but aluminium is by far the most common material.

Conductor breakage was considered a major problem. The effect of this was reduced initially by the use of distribution protective relays but these had restricted success. Finally, the possibility of live CC being on the ground after a breakage was eliminated by the use of phase current metering units in all pole mounted transformers. Any detection of phase current instability causes automatic switchgear isolation of that line section. The operation time is less than 1 second.

4.8 Australia

Covered conductors have been used in America and Australia for over 40 years. However, the initial coverings of PVC, high-density polyethylene (HDPE) and nylon gave very limited lifetimes, suffered surface degradation and were also subject to failure due to lightning damage. Problems with the use of bare overhead lines, especially when conductor breakages did not activate line protection devices, led to increased research into covered lines. Low voltage ABC came into widespread use, but the expense and other problems associated with the semi-conducting external layer restricted the use of the high voltage version of this conductor. Safety considerations (both human and wildlife), conductor clashing and tree problems, and the generally ageing medium voltage distribution networks, led to a re-consideration of the use of covered conductors in the period 1985-90. This process led to their development as one alternative to undergrounding the medium voltage system. A series of severe bush fires in Australia was blamed on arcing from the clashing of bare OHL conductors. Undergrounding was not considered a generally viable alternative due to frequent disturbances from human activities and tree growth and the high cost of repair. The high costs and short span lengths associated with fully insulated overhead systems such as HV ABC led to the development of CC conductor. The initial use of CC showed up problems of corrosion at mid span and at terminal clamps.
Early water blocking systems using a soft mastic compound caused problems in conductor stripping and high temperature stability. This was replaced by the Japanese technique of applying a non-conductive layer of ethylene vinyl acetate (EVA) to each layer of the conductor under high temperature and pressure with a final external layer, which is bonded to an XLPE external sheath on extrusion and curing. The completed conductor is intended to provide a watertight seal even at an open bare end without the need for an insulating wrap. The XLPE thickness of CC is 2.0 mm. This gave a failure rate of 80 days when exposed to abrasion by trees. To extend this period, another version, CCT, was introduced with thicker (2.3 mm) insulation. The increased diameter, however, increases the wind loading and reduces the maximum span length.

In 1987, cable failures in Italy of grey peroxide cross-linked insulated cables were put down to excessive weathering degradation. This led to a more stringent UV stability test standard using radiation down to 235 nm. Polyethylene has a maximum sensitivity to radiation of around 300 nm.

Conventional methods of improving weathering include the addition of carbon black, inorganic pigments and organic stabilisers. However, the Australian requirement of a grey insulation restricted the choices available. A balance had to be struck between good weathering, mechanical strength and expense. In the final choice (named BPH 526) the titanium oxide level was increased by a factor of three compared with HFDM 4292. This satisfied the new Italian standard and, after further trials, was also accepted by the Electricity Trust of South Australia (ETSA).

Western Power Corporation (WPC) recently addressed the problem of a fatality in 2001 due to a yacht’s mast touching bare OHL conductors by installing the Hendrix Spacer Cable on 22kV lines for a 2km river crossing over the Swan River in Western Australia [12]. They looked into several options including raising and replacing the existing bare conductor with a covered conductor. Initial consideration of HV ABC was rejected due to the risk of sheath damage by cockatoos, lightning and earth fault protection and the high cost. The use of CCT was discontinued due to the long span length problem and the thinner layer CC was rejected due to poor reliability issues. Some other CC designs were evaluated and the Spacer Cable option proved most satisfactory. In this design the whole weight of the installation is carried by the messenger, which is tensioned approximately up to one tonne. This was the strongest solution mechanically and the hard surface resisted the cockatoos chewing. Lightning protection was possible due to the elevated messenger (encased within the phase bundle in ABC) and the good visibility of the system would reduce bird collisions. The spacer cable was installed in 2004. The Spacer Cable was approximately 9% of total cost, whereas HV ABC was calculated as being at least 14% of total cost[12].

5 Historical problems of CC use in Australia

5.1 General

One real concern for all utilities is improvement in reliability. Australian utilities quickly found in the past that installing reclosers, improved switchgear and fault indicators could achieve a big improvement in reliability but there was a limit to the improvements that this technology alone could achieve. With the government and local communities paying hefty subsidies undergrounding sections of the network was tried but was ultimately too expensive
for the returns in reliability. There were also problems with the various environmental
lobbies where tree roots were being disturbed.

To get round these problems some Australian utilities had tried CC many years ago (prior to
modern plastics) and it had been an unmitigated failure. Most were pulled out as a result of
**RF emissions** and **burn-down** at insulators. (Burn-down is where the conductor burns
through or melts and falls to the ground.) In the late 1980’s, after a series of horrendous
bushfires, South Australia began installing CC with modern XLPE plastics but within about 2
years it was found that CC was **incapable of handling anything more than momentary contact** and airborne bark and tree debris lodging on the CC quickly led to RF emissions,
burn-through and numerous other problems. The Australian market then went to the greater
thickness CCT similar to the thickness of XLPE and HDPE used in the USA but did not
adopt the triple extrusion system also becoming common there. So although CCT was
considerably better than CC, it still had problems with long term contact with trees and an
ancillary problem of **badly matched insulation systems**. In one case the installation of a 4
metre jumper of CCT at 22kV on a 66kV post insulator in a high pollution zone generated
**severe RF emissions** within months as **tracking current interacted badly with the ties** on
the insulator.

The next major issue was economic lightning protection. It has been shown (§4.9) that the
CC widely used in Japan is on 6.6kV systems (Australia use 11, 22 and 33kV as distribution
voltages) and to overcome lightning burn-down, the Japanese use surge arresters with arc
gaps at every pole. As shown later (§6.4) CC behaves differently from bare wire when hit by
**lightning** and can quickly burn through, resulting in a downed conductor that no sensitive
earth fault relay can detect and one that is just waiting for a member of the public to pick up.
The Japanese arrester (CLAH) solution was considered an expensive option. A reduced
system of arresters **every fifth pole** based on local lightning intensity was tried in Australia
but **burn-downs still occurred**.

With the need to install arresters regularly the conductor needs to be bared. Australian
utilities went to water blocked HV CCT. The problem is that **stripping water blocked CCT
is not easy and has lead to some very serious injuries** to line staff because although there
are tools to take off the plastic it simply can’t remove the water blocking which by its nature
must adhere to the conductor very strongly.

The other competing design in Australia at 11kV is **HVABC** using a non-metallic screen on
each cable with all cables wrapped around an AAAC catenary. This looked **unsightly** and
had to use **very short span length**. The system also often proved more **expensive** than
undergrounding and, due to recurring faults caused by **birds** and the high cost of using cable
jointing technology its use was discontinued.

So it appears that the Australian Utilities considered these various types of CC as being a
preliminary and therefore **suboptimal design** and many are not prepared yet to adopt spacer
technology, considering it a **niche application**. Another point about all unscreened insulated
systems is that the **pollution** level is critical. Some CC systems, due to **poor sheath
material choice or line design**, can reach a pollution level that leads to system failure which
is exacerbated by a poor combination of insulation systems, terminations etc.
5.2 Concerns

Current concerns for CC use in Australia appear to centre on several major disadvantages of covered conductor use that were perceived in the early 1990’s. These may be summarized as:

Cost
- full installation costs are 10% to 20% more than for bare lines

Reliability Problems
- damage to the line by lightning strike or tree rubbing is difficult to detect
- insulation damage can lead to corrosion problems
- leakage currents at pin insulators can cause insulation damage in polluted environments (e.g. salt fogs)
- aeolian vibration is greater with BLX/CC/T than with bare lines and could cause premature failure
- care must be taken in the installation and maintenance of lines not to damage the insulation
- discharges between the helically preformed tie and the arc protection device wire and poor connection of the device can both cause radio interference

Supply Quality
- special attention needs to be paid to lightning protection which would not be needed in the case of bare lines
- the frequent use of arc gaps in the lightning protection of BLX/CC/T lines can lead to problems with the quality of supply

Safety
- some possibilities of bird and small animal electrocution at pole top arc gaps
- possible problems with conductor failure detection.

These problem areas are addressed in the next section.

6 Problems and issues encountered

6.1 Aeolian Vibration limits

Original installations of CC around the world often had problems of conductor failure due to being over-tensioned. This resulted in vibration related fatigue failures commonly at the compression fitting on the line. Lines were erected at similar tensions to bare conductors and the effect of the conductor sheath and the reduced level of self-damping in compacted CC were not appreciated. A series of tests in service \(^{[19, 20, 33, 35, 78]}\) and at specific test sites \(^{[21, 27, 32, 34]}\) on a range of CC types and sizes for use up to 132kV resulted in definitive values of tensions for AAAC conductors of 50, 120 and 185 mm\(^2\) of compacted and uncompacted types for sheath thicknesses of 2.3 and 3.3 mm. A small amount of work was done on copper \(^{[24]}\) and ACSR\(^{[31]}\) conductors and on modified sheaths\(^{[25]}\). The copper tests indicated that this CC type could be strung at higher tensions than the equivalent bare AAAC conductor and the modified sheath tests indicated substantial gains in allowable tension limits.
In addition, the effects of the support system (compression and helical fittings) and of spiral vibration dampers on allowable conductor tension was also determined \cite{29, 30}. As with all vibration measurements, the effect of local weather conditions and turbulence due to local terrain factors need to be considered. The effect of terrain on vibration has been covered by recent Cigré work\cite{18} and the approximate relationship in allowable tensions evaluated (Table 6.1).

Cigré gives a direct relationship between the span length, \( L \), conductor diameter, \( D \), and conductor mass, \( M \), expressed as a factor \( LD/M \) and the conductor tension, \( H \), and weight/unit length, \( W \), as a factor \( H/W \). This is not strictly applicable to covered conductors but the general pattern of behaviour is the same. The allowable maximum tension levels to avoid line failures due to aeolian vibration are reduced as \( L \) increases but increase as \( D/M \) decreases. The latter point has been confirmed in EATL tests\cite{21}. The overall diameter of a CC is determined to considerable extent by the sheath thickness – especially for smaller conductors. The mass of the CC, however, is determined mainly by the metal conductor. So, if the sheath thickness is constant at 2.3 mm (as is common for use at 11 kV), then conductors of increasing mass, i.e. 50, 120, 185 mm\(^2\) etc will be able to be strung at increasingly higher tensions. On top of this, the use of spiral vibration dampers again increases the allowable tension (as shown in EATL tests).

The allowable tension for a given conductor also increases with increasing air turbulence which in turn increases with increasing roughness of terrain. Four terrain types are defined in Table 6.1 along with the corresponding values of turbulence and allowable tension-to-weight ratios \( H/W \).

**Table 6.1**  Terrain types with corresponding turbulence\cite{18, 41, 74} and \( H/W \)\cite{42} values

<table>
<thead>
<tr>
<th>Terrain type</th>
<th>Terrain description</th>
<th>Turbulence %</th>
<th>tension/weight factor ( H/W )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Open water or desert, snow cover, no trees, no obstructions</td>
<td>8%</td>
<td>1000</td>
</tr>
<tr>
<td>2</td>
<td>Open, flat rural areas with no obstructions and few and low obstacles</td>
<td>15%</td>
<td>1125</td>
</tr>
<tr>
<td>3</td>
<td>Open, flat or undulating. Low density housing, open woodland with hedgerows and small trees, prairie, tundra.</td>
<td>22%</td>
<td>1225</td>
</tr>
<tr>
<td>4</td>
<td>Built-up areas with some trees and buildings e.g. suburbs, small towns, woodlands and shrubs, broken country with large trees, small fields with hedges.</td>
<td>30%</td>
<td>1425</td>
</tr>
</tbody>
</table>

The turbulence values in Table 6.1 can be reduced in low wind speed (< 10 m/s) and cold conditions as the atmosphere tends to stratify closer to the ground. At higher wind speeds, the values are more consistent and reliable.

EATL tests confirmed this behaviour when comparing the vibration limits of same size CC at 2.3 and 3.3 mm thickness sheaths (reduced tension)\cite{28} and the effect of the extent of conductor compaction (increased compaction reduces allowable tension)\cite{71}.
The tension levels indicated by the EATL work are contained within the current UK standard ENATS 43-121. These data assume a terrain type 2. In open flat terrain in Australia, a lower value related to terrain type 1 may be more appropriate. In terrain of type 2 or 3, the ENATS data may be used.

In several of the examinations of failed CC lines by EATL\textsuperscript{19, 20, 33, 35} the cause was the damage (e.g. knife cuts) caused to the metallic conductor when stripping the sheath for compression fittings. Modern CC types combine easily strippable sheaths with appropriately designed tools. This has reduced vibration failures significantly. Training courses are also available\textsuperscript{43} from EATL for linesmen not used to CC installation.

Field experience\textsuperscript{51, 53} has indicated that when properly controlled, vibration fatigue can be avoided.

### 6.2 Abrasion

Abrasion of the conductor sheath can come from contact with trees and clashing under normal operation. It can also come from contact with cross-arms or fallen trees on the line and permanently with the other phases in fault situations and storms. Abrasion can be mechanical or include some erosion due to micro-discharges phase-phase, phase-earth or phase-tree or cross-arm etc. Covered conductors commonly are either made of single hard material such as XLPE or HDPE or have a hard abrasive surface layer of these materials over a softer, typically PE, material.

EA Technology have carried out a series of tests covering abrasion with branches using an oscillating machine, trees actually on a CC line\textsuperscript{29} and clashing live phases at up to 33 kV on an oscillating machine\textsuperscript{76}. The abrasion rate for tree branches varies with the tree type but, in general, the abrasion level was not significant – taking several months before any significant mechanical damage occurred. The trees on the line caused even less damage. Experiments in Finland showed that live CC lines lasted 6-9 months with trees on the line before micro-discharges cause an earth fault. The clashing experiments\textsuperscript{76} showed that, even at 33 kV, clashing for up to one million times caused only minor, insignificant abrasion. These tests were considered equivalent to around 1000 storms of one hour each with continuous clashing at the same point on both conductors. Even at that, the damage was so slight that there would be no danger of conductor failure or system outage. In conclusion, therefore, there appears to be no problem from these conductors clashing on 33 kV networks.

Experience in Poland\textsuperscript{81} showed that there were many cases of trees or branches falling onto CC lines without any disturbances of the lines normal operation. In two distribution companies there were also several cases of trees rubbing on the conductor insulation without any disturbances to the line operation.

Mechanical abrasion is therefore not seen as a problem for CC lines using currently available conductors. Electrical degradation, however, is more serious and electrical tests on live CC breakdown on earthed cross-arms is reported in §6.3
6.3 Electrical withstand

Original CC types occasionally used sheath thicknesses down to 1.6 mm. In the case of fitting failures occasioning contact of the live CC with the cross-arm the sheath would break down in a very short time (a few minutes). Tests were conducted by EATL \cite{76} on the time to breakdown of single and triple extruded CC types, compacted and uncompacted at 11 kV and 33 kV. To reduce contact problems the tests were carried out in an earthed water tank and the time to sheath failure noted. The CC types with 2.3 mm thick single sheaths had very short lifetimes when in contact with earthed cross-arms. For 3.3 mm single sheaths, the time was extended significantly at 11 kV but was still very short at 33 kV. Triple extruded CC types lasted far longer - up to several months. The problem can also arise on long slack spans if the phases become crossed. Tests on this were carried out with two CC coils in a water tank and the time to failure with network voltage between the coils was measured. The results were similar to those for single CC failure to earth. The use of triple sheathed CC is thus the best choice for long term electrical withstand for trees, crossarms and with adjacent phases.

6.4 Lightning Protection

Lightning protection is essential for overhead CC lines. If a bare wire line is struck by lightning then a phase-phase flashover can occur at pole-tops. The arc generated will then travel along the line between the phases towards the load. Protection is then required at the equipment. If a CC line is struck by lightning any arc generated cannot move because of the sheath. Calculations indicate that a 50 mm² CC will burn through in an earth-fault-generated arc within one second. It is therefore essential to provide efficient lightning protection.

Two systems are currently in use following research by EATL\cite{36} into optimum lightning protection. The most common system is to use a power arc device (PAD) as shown in Figure 6.1, where the arc is deliberately initiated at purpose-designed electrodes and not on the conductor. These have operated successfully in Scandinavia and the UK for many years.

The second system is the Arc Protection Device (APD) shown in Figure 6.2 (and also, in use, in Figure 4.1). These can only operate successfully at high (>1 kA) fault currents and narrow phase spacing (<700 mm).

Further systems include surge arresters, either the LISA (line insulator surge arrester) on trial on an 11 kV network in the southern UK or the CLAH (current limiting arcing horn – Figure 4.6) commonly used in Japan. These reduce the lightning surge voltage and avoid circuit breaker operation and so maintain supply quality.

The PAD system requires circuit breaker operation and so affects supply quality by interrupting the supply for the down time of the circuit breaker (100 ms up to one second). It is however relatively cheap – adding only around £300/km to line costs for installation. The LISA and CLAH systems deliver good supply quality but can cost up to £1000/km for installation. EA Technology research indicated that protection needs to be applied at less than 300 m intervals and this is currently interpreted in the UK as every other pole in a distribution network.
The initial use of APDs in Scandinavia and the UK caused many problems due to the restrictions on phase spacing and fault current levels and inadequate insulation piercing connectors (IPCs). These also contributed to surface tracking problems. During the late 1990s improvements in IPCs and the greater use of PADs have been shown to deal with the lightning problem to the satisfaction of European utilities. Figure 6.3 shows a compression fitting IPC which is in widespread use in the UK. It can be seen that the solid contact made with the conductor and sheath means that moisture ingress is avoided and good contact is made with the conductor. UK utilities also use this type of IPC for earth connections when working on CC lines. Figure 6.4 shows the components of the compression fitting and an example of a conductor showing the teeth penetration. Application of this IPC type eliminates any variation due to linesmen.
An EATL review of lightning protection for CC lines\textsuperscript{[36]} covers the general theory of strikes to CC lines as well as the damage likely to be caused. It incorporates estimates of lightning frequency and risk and the full range of available lightning protection devices. It deals with the effectiveness of each device and their optimum use and position. The historical performance of such types is also reviewed and a cost-benefit analysis is included as well as recommendations. The report is applicable to CC lines world-wide.

### 6.5 Line Design and refurbishment

As indicated earlier in this report, CC line design in the UK initially used the Norwegian standard and then developed into standards by United Utilities and Scottish and Southern Energy. These were combined and updated in 1997 into a unified UK specification. The latest form of this line design – which incorporates CENELEC standards BSEN 50432 and prEN50397 – is in ENATS 43-121 (2003). This includes the line tension requirements and
allows levels of wind and ice loads to be specified. This design package has been in use in the UK for the last 8 years and has proved satisfactory for the current UK CC types. It allows the input of new conductor types by the provision of a database within the standard. There is no reason why this line design software cannot be applied in the Australian environment.

This line design package has also been applied[37] to the refurbishment of existing bare wire lines with CC, indicating the necessary pole changes required (if necessary) to maintain the existing span lengths. This has been used by several UK utilities at 11-33 kV [39, 40]. This system could also be applied to existing Australian bare wire lines for retro-fitting CC. The software is very flexible and allows specific environmental as well as mechanical values to be inputted. A demonstration of this software could be arranged under Phase 2 of this project if required. It has also been used to design 66 and 132kV wood pole CC OHL systems[38].

6.6 Insulator choice – avoiding mis-matching insulation systems

In bare wire systems the dielectric constant of the insulator used to support the line is of little significance as all the voltage drop is across the insulator. In CC systems, the voltage drop is split between the sheath and the insulator (pin, post or tension). In order to reduce the possibility of surface tracking on the conductor to a minimum it is necessary to reduce the voltage gradient along and across the sheath. A porcelain insulator has 3 times the dielectric constant of a polymeric insulator. It thus forces a larger percentage of the voltage drop to be across the sheath. With a polymeric insulator, especially one matched (e.g. of HDPE manufacture) to the CC sheath, the voltage gradient across the sheath is substantially reduced. This has been shown in salt fog [11] tests and also field experience in the UK. Calculations of the electric field strength around porcelain and glass insulators on CC lines have shown the high voltages that can be present on the conductor sheath surface[82]. The use of polymeric insulators with CC lines is thus strongly recommended.

6.7 Corrosion

This section covers corrosion to the metallic conductor itself. Corrosion of fittings is covered in §6.9. Corrosion of the conductor can occur, especially in salt polluted environments, where there is moisture ingress, either locally or along an extended section due to moisture travel along the strands. CC must be chosen to suit the particular environment in which it is used. Commonly in Sweden and Finland, CC is ‘dry’, i.e. not greased, as salt pollution is minimal. In Norway and UK, coastal salt pollution requires a CC which inhibits both local corrosion and moisture travel.

Corrosion tests were carried out both in the field and under laboratory conditions[9, 11, 19-21, 29, 44-46, 73]. These tests included artificially damaged CC (abrasion, knife cuts, shotgun damage and electrical arc and mechanically drilled holes to simulate the damage due to a lightning strike, as well as the efficiency of IPCs to seal effectively the sheath and so avoid local moisture ingress. The laboratory tests were carried according to ISO 9227 and covered 16 different CC samples, including the CCT Midland Metal type used in Australia in the early 1990s. There were distinct differences in the corrosion levels of CC types with different moisture ingress protection techniques. There were also indications that corrosion could accelerate in some CC types as the inherent corrosion protection of aluminium oxide was overcome as the trials progressed. Embrittlement of some CC strands was also noticeable.
The laboratory tests were confirmed by field tests at the EATL test site in the Shetland Isles off the north Scottish coast. This is a heavily salt polluted area. The tests showed a difference between aluminium alloy types – the CCT type showing least corrosion damage. In all the tests, the use of grease was noticeable for its protective capabilities. However, grease also tends to reduce sheath – conductor adhesion and thus affect installation methods.

Corrosion tests were carried out over a 6-year period at Lista on the southern Norwegian coast\(^{45}\). This area is renowned for salt winds from all directions except north, and for corrosion problems with bare wire OHLs. The test setup was a series of dedicated test frames as well as sections of the local MV network at different distances from the coast. The test was run by EFI (Norwegian Electric Power Research Institute) and the data has been reported\(^{45, 46}\). Artificial damage (cuts, abrasions, shotgun pellets, etc) was made to the CC. The results showed that localised (single strand) galvanic corrosion occurred at the contact point between the shotgun pellets and the covered conductor material. Modest corrosion occurred in the open cut damage areas and insignificant corrosion in the cases of abrasion. All the corrosion slowed down significantly after the first 2 years. The general conclusion was that greased products gave the best corrosion resistant performance and that the most common source of damage found was due to faulty installation and not damage in service.

### 6.8 Conductor Material

As has already been indicated in the previous sections, the conductor material (metal) can have a significant effect on corrosion and vibration levels. Three types of aluminium alloy are widely used (Al2, Al3 and Al6071 as defined in IEC 104) as well as hard-drawn copper and AACSR. There are problems with a steel-cored conductor in restricting moisture penetration, as the steel cannot be compacted. Also it is larger in size compared with AAAC, which results in increased windage and increased vibration\(^{30}\). The use of copper reduces the H/W parameter and also the conductor diameter due to its higher density. It is also considerably more corrosion resistant than AAAC. It performed well in the EATL field site tests\(^{24}\) but there may be problems with the use of IPCs in making good contact with the copper. This material has not been thoroughly investigated as the expense of using copper CC has so far outweighed the advantages.

The two AAAC types (Al2 and Al3) in common use in Europe are similar in characteristics and show little difference in corrosion or vibration performance\(^{44, 45}\). The biggest difference in performance in both these areas comes in the degree or otherwise of compaction. Compaction reduces the overall conductor size and hence the windage, but it also reduces the self-damping performance and tends to embrittle the conductor (typically compacting the strands reduces their elongation at UTS from 4% to 1.5%). Compaction, however, also significantly reduces water penetration along the strands. Tests\(^{26}\) indicated that the difference in penetration in the standard test in ENATS 43-122 is over 2 orders of magnitude between compacted and uncompacted versions.

The Swedish CC tends to use the Al6071 aluminium alloy. This is more corrosion resistant than Al2 or Al3.

An investigation into the tension requirements for alternative conductor materials on CC lines has been made\(^{72}\). This uses the ENATS 43-121 software and the aim was to find an optimum conductor material for refurbishment with CC on bare wire lines. The study looked at AAAC, copper, AACSR, ACSR and ACAR (aluminium conductor aluminium reinforced).
It concluded that AAAC and ACSR were the most suitable materials for refurbishing bare wire lines but that AACSR could prove most suitable for new construction as it combined lower sag and better vibration performance.

6.9 Sheath material

There are basically only 2 basic types of CC sheath in use – XLPE or HDPE. The XLPE can have carbon content typically of 2.5 to 3% but for one manufacturer down to 0.5%. HDPE commonly has zero carbon content, using TiO₂ as the UV inhibitor. This material may be the same for the whole sheath – as in single sheath CC – or may only form the outer abrasion and UV resistant layer. For the central layer of most triple-extruded systems, ordinary polyethylene (PE) is commonly used, both for its effective insulation properties and cheapness. A thin XLPE semi-conductive layer is now commonly used on the metal conductor to equalise electrical field effects.

UV degradation tests were carried out using a ‘weatherometer’ rig to ASTM G26 and an ‘EDF chamber’ to IEC 1109⁴⁴, ⁴⁵. The weatherometer uses ozone to test the CC sheath and does not have a wash cycle. The EDF chamber uses a daylight type UV source, a rain cycle and a salt-fog cycle. UV degradation is determined by surface resistivity measurements. The European manufactured XLPE and HDPE samples performed satisfactorily under these tests, but the Australian CCT type performed the worst and was also unsatisfactory. It is evident that carbon black is the best UV inhibitor.

Salt-fog tracking tests were also carried out in several tests¹¹, ⁴⁴, ⁷³ and indicated that the presence of carbon black tends to make the sheath susceptible to surface tracking and eventual damage. These two results for carbon black confirm the need to specify the correct sheath type for the local environment. High UV areas with no pollution may need high carbon black XLPE sheaths but, in polluted areas, the use of carbon black is not beneficial. In cases where both characteristics are present, the effect of tracking can be reduced by avoiding high electrical stresses by ‘shorting out’ IPCs to helical fittings and/or using HDPE insulators instead of porcelain. This situation is discussed in more detail in the following section.

6.10 Tracking and the use of ties

As the CC sheath is insulating (but not insulated) there will be a low level charging current flowing along its surface. This arises because the sheath forms an insulating layer between the high voltage conductor (metal) and the pin or post insulator to earth. This current will normally be less than 0.3mA. Its characteristics are:

- Current inevitably flows phase-phase or phase-ground
- Current must be low to reduce tracking and erosion, especially under polluted conditions
- Metal helical ties form an intermediate electrode and can cause discharge problems at the ends (if bare)

In cases of surface damage or local pollution, this current can increase sufficiently to cause surface tracking, eventual sheath damage and subsequent conductor failure.
Tracking has been mentioned as a problem with covered conductors with high carbon black contents in the sheath material\textsuperscript{[48, 55]}. The carbon black is there as a very effective and cheap UV inhibitor. HDPE materials tend to use the more expensive Titanium Dioxide as an inhibitor. This does not have the same tendency towards tracking. Tracking results from surface voltage stresses typically between insulation piercing connectors (IPCs) and helical fittings that are not at network voltage. In a highly salt polluted environment such as within 10km of the UK coastline, tracking can reduce conductor lifetimes to a few years (see Figure 6.5). There are several ways to reduce tracking problems:

1. Reducing voltage stress (using polymeric instead of porcelain insulators, connecting helical ties with any insulating piercing connectors (IPCs))
2. Using crimp connectors instead of electrically ‘floating’ helical ties.
3. Using reduced or zero carbon content sheath materials.

Figure 6.5 Surface tracking on an XLPE covered conductor used with porcelain insulators

Tracking can cause radio interference problems and this is covered in §6.13.

6.11 Burn-down of CC

Burn-down is when a conductor burns through or melts and falls to the ground, often as a result of lightning strikes. A CC line can suffer burn-down due to lightning strikes, excessive tracking over time, vibration fatigue or trees on the line. Burn-down due to arc generation from a lightning strike was a problem for CC lines in Scandinavia and the UK in the late 1980s and early 1990s\textsuperscript{[20]}. However, the use of improved lightning protection systems (see §6.4) has virtually eliminated this problem.

Burn-down due to excessive surface tracking currents has also occurred\textsuperscript{[77]}. This has occasionally led to problems with melting or burning of fitting covers at pole tops but nothing has been reported in the UK since 1997. Covers made to ENATS 43-120 are fire-retardant and do not exhibit this problem. Despite this, it is recommended that the surface tracking current levels be kept down to below 0.5mA by the methods described in §6.9 and §6.10. If lines do come down, then detection of this event is of great importance and this is covered in §6.13.
Another cause of CC burn-down is clashing of damaged CC. This is covered in §6.12.

The risk of burn-down can be reduced by suitable lightning protection systems, reduction of electrical stresses, improved tree cutting, reduced carbon content in the sheath material, and correct installation and tensioning.

### 6.12 Clashing

Clashing of bare overhead lines can draw arcs and cause poor supply quality, due to the need for circuit breaker operation. Clashing of CC lines in an undamaged condition is not a problem. Tests of clashing at voltages up to 33 kV have shown that, even for one million contacts, there is no problem.

One scenario where this may become a problem, however, is in the treatment of CC installation in the same way as bare conductor. In installation, the conductor sheath must not be damaged, as this can lead to arcs being drawn at the point of damage when clashing. This confirms the importance of training linesmen in CC installation – a process that is carried out by EATL in the UK[76]. Examples of bad practice are where the CC is dragged over stone walls or even driven over when on the ground. In one instance, the treads of a tracked vehicle could be identified on a CC conductor that had come down due to clashing. The tracks had exposed the bare conductor. The difference in a CC line if this occurs is that any arc generated will not travel (as on a bare wire line) but will stay in one place and is likely to burn-down the line.

### 6.13 Detection of a downed Conductor

This section looks at the detection of a downed CC, whatever the cause. The most common technique – the sensitive earth fault (SEF) system – generally operates successfully in the case of line failure and switches out the circuit[16]. However, in some cases, the SEF system will fail to detect a broken conductor (e.g. when the broken end is not in contact with the ground) and so an additional system is being developed for the 110 kV CC network in Finland[17].

A survey[16] was made of alternative techniques to detect a downed CC for the UK utilities operating this system in 1997. This concluded that the sensitivity of SEF protection may be insufficient when used with covered conductors because of the potential for extremely low fault currents to be drawn when only covered sections of the conductor are in contact with the ground. The survey also indicated that non-detection of failed CC lines by SEF was in general similar to the failure of SEF to detect downed bare conductors. A similar situation with bare conductors was noted in Finland[17; 50] when these came down over bare rocky ground. However, a different method, using the asymmetry of unbalanced load current in the 3 phases was investigated. Digital protection relays can compare phase currents and so a broken conductor can be detected by present equipment. However, a downed CC a long way from the relay may only generate a small imbalance. If this is below 10% of the nominal relay current then the system will fail to detect it. The UK survey concluded that:

1. Techniques making use of ‘intelligent’ analysis of measured parameters do not appear to be sufficiently mature for immediate consideration.
2. Fault locators using arc noise have potential but require further development
3. Three systems appear to offer a viable route to practical systems:
   a. Enhanced residual current and neutral voltage analysis techniques
   b. Phase current imbalance monitoring techniques
   c. HV and/or LV voltage detection techniques.

The use of zero sequence earth voltage relays can detect downed CC. The neutral voltage will rise if one phase is down and this system is useful in detecting high impedance faults (up to 100 kΩ). However, the fault location cannot be determined and so this system can only be used as an alarm.

Another method of detecting downed CC a long way from the relay is to use terminal phase voltage measurement. This is possible using modern modems and can be used at distances of up to 30 km from the relay. The problem here is expense.

The current situation in the UK is that increased knowledge of lightning protection, vibration limits and tracking problems has resulted in a major reduction in downed CC incidents and that in these cases SEF is considered adequate until a proven cost-effective system is available. One UK utility reported that, in their experience, the conductor does not retreat into the XLPE covering but makes sufficient contact with the ground to operate SEF and trip the circuit. Another UK utility reported that protection would operate when CCs were grounded but not when conductors came to rest on hedges and fences. This pattern is also present on bare wire lines.

In summary, the experience of downed conductors in the UK is:

1. In incidents where the downed conductor has come to ground on the source side of the break all faults were cleared by successful operation of the SEF protection
2. In incidents where the downed conductor has come to ground on the load side of the break, i.e. was back-fed via the windings on the load side transformers, the protection has not operated
3. Irrespective of whether the downed conductor is bare-wire or covered conductor, the SEF protection does not operate where the downed conductor has come to ground on the load side of the break
4. This indicates that the traditional UK overhead protection scheme performance for the covered conductor network, in relation to grounded conductors, has been comparable to that for bare-wire systems
5. Various cases were investigated where a covered conductor had fallen down to ground level. In all these cases there had been a significant visual indication of surface arcing leading to exposed bare conductor. This surface arcing is also audible and both these features can give a strong indication to the public that the downed conductor is 'live'
6. The protection afforded by the insulation material is sufficient to greatly reduce the risk of serious injury on inadvertent contact, unless of course contact was made at or very close to a bare exposed position of the conductor
7. In the case of an undamaged sheath, the capacitance of the sheath is sufficient on its own to keep leakage currents well within present UK safety standards at voltages up to and including 33kV.

6.14 The Issue of Carbon Black and CC Sheaths

CC sheaths must be designed with specific properties, including:

a) Resistance to surface discharge (tracking) erosion
b) Resistance to UV degradation
c) Sufficient mechanical properties to withstand:
   i) Installation techniques
   ii) In-service conditions
   iii) Mechanical support damage (helical fittings, etc)
d) Resistance to stress cracking by climatic conditions and pollutants.

The current tests for track resistance are in ASTM D2303 and they require a failure time of better than 600 hours in a dust-fog test for XLPE. The presence of even 1% carbon black causes XLPE to fail this standard. This problem had been overcome by the addition of aluminium-tri-hydroxide but this caused embrittlement[48]. To avoid this problem, co-polymers of polyethylene are used as a polymer base, as these are more receptive to the fillers. Tests indicate that these fillers, together with a 0.5% carbon black content can achieve a suitably tracking and weather resistant compound.

A further necessity in order to reduce tracking due to pollution is to reduce the water absorption of the XLPE sheath. The relevant standard is BS 7655 which requires a maximum of 1 mg/cm² moisture absorption. The use of 2.5 and 3% carbon black can exceed this level, but the use of 0.5% carbon black sheaths with tracking resistant fillers, such as hindered amine light stabilisers (HALS), have been tested at 0.15 mg/cm²[55]. In addition, improvements in the dispersion of carbon black through the XLPE sheath have shown improvements in tracking resistance from 1.5 kV/mm to 3.5 kV/mm. This allows line design procedures to specify the position and type of CC fittings to maintain electric field strengths to below these levels.
6.15 Radio Frequency (RF) Concerns

RF emissions on CC lines has two aspects: interference with local TV/radio reception and damage to the CC sheath. RF is a problem with CC lines because XLPE is sensitive to tracking and this can destroy the sheath. The extent of RF depends on the local electric field intensity, the surface condition of the CC sheath and the combination of various fittings and sheath material. The aspect of RF of most concern, however, is the possibility that it might cause RF interference (RFI) on local TVs and radios.

RF emission is exacerbated by inappropriate arrangement and material construction of the insulator, fittings and conductor sheath. RF measurements on bare and CC lines have been made by EATL[29]. In areas away from the coast (more than 50 km away) there has been no problem, even with the use of porcelain insulators, floating helical fittings and high carbon black content sheaths. It is therefore recognised that salt pollution is a major influence on the extent of RF. In 1996 a 20 kV CC test line was set up[54] in Austria using glass insulators and APDs separate from the pole-top unearthed fitting. RF levels of 70 dB were measured (typically UK standards require < 45 dB). A range of insulator materials and semi-conductive and metallic ties were then installed. The use of porcelain insulators and various ties produced a range of lower RF readings at 11 kV but all increased to 70 dB at 20 kV. Porcelain insulators of the solid (post) type with no internal steel pin showed a substantial reduction in RF with 0 dB at 11 kV and 33 dB at 20 kV when used with semi-conductive ties. However, the lowest RF emissions were obtained when the pole-top fitting was connected electrically to the APD and solid porcelain or polymeric insulators were used.

This work, combined with the EATL salt-fog work and field experience in the UK, has established that:

a) Porcelain or glass pin insulators and high carbon content CC sheaths should not be used in areas of salt pollution
b) RF emission can be reduced by the use of polymeric insulators and low carbon content (0.5%) CC sheaths
c) RF emission can be virtually eliminated by linking the pole-top fittings with any IPCs used – but then suitable protective covers are required to protect wildlife.

6.16 Economics of CC Use

6.16.1 Scandinavian Experience

There are several reasons why CC lines might be used rather than bare conductors. These include safety, improved reliability, reduced numbers of faults, improved supply quality and lower maintenance. Before 1990, the main faults were trees on the line (34%), lightning (26%) and vibration (11%). A survey has been made[49] of the faults on CC and bare wire lines in Finland over the period 1976-1996 - see Table 6.3[49, 63].
### Table 6.3 Fault rates on OHLs in Finland 1976-1996

<table>
<thead>
<tr>
<th>Line Type</th>
<th>Period</th>
<th>Faults/100km/y</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bare conductor</td>
<td>1990-95</td>
<td>4.5</td>
</tr>
<tr>
<td>CC line</td>
<td>1976-81</td>
<td>1.6</td>
</tr>
<tr>
<td>CC line</td>
<td>1981-84</td>
<td>1.4</td>
</tr>
<tr>
<td>CC line</td>
<td>1984-96</td>
<td>0.9</td>
</tr>
</tbody>
</table>

It is apparent that (a) the fault rate was much lower for CCs than for bare conductors, and (b) the fault rate for CCs decreased significantly over the period. This reduction in faults on CC lines was due to several factors:

- a) Increasing the sheath thickness from 1.6 to 2.3 mm
- b) Improved lightning protection systems
- c) Reduction in maximum EDS value in Finnish standard from 40 N/mm² to 35 N/mm² and the use of vibration dampers (SVDs).

The long-term reliability and fault levels of CC lines compared to bare wire lines had thus been demonstrated by 1996. Since then, further improvements in sheath material, vibration knowledge and lightning protection systems have reduced fault levels even further.

In terms of capital investment, the cost of a new line includes around 15% for bare conductor. As CC costs around twice the bare conductor cost, the use of CC increases the overall cost of a new line by about 15%. There is also the extra cost of additional lightning protection. In Finland, the cost difference for twin CC lines is 1.0 to 1.2 [49].

Lifetime costs will be reduced by a reduction in the total number of faults. Fault levels in Norway [45, 67] showed a drop from 4 per 100 km/y pre-1989 to 0.4 per 100 km/y in 1997 due to the increased use of CC lines. Similarly, Tuusula Energy OY in Finland [45, 67] found that the number of faults on their CC lines over an eight year period, dropped from a predicted 5, based on pre-1989 faults, to zero.

### 6.16.2 UK Experience

There are generally 3 primary drivers that influence utilities’ policies:

- safety
- performance
- cost
It is general practice in the UK\textsuperscript{[70]} to use ABC at LV in all cases unless planning consent is a problem and on the 11 kV network where there is a perceived safety risk to the public. CC is not used in all cases, due to a limitation on circuit capacity and in these cases heavy duty bare wire is used. It is general practice in UK utilities to refurbish around 10\% of the MV overhead network each year. Around 85\% of this will be refurbishment and 14\% new construction. The remaining 1\% will be undergrounded. The refurbishment is split 50-50 between bare and CC construction in some utilities. Technical constraints generally mean that no single CC or fully insulated design covers all the utilities’ needs and wholesale introduction of CC is not envisaged, mainly due to the problem of broken conductor detection. It is conceded, however, that the use of CC in appropriate situations contributes significantly to the reduction of accidents to the public\textsuperscript{[61]}. An analysis of statistics by two UK utilities over the last 10 years of CC use has shown a very low incidence of fatalities or injuries associated with CC lines. Figures supplied\textsuperscript{[70]} show that over a 13 year period in the UK, fatalities and injuries on bare wire lines were $2 \times 10^{-4}$ per km/year compared with zero for ABC lines (based on 4 years data).

Scandinavian data\textsuperscript{[49]} indicates that maintenance costs on CC lines are substantially lower than bare wire and that, over a 40 year lifetime, this reduction more than offset the higher capital cost of CC lines. However, some UK utilities state that costs in respect of operation and maintenance are based on inspection and renewal rates and as such are the same for CC and bare wire lines. The extra cost of installing CC needs therefore to be justified on supply quality, reliability and safety alone. It is general policy, therefore, in some UK utilities to install CC lines only:

- a) Within 20 km of the coast
- b) Through wooded and forested areas and orchards
- c) At all official recreational sites
- d) In situations where CC will give a higher performance than bare wire
- e) In high risk locations, e.g.
  - i) vandalism-prone sites
  - ii) unofficial recreational sites
  - iii) farmyards, etc
  - iv) sites where large vehicles or ladders are in use.

The costs of an OHL can be broken down as:

- a) Installation
- b) Conductor
- c) Cross-arm
- d) Poles
- e) Pole-top hardware
- f) Lightning protection
Installation costs may be higher with CC lines due to the increased care level necessary so as not to damage the conductor. The use of CC can add 15-20% to the overall cost compared with bare wire. The cross-arm is generally smaller and lighter and more easily handled. It is therefore cheaper to install and may have additional long-term benefits for linesmen with lower stress on the back. Poles are generally heavier and taller for CC lines due to the increased sag. However, the incremental cost of the extra height is quite small in terms of overall installation costs and the use of stronger poles may benefit increased security. Pole-top hardware may be slightly cheaper with CC lines due to the increased use of helical fittings which are easier and cheaper to install than bare wire fittings. Lightning protection is an additional cost for CC lines, but this may be balanced partially by fewer faults due to lightning. The gains from reduced weather outages (no clashing, fewer problems with blown debris and trees), improved third party safety, better pole-top working conditions (with shorter cross-arms), reduced vandalism and being more environmentally friendly to wildlife are very difficult to quantify.

A report covering the first UK utility to install substantial amounts of CC detailed the reliability of the system\cite{66, 68}. In terms of lightning related faults, Southern Electric (now Scottish & Southern Energy) installed APDs on every pole in high strike-density areas, alternate poles in medium strike-density areas and on every third pole in low strike-density areas. Vibration faults had been the major cause of line failures (45%) but these faults were reduced due to the adoption of the lower EDS values now given in ENATS 43-121 and the use of SVDs when higher tensions were required\cite{51}. Other vibration failures were related not to the conductor but to the use of plastic binders, which were then discontinued. Trees falling on the line caused no failures but, according to UK regulations, the power had to be shut off before their removal. The second major source of faults (34%) was incorrect installation (poor compression of dead ends and joints). This was rectified by training of in-house personnel and contractors. Detection of a downed conductor was improved by installing pole mounted reclosers with instantaneous SEF at the end of every new section of CC line. In the first two years of CC use the CML dropped by 58% on the CC lines compared with bare wire. The current on-going fault rate is less than 1 per 100 route km/yr.

### 6.16.3 UK Government survey

The UK Department of Trade and Industry (DTI) carried out research into the safety improvements from CC use in the UK\cite{70}. This concluded that there was no doubt that 11kV CC lines have a much greater safety record than bare wire lines in the UK. It stated that 4 fatalities and 6 injuries per year would have been saved if CC use had been more widespread in the UK. Despite this, the main reason for CC use was system reliability by preventing faults due to wind blown debris, fallen trees and conductor clashing. This had been confirmed during the October 2002 storm\cite{75}. The report confirmed that CC lines had been seen to significantly reduce the risk of death caused by vehicles, machinery, scaffolding, masts, aerials, flagpoles, lampposts and ladders coming into contact with overhead power lines whilst at the same time providing a satisfactory reliability of supply. Most utilities stated that capital costs of installing CC were 10 to 18% higher than for bare wire lines. They also stated that LV ABC was over 20% more expensive to install than bare wire LV but that installing LV ABC was a firm policy in all the utilities.
6.17 Alternatives to CC and HV ABC

In the 1980s, several European countries had started to use LV ABC as a replacement for bare copper wire for voltages < 1000 V. This was generally successful and its use was then extended to 11 kV (in the UK) and 20 kV (in Scandinavia). In this case, there were many problems with fittings, short spans and micro-discharges. Its use was therefore discontinued in many areas. In Sweden, a different version was developed for use as a temporary HV supply. This became known as ‘Universal Cable’ (see §2.5) as it could be used overhead, underground or under water. It is sold commercially as Axces and Excel cable and these are fully described in §2.5. It has been tested in several weather environments\cite{58,59} for mechanical suitability on spans up to 200 m and for electrical suitability for use in UK\cite{60}. The system is suitable for long-term reliable operation on lines with few connections. The construction means that connections to pole-mounted equipment are of the cable type and so relatively expensive. An alternative version has been developed in Finland by Pirelli Cables & Systems, Oy. Whereas the Axces/Excel type is a 3-phase system covered by a single overall earth screen and sheath, the Finnish type consists of three individual phases wrapped around each other in similar fashion to LV ABC. The main advantages of an aerial cable system are the improved protection from lightning, lack of damage when trees fall on the line, elimination clashing, the safety of a fully insulated system, safe even when on the ground and the lack of crossarms and insulators. Its disadvantages include expense and the difficulty of making joints (cable technology) compared with CC lines.

Another alternative to normal CC use is the Hendrix Spacer cable. This has been fully described in §2.4 and is further detailed in Appendix IV. The main advantages are being able to string at higher tensions, elimination of vibration problems for the CC, low lightning susceptibility (due to overhead messenger), very much reduced chance of broken conductor reaching the ground, operation already established at voltages up to 69kV, complete HDPE system with no conventional crossarms or insulators and jointing as normal CC lines. Its disadvantages include some difficulty in installation of the interphase spacers and acceptance of its unusual design. Both the aerial and spacer cable systems are well established for use in forested areas.

6.18 Span lengths

Span lengths for horizontal 3-phase CC lines are generally shorter than for bare wire lines due to the greater weight (small effect), greater snow/ice load (main effect) and greater windage (small effect). The limiting factors are not the conductor but the crossarms and poles. Specific long span lengths are possible as has been demonstrated on the 11kV CC network of one UK utility which has spans up to 400m. As crossarms are generally narrower, lighter and cheaper than on bare wire lines, strengthening these for long spans normally does not present a problem. The factors to consider on long spans (>150m), therefore are the support structures and the sag. Higher tensions and/or tall poles are likely to be required than for bare wire lines. In a refurbishment situation where the poles and crossarms of a bare wire system are to remain, current span lengths can normally be maintained with a replacement of around 30% of the poles due to height requirements. This can all be demonstrated by using the ENATS 43-121 software design package.

Span lengths for aerial cable again depend on structure strength. No crossarms are used and the conductor is held close to the pole so the moment of the conductor load is reduced.
compared with a standard bare wire line. The lighter Excel aerial cable is generally strung at
span lengths of 60-100m but the Axces cable has been used in spans up to 200m. Some
companies in Sweden and the UK use this type of cable on LV poles along with the existing
LV supply.

Span lengths for spacer cable can be longer than the equivalent bare wire line again due to the
fact that crossarms are not used and the conductor load is maintained close to the pole line.
However, depending on span length, taller poles may be required at short span lengths due to
the spacer construction. For longer spans the higher tensions used for the support messenger
compared with copper or aluminium bare wire means that spacer cable will have reduced sag
and so may not require taller poles if being used as a refurbishment system.

6.19 Sheath stripping

Sheath stripping was a major source of concern when CC was first introduced into the UK.
As the CC sheath was used with helical fittings to hold up the line, the adherence of the
sheath to the main conductor was important. But high adhesion tended to make sheath
stripping difficult. Linesmen tended to use knives to strip the conductor and this was
considered a dangerous practice as well as risking damage to the conductor and the onset of
early vibration fatigue. This led to the development of sheath stripping tools which are now
used throughout the CC networks in Europe. These are easy and safe to use and do not
damage the conductor. Sheath stripping is therefore not considered a problem any more as
linesmen are now trained and ‘educated’ into the current safe practices[43].

6.20 Safety for human and wildlife contact

6.20.1 Wildlife

A CC line is more obvious to flying birds than a bare conductor line, allowing them more
time to deviate from their intended flight path. Also, birds taking off from lines near to poles
are unlikely to touch bare conductor and get electrocuted. At present bare wire lines have
warning balls that make the line more obvious to birds and (near airports) to low flying
aircraft. These and other types of ‘bird diverters’ are not always successful and can be
unsightly. They can also cause conductor damage.

Small animals such as squirrels, that use OHLs as pathways, can be electrocuted at pole tops
if the conductor fittings are not covered. Several types of insulating covers for compression
and helical fittings and IPCs are currently in use in the UK.

6.20.2 Human life

The most serious risk for human contact is a downed CC that is still live. Detection of a
downed CC is covered in §6.11. The risk to human life is covered by the test for current
drawn by permanent firm (not short term accidental) contact in ENATS 43-122. This gives
the maximum current drawn at various voltages when the conductor is handled by a human.
It assumes a 1000Ω impedance i.e. a human being with no shoes. Under dry conditions,
currents were found to be below 0.5mA for conductor sizes up to 120 mm² at a network
voltage of 11kV (6.3kV phase to earth), and also for 50mm² CC at 33kV (19kV phase-earth).
Currents increase with increasing voltage, increasing conductor size, and wetness. Some test
data[61] are given in Tables 6.4 and 6.5.
Table 6.4  Current drawn by firm contact with live CC at 11kV (phase-phase) under dry, wet and saltwater spray conditions

<table>
<thead>
<tr>
<th>Conductor</th>
<th>Dry</th>
<th>Wet (after 24 hrs immersion)</th>
<th>Saltwater Spray</th>
</tr>
</thead>
<tbody>
<tr>
<td>35 mm²</td>
<td>0.35mA</td>
<td>0.39mA</td>
<td>0.5mA</td>
</tr>
<tr>
<td>70 mm²</td>
<td>0.41mA</td>
<td>0.43mA</td>
<td>0.9mA</td>
</tr>
<tr>
<td>70 mm²*</td>
<td>0.31mA</td>
<td>0.36mA</td>
<td></td>
</tr>
<tr>
<td>120 mm²</td>
<td>0.49mA</td>
<td>0.54mA</td>
<td>1.2mA</td>
</tr>
</tbody>
</table>

Table 6.5  Current drawn by firm contact with live 50mm² CC at various phase-to-earth voltages under dry conditions

<table>
<thead>
<tr>
<th>kV</th>
<th>Leakage current (dry)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>0.1mA</td>
</tr>
<tr>
<td>10</td>
<td>0.2mA</td>
</tr>
<tr>
<td>15</td>
<td>0.35mA</td>
</tr>
<tr>
<td>19</td>
<td>0.45mA</td>
</tr>
</tbody>
</table>

The UK HSE safety level is 10mA and so these levels would be noticeable by the person but not dangerous. The basic idea is that someone may pick up a downed conductor but is unlikely to pick it up by the end – much more likely to pick it up around 0.5m from the end or further. On that basis there should be no danger to human life.

To date, in the UK, there have been no recorded human fatalities associated with CC lines since they were introduced in 1994 to 2003\(^{[70]}\). For the same amount of bare wire lines, 7 fatalities would have been expected.

In summary, CC use in Scandinavia over the past 25 years and in the UK over the last 13 years present a large enough sample (with over 20,000 route km installed) to see the effects of reducing fatalities. The results confirm previous experience in Japan: there has been a significant reduction in overall fatalities and deaths associated with accidental contact have been virtually eliminated.

In the UK in the period 1990 to 2003 the number of fatalities directly associated with actual contact with all types of 11 kV OHL was 69. It is interesting to note that undergrounding cables does not avoid fatalities. One UK utility has reported that they have more injuries associated with contact with underground cable than with OHLs.
6.21 Fittings

Most utilities in Scandinavia and Japan use compression fittings on CC lines. These either incorporate the sheath end to avoid moisture ingress or use a separate cover for this purpose. In the UK every attempt is made not to strip the sheath. So at intermediate, tension and terminal poles the use of helical fittings is becoming common practice. At terminal poles the conductor can be fed directly to the pole mounted equipment or cable junction. At tension poles an in-line connector is used on the connecting jumper. These connectors incorporate water resistant hot or cold sealing covers. At spur junctions the compression IPC is used to T-off the phase connections. With this practice the possibility of moisture ingress and corrosion is greatly reduced as well as providing ease of fitting with safe procedures.

CC lines also require vibration dampers if used at high tensions. The PLP (UK) type SVD is commonly used. These are fitted on the conductor next to the pole very easily and quickly. In some cases noise from these SVDs can be a problem but this is solved by adding a further SVD. These are lightweight plastic material and do not add to the conductor load in any significant manner.

6.22 Pole failures

Poles fail when subjected to forces beyond their capability. This can occur due to pole weakening through animal, insect or fungal attack or simply through age. In the UK, pole strengths are determined on the basis of conductor and equipment loads under specified weather conditions. These forces are generally compressive or crippling loads due to excessive conductor load due to wind/ice loads. These loads generally increase gradually over a period of hours. Pole failures can also result from sudden impulsive loads due to trees falling on the line or torsion forces due to the failure of an outer phase conductor. Weak links are used by some utilities to take up these forces and allow the pole and remaining conductors to survive. One such link is given in ENATS 43-40 and is used in a UK utility. However, due to the possibility of these links failing under ‘normal’ heavy load conditions, most utilities do not use them, although there is current work in this area within Cigré SCB2 (Overhead Lines) committee.

In terms of CC use, these lines are generally of narrow construction such that falling trees tend to be held by all three phases rather than just 1 or 2 as is commonly the case for the wider spread bare wire lines. The load is therefore less likely to be torsional but more likely to be simply unbalanced as far as the pole top goes. The use of helical fittings rather than compression allows the CC to slip under the impulse forces due to falling trees. The load left is then a static load due to the tree weight. On most occasions the line can withstand this overload for short periods until a repair team is available, although reduced ground clearance over this period can be a problem. Storms in Sweden in 1998 and the UK in 2002 showed a large number of pole failures due to trees on bare wire lines but virtually none on CC lines. Experience in the North East USA also demonstrated the effectiveness of CC lines as well as the spacer cable type construction. In the USA CC is also known as tree conductor because of its generally good performance in forested areas.

The storms of January, 2005, in Sweden, however, did show that lines with aerial cable performed even better than CC lines. Experience in central Europe with aerial cable using weak links has also proved successful. These weak links are specifically designed to avoid pole failure when trees fall onto the line. They are commercially available and are used for
suspension or tension clamps which drop the conductor in the event of an abnormal load due to a fallen tree. With this technique the cable and pole are normally undamaged and the cable just needs to be lifted back in position again. The link failure levels are set at 4kN for Excel and 13kN for Axces cable.

6.23 Sheath colour and operating temperature

Several different sheath colours are available for CC use but tests conducted in Finland by Nokia Cables[29] indicated that the tracking resistance of coloured XLPE was worse than the black version. The only colours used widely apart from black are therefore the grey TiO₂ HDPE version and the green polyethylene by Amo Kraft in Sweden which is used for recyclability purposes. However, these thermoplastics tend to have a lowering operating temperature than XLPE and without the black colour, the sheath can rise to higher temperatures. This could be a concern, especially in Australia with high temperatures combined with high loads. The designs used in the early 1990s in Australia would not work effectively with full load and high air temperature.

7 Specific issues which may result in more widespread adoption of covered conductors in Australia

7.1 Research and development 1990-2005

The rapidly expanding use of CC in Europe in the early 1990’s brought up many problems – several of which echoed the concerns of the Australian utilities. This report has highlighted many areas of that research and the development of new conductors and fittings as well as line design aspects. Section 5 of this report highlighted Australian concerns and all the areas mentioned have been considered within section 6 in terms of the R&D work done and the field experience gained over the last 15 years. Evidence that CC use is proving a good investment for many countries has been shown by the rapid refurbishment processes going on in Central and Eastern Europe since 1997. The problems thrown up in the earlier years were then beginning to be solved.

7.2 Specific Concerns addressed

7.2.1 RF emissions, tracking and insulation systems

This has been addressed in §6.15, §6.14, §6.10, §6.8 and §6.9. RF emissions generally comes from tracking and micro-discharges across insulation in polluted areas. The use of low or zero carbon black content sheaths with fittings bonded together and the use of appropriate covers have significantly reduced this problem. The use of polymeric rather than glass or porcelain insulators also has a significant effect in reducing surface voltage levels. In UK experience RF emissions is not a problem away from the coast.

7.2.2 Momentary and long term contact

Momentary contact with live CC lines is not dangerous according to laboratory data and extensive field experience. Permanent contact by a firm hand (human contact) has also been
shown to be well within current safety levels. Long term contact of CC with trees, crossarms
and other phases has been shown not to be a problem as long as triple extrusion CC types are
used. Some tests have shown that such contact can last for many months without damage.
This has been covered in §6.3 and §6.20.

### 7.2.3 Lightning

Major developments in terms of lightning protection have been made. Line failures due to
lightning are now rare and generally due to incorrect installation of the conductor or fittings
which can be reduced by the training of linesmen. This has been addressed in §6.4. The
most common protection is by specific types of arc gaps but surge arresters are also used for
high strike-density areas.

### 7.2.4 Burn-down and line failures

The various causes of burn-down have been addressed in §6.11. The main causes were
lightning, vibration and tracking. These have all been addressed in the individual sections
§6.1, §6.4 and §6.10. This sort of event is very rare today and rarely due to equipment or
conductor problems. Personnel training plays an important role as does correct equipment
purchase.

### 7.2.5 Sheath stripping

This is covered specifically in §6.19. It was a concern both for safety and conductor damage
issues but the developments in conductor sheaths and stripping tools as well as operator
training have virtually eliminated the problem.

### 7.2.6 Alternatives to CC

Various alternatives to the standard horizontal 3-phase CC system have been discussed. The
most common in Europe is the aerial cable system (§2.4) and in other countries including the
Americas the spacer cable system (§2.5). These are also discussed with reference to past
experiences with HV ABC is §6.17.

### 7.2.7 Span lengths

In the UK CC has been used in span lengths up to 400m. The specific line design package
included within ENATS 43-121 has been shown to be applicable to CC lines in many
countries and should also apply to Australia. This topic is specifically covered in §6.18.

### 7.2.8 Wildlife

CC is often used in the UK on the flight paths of migratory birds as well as near estuaries and
other areas where birds congregate. The lines appear to be more visible to birds than bare
conductors and so avoid both loss of bird life and power supply by avoiding contact. Small
animals can climb poles and run along overhead lines. As long as suitable covers are used at
pole tops then these animals also will not suffer loss of life and the supply will remain secure.
7.2.9 Suboptimal design and niche application

With well over 100,000 route kilometres of CC line installed world-wide this can no longer be considered a ‘niche’ application. CC is used to improve line reliability and supply security as well as for safety. Section 4 has covered the world-wide use of CC and its alternatives and its continued widespread growth in use. The CC design has been improved substantially over the last 15-20 years due to extensive research in many countries and in particular at EATL in the UK. Its many initial problems have been addressed and solutions found to virtually all of them.

7.2.10 Detection of a downed conductor

One remaining concern for CC use is a cost-effective method of detecting a downed conductor. Most countries are content for the present time with SEF detection although other techniques are still being investigated and trialled. This is covered in §6.13 and the experience of utilities with both bare and CC systems has been given. The performance of SEF and the low level of current drawn by human contact with the sheath of a downed CC have proved adequate for most utilities. Failures of SEF are common with bare wire systems also but these are unforgiving if touched.

7.2.11 Economics of CC use

CC lines are more expensive to install than bare wire lines (see §6.16) but they have proved in many countries to be more reliable with substantially fewer faults and outages than bare wire systems. They combine safety with security of supply even in bad weather and polluted environments. The economic gain from this long term safety, reliability and security is difficult to assess whilst utilities have a mixed network of bare and CC lines. This is why some countries have adopted specific policies of areas for CC and bare wire use so that line maintenance schedules can be targeted efficiently.

7.3 Specific issues

Each utility has its own specific problems and only by a detailed investigation can these concerns be addressed to see if more widespread use of CC could provide a solution. Most utilities would be happier if the specific issue of detection could be solved in a cost-effective manner. Solutions are available but these are currently proving too expensive for most countries. Despite this, the experience of SEF combined with appropriate recloser placement and operation has succeeded very well in the UK. With CC use widespread in Europe since the mid 1980s there has still been no fatality associated with CC use and no problems from downed conductors apart from temporary loss of supply. The widespread use of CC in the heavily forested areas of north east America and the dry interior of Brazil have also been shown to be reliable and efficient. Many issues have been related to lack of training for linesmen and this is seen as an important issue to be addressed if CC use is to be increased in Australia.

Confidence may also be required in the application of the CC line design package, used extensively in the UK, to the Australian environment.
8 Summary

1. The various issues that restricted the spread of CC in Australia after the initial installations in the early 1990s have been addressed.

2. Substantial and significant research and development in all areas of CC use has been carried out in Europe over the last 15-20 years.

3. The spread of CC in Europe and other countries world-wide shows that CC is no longer a niche conductor but could prove significant advantages in terms of safety, reliability and security to the Australian Power network.

4. The economics of CC use depends on the inspection and maintenance procedures of the utility and the cost benefit put on safety, reliability and fault reduction. CC are more expensive to install whether in new build or refurbishment than bare wire systems. Some utilities state that the lifetime costs are lower due to greater reliability and reduction in fault levels. Others state that their line patrols etc still need to be carried out and so no reduction in lifetime costs is apparent.

5. CC is accepted world-wide as having a major impact on safety levels for both human and wildlife. However, some utilities state that this alone does not justify the higher initial capital cost.

6. The problem of detecting a downed conductor is still the subject of research. Solutions are available but some utilities consider them not to be cost-effective at present. However, most utilities consider that the use of SEF and recloser strategies is sufficient to meet safety requirements and that the performance of downed CC detection is very little different than that of detection of a bare wire conductor downed on hedges or high resistivity ground.

9 Recommendations

1. It is recommended that presentations be made to relevant Australian utilities concerning this report and that these utilities be given the opportunity to explain their particular environmental and other issues that have restricted their use of CC.

2. It is recommended that these presentations be made by relevant experts in the CC field.

3. It is also recommended that a CC conference or seminar/workshop be held where experts in areas related to CC use in Australia and the rest of the world be invited to share expertise and resolve outstanding issues i.e. the holding of a seminar or workshop on CC use in the Australian environment. This may provide a route for a way forward for improving the Australian power network in a reliable and cost-effective manner.
10 References

1. Web-site www.mce.gov.ae

2. CENELEC standard prEN50397 for CC up to 36kV


10. Wareing J B, Chetwood PA, ‘Vibration tests on new and old CC samples from Finland and Sweden’ EATL Report 5806, November 2004

11. Wareing J B ‘Tracking tests on new and old CC samples from Finland and Sweden’ EATL Report 5779, September 2004


61. **Wareing J B**: ‘Safety aspects of CC use in the UK and Finland’ Proc of Int Cov Cond Conf Helsinki, Finland, October, 2000


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70. **UK Department of trade and Industry:** ‘Research & Analysis of a Possible Safety Improvement Involving the Selective Replacement of 11 kV/LV Bare-Wire Overhead Lines with Ones having Covered/Insulated Conductors’ The Engineering Inspectorate, DTI, London, UK.


77. **Hughes D T,** ‘Covered conductor failure, Quemford Gate Spur’ EATL Report T2366, November, 1997


82. **Pihler J,** ‘Electric field distribution for CC lines with porcelain and glass insulators’ Int Cov Cond Conf Helsinki, Finland, October, 2000.
Appendix I

TECHNICAL SPECIFICATION: Pirelli SAX70/GR-T

Medium voltage conductor with semi-conducting screen

Rated voltage 1 - 33 kV
Standard Construction and tests i.a.w. SFS 5791:1994 (where applicable), EATS 43-122
Reference standards EN 10 002-1, HD 605 S1, IEC 60104, IEC 60228, IEC 60811, EN 50183
Temperature rating Max. conductor operating temperature: 80°C

Construction

Wire

All aluminium alloy wire (Al 2) i.a.w. IEC 60104 Type A.

Properties of wire before stranding:
- Tensile strength (min.) N/mm² 325
- Elongation at break on 250mm (min.) % 3.0
- Resistivity (max.) nohm m 32.840

Conductor

Round, stranded and compacted longitudinally water-tight conductor.

Approximate diameter mm 9.7
DC resistance at 20°C (max.) ohm/km 0.493
Breaking load (min.) kN 22.5
Final modulus of elasticity N/mm² 62500
Coefficient of linear expansion 1/°C 23.0×10⁻⁶
Direction of laying of the external layer: right handed ‘Z’
Water-tightening method: water-swellable gel in the conductor interstices and a longitudinal water-swellable tape on the surface of the conductor.

Conductor screen

Semi-conducting copolymer compound

Nominal thickness mm 0.3

Covering

Black XLPE compound

Nominal thickness mm 2.3

Complete cable

Approximate diameter mm 15.3
Approximate weight kg/km 285
Bending radius m 0.23
Current carrying capacity ¹ A 310
Thermal short circuit current for 1 s (max.) ² kA 6.4

Marking

Marks of origin Embossed on the covering at max. intervals of 1 m: type, manufacturer, trademark and cross-sectional area, year of manufacturing. For example: PIRELLI FINLAND 70CC 1-33kV 2003 AL.2 Danger of Death Do Not Touch

¹ Ambient temperature 20°C, conductor temperature 80°C.
² Conductor temperature at the beginning of the short circuit 40°C, at the end of the short circuit 200°C.
**TECHNICAL SPECIFICATION: Pirelli SAX50/GR-T**

Medium voltage conductor with semi-conducting screen

**Rated voltage** 1 - 33 kV

**Standard** Construction and tests i.a.w. SFS 5791:1994 (where applicable), EATS 43-122

**Reference standards** EN 10002-1, HD 605 S1, IEC 60104, IEC 60228, IEC 60811, EN 50183

**Temperature rating** Max. conductor operating temperature: 80°C

**Construction**

**Wire**

*All aluminium alloy wire (Al 2) i.a.w. IEC 60104 Type A.*

Properties of wire before stranding:

- Tensile strength (min.) N/mm² 325
- Elongation at break on 250mm (min.) % 3.0
- Resistivity (max.) nohm m 32.840

**Conductor**

*Round, stranded and compacted longitudinally water-tight conductor.*

- Approximate diameter mm 7.8 – 8.2
- DC resistance at 20°C (max.) ohm/km 0.702
- Breaking load (min.) kN 15.5
- Final modulus of elasticity N/mm² 62500
- Coefficient of linear expansion 1/°C $×10^{-6}$

Direction of laying of the external layer: right handed ‘Z’

Water-tightening method: water-swellable gel in the conductor interstices and a longitudinal water-swellable tape on the surface of the conductor.

**Conductor screen**

*Semi-conducting copolymer compound*

- Nominal thickness mm 0.3

**Covering**

*Black XLPE compound*

- Nominal thickness mm 2.3

**Complete cable**

- Approximate diameter mm 12.3
- Approximate weight kg/km 215
- Bending radius m 0.19
- Current carrying capacity 1) A 245
- Thermal short circuit current for 1 s (max.) 2) kA 4.3

**Marking**

Marks of origin Embossed on the covering at max. intervals of 1 m: type, manufacturer, trademark and cross-sectional area, year of manufacturing. For example: PIRELLI FINLAND 70CC 1-33kV 2003 AL.2 Danger of Death Do Not Touch

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1) Ambient temperature 20°C, conductor temperature 80°C.

2) Conductor temperature at the beginning of the short circuit 40°C, at the end of the short circuit 200°C.
Appendix II

Ericssons Network Technologies BLL Conductor

Covered Conductors for overhead distribution

Conductor: Circular with a core of zinc-coated steel wire surrounded by 6 hard drawn aluminium wires.
Longitudinally watertight by means of a dry extruded material
Inner conductive layer Extruded Covering: PE, black with carbon black content > 2% by weight
Marking: CCST + conductor cross section, material and design,

20 kV + ERICSSON NT E. Year, metre marked
Rated voltage: 12/20 V
Maximum conductor temperature: 70°C
Standard: prEN 50397-1

Technical description BLL04036

Conductor area 99 mm²

Design: 1 steel wire in centre
6 Al-wires in 1st layer

Wire diameter: 4.25 mm
Outer diameter of complete line: 12.10 – 12.25 mm
Pitch: 160 -170 mm
Direction of laying: Right (Z)
Resistance at 20°C (max): 0.353 ohms
Tensile strength (min): 29.22 kN

Manufactured according to Standard EN50182
Longitudinal water tight by extruded material.

Technical description BLL0403

Conductor area 62 mm²

Design: 1 steel wire in centre
6 Al-wires in 1st layer

Wire diameter: 3.37 mm
Outer diameter of complete line: 9.60 – 9.75 mm
Pitch: 128 – 135 mm
Direction of laying: Right (Z)
Resistance at 20°C (max): 0.563 ohms
Tensile strength (min): 18.64 kN

Manufactured according to Standard EN50182
Longitudinal water tight by extruded material.
## TECHNICAL SPECIFICATION: Amo Kraft BLL

**Type:**
CCST 50-Al2A WK 20kV (BLL)

**Date/edition:**
021126/1

**Issued by:**
R.S

**According to customer spec.:**

**According to standard:**
pr EN 50397-1

**Supplier:**
UK

### Parameter

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<th>Material</th>
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### TECHNICAL SPECIFICATION: Amo Kraft BLX

**Type:**
CCSX 50-A12A WK 20kV (BLX)

**Date/edition:**
021126/1

**Issued by:**
R.S

**According to customer spec.:**

**According to standard:**
pr EN 50397-1

**Supplier:**
UK

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**Marking:**
Appendix IV

HENDRIX WIRE & CABLE SPACER CABLE SPECIFICATION – 15 – 46kV

A4.1 General

This Appendix gives more detail of the Hendrix Spacer cable as supplied by the manufacturer. The system is designed to withstand short term phase to phase contact or phase to ground contact without causing an outage and capable of operating at 75 °C under normal conditions and at 95 °C under emergency overload conditions at ambient temperatures of -40° C to +49° C.

A4.2 The Covered Conductor

A4.2.1 Conductor

The conductor material is 1350-H19 aluminium concentric round regular strand and also compact concentric strand in accordance with ASTM B 400. Copper conductors are available upon request.

A4.2.2 Conductor Sheath

The conductor shield has an extruded black semiconducting polymer layer with a nominal thickness from 0.25mm. A further two layers are thermally bonded to each other and to the conductor shield. The first layer is an extruded natural low density polyethylene which shall comply with ASTM 1248 for Type I, Class A, Category 5, Grade E3 material and the outer layer an extruded black track resistant high density polyethylene. A grey outer layer is available upon request.

A4.2.3 Conductor sizes

The conductor comes rated for 15, 25, 35 and 46kV lines. In general, the 15kV version has a 3.3mm sheath, the 25kV version 6.7mm, the 35kV version 8mm and the 46kV version 10.7mm with conductor sizes from 27 to 440mm².

A4.3 Messenger Wire

The messenger is an alumoweld or alumoweld-aluminum stranded wire. Alumoweld strands are hard drawn aluminum clad steel and aluminum wires are hard drawn 1350-H19 temper. The stress limit on the messenger is 60 % of its ultimate strength when loaded with cables, spacers and the ice and wind loads according to NESC code (ANSI C2). A messenger with a
breaking strength of at least 45kN is used for 15kV systems and 76kN for systems up to 46 kV. Higher strength and messengers, copperweld messengers or fiberoptic messengers are available.

**A4.4 Spacers**

The spacers support the phase conductors in a diamond configuration at 10m intervals with a phase to phase spacing of at least 178mm at 15 kV and at least 273mm at 46 kV. The leakage distance between any two phases or any phase to messenger is at least 267mm for 15 KV and at least 450mm for up to 46 KV. The spacer is a moulded grey track resistant HDPE with a dielectric constant equal to that of the cable insulation.

The spacers have four ring ties of ultraviolet resistant EPR rubber to secure the messenger and conductors. These may be applied with a hot stick.

**A4.5 Pole Hardware & Brackets**

The support brackets are not stressed beyond 50 % of their ultimate strength when subjected to the NESC ice and wind loading conditions. Tangent brackets are fabricated from T6 heat treated 356 aluminum alloy or ductile iron galvanized to ASTM A-153. They are 356mm long for 15kV systems and 610mm long for systems up to to 46 kV. Angle brackets are fabricated from galvanized steel channel iron. The bracket are designed to support the conductors in a compact triangular configuration on polyethylene pin type insulators. Deadend brackets are fabricated from galvanized steel channel/angle iron. There are also miscellaneous hardware such as covered tie wire, transformer tap wire, wildlife guards, deadend insulators, deadend grips, shackles, clevises, angle clamps and insulator pins.
Appendix V

General Design data for ENATS 43-121

A5.1 Conductors

The minimum factor of safety on conductors of cross sectional area up to and including 35mm² copper equivalent (including 50mm² and 60mm² aluminium alloy) are 2.5 on their nominal breaking load. The minimum factors of safety on larger conductors are 2.0 on their nominal breaking loads. Factors of safety are included in the conductor database.

Experience has shown that the self-damping of 50 mm² aluminium alloy CC requires a maximum Everyday Design Stress (EDS) of 28N/mm² (at 5º C) to reduce Aeolian vibrations to an acceptable level in open terrain.

Vibration tests have shown that an EDS of 35N/mm² is acceptable for larger conductor sizes. The EDS can be increased where lines are located in hilly/wooded terrain or where vibration dampers are installed. Vibration tests have shown that large diameter covered conductors do not appear to have serious vibration problems at tensions around 20% RBS. This equates to EDS values of 59N/mm² and 63N/mm² for 120CC and 185CC respectively.

A5.2 Crossarm Assemblies

Crossarm assemblies have been designed in accordance with BS 449 part 2 and the steelwork sections selected using a deterministic design approach on the following basis:

Single crossarm assemblies - 50CC maximum span - normal environment

Double crossarm assemblies - 120/185CC maximum span - normal environment.

A5.3 Supports

The stresses created in intermediate supports are bending stresses due to windage on conductors, the loading point being 159mm above pole tops. (Note: this dimension is the standard for 11kV construction and equates to 260mm above the top flange of the crossarm, but may need to be increased for higher voltages).

The stresses created in stayed supports are crippling stresses due to stay tension and vertical conductor loads acting at the pole top. The strength of supports is derived from formulae contained in BS 1990 part 1.

A5.4 DESIGN DATA (Deterministic Design)
A5.4.1 Conductors

The minimum factor of safety on conductors of cross sectional area up to and including 35mm² copper equivalent (including 50mm² and 60mm² aluminium alloy) is 2.5 on their nominal breaking load. The minimum factors of safety on larger conductors is 2.0 on their nominal breaking loads. Factors of safety are included in the conductor database.

A5.4.2 Crossarm Assemblies

The minimum factor of safety on all crossarm assemblies is 2.5 on the ultimate strength of the steel.

A5.5 DESIGN DATA (Semi-Probabilistic Design)

A5.5.1 Preamble

Lines designed in accordance with this Specification will withstand all the likely weather related loadings as identified by EATR 111 and found within the UK. EATS 43-40 was both a performance and design specification which was developed to allow quantitative assessment of this requirement. It provides National Maps and conductor data applicable to wood pole construction at any location in the UK up to 500m above sea level which, in the absence of better local information, permit ready assessment of the magnitude of the likely most onerous conditions. This Specification therefore provides a method of determining basic weather dependant mechanical loads which structures must be capable of withstanding.

A5.5.2 Conductors

Conductor Freezing Point Tensions is derived from the conductor data detailed in clause A5.1 through the use of the “SAGNTEN” spreadsheet.

A5.5.3 Crossarm Assemblies

The yield stress for crossarm assembly steelwork is not exceeded for all likely load conditions when employing a semi-probabilistic approach. The allowable stress used in the software is 275/1.1 = 250 N/mm². This is a higher stress than that adopted in EATR 111 because the yield stress of mild steel has been revised in BSEN 10025.

The maximum loadings applied to insulator pins is limited to 6.4kN (yield stress of the steel) and not 10kN MFL as quoted in BS 3288. Note that this is a different value to that adopted in EATR 111.