Paper insulated cables have been in use longer than any other type of cable insulation and are still a favourite with engineers. When selected properly and installed correctly, paper insulated cables can be relied upon to provide satisfactory and trouble-free performance.

Paper insulated, lead covered cables can be used in many electrical distribution and reticulation applications including:
- The petrochemical industry
- Mining a special construction for shaft installation is available with water blocking and flame retardancy,
- Fire and explosion hazardous areas.
- Sub-marine cables.

Manufacture of paper insulated cables
Paper insulated cable manufacture at Aberdare Cables is carried out in accordance with SANS 97. The paper insulation is made up of layers of long-fibred paper tapes made from high-grade wood pulp, the texture and quality of which are controlled carefully to eliminate imperfections. The paper tapes are lapped helically around the conductors to form a complete compact and smooth covering with the radial thickness required according to the voltage of the cable. The outer layer is generally numbered to enable positive core identification. (the laid-up cores are bound with further layers of helically applied paper tapes for belted-type cables, or copper woven tapes for screened cable).

As paper itself is a hygroscopic, fibrous material, its electrical properties are rather poor. It must therefore be dried thoroughly under vacuum and impregnated with a stable, electrical grade, non-draining compound. This compound has a drop point greater than 80°C which means that the impregnant does not migrate under normal operating conditions or when installed on gradients.

To protect the impregnated paper insulation from contact with water during its intended life, an extruded seamless sheath of lead or lead alloy is applied by means of a lead extruder (ductility and durability are essential features of the sheathing). Although ductile, pure lead is liable to fail by cracking when exposed to mechanical vibration such as may occur on bridge crossings or near railway tracks, and in these circumstances lead alloy E is preferred.

This has a considerably higher tensile strength than pure lead, particularly under alternative mechanical stress.

As the lead sheath requires protection, a bedding of bitumen-impregnated paper and fibrous material or an extruded plastic layer is applied to prevent the lead from being deformed by the armouring. An armouring of steel wire or double steel tape is then applied to give the cable full mechanical protection.

The final stage calls for an outer serving of bituminised fibrous material applied over the armour. An extruded plastic serving may also be used. The paper insulated cable is now complete and moves to the testing stage.

The SANS specification allows for heavy duty cables which are generally used in mines or other onerous conditions. Such cables are manufactured with thicker insulations, lead sheaths, armouring and sheathing.

Quality control and testing
As electric power cables are manufactured to provide many years of service, the raw materials used must be of the highest quality and must conform to the specifications laid down by SABS. This also means that the production process must be controlled carefully, particularly in areas where heating, drying or cooling cycles can be critical to the overall characteristics and electrical properties of the cable. Chemical, physical and electrical tests are carried out at various stages of manufacture. Final tests are all in accordance with SANS 97. Quality assurance systems are in compliance with SABS ISO 9000 series (see Fig. 1).

Grouping of cables in air
Cables may be grouped in air without derating provided that:
- In horizontal formation, the clearance is no less than six times the overall diameter of the cable or 150 mm, whichever is least.
- In vertical formation, the clearance from a supporting wall is no less than 20 mm; the vertical clearance between cables is no less than 150 mm, and the cables are installed in a horizontal plane if the number of cables exceeds four (see Table 1).

Short circuit ratings of cables
Short circuit conditions do not lend themselves readily to rigid treatment. The variables are known but their interaction is extremely complex. In the case of armoured, lead sheathed cables with conductors greater than 240 mm² in particular, earth fault currents may increase the lead sheath temperatures to above tolerable limits. An absolute sheath temperature of 170°C (below the melting point of jointing metal) should not be exceeded. The maximum permissible conductor temperature is 160°C for conductors with soldered lugs and ferrules and 250°C for conductors with crimped or welded lugs and ferrules.

In calculating the factors for short circuit ratings provided for guidance in Table 2, it was assumed that symmetrical 3-phase short circuit currents occur under full load conditions, and that adiabatic conditions

<table>
<thead>
<tr>
<th>Max. sustained conductor temperature (°C)</th>
<th>Air temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>30</td>
</tr>
<tr>
<td>70</td>
<td>1.00</td>
</tr>
<tr>
<td>80</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Table 1: Derating factors for variations in air temperature.
prevail, i.e. no heat is lost from the conductors during the fault conditions.

For times other than one second, divide the calculated 1 second short circuit current rating by the square root of the actual time in seconds for which the short circuit rating is required.

Example

120 mm², 11 kV screened 3-core copper conductor cable with soldered ferrules or lugs:

(Maximum permissible conductor temperature = 160°C).

Temperature of conductors at inception of short circuit = 70°C.

One second short circuit current rating

\[ = 120 \text{ mm}^2 \times 0.115 \text{ kA/mm}^2 \]

= 13.80 kA

Two second short circuit current rating

\[ = \frac{13.8 \text{ kA}}{\sqrt{2}} = 9.76 \text{ kA} \]

Table 2: Factors for the determining of one-second short-circuit ratings of cables kA/mm².

<table>
<thead>
<tr>
<th>Conductor material</th>
<th>Sustained conductor inception temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>70°C</td>
</tr>
<tr>
<td>Maximum permissible conductor temperature</td>
<td>Copper</td>
</tr>
<tr>
<td>160°C</td>
<td>0.115</td>
</tr>
<tr>
<td>250°C</td>
<td>0.154</td>
</tr>
</tbody>
</table>

Lead sheathed cables subject to vibration

Lead sheathed cables to be installed in positions subject to moderate vibration such as bridges, tunnels, factories, mine shafts etc. should have sheaths of lead alloy E, and should preferably be armoured.

Corrosion of lead sheaths

Some installation conditions may be aggressive to lead sheaths which are protected only with conventional bitumen impregnated textile bedding and/or serving. This condition may occur in soils that are otherwise relatively inert.

Heavy sporadic rain in predominately dry areas tends to accumulate in the disturbed terrain of a cable trench. Subsequent evaporation concentrates any dissolved salts and organic compounds which, together with differential aeration in contact with the lead sheath, can supply the electrolyte and cause a galvanic corrosion of the lead.

Earth currents arising from local arc furnaces or DC traction may further complicate the process of corrosion. When this condition is known to exist, as may be evidenced by relatively frequent replacement of metal water pipes in the area, it is recommended that the conventional bedding and/or serving be replaced by an extruded PVC sheath which is fully protective for most conditions of installation.

Graphite coated PVC sheaths are available when it is intended to carry out regular (bi-annual) sheath integrity tests on the installed cables. When such graphite coated PVC sheathed cables are tested, the leakage current flowing through the sheath during the application of 10 kV DC for one minute shall be typically less than 5 mA/km.

Vertical installations

The problem of drainage of impregnant from fully impregnated cables installed vertically or on steep gradients has been reduced significantly by the use of non-draining compounds. Non-draining impregnants are designed to remain solid at normal operating temperatures.

Nevertheless, cables so installed which are likely to be subjected to repeated overloads are recommended to be of the drained type. In this design a full impregnating cycle is applied which consists of a period of drying under heat and vacuum followed by full impregnation under heat and pressure. Before exposing the cable to the atmosphere, the surplus impregnant is withdrawn during a further period of heat and vacuum.

A drained type cable may be subjected to short circuit conditions, resulting in a maximum conductor temperature of 160°C without significant downward movement of the dielectric.

Extra dielectric thickness is applied to minimise the dielectric stress in the drained installation.

Installation of cables

Low ambient temperatures

Unless precautions are taken to heat the cables above 10°C for at least 24 hours prior to installation, the cables should not be installed at temperatures lower than this. This may be achieved in the field by the judicious use of heaters around the cable drums under a tarpaulin shield.

Handling of drums

The drum of cable should be mounted properly on cable jacks or on cable trailers with support bars of adequate strength relative to the drum width and mass and also to the distance between the bar supports. Collars must be worn to avoid axial creeping of the drum during drum rotation. If the inside end of the cable is protected by a metal covering, this and any securing ties must be removed before paying off the cable. The drum should not be allowed to overwind during
withdrawal of the cable, since dangerous kinks may form and the creation of loose convolutions may cause the inner end to creep out of the cable drumhole. This creep must be allowed to take place.

**Minimum bending radii**

Cable bending should be done slowly and carefully and the precautions mentioned here should be followed when applicable. Electric cables should not be bent to radii less than those derived from Table 3.

**Handling and installation of cables**

Refer to SANS 10198 The selection, handling and installation of electric power cables of rating not exceeding 33 kV. In particular, care must be taken in handling and transporting cables, since damage may seriously impair subsequent cable performance and life.

**Transfer of drums**

Under no circumstances should a drum of cable be dropped during transport to or unloading on site. Rolling of a drum of cable must always be in the direction of the arrow marked on the flange, otherwise loose convolutions of the cable develop which may result in damage to the cable during subsequent pay off.

**Shaft cables**

Shaft cables, which are installed during subsequent pay off, may result in damage to the cable. Loose convolutions of the cable develop or ancillary electrical equipment.

<table>
<thead>
<tr>
<th>Rated voltage</th>
<th>≤ 11 kV</th>
<th>22/33 kV</th>
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<tbody>
<tr>
<td>Single core</td>
<td>20 x d</td>
<td>25 x d</td>
</tr>
<tr>
<td>Multi core</td>
<td>12 x d</td>
<td>15 x d</td>
</tr>
</tbody>
</table>

\[ d = \text{overall diameter of cable (mm)} \]

Table 3: Electric cables should not be bent to radii less than these values.

vertically, are often exposed to moist corrosive atmosphere, and are sensitive to mechanical abuse. Special design measures are taken to enhance cable performance under these conditions:

- Process changes to ensure that the impregnating compound cannot migrate. This provides the cable with improved drainage performance at operating temperature.
- Employing a fully water blocked, helically applied galvanised steel wire armour layer over the lead for mechanical protection against damage caused by rockfalls and vibration caused by air buffeting from high-speed skips passing close by. A suitable water blocking compound encapsulates these wires to retard corrosion and to prevent free water from being piped to joints, terminations or ancillary electrical equipment.
- The whole cable is sheathed in flame retardant, low halogen PVC which acts as an initial fire and mechanical barrier.

**South African specifications**

The local specifications that apply are:

- SANS 97: Electric cables - impregnated paper insulated metal-sheathed cables for rated voltages 3,3 kV to 19/33 kV.
- SANS 182: Copper and aluminium overhead conductors.
- SANS 1339: Electric cables cross-linked polyethylene (XLPE) insulated cables for voltages from 3,8/6,6 kV to 19/33 kV.
- SANS 1418: Aerial bundled conductor systems.
- SANS 1507: Electric cables with extruded solid dielectric insulation for fixed installations, 300/500 V to 1900/3300 V.
- SANS 1520: Flexible electric trailing cables for use on the mines, 640/1100 V to 19/33 kV.
- SANS 1574: Electric cables – flexible cords and flexible cables to 600/1000 V.
- SANS 1576: Electric cables single core arc welding cables.
- SANS 1713: Electric cables medium voltage aerial bundled conductors for voltages from 3,8/6,6 kV to 19/33 kV.

Contact Antony Falconer, Aberdare Cables, Tel 011 396-8000, afalconer@aberdare.co.za

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“The book puts a complex and controversial topic into layman’s language. It is easy to read and grasp, and will, in my view, contribute to broadening the debate on energy systems of the future. It is well written and lucid, and should appeal to the educated public here and abroad.”

Tony Britten, corporate consultant at Eskom

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**Table 3**

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\[ d = \text{overall diameter of cable (mm)} \]