High Stress Design in the High Voltage (42kV-132kV) Cable Range

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SYNOPSIS

Improvements in cable insulating materials, the handling of these materials and production processes and facilities have now made it possible to produce XLPE insulated cables in the extra high voltage range (220kV-500kV). Advantages for the high voltage (42kV-132kV) cable range, due to these advancements, have included being able to push the electrical stress, traditionally associated with this range of cables, to higher limits.

Particular attention is given to the cable design stress at the conductor/insulating interface and at the insulating/accessory interface. It goes without saying that the increased cable electric stress means that accessories also need to be capable of handling a higher electrical stress when compared to traditional designs.

African Cables Limited has recently successfully type tested 132kV, in-house produced, high stress design cables fitted with Pirelli terminations and joints. Cable stress has been increased some 25% compared to the previous design while the accessory interface stress has been raised some 33%.

One of the major advantages of the high stress design cable is its smaller diameter. Less material is used in manufacturing the cable and consequently the cost savings associated with the design are passed on to the end user.

1. INTRODUCTION

African Cables has manufactured two high stress 132kV XLPE cables, comprising a 300mm² and a 1000mm² copper conductor, in order to test a high stress design in terms of the IEC 60840 test specification.

Figure 1 illustrates the individual components that constitute the 1000mm² high stress cable.

The challenge for any manufacturer of a high stress design cable is to design a cable with stress levels that are acceptable, firstly from a material and process point of view, and secondly from an accessory interface point of view. With this taken into consideration, the maximum electric stress at the conductor/inner semi-conducting interface of the cable was designed to 8.0 kV/mm, as opposed to the existing design stress of 6.4 kV/mm. The stress at the accessory interface was designed to 4.0 kV/mm as opposed to 3.0 kV/mm.

The increase in stress was achieved by reducing the XLPE insulation thickness from 20mm to 15mm on the 300mm² cable and 17mm to 15mm on the 1000mm² cable. Cable stress at the conductor interface was increased by 25%, and that at the accessory interface by 33% when compared to the existing design stress levels.

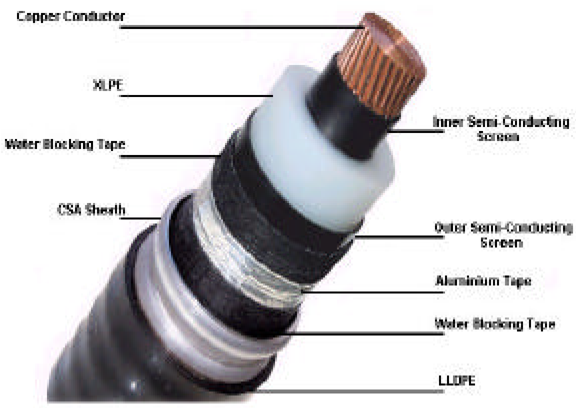

Figure 1: Components of the 1000mm² high stress cable manufactured by African Cables

2. BACKGROUND

2.1 ELECTRIC STRESS THEORY

The radial electric stress distribution of a single core circular cable is as illustrated in Figure 2. The maximum stress occurs at the conductor surface, reducing in a hyperbolic curve, and becoming a minimum at the outer surface of the outer semi-conducting screen [1].

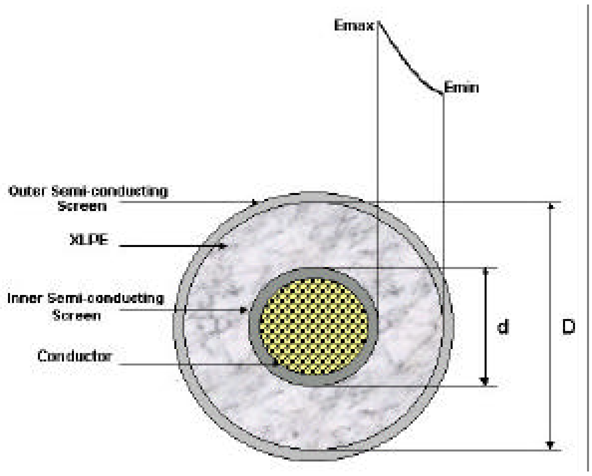

Figure 2: Electric Stress in a single core cable

The maximum electric stress, E_{max}, which occurs at the conductor or inner semi-conducting interface is defined by equation 1. The minimum electric stress, E_{min}, which occurs at the outer semi-conducting screen or the inner surface of the sheath, is defined by equation 2 [1].

$$E_{max} = \frac{2.U_0}{d.\ln\left(\frac{D}{d}\right)} \text{ kV/mm} \qquad \text{.....Equation 1}$$

and,

$$E_{min} = \frac{2.U_0}{D.\ln\left(\frac{D}{d}\right)} \text{ kV/mm} \qquad \text{.....Equation 2}$$

where,

U_0 = Phase voltage to earth (kV)
D = Diameter over XLPE insulation (mm)
d = Diameter over inner semi-conducting screen (mm)

2.2 MANUFACTURING

Work on HV cables has shown that to raise the electric stress of XLPE cables it is essential that the extruded insulation is of high cleanliness, free of contamination and manufacturing defects, and that the screen interface is smooth [2]. In addition, an integrated extrusion plant employing a Vertical Continuous Vulcanising (VCV) process line is required. African Cables easily met these two criteria by carefully selecting imported insulating materials and by making use of their refurbished VCV extrusion line – the only one of its kind in South Africa.

The cable core is triple extruded and crosslinked in the fully enclosed process in which the inner semi-conducting screen, the XLPE insulation and the outer semi-conducting screen are applied simultaneously to the pre-heated cable conductor. Specialised in-line inspection techniques using X-rays are employed to monitor the dimensional accuracy of the extruded core, with the final cleanliness of the insulation being verified by careful microscopic examination of dissected cable samples from each drum length (Figure 3). These examinations confirm the correct levels of insulation cleanliness, dimensional accuracy, crosslinking, moisture content, ageing performance and that degassing of the by-product has been achieved.

The VCV process is inherently the best method for the manufacture of cables with large insulation diameters and heavy conductors due to the vertical orientation of the conductor during the extrusion and crosslinking process. The force of gravity acts along the axis of the conductor, thereby assisting in the formation of a concentric and cylindrical insulation geometry, independent of the viscosity of the XLPE insulation.

The final stage of HV cable manufacture is the high voltage test, which comprises an HV withstand and a partial discharge detection test [3]. These tests take place in African Cables sophisticated HV Routine Test Lab (Figure 4). The tests are of short duration, typically 30 minutes, and are capable of detecting the defects that initiate partial discharges, as small as one pico-coulomb. Such defects lead to gradual deterioration of the XLPE and eventually breakdown may occur.

Figure 3:Routine microscopic examination of high voltage cable samples

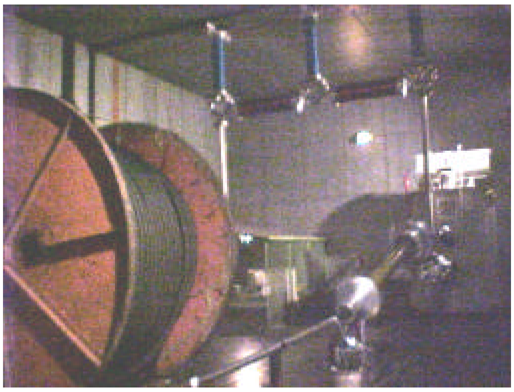

Figure 4: HV Routine Test Lab – HV Testing of high stress cable core

2.3 HV ACCESSORIES

The manufacturing quality standards developed for high stress cables have also been applied to the design, manufacture and jointing of the accessories. In particular the accessories have to operate at the increased level of stress at the cable outer insulation screen, this being directly proportional to the value of cable design stress at the conductor screen. It follows that the outer insulation stress is highest on cables with larger conductor sizes. It is therefore essential that the accessories are designed to be completely compatible with the particular type and conductor size of high stress cable.

The jointing process is critical to the reliable operation of the accessories. In particular the cable screen has to be removed with precision and the exposed insulation carefully prepared to achieve the surface finish necessary to form the electrically stressed interface with the accessory insulation.

The following Pirelli HV terminations and joints were type tested with the locally manufactured high stress design cable: an Outdoor Porcelain Sealing End; an Outdoor Polymer Sealing End; two SF6 Immersed Dry-Type Sealing End; a Straight Joint; and an Insulated Joint [see Annex A].

3. TYPE TESTS ON HIGH STRESS CABLE AND ACCESSORIES TO IEC 60840

In order to prove the compatibility of HV cable and cable accessories, it is necessary to perform Type Tests in accordance with the IEC 60840 test specification. In terms of the IEC 60840 standard [3], type tests are defined as tests that are performed on a specific type of cable or a cable and its accessories, before they can be supplied on a general commercial basis.

During type testing the cable and its accessories must demonstrate their satisfactory performance for the intended application, and if successful the cable and its accessories may be offered as a fully approved type tested cable system. Once approved, type tests do not have to be repeated unless significant changes have been made to the cable or accessory materials, or to the design and manufacturing process.

When the type tests have been successfully performed on one type of cable with a specific value of rated voltage and on two samples with different cross-sectional areas of conductors, the type test approval is also valid for [3]:

a) Cables with the same conductor cross-section, with slightly different rated voltage but belonging to the same voltage group as the tested cable.
b) Cables of similar construction, in the same rated voltage group and with the same conductor cross-section.
c) Cables in the same rated voltage group with all cross-sectional areas of conductors lying between the two on which the tests were made.

For the above reasons African Cables chose 132kV, the highest voltage and subsequently the highest stress level in the HV group (42kV-132kV) and two conductor cross-sections, a 300mm² and a 1000mm². Type test approval could then be claimed for the entire HV group with conductor cross-sections ranging between 300mm² and a 1000mm² copper and aluminium.

All type tests were conducted at SABS National Electrical Test Facility (NETFA). Figure 5 illustrates the type test loop on the 132kV 1000mm² Cu high stress cable and accessories. The test loop constituted of the 1000mm² high stress cable; one porcelain ODSE; one polymeric ODSE; one straight joint; two SF6 immersed sealing ends connected together in a chamber, and one insulated joint [Annex A].

The following tests were conducted on the cable samples to IEC 60840 requirements over a duration of about 7 weeks:

1) Electrical Tests
- The bend test followed by a partial discharge test
- Heating cycle voltage test
- Lightning impulse voltage test followed by an ac voltage test
- Partial discharge tests

2) Non-Electrical Tests
- Dimension checks
- Mechanical properties of thermo-plastic components
- Compatibility of materials
- Pressure tests at high temperature on cable sheaths
- Hot set and shrinkage tests on XLPE

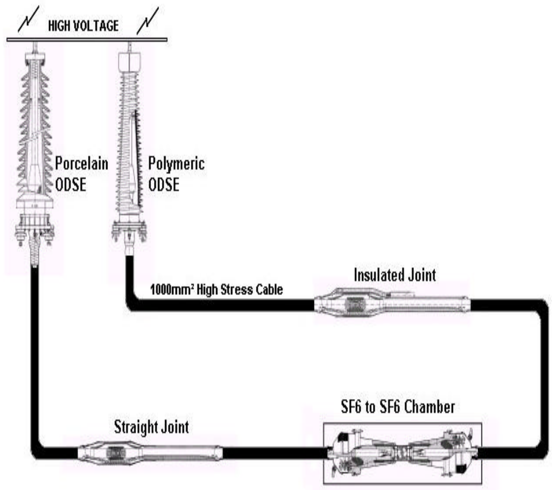

Figure 5: Type Test loop on 132kV 1000mm² Cu high stress cable and accessories

Type tests conducted at SABS NETFA were successful and African Cables was awarded type test certificates to confirm compliance of the high stress design cables and accessories to IEC 60840. The certificates of compliance are valid for high stress HV cables in the range 42-132kV, and conductor sizes in the range of 300mm² - 1000mm² copper and aluminium. A complete cable system with high stress HV cables and accessories was thus approved and is now on offer to customers.

4. CONCLUSION

Comparisons between the high stress cable and existing cable designs show that not only has the stress levels increased, but a reduction in cable weight and cost savings are achievable.

An increase in design stress has been achieved by the manufacture of clean and geometrically precise insulation from a plant integrated with African Cables VCV extrusion line, the only one of its kind in South Africa, which is essential to manufacture high stress HV cables.

Two high stress cables comprising of a 300mm² and a 1000mm² copper conductor with various Pirelli accessories were type tested at SABS NETFA. African Cables was awarded type test certification to confirm that the high stress system complied with the requirements of IEC 60840.

African Cables now offer a fully type tested high stress HV cable system to customers, ensuring reliability and cost effectiveness.

REFERENCES

1. ‘Electric Cables Handbook’, Second Edition, McAllister D, Bungay.E.W.G
2. Gregory.B, Attwood.J.R, Dickson.M, ‘Development Of High Stress HV and EHV XLPE Cable Systems’, CIGRE 21-108, 1998
3. ‘Power Cables with extruded insulation and their accessories’, IEC 60840, Ed.2,1999-02
4. Takehana.H, ‘The Upper Limits Of Electrical Stress of XLPE Cables’, CIGRE WG21, 2000
5. ‘Criteria for Electrical Stress Design of HV Cables’, CIGRE WG21.04, Electra 169, 1996
6. ‘Power Cables and their application’, Heinhold.L, SIEMENS
7. ‘Power Cables, Their Design And Installation’,Barnes.C.C
8. ‘High Voltage Cable Standards’, Vol.2, Pirelli
9. ‘Cable connections for gas-insulated metal-enclosed switchgear…’, IEC 60859, Ed 1, 1986

ANNEX A : ACCESSORIES UTILISED FOR THE TEST

132kV OUTDOOR TERMINATIONS

The 132kV Outdoor Termination (ODSE), Figure A-1 & A-2, is constructed from porcelain and polymeric material respectively, which serves as the main insulator. The sealing ends are suitable for connection to single core polymeric cables up to system voltages of 145kV. The design will accept cable with conductor sizes up to 1000mm², in either copper or aluminium.

The connection to the conductor is by means of a compression ferrule or CAD weld, depending on the conductor material. The electric field control is provided by means of a semi-conducting rubber electrode (stress cone). The surrounding medium is silicone fluid or polyisobutene [8].

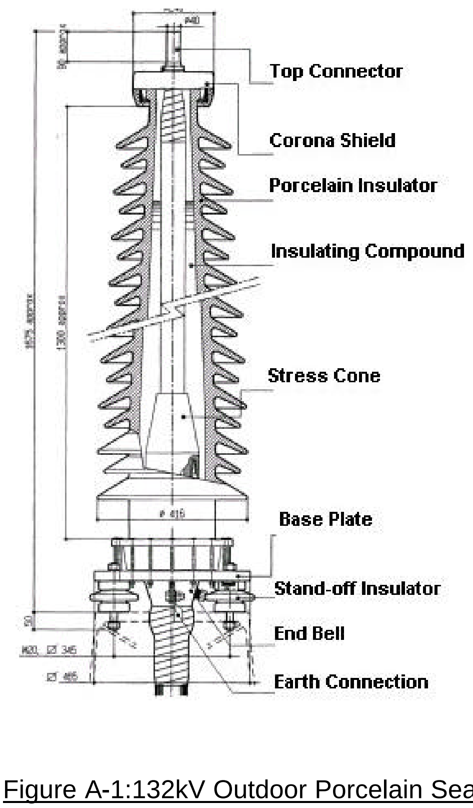

Figure A-1:132kV Outdoor Porcelain Sealing End

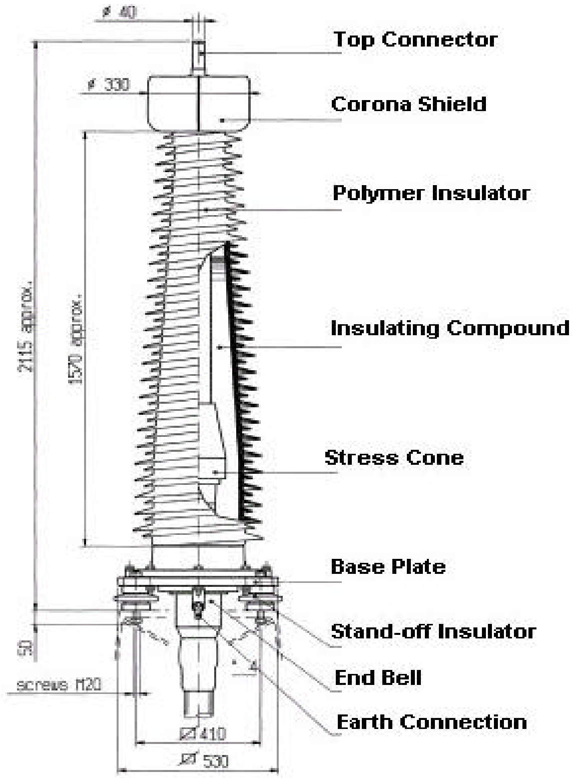

Figure A-2: 132kV Outdoor Polymer Sealing End

132kV SF_6 IMMERSED DRY-TYPE SEALING END

The 132kV SF_6 Immersed Sealing End, Figure A-3, is suitable for connection of a single core polymeric insulated cable to SF_6 filled switchgear or oil filled transformer end boxes. The sealing end is composed of a quartz filled epoxy resin insulator that can be mounted directly into the switchgear or transformer end box by means of a retaining ring. The connection interface is in accordance to IEC 60859 [9].

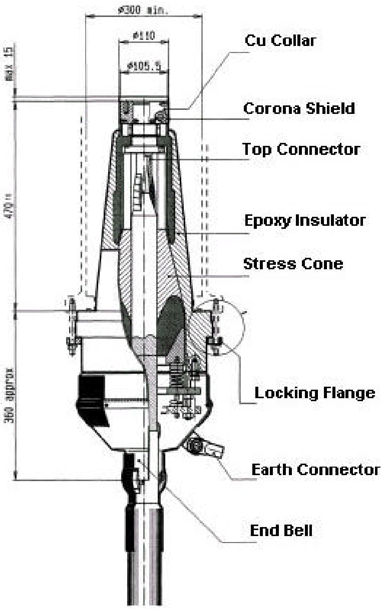

Figure A-3: 132kV SF_6 Immersed Dry-Type Sealing End

STRAIGHT AND INSULATED JOINTS

Straight joints, Figure A-4, are suitable for the connection of single core polymeric cables with conductor sizes up to 1000mm², either copper or aluminium. The joint essentially consists of a one piece moulding with an integral semi-conducting outer screen and stress control components. Stress control is so designed that the electric stress is reduced in the areas of contact between the joint and the cable. The advantage of a premoulded joint lies in the fact that all parts produced are factory tested. This avoids any manufacturing defect and means that once the joint is assembled, its reliability is comparable to that of the cable.

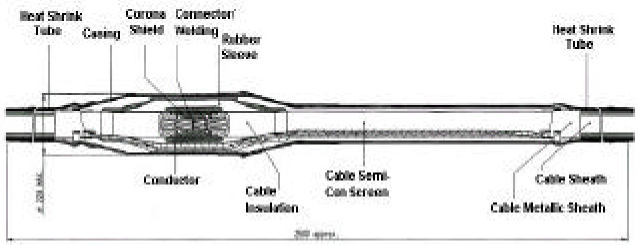

Figure A-4: Premoulded Straight Joint for extruded cables with Cu or Al conductors

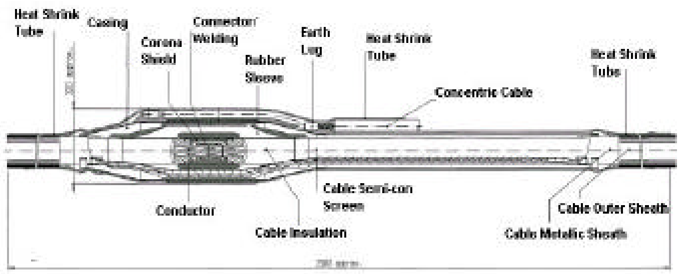

Figure A-5: Insulated Joint for extruded cables with Cu or Al conductors

Figure A-5, illustrates an insulated joint which is similar to the straight joint with the only exception being an additional concentric bonding cable lead and a non-continuous screen. The concentric cable is essential for special bonding techniques, such as in cross-bonded or single point bonded systems.