ABSTRACT

In order to tackle the deregulated market with confidence and in a realistic way, the Belgian utilities reconsidered their approach to the products supplied.

For the 36 kV cable networks, they redefined the cables more in terms of performance rather than of construction regulations as in the past, while maintaining a high level of quality. Cable pulling and installation aspects were also considered in the optimisation process.

Based on a long experience in the high and medium voltage field, 36 kV cables were designed with lower insulation thickness.

The expected short circuit current allowed a lower screen cross-section, which in turn leads to lower sheath losses.

Reduction in outer sheath dimensions was also considered as tough HDPE was chosen for the material. From the quality point of view, it was still considered essential to meet present IEC and European specifications.

Due to higher dielectric stresses in the cable insulation, some studies on accessories were necessary to evaluate the stresses in the premolded joints and terminations.

Cable systems with outdoor and indoor terminations and with joints from two manufacturers were type tested according IEC specifications, as well as being subjected to long term testing with heat cycles to check the performance of the system.

Modifications to the accessories for the new cable design, as compared to the older type of cable with thicker insulation, were also considered and tested. All tests were successful. These economical cables have been produced for the Belgian utilities for a year now, routine tested at 4 U₀, as usual, with partial discharge tests at 2 U₀ (partial discharge level < 2 pC).

The amount of field experience is not yet very great, but results so far are satisfactory. The utilities therefore intend to ask the Belgian Electrotechnical Committee to take the necessary steps to have the new construction of 36 kV cable included in European standards.
INTRODUCTION

In the medium voltage field, Europe has a long tradition with mass impregnated paper insulated cables. The insulation thickness is specified both in national standards and in IEC standards. When synthetic-insulating materials appeared on the market, mass impregnated paper insulation was gradually replaced first by polyethylene (PE) first, and later by cross-linked polyethylene (XLPE) and ethylene propylene rubber (EPR). The insulation thicknesses were chosen the same as before due to a lack of knowledge of these new products.

Since the introduction of XLPE in the cable industry, significant improvements in the quality of semi-conducting and insulating materials and in the manufacturing process have led to the development of high voltage and extra high voltage XLPE cables with dielectric stresses becoming higher and higher.

Twenty years ago a 60 kV XLPE insulated cable had an insulation thickness of about 13 to 16 mm. A 60 kV cable nowadays has the insulation thickness of a 36 kV cable produced in the 1980s, i.e. (about 9mm). This evolution was made possible by the development of premolded joints with high reliability.

So far, however, the thickness of XLPE insulation for medium voltage cables has not changed, despite the fact that almost as much progress has been made in medium voltage insulating material as in the high voltage field. The level of quality and the high productivity of medium voltage cables produced today with modern equipment and materials are such that almost no further reduction in cost can be expected without any design changes.

To make further savings, innovation was essential.

SPECIFICATION FOR A NEW CABLE

In view of the situation described above and also in order to tackle with confidence and realism the deregulated market, Electrabel decided to reconsider its approach to the products supplied, in order to tackle the deregulated market with confidence in a realistic way. In 1998, it decided to redefine the cables for the 36 kV network in terms of performances rather than construction regulations as in the past. Nevertheless it was considered essential to maintain the existing high level of quality in order to ensure good reliability and excellent service to the customers.

Electrabel sent a questionnaire to several cable manufacturers, inviting them to propose a new 36 kV cable of the right quality at the lowest cost giving reasons for their choice.

The main specification for the new product were as follows:

Network conditions

Voltages $U_0/U (U_n) : 20.8/36 (41.5) \text{kV}$
Category of network (IEC 502) $^1$ A
Short circuit current:
- Single phase: 4 kA eff. – 1 second
- Three phase: 25 kA eff. – 1 second
Insulation level:
- Impulse level : 170 kV peak
- Routine test level: $4 U_0 \sin$ AC - 5 minutes

Cable

Conductor:
- Material and construction to be chosen to guarantee the most economical cable.
Insulation:
- XLPE or any other material giving the same performance.
- Insulation thickness may be reduced, but the performance of the cable system must be maintained.
Screen:
- To suit the short circuit conditions.
- Longitudinal watertightness still preferred.
Sheath:
- PE or PVC, red colour, with good mechanical quality; black colour accepted if less expensive.

$^1$ New designation of IEC : IEC 60502
Tests on cables

IEC 60502-2 is applicable except for dimensions and routine tests where the prescriptions are more severe:

- Dielectric test at 4 \( U_0 \) - 5 minutes;
- Partial discharge level at 2 \( U_0 \leq 2 \) pC.

Accessories:

- Accessories shall fit the new cable and pass different type tests required by the relevant standards.

There must be two suppliers of accessories.

Special conditions for installation work

- Must be possible to connect the new cable to the classical cables already installed.
- Must be possible to install longer lengths than before
- Test after installation on insulation:
  - 3 \( U_0 \) at 0.1 Hz or 2 \( U_0 \) at 50 Hz - 60 minutes;
  - on outer sheet: 10 kV - 2 minutes.

TABLE I: Comparison of conventional and new XLPE 36 kV cable structure.

<table>
<thead>
<tr>
<th></th>
<th>Old design</th>
<th>Proposed new design</th>
<th>Reason for changes</th>
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<tr>
<td>Conductor</td>
<td>Copper (Cu) or aluminium (Alu)</td>
<td>Aluminium</td>
<td>Aluminium less expensive than copper for same rate of current (^2)</td>
</tr>
<tr>
<td>XLPE insulation</td>
<td>8.8 mm</td>
<td>6.0 mm</td>
<td>- 20 years of experience of high voltage cables</td>
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<tr>
<td>Thickness</td>
<td></td>
<td></td>
<td>- excellent long duration test results in water at</td>
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<td></td>
<td></td>
<td></td>
<td>12 kV/mm (evaluation of the susceptibility to</td>
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<td></td>
<td></td>
<td></td>
<td>watertreeing)</td>
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<tr>
<td>Metallic screen</td>
<td>Copper wire screen,</td>
<td>Copper wire screen,</td>
<td>- 20 mm(^2) copper wire screen is sufficient for the</td>
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<td></td>
<td>25-35 mm(^2) depending on</td>
<td>20 mm(^2)</td>
<td>required short circuit current of 4 kA, 1 s.</td>
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<td></td>
<td>conductor cross-section</td>
<td>Longitudinally</td>
<td>- Screen of lower cross-section gives less sheath</td>
</tr>
<tr>
<td></td>
<td>- Longitudinally watertight</td>
<td>watertight</td>
<td>losses during service.</td>
</tr>
<tr>
<td>Sheath</td>
<td>HDPE sheath</td>
<td>HDPE sheath</td>
<td>HDPE is mechanically very tough.</td>
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<tr>
<td></td>
<td>Thickness of 3.2 to 4.0 mm</td>
<td>Thickness according to</td>
<td></td>
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<tr>
<td></td>
<td>depending on conductor</td>
<td>IEC 60502 (reduction of about 1 mm)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>cross-section</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Choice of a new economical cable

In table I, the new cable is compared to the earlier conventional cable.

Conductor

Alu conductor was chosen mainly with cross-sections of 400 and 630 mm\(^2\). Cable with Alu conductor is substantially less expensive than equivalent copper cable with the same structure.

Insulation system

The XLPE was maintained as the insulation material. The quality of this material is excellent and its manufacturing process (triple extrusion) is well known and perfected.

The thickness of insulation was reduced from 8.8 mm to 6.0 mm. This leads to a dielectric stress of 4.2 kV/mm at the inner semi-conducting layer and 3.1 kV/mm over insulation.

\(^2\) Cost ratio between aluminium and copper cable could be influenced by the level of prices on the stock exchange.
The arguments in favour of such a change are:

- Major improvements in the quality of the material, as well in smoothness of semi-conducting materials and cleanness and extrudability of insulation material.

- 36 kV cables produced under similar conditions to high voltage cables (triple extrusion, extraclean insulation material, etc.). More than 20 years experience in production of high voltage cables with higher dielectric stresses than those of the newly designed 36 kV cable.

- Similar cables tested for 2 years under 12 kV/mm stress in water at 50° C (according to VDE specifications) with a residual breakdown level of more than 40 kV/mm.

**Metallic screen**

The copper wire screen on conventional cable was either 25 mm² or 35 mm², depending of the conductor cross-section. For the expected short circuit current of 4 kA during 1 second, a copper wire screen of 20 mm² was considered as sufficient. Despite the earthing resistance considerations for the global network, the lower screen cross-section was accepted by the users.

As the lower cross-section has a higher resistance, it leads to lower losses in the screen during service, which is a further advantage for the operating costs.

**Outer sheath**

Depending on the diameter of the cable, the sheath thickness of a conventional 36 kV cable prescribed by the Belgian standards (NBN C33-323), lies between 3.2 and 4.0 mm.

High density polyethylene (HDPE), considered as the toughest material, has very good mechanical behaviour against abrasion and mechanical impact.

The thicknesses proposed by IEC 60502.2 were considered sufficient. This leads to a reduction of the thickness of around 1 mm. If mechanical damage due to this sheath reduction during later installation work is not acceptable, the sheath thickness may be reconsidered.

**Overall dimensions**

The new cable design leads to a reduction of about 8 mm in the outer cable diameter. This makes it possible to much longer lengths on a given drum and to reduce the number of joints during installation.

**Costs**

Cost reduction is around 20 % compared with a conventional cable with the same cross-section.

**Accessories**

Accessories had to be chosen to fit the new cable design. The utility companies wanted to have at least two possible suppliers. Premolded and heat shrinkable accessories were tested on the new cable.

Computer calculations showed that dielectric stresses inside the premolded joint bodies were not higher with the new cable design and that interface stresses were not critical.

**Acceptance tests**

**Cable system test.** To evaluate the quality of the new cable design with the different type of accessories, the cable system mainly had to comply with the following test sequence in addition to the routine tests at 4 $U_0$:

- 100 heat cycles up to 100° C at 2 $U_0$;
- Hot impulse test at 170 kV after 20 and 100 heat cycles;
- 2.5 $U_0$ AC – 15 minutes, after impulse test, followed by a partial discharge test at 2 $U_0$;
- The partial discharge level had to be below 2 pC.

These tests were performed successfully on a 400 mm² Alu cable with the two types of accessories chosen.

Moreover the system passed a 200 kV impulse test which was done to check the safety level of the cable and accessories chosen.

**Test of new cable connected to a conventional XLPE cable.** A test loop was set up, with a conventional 240 mm² Cu cable with 8.8 mm insulation thickness was jointed with a new 400 mm² Alu cable with 6 mm insulation. Long term tests were successfully run at 2.5 $U_0$ with heat cycles up to 100° C for more than 2500 hours.

**Test of new cable connected to a paper insulated cable.** The compatibility of the new 36 kV cable was also checked with the shrinkable joints without any problems being found.
Field experience

After all these tests the cable system was accepted by the Belgian utilities. Several hundred km of 36 kV 400 mm² and 630 mm² Alu cables of this “lean” design have been produced, successfully routine tested at 4 $U_0$ with partial discharge levels below 2 pC (at 2 $U_0$). These cables have been installed in the network and energised without any particular problem.

The experience so far is short, but the utilities and the cable manufacturer are confident.

CONCLUSION

In order to reduce the cost of the 36 kV cable, Electrabel redefined cables in terms of performance rather than construction regulations as in the past. This allowed cable to be designed with lower insulation and sheath thickness and reduced screen cross-section, which led to a cost reduction of 20 % on cables. Tests on the new lean cable with accessories were performed successfully. Several 100 km of the new cables have been installed in the network since the end of 1998. The utilities intend to ask the Belgian Electrotechnical Committee to take the necessary steps to have the new construction of 36 kV cable included in European standards.