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Design of new 150 kV XLPE cable system for the Belgian electrical network

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Résumé

Le secteur électrique belge a annoncé en novembre 1992 une nouvelle politique d'implantation des réseaux Haute Tension impliquant un recours plus fréquent à des liaisons souterraines de 30 à 220 kV. De nouveaux systèmes de câbles ont été développés pour proposer des solutions plus économiques et plus fiables. A titre d'exemple, ce rapport détaille les composants des liaisons 170 kV et les essais réalisés pour leur validation.

Abstract

The Belgian electrical sector announced in november 1992 a new policy for the implementation of High Voltage networks, leading to a more frequent use of underground cables from 30 to 220 kV levels. New cables systems have been developed to offer more economical and reliable solutions for underground links. As an example the paper details the 170 kV cable system components and the different tests performed for their validation.

1- Introduction

Given the increasing resistance of both the population and the administration responsible for town and country planning to the idea of new overhead line projects, the Belgian electrical sector announced in November 92 a new policy for the implementation of HV networks.
Among its elements, this policy provides that the total length of overhead lines be frozen at its 1992 level, in the 30 to 220 kV range.
This decision had lead to more frequent use of underground cables at these voltage levels.
As an example, taking into account the need of a transmission power rating increasing for these new underground links, a new 170 kV cable system with a transmission capacity of 245 to 290 MVA (continuous rating) was considered. Besides, as the costs of an underground link are significantly higher than an equivalent overhead line, it is of the greatest importance to improve the reliability of the underground systems as much as possible and also to take advantage of the present state-of-art for the highest voltage levels to reduce, by this way, the costs of the HV underground links.
In order to achieve these purposes, different developments were conceived and tested. The most significant ones are described here after.

2- Developments of components, the 170 kV cable system example

One way to reduce the costs of underground cables and, in the meantime, to improve their reliability consists in applying the technical improvements made in the recent developments for the highest voltage (400 and 500 kV) to the HV level.

As an example, a novel 170 kV cable system with a transmission capacity of 245 to 290 MVA was considered and new corresponding components were derived from the present research level of the 400 kV and 500 kV to offer the best technico-economic solution.

2-1- Cable

2-1-1- Basic requirements :

- Permanent transmission capacity : 1050 A in a direct buried trefoil configuration
  (in the following conditions :
  - depth : 3 m;
  - ground temperature : 15 °C;
  - thermal resistivity :
    . natural soil : humid : 1.0 K.m/W
    dried-out : 2.5 K.m/W;
    . special backfill : dried-out : 1.0 K.m/W).
- Maximum peak value of the cyclus : 1180 A
- Short-circuit rating : 38.5 kA / 0.25 s and 100 KA peak
- BIL = 750 kV peak

- Radial and longitudinal water tightness
- Insulation : cross-linked polyethylene
- Over sheath = HDPE (e ≥ 4.5 mm)
- After a long duration prequalification test, other tests according to IEC 840
- Routine testing : the test voltage shall be 3.5 Uo provided that the electrical stress shall not exceed 25 kV/mm during the test.

2-1-2- Cable dimensioning

2-1-2-1- Insulation
The insulation wall thickness dimensioning is made taking into account :
a) the maximum AC stress in service operating stress on the conductor
b) the external stress allowed by accessories (operating stress over insulation)
c) the acceptable AC breakdown risk level in service
d) the maximum lightning impulse stress (on the conductor)
e) the AC stress for the routine test

170 kV cables are extruded in a vertical line, commonly used to manufacture 245, 420 and 525 kV cables, of the same design and using the same compounds : one can thus expect the same performances, with regard to the acceptable electrical stresses. Cable systems including cable and accessories have been long term tested with stresses of 34 kV/mm on the conductor and 14 kV/mm over insulation.
These results have enabled to validate the possibility of operation under high service stresses as specified by the French standard C 33-253 for cables up to 290/500 (525) kV.
In this way, for the 170 kV level, electrical stresses of 10 kV/mm on the conductor and 4.5 kV/mm over insulation allow an important reduction of the insulation wall thickness while keeping a good safety margin, as proved by the highly satisfactory service records obtained on hundreds of 130/225 (245) kV cables designed with the same stresses. Higher values of the operating stresses are even not excluded in the future if the stresses considered for the 400 kV – 500 kV level would be used. This second step requires nevertheless new development of accessories and for this reason was not considered at this stage.

<u>Lightning impulse stress</u>

In order to take into account the lightning impulse at increased temperature (95°C), a moderate value of maximum electric strength equal to 85 kV/mm was selected, based on many short term test carried out on XLPE 245, 420 and 525 kV cables.

<u>Routine testing</u>

Since the electrical stress at 3.5 Uo corresponds approximately to 25 kV/mm, if an external operating stress of 4,5 kV/mm is adopted, the routine test duration provided by the IEC 840 standard could be respected.

2-1-2-2- Conductor sizing

To provide the transmission capacity specified, two conductors have been considered :
1200 mm² copper
2000 mm² aluminum
These two conductors offer approximately the same transmission capacity.
Due to the lower weight of the cable and its lower cost, the 2000 mm² aluminum conductor was selected.

2-1-2-3- Optical fibre integration

Optical fibre, placed in a stainless steel tube are inserted in a lapping of semi-conducting fillers helically laid on the cable core. Besides, layers of swelling tapes are wounded under and above the fillers providing for the longitudinal water-tightness barrier of the cable.

2-1-2-4- Radial water-barrier and metallic screen

To prevent the ingress of moisture and to provide the short-circuit current carrying capacity, a 3 mm thick lead sheath is extruded over the cable core and the swelling tapes layer. Finally, an HDPE over sheath is extruded over the lead sheath.

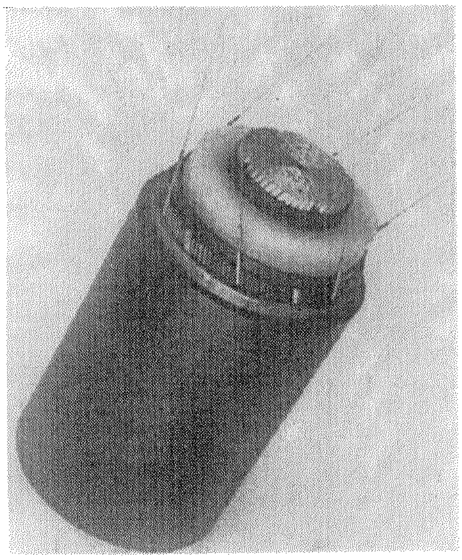

Fig 1 - Cable construction

2-1-3- Cable manufacturing

As 245, 420 and 525 kV XLPE cables, 170 kV cable is manufactured on a vertical line installed in a shaft of 100 m depth.

Insulation is achieved following a Completely Dry Curing and Cooling process (C.D.C.C.) with common extrusion of the three layers in a triple head.
After insulation, the cable is treated in an oven to eliminate some by-products; after this treatment, the water content of XLPE is < 100 ppm.

2-2- Accessories

Prefabricated accessories for supertension extruded cables have been developed more than 10 years ago and described in many occasions. Referring to the work prepared by the CIGRE WG 21-06, the proposed accessories for the 170 kV level are of the following types :

a) terminations :
- stress cone and composite or porcelain insulator for the outdoor termination;
- as variant, completely synthetic termination for the outdoor termination;
- stress cone and insulator or directly immersed for the Metal Enclosed GIS termination.

b) joints :
- one piece premoulded joint.

2-2-1- Outdoor termination

a) With insulator
Outdoor terminations include a factory premoulded silicon stress cone, either oil or SF6 gas as insulating fluid and are housed in a composite insulator as shown in fig 2 with a rigid core of conical shape onto which elastomeric sheds have been extruded. Such kinds of insulators were chosen for their safety, ease to handle and shock resistance during transportation and installation as also for their excellent behaviour in polluted areas. The standard connecting box, placed under the termination, allows the linking of optical fibres inserted in the 150 kV cable to the substation building through a common optical fibre cable.

b) Without insulator (synthetic termination)
Synthetic terminations have been considered and have been adopted for 170 kV provisional links operated since November 1997 for evaluation of their ~~behaviour. This type of termination will probably be~~ the solution in a near future.

2-2-2- Metal Enclosed GIS terminations

Using the same elastomeric factory premoulded stress cone, two designs are available.
- with insulator to comply with IEC 859 . The SF6 gas inside the insulator can be provided by the GIS by means of a passage way through the insulator or can be segregated.
- without insulator, as for example described and specified in French standard C 33-062 or to comply with any special customer requirement.

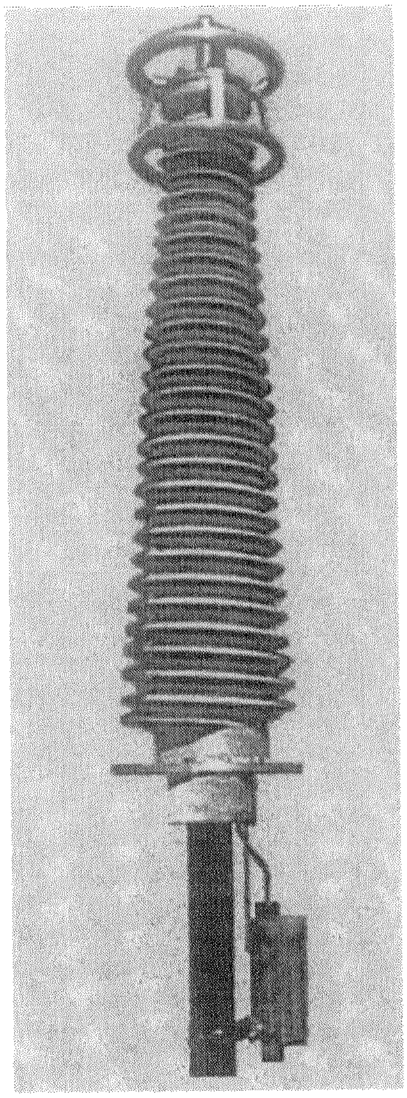

Fig 2 - 170 kV Outdoor Termination
with composite insulator

2-2-3- Joints

Using the same premoulded components as the "one piece" premoulded joints in use in several 245 kV grids since 1989 with good outcome of experience, joints can include a shield-break to allow cross-bonding connections. In addition, the joint also enables the splicing of the optical fibres inserted in the two cables sections to joint with the required shield-break insulation level.

3- Tests on cables and accessories

3-1- Test according to IEC 840 with customer's special requirements.
Main following tests were performed :

3-1-a) Routine tests

- Partial discharge test
- Voltage test
- Electrical test on non metallic sheath

	Requirements	Results
Partial discharge test	Sensitivity ≤ 1 pC Magnitude ≤ 2 pC under 2Uo (174 kV)	Sensitivity 1 pC Magnitude 1,2 pC at 174 kV
Voltage test	30 minutes at 3.5 Uo (304.5 kV)	30 minutes at 304.5 kV AC no failure
Electrical test on non metallic sheath	1 minute at 25 kV DC cable immersed in water	1 minute at 25 kV DC cable immersed in water no failure

Table 1

3-1-b) Special tests

All special tests included in IEC 840 were carried out with success.

3-1-c) Water penetration test

Water penetration test was made on the cable equiped with optical fibres, after 3 bending cycles.

	Requirements	Results
Bending test	3 bending cycles Diameter of the test cylinder not greater than 25 (D + d) + 5 % (3801 mm)	3 bending cycles Diameter of the cylinder 3600 mm
Water penetration test	24 hours room temperature + 10 heat cycles no water may emerge from the ends (at 1.5 m)	24 hours room temperature 10 heat cycles no water emerged

Table 2

3-1- d) Type tests

- Tests on complete cable system : heating cycles voltage test according to IEC 840

	Requirements	Results
Partial discharge test	Sensitivity ≤ 1 pC Magnitude ≤ 2 pC under 2 Uo (174 kV)	Sensitivity 0.9 pC Magnitude 1.5 pC under 174 kV
Bending tests	3 bending cycles Diameter of the test cylinder not greater than 25 (D + d) + 5 % (3801 mm)	3 bending cycles Diameter of the cylinder 3600 mm
Partial discharge test after bending	Sensitivity ≤ 1 pC Magnitude ≤ 2 pC under 2 Uo (174 kV)	Sensitivity 0.9 pC Magnitude 1.5 pC under 174 kV
Partial discharge test after joint installation	Sensitivity ≤ 1 pC Magnitude ≤ 2 pC under 2 Uo (174 kV)	Sensitivity 0.9 pC Magnitude 1.5 pC under 174 kV
Partial discharge test on complete set up before heating cycles voltage test	Sensitivity ≤ 1 pC Magnitude ≤ 2 pC under 2 Uo (174 kV)	Sensitivity 0.9 pC Magnitude 1.1 pC under 174 kV
Heating cycles voltage test	2 Uo during 480 h 20 heat cycles for 95°C ≤ θ ≤ 100°C	174 kV during 542 h 22 heat cycles 95°C ≤ θ ≤ 100°C
Lightning impulse test	10 impulses ± 750kV 95°C ≤ θ ≤ 100 °C	10 impulses ± 750 kV no breakdown
Voltage test	2.5 Uo during 15 min ambiant temp.	2.5 Uo – 15 min no breakdown
Partial discharge test	Sensitivity ≤ 1 pC Magnitude ≤ 2 pC under 2 Uo (174 kV)	Sensitivity 0.5 pC Magnitude 1 pC under 174 kV

Table 3

- Additional heating cycle voltage test (long duration prequalification test)
  After completion of the IEC 840 heating cycle voltage test 80 additional cycles under 2 Uo were performed followed by lightning impulse tests.

	Investigation program	Results
Heating cycle voltage test	2 Uo (174 kV) during 1920 h ≥20 cyles (8 h/16 h) with 100 ≤ θ ≤ 105°C	2 Uo (174 kV) during 2166 h 39 cyles (8 h/16 h) with 100 ≤ θ ≤ 105°C
Lightning impulse test	10 impulses at ± 750 kV; 95 ≤ θ ≤ 100°C	10 impulses at ± 750 kV; no breakdown
Voltage test	15 minutes at 217.5 (2.5 Uo) 240 (2.75 Uo) 261 (3.0 Uo) 283 kV (3.25 Uo) 1 hour at 304.5 kV (3.5 Uo)	15 minutes at 217.5 240 261 283 kV 1 hour at 304.5 kV no breakdown

Table 4

4- Developments concerning the cable system

4-1-Temperature measurement sensors.

To get a better knowledge of the actual thermal stresses during the operation of high voltage underground cables, it was decided to use optical fibres for temperature measurement along the entire length of scheduled high voltage lines.

These optical fibres (both monomode and multimode) are inserted in one of the three cables of each circuit.

As breaks in the fibre could occur during laying , and in order to check the appropriate design of the cable, a special type test program including bending tests following IEC 840 and additional pulling and bending tests representative of on site handling was performed on a full 500 m cable length (see details here under).

For each cable length equipped with optical fibres, the optical characteristics of the fibres shall be measured in the factory and on site before and after laying operations :

- attenuation by reflectometer at 1310 nm and 850 nm (for θ = 20°C) for each multimode fibre
- attenuation by reflectometer at 1310 nm and 1550 nm (for θ = 20°C) for each monomode fibre.

Maximum acceptable values of attenuation shall be:

	Type of optical fibre			
	Multimode 50/125 µm		Monomode 9/125 µm	
	850 nm	1310 nm	1310 nm	1550 nm
In the factory and before laying	3.0	1.0	0.4	0.25
After laying	3.5	1.15	0.45	0.30

Table 5

4-1-1- Tests on optical fibres temperature measurement system

4-1-1-1- Tests during manufacturing process

Attenuation measurements have been made at different steps of the manufacturing process : before and after laying of the stainless steel tubes (housing optical fibres) on the cable core , after lead sheath extrusion , and after jacketing . After the complete manufacturing process , the values comply with the customer requirement given in Table 5.

4-1-1-2- Tests during laying process

Special laying tests have been performed both in straight line route and bending route on the same cable length .
Attenuation measurements have been made before and after laying of the cable

a) straight line laying:
520 m of cable have been pulled with synchronized power drive rollers installed at 100 m intervals.

b) bending line laying:
Four curves with a bending radius of 2085 mm (17 to 18 times the outside diameter of the cable) were prepared along the cable route according to the sketch given in Fig 3.

Table 6 gives compared results of the measurements made after laying in both configurations. All values comply with customer requirements and proved that no mechanical stress was induced on optical fibers in the different life stages of the cable construction as also during the laying operations.

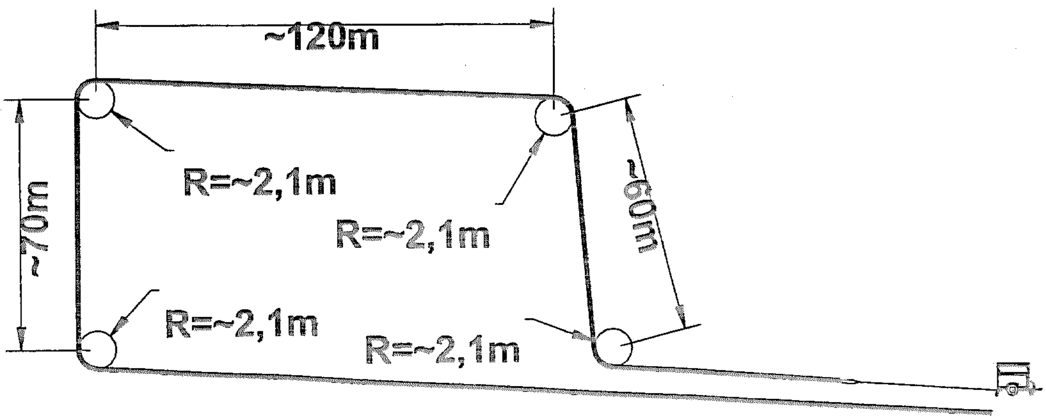

Fig 3 - Bending route for laying tests

Tube	O.F	λ (nm)	Attenuation (dB/km)			Requirements
			Straight route	Bending route	Δ	
1 Monomode	1	1310	0,372	0,372	0	Monomode OF 1310 nm < 0,45 dB/km 1550 nm < 0,30 dB/km
	1	1550	0,248	0,206	-0,042	
	2	1310	0,386	0,386	0	
	2	1550	0,270	0,218	-0,052	
2 Multimode	1	850	2,428	2,432	+0,004	
	1	1310	0,512	0,522	+0,010	
	2	850	2,304	2,304	0	
	2	1310	0,496	0,500	+0,004	
3 Multimode	1	850	2,480	2,462	-0,018	
	1	1310	0,490	0,528	+0,038	
	2	850	2,338	2,252	-0,114	
	2	1310	0,462	0,522	+0,060	
4 Monomode	1	1310	0,362	0,356	-0,006	Multimode OF 850 nm < 3,50 dB/km 1310 nm < 1,15 dB/km
	1	1550	0,158	0,200	+0,042	
	2	1310	0,398	0,394	-0,004	
	2	1550	0,220	0,204	-0,016	
5 Multimode	1	850	2,462	2,558	+0,096	
	1	1310	0,498	0,520	+0,022	
	2	850	2,282	2,352	+0,070	
	2	1310	0,490	0,492	+0,002	
6 Multimode	1	850	2,400	2,486	+0,086	
	1	1310	0,496	0,518	+0,022	
	2	850	2,268	2,324	+0,056	
	2	1310	0,490	0,506	+0,016	

Table 6

4.2- Cross-bonding

To improve the transmission capacity of the supertension cable systems, a new cross-bonding technique has been adopted, and is described in Fig. 4.

One or two ground cables (depending on the length of the circuit) are laid in parallel with the screens at each joint bay between each ternary section and to the ground at both ends of the circuit. Surge arresters are connected in star formation and the common point of the arresters is not connected to the ground cable nor to any local earth. They are housed in an external box and are dimensioned to withstand the DC sheath test without triggering.

5- Conclusion

New components have been developed to offer more economical and more reliable underground links to meet the need of the Belgian electrical sector regarding XLPE cables systems in voltage ranges up to 220 kV.
As an example, 170 kV components have been successfully qualified according to a testing procedure prepared on the basis of IEC 840 and its future amendments and including severe additional requirements concerning partial discharges level and temperature measurement system.

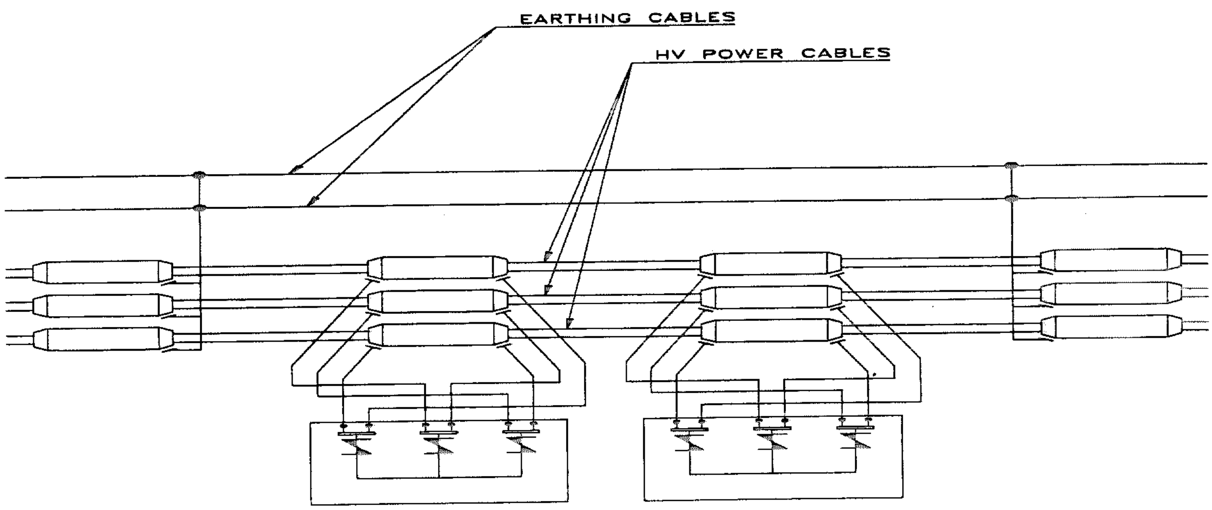

Fig 4 - Cross Bonding System