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LARGE PROJECTS OF EHV UNDERGROUND CABLE SYSTEMS

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ABSTRACT

European manufacturers had greatly contributed to the preparation of IEC 62067. Several big projects of underground cable systems up to 500 kV have now been carried out by European manufacturers throughout the world. CIGRE recommendations and later on IEC 62067, have been in all cases the customer technical requirement. This paper summarizes this experience developed by European Companies. The purpose of this paper is two-fold:

- to describe the big projects installed by European manufacturers from 345 kV to 500 kV taken into account by CIGRE B1.06 in its work, providing data on the electrical stresses adopted for the cable, on the accessories and the installation conditions,
- to analyse to which extent the recommendations of CIGRE B1.06 address the issues outlined in Paper A.2.5 of Jicable 2003.

KEYWORDS

EHV Cable systems, IEC 62067, Revision of qualification procedures, CIGRE Technical Brochure 303, Jicable 2003 Paper A.2.5

INTRODUCTION

In Jicable 2003, paper A.2.5 [1] recalled the first experience gained by European Cable Manufacturers and described the main first big European cable projects.
As recalled, each time, tests specifications included in IEC 62067 published in 2001[2] (or CIGRE recommendations of Electra 151[3]) had proved to be the expected sole of the technical specifications attached to each individual project. Each time, to better fit to the specific features of the project, additional tests were felt necessary to demonstrate the performance of the proposed cable system in the proposed installation configuration according to various CIGRE recommendations.
Since June 2003, all big projects mentioned in Paper A.2.5 have been successfully completed and other big projects have been carried out by European cable manufacturers in and out of Europe.
Despite its broad range of application, the IEC standard does not cover all requirements. Furthermore, in order to be able to provide to users the last available technologies, it appeared very soon important to establish a testing regime which, once the capability of a cable system supplier to produce EHV cable system is proven, allows the qualification of innovative solutions with stringent requirements but implying shorter test durations at acceptable costs.
All these issues were listed in Paper A .2.5
At this time, CIGRE Working Group B1.06 had just been launched by Study Committee B1 with the goal to prepare recommendations for evolutions of IEC 62067 taking into account the expected innovations in cable technology, the need to reduce the time to market and the overall cost to introduce new evolutions as well as service experience collected by the Cable Industry.
The work of CIGRE WG B1.06 has been completed in August 2006 and has been published in CIGRE Technical Brochure 303[4]. Chapter Two of Technical Brochure 303 gives the recommendations for EHV cable systems. These recommendations have been based on the experience gained on installed EHV cable systems inventoried in Chapter One. An important part of this service experience is coming from European cable projects. These projects will be described in detail in 2.2.

EXPERIENCE OF EHV CABLE SYSTEMS CONSIDERED BY WG B1.06 IN TB 303

Summary of TB 303

Four main chapters compose TB 303.

Chapter One, as an Introduction, recalls and details the Scope of Work and the Terms of Reference of WG B1.06 and gives an overview of the service experience of HV and EHV cable systems till August 2006 as well as a survey of experience obtained by testing EHV cable systems.
Much of the service experience with HV XLPE cable systems is based on cables with moderate design stresses. XLPE has only recently become the insulation of choice for many utilities for EHV transmission circuits. The introduction of XLPE for longer transmission circuits has generally followed the completion of a one year heat cycle voltage test called prequalification (PQ) test, which was recommended by CIGRE in 1993 in Electra 151 and afterwards specified in IEC 62067, Ed1 in 2001.

Chapter Two covers long duration tests on EHV cable systems and the different features which are examined:

- Design concept
- Electrical performance of cable and accessories
- Performance of a cable system under prolonged heat cycling
- Aspects of installation design and practice

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- Ability of the Installer to joint in realistic conditions rather than laboratory conditions

Chapter Three similarly covers long duration tests on HV cable systems.
Due to experience on EHV cable systems it has become more common nowadays to produce cables with reduced insulation thickness at the high voltage level. Higher dielectric stresses nearly as high as in the EHV field not only at main insulation but also at the interfaces between cables and accessories can be seen.
Taking into account that service experience on HV cable systems working at usual stresses collected so far was rather good, the WG B1.06 recommended that cable systems should be considered rather than cables or accessories alone when higher stresses are adopted.

Chapter Four lists the conclusions of the Working Group. These recommendations will be developed in part 3 hereunder.

Chapter Five contains all the annexes introduced in chapters one to four and specially:

- A functional analysis which is a useful tool for engineers for the choice of appropriate tests
- The inventory of tests missing in IEC standards

Inventory of large EHV transmission cable systems considered by WG B1.06

Table 1 recalls the EHV Cable Systems taken into consideration by B1.06 to prepare its recommendations;

Then, from 2.2.1 to 2.2.9, detailed information on most of these systems will be provided.

Country	Rated (Ø- Ø) voltage	Type of joints (1)	Number of joints	Number of outdoor/SF6 terminations	Type of installation (2)	Route length	Number of circuits	Conductor cross-section/ Transmission capacity in Winter	Commissioning year
	(kV)					(km)		mm²/(MVA)	
Denmark (Copenhagen:Southern cable route) [54]	400	CPFJ	72	3/3	DB	22	1	1600 Cu / 975	1997
Denmark (Copenhagen:Northern cable route	400	PMJ	42	3/3	DB	12	1	1600 Cu / 800	1999
Germany (Berlin/BEWAG Mitte-Friedrichshain)	400	CPFJ+PMJ	48	0/12 (double systems)	T	6.3	2	1600 Cu / 1100	1998
Germany (Berlin/BEWAG Friedrichshain-Marzahn)	400	CPFJ+PMJ	30	0/12 (double systems)	T	5.5	2	1600 Cu /1100	2000
Japan (Tokyo (3) [55]	500	EMJ	264	0/12	T	39.8	2	2500 Cu / 2400 (4)	2000
United Arab Emirates (Abu Dhabi)	400	PMJ	12	12/12	D&M	1.3 (5)	4	800 Cu / not available	2000
Spain (Madrid)	400	CPFJ+PMJ	96	12/0	T	12.8	2	2500 Cu / 1720	2004
Denmark (Jutland)	400	PMJ	96	36/0	DB&D	14.5	2	1200 Al / 1200	2004
United Kingdom (London)	400	CPFJ	60	0/6	T	20	1	2500 Cu / 1600	2005
The Netherlands (Rotterdam)	400	PMJ	3	6/0	DB&D	2.25	1	1600 Cu / 1000	2005
Austria (Wienstrom)	380	PMJ	30	6/6	DB&T&M	5.2	2	1200 Cu / 1400	2005
Italy (Milan)	380	PMJ	66	12/0		8.4	2	2000 Cu / 2100	2006

(1) CPFJ = Composite Prefabricated joint, PMJ = Premoulded Joint, EMJ = Extruded Moulded Joint
(2) T= Tunnel, DB = Directly Buried, D = Ducts, D&M = Ducts and Manhole
(3) Cable system prequalified following Japanese Specification [48]
(4) 1200 MVA / circuit with forced cooling in the future, 900 MVA / circuit now
(5) 15 core kms / 4 circuits X3 phases = 1.3 km

Table 1: Major EHV Underground Projects

The Bewag project (stages 1 and 2) in Berlin

After completing the pre-qualification test for a 400 kV XLPE cable system in accordance with the testing recommendations of CIGRE in 1995 the public utility of Berlin, Bewag put an order in 1996 for the supply and installation of two 400 kV XLPE cable systems in an approx. 6.3 km long underground tunnel in the centre of the German capital [5].

The tunnel was constructed in a depth of 25 to 35 m below the ground level and has an inner diameter of 3 m. The cable system has a transmission capacity of 1100 MVA per circuit in the air ventilated tunnel using a 1600 mm^2 segmented copper conductor. The cable circuits are part of a diagonal transmission link between the transmission grids west and east of the capital.

The cable installation was in vertical flat arrangement on specially designed cable saddle supports with a distance of 7.2 m and a short circuit proof spacer located in the middle of each span. The cable route was divided into nine laying sections with a laying length of approx. 730 m. At both substations GIS terminations were installed and for interconnection of the cable lengths pre-fabricated sectionalising joints for cross-bonding of the cable screen. For symmetrical cross-bonding the cable route is consisting of three major cross-bonding sections with three minor sections within each major section.

During the commissioning tests at the end of the installation period the cable circuits were tested with an AC voltage of 230 kV (U_0) and partial discharge measurements in parallel at all accessories followed by a heating period of four weeks and a final AC testing with 400 kV (1.73 U_0) together with partial discharge measurements on the accessories again. The cable circuits went into service in December 1998 [14].

The Bewag utility awarded a second 400 kV cable contract at the end of 1998 for the supply and installation of two 5.4 km long XLPE cable circuits again in an underground tunnel. The cable, accessories and laying arrangement are similar as in the first Bewag project mentioned above. Only the individual cable length was further increased up to 930 m. The cable route was divided into six equally long laying sections resulting in two major cross-bonding major sections. These cable circuits completed the diagonal link between the transmission grids west and east of Berlin. The testing was carried out in same manner as for the first project and handing over was in July 2000 [6].

The NESA Metropolitan Power Project in Copenhagen

This 400 kV AC XLPE cable project was part of a major scheme to modernize and upgrade the high voltage network of Copenhagen by eliminating almost all overhead transmission lines from densely populated areas. The cable project was split into two stages. The southern route consisted of a 22 km cable link and its commissioning took place in 1997 [7]. The northern route consisted of a 12 km system, commissioned in 1999 [8].

In total 104 km, including internal cabling, of 400 kV XLPE cable with a 1600 mm² copper conductor, lead sheath and PE outer sheath were delivered. All cables were laid in flat formation on concrete and covered with weak mix.

The burying depth to cable center was 1.5 m. The cable lengths were up to 880 m with a maximum drum of 5 m diameter and a weight up to 45 ton. Due to the fact that the project was the first of its type in the world, an intensive development program was undertaken to qualify the 400 kV XLPE cable, prefabricated joints, outdoor termination and GIS termination to international standards. The demanding jointing work, which required very specific temperature, humidity and hygiene conditions, was performed by specially trained personal. A total of 114 cable joints, 24 GIS terminations and 12 outdoor terminations were installed during the project which has a power capacity of 1000 MVA.

The REE Barajas project in Madrid

AENA, the Spanish airport authority, is extending the international Airport Barajas, Madrid. This extension includes the construction of two new runways. As the existing 400 kV overhead transmission lines operated by REE would obstruct incoming planes, they will have to be dismantled and replaced by 2 cable circuits installed in a tunnel crossing under the new runways [9].

Every cable circuit will consist of 39 km of 400 kV XLPE insulated power cables showing a copper conductor cross-section of 2500 mm^2, with 6 segments, with individual cable lengths up to 850 m.

Each cable circuit contains 48 pre-fabricated joints, sectionalised, straight and earthed, and 6 outdoor terminations plus all required bonding cable and SVLs for the cross bonding arrangement. Additional current transformers and lightning arrestors for protection of the total cable system are installed.

The cable system is installed in a flat formation with a phase distance of 500 mm in a 2 m wide surface tunnel with a height of 2.2 m.

In order to ensure the required maximum power of 1700 MVA per circuit (winter conditions) a special forced ventilation system has been provided in the tunnel.

Commissioning took place in early 2004.

The NGC Elstree project in London

For 1600 MVA bulk power transmission in the London underground a 400 kV XLPE cable system was planned and developed to fulfill the increased power consumption of the megapolis [10].

A 20 km long tunnel with an inner diameter of 3 m was driven through the London underground in a depth of approximately 30 m which allows a straight route independent from the surface situation.

The tunnel shows a cooling system with forced air to increase the transmission capacity of the cables which are installed in a vertical flat formation. Temperature monitoring along the tunnel route and cable screen helps optimize the load situation of the cable to ensure a continuous transmission capacity of 1600 MVA for one cable system.

The delivered cable length up to 1000 m needed total drum weight of 47 ton which were to be handled during production, shipping, and installation. This extreme long

cable length was chosen to reduce the total number of joints.
The complete cable system consists of 60 km XLPE cable, 60 cross-bonding joints and 6 GIS terminations. The 6 segmental copper conductor is watertight and shows a cross section of 2500mm^2. A continuous cross-bonding arrangement was chosen in order to avoid additional earthing efforts at the joint positions.
The cable outer sheath shows an extruded flame retardant layer to prevent the development of fire along the tunnel.
All accessories show integrated PD-sensors which makes an easy PD test during the AC on-site test possible.
On-site testing and commissioning took place in 2005 .

The ELTRA Jutland Project

The building of a 400 kV connection between Aalborg (North Jutland) and Århus (transformer station in Trige) will completes the ring of the main Jutland high-voltage grid [11].
Planning and government evaluation of the 140 km line have been going on for more than ten years. The Danish Energy Council approved the project in early March 2001 and the high-voltage transmission line entered operation in 2004.
The overall project for the establishment of this 400 kV high-voltage connection between Århus and Aalborg includes sections with underground cables. The three 400-kV cable sections run across Mariager Fjord and the Gudenaa Valley, as well as through the Indkilde Valley, with an overall underground route length of 14 km.
Considered together, the three siphons are one of the world's largest cable projects. It is also the first time that 400-kV cables are buried under agricultural land and natural reserves. For all three cable sections in connection with the Århus-Aalborg project, two 400-kV cable systems were laid in parallel.
Special attention has been given to the transition compounds design: requirements and integrated functions, mitigation of the visual impact thanks to aesthetic design, use of composite insulators for improved safety.
Type tests according to IEC 62067 on complete cable system as well as tests on individual components were performed, including type tests on aluminium laminated screen: mechanical tests, corrosion tests and water-tightness tests according to CIGRE recommendations issued by CIGRE WG 21.14 in 1992 [12].
84 km of 1200 mm² Al cable, 96 one-piece pre-moulded joints and 36 outdoor terminations with composite insulators have been installed [13]. Final commissioning tests were performed in 2004.
They included an AC test at 1.7 U_0 for 1 hour.

The Rotterdam project:[14]

Overview
Part of the 380 kV grid reinforcement project in the Netherlands is to complete the double circuit loop in the province of Zuid-Holland. This meant crossing the river Nieuwe Waterweg and the adjacent Calandkanaal. Both waterways connect the Rotterdam harbours with the open sea. Between the Nieuwe Waterweg and the Calandkanaal there is a finger of land approximately 70 m wide
Because the vertical clearance for the entry to Rotterdam harbour will be approximately 200 m, an overhead crossing of the waterways was not considered suitable. In that case three Eiffel towers in a row would have been constructed. The grid owner decided to use a double circuit underwater crossing using horizontal directional drilling.
The cables will be joined into the existing 380 kV overhead line which is in temporary operation at 150 kV. The capacity of the overhead line is 4000 A (2635 MVA). To match this continuous rating, three cables per phase would be necessary. The question was to find a solution that is economically more attractive.

Circuit details
The entire crossing of the two waterways was too long (approximately 1500 m) to cover with one directional drilling and the use of PE tubes. Therefore the drillings have been carried out in 2 stages; northwards from the finger of the land across Nieuwe Waterweg (811 m) and southwards under the Calandkanaal (693 m). On the finger of land, joints will be placed and there was a cable route in a trench connecting the two landing points of the drillings.
After careful evaluation of the possible solutions it was decided to install a forced water circulation system to equalize local hot spots in the directional drilling with cooler sections of the directional drilling. Normally the ground layer with the highest thermal resistance determines the necessary conductor size.
A small layer of ground with a high thermal resistance (1.05 Km/W) could have caused a hot-spot, but water circulation (without active heat exchanger) allowed the desired ratings with a copper conductor size of 1600 mm² rather than over 2500 mm².
The land part of the cable connection (to the transition compounds on both banks), is approximately 700 m. Cable is direct buried in a trench, which is filled with a special back-fill material.

Technical Details
The requirements for the final stage of the project are shown in Table 2. Introduction of an overload factor and carrying out the project in stages over a number of years (as the load grows) allows a more economical solution (Table 3)

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Requirements final stage			
Ampacity [A]	Rating [MVA]	Circuits in use	Duration
4000	2645	1	1 week
3250	2140	1	Repair time side circuit
2500	1645	2	Continuous

Table 2 : Final requirements

Project stages					
Stage [year]	Voltage [kV]	Ampacity [MVA]	Load factor	Cable/phase	Remarks
-2005	150	280	1.0	1x 800 Cu 150 kV	Oil- filled cable from 1971
2005-2009	150	500	0.86	1x 1600 Cu 380 kV *	In operation under 150 kV
2009-200x	380	1000	1	1x 1600 Cu 380 kV *	Depends on load growth
200x-	380	1645	1	2x 1600 Cu 380 kV *	2635 MVA for one week

* Include forced water circulation.

Table 3 : Staged requirements as the load grows.

The forced water circulation system is an economically attractive solution because of the lower initial investment cost, even allowing for the higher joule losses, extra costs of maintenance and electricity for the pumps.

To meet the final requirements 2 cables per phase are required, but the second set can be postponed until necessary. Extra tubes for these cables are already installed in the first run.

To avoid extra joints (12 in the final state) and because it was not possible to create a balanced cross-bonding system, the system now has a single bonded earth system and two separate earth cables of 240 mm² Cu.

The Wienstrom project in Vienna

More than 20 years ago the Electric Utility of the city of Vienna (Wienstrom Gmbh) realized three 380 kV fluid filled cable connections for the penetration into the city from the south direction. Each one of these links, currently in service, consists of two FF cables having 1200 mm² copper conductor, laid in trench with the possibility of increasing the capability by adopting the forced cooling. Due to the city expansion and the increased demand of energy, a new connection penetrating from the north direction was necessary [15]. This new connection, was realized and put in service in 2005, and is a double 380 kV XLPE cable circuit with 1200 mm² Milliken copper conductor. Each circuit is 5.2 km long mainly laid inside the city and connected to an overhead line 9.1 km long outside the city. The two cable links are installed directly buried in trenches at the sides of the roads in order to minimize the effect on traffic during the installation operations; consequently the circuits are also sufficiently spaced in order to avoid the mutual thermal influence. At the station inside the city, the terminations are for the entrance in the gas insulated switchgear (GIS), while at the other side are outdoor for the connection to the incoming overhead line at the transition station.

As for the existing FF cables these two new connections are designed for the requested rating of 620 MVA in each circuit in normal conditions with the possibility to increase in the future the rating up to 1030 MVA in each circuit with the activation of the forced water lateral cooling system.

Design of the cable

Apart of the conductor cross sectional area necessary to sustain the requested load, the XLPE cable was designed for the maximum system voltage Umax =420 kV and for lightning impulse level (BIL) of 1425 kV. The metallic screen is composed of a copper wires screen in conjunction with an impervious welded smooth aluminium sheath. The total size of the metallic screen was selected to obtain a “Cable Reduction Factor” of 0.05, as requested in order to minimize the induced voltages in the parallel telecom cables in case of fault of the 380 kV system to ground. The outer sheath is made of polyethylene, suitable for direct buried cables, with a conductive coating necessary for the verification of the integrity of the outersheath.

Installation

The cable is installed directly buried in a trench at depth of 2.7 m, due to the requirements of the Austrian law the EMF value at the soil level shall not be higher than 15 µT at any point. In order to maintain this EMF value and the requested current rating, the cables were laid in an open trefoil formation by adopting special spacers to maintain the cables and the cooling pipes in their position during the trench refilling Figure 1 shows a sketch of the trench arrangement.

In order to maintain the request rating in normal and forced cooling conditions, the joints were installed in air in concrete manholes, see Figure 2, the axial spacing between the joints was reduced at a minimum but in order to maintain the requested EMF value at the soil level, it was necessary to install two passive loop conductor circuits inside the manhole. The average distance between consecutive joint bays is 850 m.

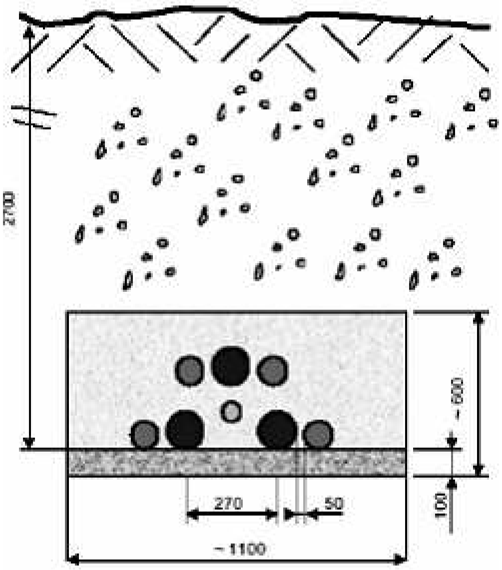

Figure 1: Trench arrangement; black: 380 kV cables, grey: water cooling pipes, in the centre of trefoil DTS/RTTR fibre optic cable.

Tests

A representative loop of the 380 kV cable system containing GIS and outdoor terminations, joints and 30 m cable was subjected to a full type test program according the IEC 62067 standards.
After the installation the cable system was subjected to the AC test at 260 kV for 1 hour. During the same test, the joints ant terminations were subjected to the partial discharge measurements and the cable accessories were provided with sensors in order to repeat the partial discharge measurement in the future.

Figure 2: View of the joints manhole

<u>The Turbigo-Rho project in Milano</u>

The transmission grid area in the north of Italy, and particularly in proximity of Milano, is very congested and the realization of new transmission connections was deemed necessary to sustain the increased power demand and to assure the security of the power supply [16]. A new 380 kV transmission line between the big power plant of Turbigo and the station of Ospiate and Bovisio in the suburb of Milano was realized and commissioned in 2006.
During the authorization procedure for the construction of this 28 km long line a number of problem have been encountered in particular for the crossing of high populated sites and environmental parks and protected areas. In order to resolve this situation the undergrounding of 8.4 km of this line was decided, Figure 3 shows a sketch of the layout.

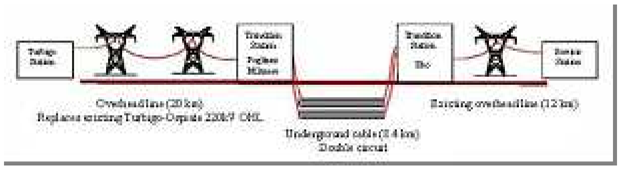

Figure 3: Lay out of the Turbigo-Rho 380 kV line.

The underground cables are requested to maintain the same rating of the overhead line, for this reason two cables per phase were necessary each one with a current rating of 1600 A for a total continuous rating of 3200 A.

Design of the cable

In order to carry the requested continuous current load the a copper conductor 2000 mm² was necessary, the XLPE cable was designed for the maximum system voltage Umax =420 kV and for lightning impulse level (BIL) of 1425 kV. The metallic screen is an impervious welded smooth aluminium sheath firmly bonded to the outer polyethylene sheath that is covered by a conductive coating necessary for the verification of the integrity of the outersheath,.

Installation

The cable is installed directly buried in a trench at dept of 1.7 m, the two cable circuits are laid in two different trenches in flat formation spaced. The two trenches are realized at the sides of heavy traffic roads, operations are conducted in different times in order to minimize the impact on viability, Figure 4 is giving a picture of the works. Extremities of the cable connections have outdoor terminations both sides that are installed inside the overhead-underground transition structures.

Figure 4: Installation operation along heavy traffic road

In some points the cable route is passing in close proximity of existing residences, in these points it was necessary to adopt counter measures for the mitigation of the magnetic field emission. According to the Italian law all the new projects shall guarantee a maximum magnetic field of 3 µT in proximity of residences, in order to maintain this values the cable are installed in a special high magnetic permeability steel raceway, see Figure 5.

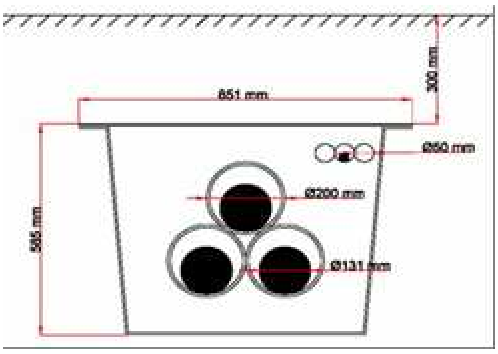

Figure 5: Metallic raceway for the EMF mitigation.

Due to the presence of a number of other services along the same route, and the need to avoid possible damages by third parts, the cable position is clearly identified and continuously marked with labels see Figure 6.

Figure 6: Marking of the cable position along the route.

Monitoring

A DTS continuous monitoring of the temperature of the cable system is provided by the adoption of a fibre optic cable placed in contact with the hottest cable in the trench. One of the most peculiar aspect of this project is the continuous monitoring of the partial discharges of the cable accessories, a sensor is placed on each joint and termination and connected to the acquisition unit, trough an Ethernet LAN data are transferred to the main server at the remote control room.

Figure 7: Turbigo-Rho transition station

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Design criteria adopted for 400 kV projects

Project	Cable	Cable length (km)	Conductor	Electrical stresses IN/OUT (kV/mm)	Metallic screen	Outer sheath	Joints	Terminations	Installation type
Berlin	A	35	1600 mm^2 Cu 5 segments	11.5/5.4	Cu wires Al laminated sheath	PE with flame retardant varnish	39 composite pre-fabricated	12 GIS	Tunnel + forced ventilation
	B	16	1600 mm^2 Cu 5 segments	12.5/6.2	Cu wires Al laminated sheath	PE with flame retardant varnish	15 premoulded one piece	6 GIS	Tunnel + forced ventilation
	C	19	1600 mm^2 Cu 6 segments	12.5/6.2	Corrugated Al	PE with flame retardant varnish	24 premoulded one piece	6 GIS	Tunnel + forced ventilation
Copenhagen		104	1600 mm^2 Cu keystone	11.5/4,9	Extruded Lead	PE with semi conducting layer	72 composite pre-fabricated 42 premoulded one piece	24 GIS 12 outdoor porcelain	Direct buried (concrete & weak mix)
Madrid	A	39	2500 mm^2 Cu 6 segments	11.6/6.5	Cu wires Al laminated sheath	PE with flame retardant layer	48 composite pre-fabricated	6 outdoor porcelain	Tunnel + forced ventilation
	B	39	2500 mm^2 Cu 6 segments	12.5/7.2	Al Welded laminated sheath	PE flame retardant	48 premoulded one piece	6 outdoor porcelain	Tunnel + forced ventilation
London		60	2500 mm^2 Cu 6 segments	11.6/6.5	Cu wires Al laminated sheath	PE with flame retardant layer	60 composite pre-fabricated	6 GIS	Tunnel + forced ventilation
Jutland		84	1200 mm^2 Al stranded	12.6/6	Al wires Al laminated sheath	PE with semi conducting layer	96 premoulded one piece	36 outdoor composite	Direct buried and ducts
Rotterdam		13,5	1600 mm^2 Cu	11.8/5.9	Extruded lead	PE	6 premoulded one piece	12 outdoor composite	Direct buried+ pipes
Vienna		31.2	1200 mm^2 Cu 5segments	12.1/5.7	Cu wires+ Al welded sheath	PE	30 premoulded one piece	6 outdoor porcelain+ 6 SF6	Direct buried + lateral cooling
Turbigo-Rho		50.9	2000 mm^2 Cu 6segments	11.8/6.4	Welded Al sheath	PE	66 premoulded one piece	12 outdoor porcelain	Direct buried and ducts

Table 4: Design criteria adopted for 400 kV projects

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RECOMMENDATIONS OF CIGRE B1.06

Much of the service experience inventoried with HV XLPE cable systems is based on cables with moderate design stresses.
There is still limited experience with EHV XLPE cable systems. The designs, manufacturing methods and materials employed in joints and terminations differ significantly amongst manufacturers. Consequently, the service experience from any particular system cannot necessarily be taken as a guide to the likely service experience of other systems.

From the existing service experience in EHV cable systems in both long duration tests and in operation, it is confirmed that a **Prequalification test (PQ test)** is still necessary to demonstrate the long term reliability. Improvements of this test are proposed such as measurement of partial discharges as a mean to provide early warning and offer possibility of repair before failure.

A procedure to be adopted in case of failure of a component during the PQ test is introduced and a modification to the final impulse test is proposed.

As mentioned in the Terms of Reference, changes in an already prequalified cable system have been evaluated. A procedure of extension of qualification has been recommended and a table was given to indicate in main cases of changes the test sequence to adopt, instead of repeating the complete PQ test.

A new test called **Extension of Qualification Test (EQ test)** has been, mainly to address cases of changes of or in accessories. This test shall be performed in an “indoor” laboratory on one or more samples of complete cable of the already prequalified cable system. At least two accessories of each type that need the extension of qualification shall be tested. A total of 80 heating cycles shall be carried out of which the last 20 cycles shall be under a voltage of 2 U_o.

Main recommendations from WG B1.06 to IEC for further consideration in future editions of IEC 62067 are :

- To maintain a prequalification (PQ) test for the basic qualification of a new cable system.
- To allow in case of a failure of an accessory the continuation and completion of the PQ test for the undisturbed components of the loop.
- To introduce in case of less significant changes/modifications at prequalified components a simplified long-term test (80 cycles) called “Extension of prequalification (EQ) test”.
- To perform the lightning impulse test at the end of the PQ test at the complete test loop or, in case of practical problems with test equipment, in any other test arrangements, which include the accessories.
- To include sample tests at accessories in IEC 62067 as in IEC 60840 Ed3 [17]. These tests are intended to check not only the intrinsic quality of the accessory, but also the quality of the installation, which is critical at the EHV level.

As already said before, due to experience on EHV cable systems it has become more common nowadays to produce cables with reduced insulation thickness at the high voltage level. Higher dielectric stresses nearly as high as in the EHV field not only at main insulation but also at the interfaces between cables and accessories can be seen.

Taking into account that service experience on HV cable systems working at usual stresses collected so far was rather good, the WG B16-06 recommended that cable systems should be considered rather than cables or accessories alone when higher stresses are adopted.

After giving detailed examples of calculated stresses (AC and impulse) in different types of accessories, the WG recommended to adopt a prequalification procedure when electrical stresses are above given limits.

A Prequalification (PQ) test shall be performed only on cable systems where the calculated nominal electrical stresses at the conductor screen will be higher than 8 kV/mm and/or at the insulation screen higher than 4 kV/mm. This prequalification test can be omitted in some special cases. Contrary to the prequalification test for EHV systems, in this case the proposed test is simplified because it can be performed in an “indoor” laboratory and 180 cycles are required instead of one year/180 cycles

The proposed layout of cable system has been described as well as the test sequence.

Then changes in a prequalified cable system were addressed. The **Extension of prequalification test (EQ)** was proposed to be the same as for EHV systems.

As a summary and conclusion from its reflections WG B1.06 made the following recommendations to IEC for further consideration in future editions of IEC 60840:

- To introduce a prequalification (PQ) test for those HV cable systems where the calculated nominal electrical stress at the conductor screen will be higher than 8 kV/mm and/or at the insulation screen higher than 4 kV/mm.
  This test need not to be performed if
  - cable systems with the same constructions and accessories of the same family have been prequalified for higher rated voltages
  - equivalent long term tests have been already successfully carried out
  - good service experience at cable systems with equal or higher stresses can be demonstrated
- To allow in case of a failure of an accessory the continuation and the completion of the PQ test for the undisturbed components of the test loop.
- To introduce in case of less significant changes/modifications at prequalified components a simplified long-term test (80 cycles) called “Extension of prequalification (EQ) test”.
- To perform the lightning impulse test at the end of the PQ test on the complete test loop or, in case of practical problems with test equipment, in any other test arrangements, which include the accessories.

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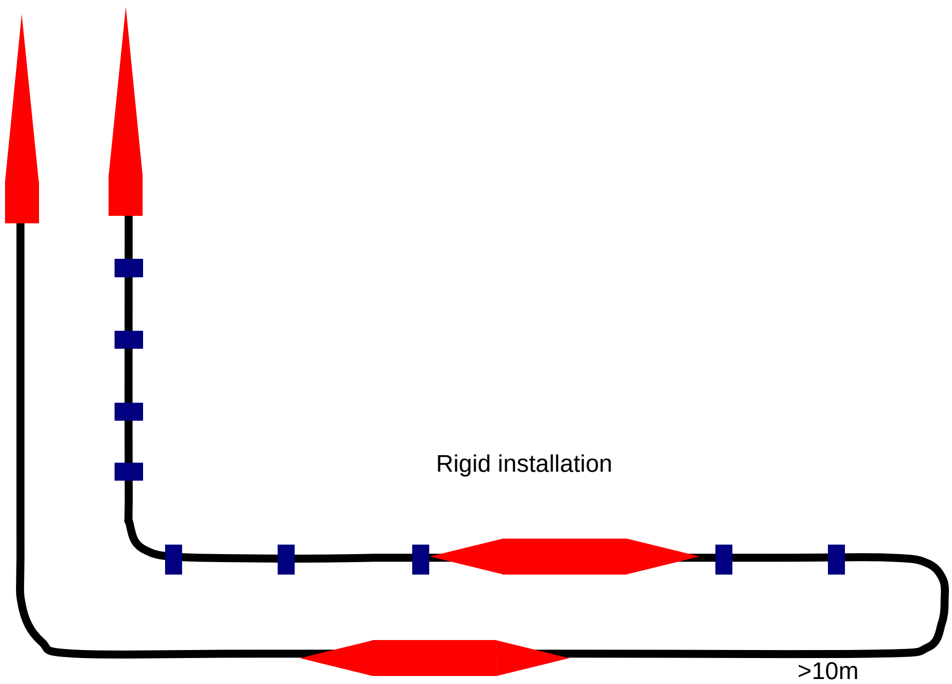

Figure 8: Extension of Qualification test loop

The main conclusions of the Working Group are:

- Concerning EHV Cable systems: there is not sufficient service experience on EHV cable systems collected so far to introduce major changes to the existing initial Prequalification test. This PQ test has to be repeated in case of extension of the range of approval. Within the range of approval, a new test called Extension of Qualification test is proposed to control changes in already prequalified cable systems instead of repeating the complete PQ test. This new test can be carried out on a laboratory loop and will comprise 80 heating cycles combined with voltage application at 2 U_o for the last 20 cycles.
- Concerning HV Cable systems: a prequalification test is recommended for design stresses above 8 kV/mm on the conductor or 4 kV/mm over insulation. This test can be carried out on a laboratory loop and will comprise 180 heating cycles combined with voltage application at 1.7 U_o. This PQ test has to be repeated in case of extension of the range of approval.
  Within the range of approval, a new test called Extension of Qualification test is proposed to control changes in already prequalified cable systems. This new test can be carried out on a laboratory loop and will comprise 80 heating cycles combined with voltage application at 2 U_o for the last 20 cycles.

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CONCLUSION

In 2003, the conclusions of report A.2.5 were:

- There are limits in IEC 62067
- IEC 62067 covers all basic and mainly electrical aspects of XLPE insulated cable systems
- Recent transmission projects have shown that additional issues should be addressed
- Time to market of innovative solutions could be showed down due to absence of appropriate test procedures and the vague definition of "substantial changes".

Consequently, main recommendations of the authors were:

- state of the art of partial discharges techniques should be considered for PQ tests, type tests, routine tests and after-laying tests,
- additional tests may be needed to ascertain the suitability of cable systems to specific conditions,
- a new testing regime is necessary for innovative solutions to provide to users the last available technologies.

An impressive development of transmission underground cables was registered in the last years. Thanks to the development and prequalification test recommended by the relevant IEC standards and Cigre study, a high level of reliability has been reached making more confident the adoption of EHV XLPE cable systems. Based on the service experience of existing EHV cable systems, TB 303 issued by CIGRE WG B1.06, provides recommendations for the evolution of IEC 62067, proposing a new test called “Extension of Qualification Test” for innovative solutions. Functional analysis proposed by CIGRE WG B1.06 is a good tool for the choice of appropriate additional tests to take into account specific features of a peculiar project.
As a whole, TB 303 is a great step forward.

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