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REVISION OF QUALIFICATION PROCEDURES FOR HV AND EHV AC EXTRUDED UNDERGROUND CABLE SYSTEMS

Working Group B1.06

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SUMMARY

Introduction

IEC test requirements have evolved over the years from the component-based approach in IEC 840 to the system based approach. Accessories are considered together with the cable, in IEC 62067 Ed.1 and in the most recent edition of IEC 60840 Ed.3.

In its meeting in Madrid of 2001, Study Committee B1 decided to install a Task Force TF 21.11 to get SC B1 prepared to issue future 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.
TF 21.11 issued in 2002 a proposal of Terms of Reference and Scope of Work for a new Working Group which was launched as WG B1.06 in Paris Study Committee meeting in 2002.
In July 2005 WG B1.06 circulated its final draft of report for approval by SC B1. Comments were received from France, Japan, The Netherlands and Italy.
As time schedule for issuing the new Edition of IEC 62067 Ed.1 was critical, SC B1 agreed to go in more detailed recommendations and decided in its meeting of Rosenön (SE), September 2005 to launch a Task Force to finalise the report and write clear and practical recommendations for appropriate changes in IEC 62067 Ed.1 and IEC 60 840 Ed.3.

This report is the result of the Work of WG B1.06 and of the Task Force.

Chapter One of the report is an Introduction, which recalls and details the Scope of Work and the Terms of Reference and gives an overview of the service experience of HV and EHV cable systems so far as well as a survey of experience obtained by testing EHV cable systems.
At voltages up to and including 150 kV extruded insulation has largely superseded paper-insulated cables for new installations**.**
Much of the service experience with HV XLPE cable systems is based on cables with moderate design stresses. A new generation of 'slim-design' HV cables is being developed, with similar technology and design stresses to those seen in EHV XLPE systems. Hence historical service experience with HV cable systems is not necessarily a good guide to the likely future service experience of these novel systems.

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 been facilitated by the use of a one-year heat cycle voltage test called Prequalification (PQ) test, which was recommended by CIGRE in 1993 and afterwards specified in IEC 62067 Ed.1 in 2001.
Following the successful completion of a number of PQ programmes, some large 400 and 500 kV cable circuits have been installed and commissioned.

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. Thus the service experience from any particular system cannot necessarily be taken as a guide to the likely service experience of other systems. The long term behaviour of an EHV system has to be demonstrated by a well specified PQ test.

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

From the existing service experience in both long duration tests and in operation as mentioned in chapter one, 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.
Then changes in an already prequalified cable system are evaluated. A procedure of extension of qualification is recommended and a table is 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)** is proposed mainly in case of changes of or in accessories. This test shall be performed in a 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_0.

As a summary and conclusion from its reflections WG B1.06 makes the following recommendations to IEC for further consideration in future editions of IEC 62067:

- 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 Ed.1 as in IEC 60840 Ed.3. 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.

Chapter Three similarly covers long duration tests on HV cable systems.
Due to experience on EHV cable systems it becomes more common nowadays to produce cables with reduced insulation thickness at the high voltage level. This leads to 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.
In the meantime, new types of accessories are appearing on the market, of course with no earlier experience. These accessories should be able to fit to the older types of cables with

thicker insulation and the newer types of cables with reduced insulation (changes of an existing HV link with a new cable type or repair of an older link).
Taking into account that service experience collected so far on HV cable systems working at usual stresses was rather good, the Working Group recommend 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 recommends 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 listed in Chapter 3.
Contrary to the Prequalification test for EHV systems, in this case the test is simplified because it can be performed in a laboratory and 180 cycles are required.
The proposed layout of cable system is described as well as the test sequence.
Then changes in a prequalified cable system are addressed. The Extension of Prequalification test (EQ) is proposed to be the same as for EHV systems.

As a summary and conclusion from its reflections WG B1.06 makes 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 needs 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 at the complete test loop or, in case of practical problems with test equipment, in any other test arrangements, which include the accessories.

Chapter Four lists the conclusions of the Working Group. Main ones are:
- <u>EHV Cable systems:</u> 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_0 for the last 20 cycles.
- <u>HV Cable systems:</u> 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_0. 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_0 for the last 20 cycles.

Chapter Five contains all the Annexes introduced in previous chapters

Annex 5.1: Terms of Reference
Annex 5.2: Membership
Annex 5.3: Sensitivity to PD

In this annex the sensitivity of partial discharges in XLPE cable insulations to change of electrical stresses is investigated. The conclusion is that dimensional changes, especially reduction of insulation wall thickness, can result in considerable higher stresses at defects such as voids or fissures, thus increasing the risk of inception of partial discharges.

Annex 5.4: Functional analysis

- A “Functional Analysis Method” is recommended as means for a systematic assessment of the significance of changes/modifications at components of a cable system and thus for the choice of the appropriate test (e.g. PQ or EQ).
- Based on the application of the “Functional Analysis Method” to the most important components of actual cable systems, guides to test procedures are given in case of
    - exchange of a cable and/or accessory in a prequalified cable system
    - modification of a cable in a prequalified cable system
    - modification of an accessory within the same family in a prequalified cable system

Annex 5.5: Tests missing in IEC

As a result of the functional analysis exercise (see Annex 5.4), a number of tests that are not included in IEC 60840 Ed.3and IEC 62067 Ed.1 have been identified. These tests are generally performed as development tests and are summarized in Annex 5.5 for future consideration by IEC.

Annex 5.6: Bibliography

1. INTRODUCTION

1.1 General

Extra high voltage (EHV) cable systems are designed and built to transmit bulk electrical power. For this reason, it is imperative that they attain the highest possible reliability. At the same time, the transmission capacity of the high voltage (HV) cable links is continuously increasing. This is why reliability considerations of cable installations in this category are also becoming very important**.**

Accessories are an integral part of a cable system. Their performance together with that of the cable determines the overall reliability of the circuit. Accessories are installed by hand, and therefore their reliability is determined by a combination of good design, clear instructions, quality assurance (QA) and the skill of the fitters. The long-term Prequalification (PQ) test was developed to build confidence in the operation of XLPE cable at EHV levels. A PQ test demonstrates the quality of the overall design of the system together with the quality of assembly.

IEC test requirements have evolved over the years from the component based approach in IEC 840 to the system based approach, where accessories are considered together with the cable, in IEC 62067 Ed.1 and the most recent edition of IEC 60840 Ed.3.

The IEC has published series of test specifications for HV and EHV cables, accessories and cable systems:

- In 1988, the first specification was published. IEC 840 (renamed later as IEC 60840) is for cables up to 150 kV (U_m=170 kV) [1]. In this specification, type tests, routine and sample tests were prescribed for cables only.
- In 1999 IEC revised this specification and IEC 60840 Ed.2 was published, in which accessories were included in type testing [2].
- In 2004 IEC published a third edition, IEC 60840 Ed.3, in which type tests on cable system and routine and sample tests on prefabricated accessories were introduced [2].
- In December 1993 CIGRE Working Group 21.03 published in Electra recommendations for PQ tests, type tests, sample and routine tests for extruded cables and their accessories for voltages above 150 kV (U_m = 170 kV) up to 400 kV (U_m = 420 kV) [3][4]. In 1997, the voltage range was extended to 500 kV (U_m = 525 kV) [5][6]. In these recommendations, type tests, routine and sample test procedures were based on those from IEC 840. Long term AC stressing together with heat cycles up to the maximum operating temperature followed by impulse tests were prescribed to demonstrate the long-term electrical and thermo-mechanical performance of the system (PQ test). It was considered to be imperative that the test set-up reflected real installation conditions. Test specifications recommended by WG 21.03 were then implemented in IEC 62067 Ed.1 [7] published in October 2001.

The PQ tests recommended by CIGRE and incorporated into IEC 62067 Ed.1 have been accepted worldwide. As a result, only those manufacturers whose products have passed long-term PQ tests have been allowed to participate in subsequent EHV cable projects.

1.2 Scope and terms of reference of WG B1.06

It is inevitable that over a period of time an approved cable system undergoes some changes, such as modifications to the cable construction, higher stress, new type of accessories, new manufacturing processes, etc. However, there is little incentive to the manufacturer to make incremental improvements to the product, since these might invalidate the previous 'approval' and require the long and expensive PQ test to be repeated. Reducing the amount of testing needed would encourage manufacturers to introduce design improvements or measures to reduce cost. For this reason, CIGRE Study Committee B1 launched Working Group WG B1.06 with the task of revising the qualification procedures for underground high voltage cable systems.

The WG was asked to examine how it might be possible to qualify a modification to a cable system without making the full set of tests which are presently recommended or specified in standards. All tests, PQ and type tests were to be reviewed, although the PQ test has received greatest attention, as it is the most costly and the longest.

The full scope and terms of reference of the WG are given in Annex 5.1.

The membership of the Working Group is shown in Annex 5.2

1.3 Experience

1.3.1 Ageing of extruded polymeric insulation

The ageing behaviour of extruded insulation of cables under dielectric and/or thermal stress has been studied extensively [8-16]. No significant ageing could be detected, even with the most sophisticated test methods presently available [15].

Locally there may be weak points in the insulation: impurities or voids in the insulation or protrusions at the interface with the semi-conductive screens. These defects may initiate ageing or accelerate degradation of the cable insulation. In modern cable factories great care is taken to avoid these defects: extrusion of extremely clean insulation materials, extrusion of very smooth semi-conductive materials, careful handling of insulation and semi-conductive materials, etc. Before leaving the factory, the finished cable is submitted to a routine electrical withstand test together with measurement of partial discharges. The effectiveness of these routine tests on HV cables is good as there are very few cable breakdowns on installed systems.

Other ageing factors (i.e. factors that may affect the capability of components to fulfil their roles) are described in the 1992 report from WG 21.09 published in ELECTRA 140, 'Considerations of ageing factors in extruded insulation and accessories' [17]. The main "ageing" factors considered in this report are the locked-in mechanical stresses and shrinkage of cable insulation or outer sheath, maximum operating or overload temperatures affecting radial expansion and possible permanent deformation and reducing AC and impulse breakdown strength, deformation under temperature and externally applied mechanical stress, etc.

The conclusion of this report is: "the extruded polymeric insulants used in high voltage cables do not appear to exhibit property changes that can be measured easily or that can be said to be significant in terms of cable life reduction when contaminants from external sources, e.g. water, oil and sulphur are avoided. For accessories the same may be stated."
In order to evaluate, to some extent, the electrical ageing aspects of a cable system, a type test is prescribed in IEC 60840 Ed.3. In IEC 62067 Ed.1, the PQ test is supposed to evaluate the long-term electrical, thermal and mechanical behaviour of the cable system in an environment near to the conditions in the field.

1.3.2 Experience with HV extruded cable systems up to and including 150 kV

The evolution of XLPE MV and HV systems commenced in the 1960s. In the 1970s, the first commercial 90-132-154 kV XLPE systems were installed in Europe and in Japan.
The results of a survey made by CIGRE WG 21.09 on cable, associated accessories and service stresses and lengths installed in different countries were published in ELECTRA 139 in 1991 [18]

CIGRE WG 21.10 has published in Electra 137 [19] a survey on the service performance of HV AC cable systems. The failure rate of extruded cable systems was very low (0.1 failures per 100 circuit km per year on cables and accessories - external failures were not included). A new Working Group (WG B1.10) was set up in 2004 to update the service experience data.

There are a number of designs of joints and terminations currently in use and an industry standard has not yet evolved. WG 21.06 has described and illustrated the different types of accessories in use [20].

At voltage up to and including 150 kV extruded insulation has largely superseded paper-insulated cables for new installations.

Much of the 'good' experience with HV XLPE cable systems is based on older cable with moderate design stresses. A new generation of 'slim-design' HV cables is being developed, with similar technology and design stresses to those seen in EHV XLPE systems. Hence historical service experience with HV cable systems is not necessarily a good guide to the likely future service experience of these novel systems.

1.3.3 Experience with EHV extruded cable systems at voltages above 150 kV

Whilst cable with extruded insulation is in general use for electricity distribution and at the lower transmission voltages, 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 been facilitated by the use of the PQ test.

1.3.3.1 Prequalification test experience

As cable makers started to develop EHV XLPE cable systems, they needed testing programmes both to monitor their own progress and to give customers confidence in the products being developed. Initially, these testing programmes were agreed on a local or national basis. For example, France used a 250-cycles test for 6000 hours at $\sqrt{3}\,U_0$, while

Belgium adopted a 100-cycles test at 2 U_0. Japan used a half-year test at relatively low electrical stress based on the degradation factor of the insulation system.

Plans to install major 400 kV cable systems led CIGRE to set up a working Group to consider an international test specification. The tests were developed to give confidence that cable systems passing the tests would have a fault rate in service lower than 0.2 faults/100km/year. In 1993 CIGRE WG 21.03 published a test program for cable systems above 150 (170) kV [3] and [4] and IEC published a specification based on these documents IEC 62067 Ed.1 in 2001 [7].

In IEC 62067 Ed.1 the definition of the PQ test is as follows: “a test made before supplying on a general commercial basis a type of cable system covered by this standard, in order to demonstrate satisfactory long term performance of the complete cable system. The PQ test need only be carried out once unless there is a substantial change in the cable system with respect to material, manufacturing process, design and design levels”.

It is useful to examine some of the early French experience of prequalification testing. The French (EDF) specification required a long-term test of duration 6000 hours, although many of the tests were continued beyond this. The specified voltage was $\sqrt{3}\,U_0$ for 250 heat cycles (167 cycles at maximum service temperature and 83 cycles at emergency temperature).

Figure 1.1 summarizes long-term test results on 220 kV cable at the EDF laboratories. Design stresses for the cables (at U_0) were 8.5 kV/mm at the conductor screen and 4.2 kV/mm at the insulation screen.

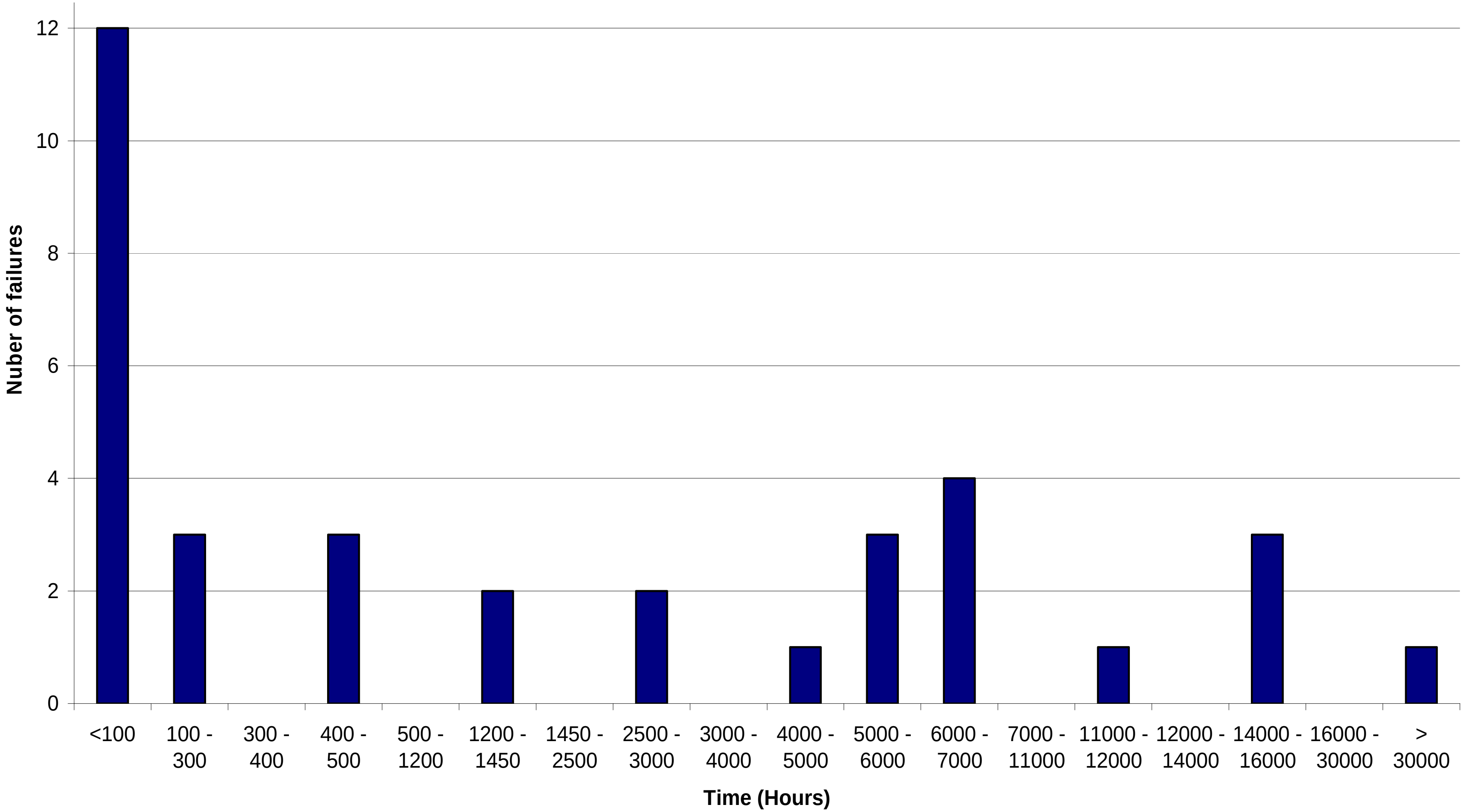

Figure 1.1 Results of long-term tests on 220 kV cable

The defects causing breakdown in less than 10 hours were mounting errors in accessories (5 in joints and 2 in terminations). Eight of the test lengths that failed prematurely contained artificial defects in their terminations. These tests were to simulate a defect found in the field. They showed that this type of PQ test is effective in distinguishing between defective and well-made accessories.

The tests are all from the early stages of development of 220 kV cable systems (pre 1980). Only 2 breakdowns occurred on cables themselves (150h and 36000h). All the other breakdowns were in the accessories. This indicates the important role of accessories in determining the overall reliability of the cable system and the importance of carrying out tests on the cable and accessories as a system.

Some of the tests carried out by connecting the cable between phase and earth of the 400 kV network highlighted the problems associated with this approach. Four of breakdowns occurring after about 6000 hours happened during a thunderstorm with lightning strikes falling on the adjacent overhead line. The defects responsible for the cable failures could not be determined because the cables had experienced the full short circuit current of the 400 kV network and suffered significant local damage at the failure site. The use of a dedicated test transformer provides far better control of the test voltage (avoiding system disturbances) and limiting the short circuit current allows better forensic examination of the failure site.

The occurrences of failures over a wide range of times (up to 16000 hours) suggests that it is not advisable to reduce the duration of the 8760 hours PQ test.

In 2001 Parpal [22] summarized the early experience from a number of PQ tests [23-30]. Subsequently, most of the major EHV cable makers have successfully completed PQ tests on 400 or 500 kV XLPE cables often with large conductors (2000 and 2500 mm²).

1.3.3.2 Service experience

The evolution of EHV systems followed with the first EHV XLPE systems being installed in the voltage range 220-275 kV in the late 1970s. Widespread commercial use of XLPE cables up to 230 kV was not seen until the 1980s. The first 275 kV XLPE systems with joints were installed in Japan in 1989 [21]. These were qualified using Japanese utility specifications.

In France cables insulated with low-density polyethylene (LDPE) preceded XLPE and were first installed at 225 kV in 1969. Since then more than 1000 km of LDPE cable has been installed with field-moulded joints and around 600 km of high-density polyethylene (HDPE) cables with good service experience.

The first 400 kV LDPE cables were installed in France in 1985 and XLPE in 1999. In total, 40 km of cable and 21 back-to-back joints have been installed.

The world's first 500 kV XLPE system was commissioned in Japan in 1988 and two subsequent circuits were commissioned in 1988 and 1991. These were relatively short circuits without joints.

Following the successful completion of a number of PQ programmes, some large 400 and 500 kV cable circuits have been installed and commissioned. These are summarized in Table 1.1.

Although the service experience is limited, all the EHV installed systems subjected to the IEC 62067 Ed.1 PQ procedures have, to date, demonstrated satisfactory behaviour. A more precise picture about the service experience of these cable systems will be available when WG B1.10 "Update of service experience on underground and submarine cables" will conclude his task in 2007.

There is still little service experience with XLPE EHV and it cannot be regarded as sufficient to have demonstrated the long-term reliability of such systems. Also the designs, manufacturing methods and materials employed in joints and terminations differ significantly amongst manufacturers. Thus the service experience from any particular system cannot necessarily be taken as a guide to the likely service experience of other systems.

345 kV Cables installed in a long Tunnel in Korea

Table 1.1: Major XLPE cable systems at 400kV and above. (Data supplied by CIGRE WG B1.07, March 2006)

Country	Rated (ϕ- ϕ) voltage	Type of joints (1)	Number of joints	Number of outdoor/SF_6 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

CPFJ= Composite prefabricated joint, PMJ=premoulded joint and EMJ=extruded moulded joint
(2) T=tunnel, DB=directly buried, D=ducts, D&M=ducts and manhole
(3) Cable system prequalified following Japanese Specifications [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

2. LONG DURATION TEST ON EHV CABLE SYSTEMS (170 < $U_m \leq$ 550 kV)

2.1 General

The prequalification (PQ) test was introduced to compensate for the lack of service experience with XLPE insulated cables above 150 kV (Um =170 kV).

The PQ test checks the performance of the cable/accessory system under realistic conditions. Features examined include:

- Design concept (for example, some early PQ tests at CESI Laboratory showed that a number of taped joints designs did not perform well in long-term tests).
- Electrical long-term performance of accessories and cable.
- Performance of the cable system under prolonged heat cycling (e.g. thermal-mechanical aspects, shrinkage). The 20 thermal cycles specified in the type test are not sufficient to test for the effect of cable insulation shrink-back within the assembled accessories.
- Aspects of installation design and practice. For example, PQ tests have shown that insufficient attention was paid by some installers to arrangements for clamping the cable adjacent to the joint.
- The ability of the installer to mount accessories under realistic conditions rather than in the test laboratory. In some cases, this has highlighted the need for improvements in jointer training. Although not every aspect of the work is tested, the PQ process gives a good indication of the overall competence of the supplier of the cable system.

Although some manufacturers have learnt rapidly from problems in the early PQ tests, this knowledge has not been widely shared. Accessories (and sometimes cables) are still experiencing problems during PQ and type testing and sometimes also in service. The WG has the opinion that the state of the art of XLPE cable technology is not sufficiently advanced that the competence of every manufacturer can be assumed without evidence. Until such time that a significant body of service experience has built up, the WG feels that a PQ test is still necessary.

2.2 Revision of the present prequalification test procedure

The prequalification test procedure detailed in IEC 62067 Ed.1 has been reviewed by the WG. The main items addressed in order to look for a possible simplification/optimization were:
- the range of Type and PQ approval in relation with the calculated nominal electrical stresses
- the duration of the heating cycle voltage test
- the procedure in case of a component failure during the test
- the voltage control at the end of the test.

Regarding a possible widening of the present range of type and PQ approval WG looked very carefully to the sensitivity to change of electrical stress in relation with the generation of partial discharges. It is recommended to keep the relevant sub-clauses in IEC 62067 Ed.1 and in IEC 60840 Ed.3 as they are, see Annex 5.3.

2.2.1 Duration of the heating cycle voltage test

There is no clear evidence for recommending that the number of 180 heat cycles, presently specified, should be reduced. It is well known that, if the heating cycles were not correct in terms of temperature drop, the thermo-mechanical behaviour of the cable system would not be checked adequately.
There is, also, no possibility to reduce the overall length of the test to 180 days, because a daily heat cycle is not possible in many practical conditions.
In fact, for cables installed in air or for buried smaller conductor cables with one day cycle it will be possible to reach, at the end of the cooling period, a conductor temperature near to ambient temperature. When testing a large conductor cable buried in the ground it is not always possible to achieve a correct cooling temperature in 16 hours, due to the long thermal time constant of the cable and/or its surrounding. Thus the actual duration of the test could vary from 6 months for a cable system installed in a tunnel to one year for large conductor cables installed in the ground.
In order to avoid a significant difference in duration of the prequalification test as a function of the cable construction and installation conditions, WG B1.06 suggests for the heating cycle voltage test of the prequalification test the duration of one year.

In addition, the practical experience detailed at section 1.3.3 has shown that the duration of the voltage application is an important factor, because failures in accessories during PQ testing have occurred throughout the one-year test period [22, 23, 28, 29, 49, 50, 52]. This is another reason why the one-year heat cycle test with AC voltage on the system is needed to check the long-term electrical behaviour of the system under test.

Because of these two reasons, it is recommended to maintain the present one-year duration (8760 hours).

Where partial discharge (PD) tests have been performed at regular intervals during the long-term test, it was noted that PD activity could initiate at any moment during the test. For this reason it is recommended to perform partial discharge measurements on the test assembly to provide an early warning of possible degradation and to enable the possibility of a repair before failure.
The WG considers that it is not easy to specify a PD test on the whole loop as compulsory, because it can be difficult to achieve an adequate sensitivity when carrying out a PD test at an unscreened location. This makes it currently difficult to define a level of background noise that can be achieved in practice.

2.2.2 Procedure in case of a system component (cable and/or accessory) failure during the test

The present IEC 62067 Ed.1 standard does not allow any failure during the heating cycle voltage test.
However, taking into account that this test is very onerous, the WG considers that replacement/repair of an accessory failed during the test should be allowed and the test continued because the replaced/repaired accessory cannot influence the behavior of the other ones.
On the contrary it is not allowed to repair a cable failure, unless it is caused by an accidental external damage or the same cable has already been prequalified.

At the end of the 180 loading cycles /one year test and impulse test only the successfully tested accessories will be prequalified, while the accessory/ies subjected to repair or replacement will not be prequalified.

However, it is in the option of the cable/accessory manufacturer to continue the test on the replaced/repaired accessory/ies until it/they complete the 180 loading cycles / one year test and impulse test. In this case also these accessories are prequalified.

In the event that during this test another component, fully prequalified (including the final impulse test), fails, it is possible to repair it and continue the test until the second run is completed on the replaced accessory/ies.
The failure of the component already prequalified (which in this case acts as a laboratory test component) does not violate its prequalification and should not be mentioned in the test report.

2.2.3 Final control test

A lightning impulse withstand test is an effective way of demonstrating that interfacial pressure within accessories has not relaxed during the PQ test. Also it enables to check that no irregularity in the semi-conducting screen of the cable has been generated due to thermo-mechanical forces at for instance bends. As such, the impulse test on the complete test loop should form an important part of the PQ test sequence.
At present, IEC 62067 Ed.1 requires a hot lightning impulse test on one or several pieces of cable cut from the PQ test loop. As an alternative to this, a test on the whole loop is permissible.
The WG has the opinion that after long-term testing, a hot lightning impulse test on the whole test loop is desirable as a check on the insulation properties at the interfaces, in the accessories and in the cable. In fact a check on the insulation properties of the cable only is not sufficient. The WG recommends that IEC 62067 should require a test on the whole loop.
Only in case suitable impulse test equipment is not available at the test site, the impulse test can be carried out in any other test arrangement on cable sections, which include the accessories from the test loop, again as a check on the insulation properties at the interfaces, in the accessories and in the cable (*).
.
(*) NOTE: If the energy of the impulse generator is not sufficient to test the whole cable length, the test loop could be cut, without moving the accessories, into appropriate sections, which then are available to be tested with auxiliary terminations.

2.3 Changes in a prequalified cable system

2.3.1 Evaluation of changes in a prequalified system

According to IEC 62067 Ed.1 the PQ test need only be repeated if there is “a substantial change in the cable system with respect to material, manufacturing process, design and design levels”. A substantial change is defined as one, which might adversely affect the performance of the cable system and puts the responsibility on the supplier to make the detailed case that a change is not substantial.

There is however no internationally agreed method by which the supplier and purchaser can evaluate the evidence and come to a decision as to whether the PQ test or other tests need to be repeated or not.

In order to cover this matter and to evaluate what changes must be considered as "substantial", the WG has adopted the Functional Analysis Method described in Annex 5.4. This method correlates the function performed by a certain item to the tests required to check that function. As a result a number of changes to the components of a cable system that require the repetition of the long-term test were identified.

However it was realized that some of these changes do not require the repetition of a full Prequalification test, but a simplified long-term test called "Extension of Prequalification (EQ) test" could be adopted (see sections 2.3.2 and 2.3.3).
The Working Group considers that allowing a shorter laboratory based long-term test rather than requiring the cable/accessory maker to repeat the full PQ test, will encourage incremental improvements in technology, whilst reducing the risk to the customer.

The main situations of changes that can be found in practice are:
- The exchange of components (cable or accessories) already prequalified in systems from different manufacturers and/or from different plants of the same manufacturer.
- The modification to cable components in a prequalified system
- The modification to accessory components in a prequalified system

As far as the accessories are concerned, it is important to observe that accessories of different manufacturers make may significantly differ in design, material and construction. For instance a premoulded joint and a taped joint are substantially different and require a specific Prequalification test (if not already prequalified). For this reason the concept of accessory families for each type of accessory, i.e. joints, metal enclosed terminations and outdoor/indoor terminations has been introduced. The names of the accessory families are defined in the CIGRE Technical Brochure 89 [20] and are summarized in Table 2.1

Table 2.1 Accessory family definitions

Accessory families	
1	*Joints*
1.1	Taped joints
1.2	Pre-moulded joints
1.3	Composite joints
1.4	Field moulded joints
1.5	Heat shrink sleeve joints
1.6	Back to back joints
1.7	Transition joints
1.8	Branch joints
2	*Metal enclosed terminations families (SF6 and oil immersed)*
2.1	Stress cone and insulator type
2.2	Deflector and insulator type
2.3	Prefabricated composite dry type
2.4	Capacitor cone and insulator type
2.5	Directly immersed termination type
3	*Indoor and outdoor terminations*
3.1	Prefabricated elastomeric sheds and stress cone type
3.2	Heat shrink sleeve type
3.3	Elastomeric sleeve type
3.4	Stress cone and insulator type
3.5	Deflector and insulator type
3.6	Capacitor cone and insulator type
3.7	Prefabricated composite and capacitor cone and insulator type

The three main types of changes that can occur in a prequalified system and the relevant type of qualification test required in each case are discussed below.

2.3.1.1 Exchange of cable and/or accessory in a prequalified cable system

In Table 2.2 a guide to the selection of test procedures is given for the extension of the prequalification of a prequalified cable system in case of an exchange of cable and/or an accessory by another cable and/or accessory (from the same family or from another family), see Table 2.1.

The selected procedure depends on the calculated electrical stresses at the insulation screen of the other cable and/or accessory with respect to the calculated electrical stresses at the insulation screen of the originally prequalified cable system and on the prequalification of the cable system containing that other cable and/or accessory.

Table 2.2 – Test procedures in case of an exchange of a cable and /or accessory in a prequalified cable system

Cable and/or accessory	Already qualified on another cable system within the *same or higher* insulation screen stress	Already qualified on another cable system with a *lower* insulation screen stress or *not qualified*
cable	12.5 + XX [2]) (non electrical TT + EQ [1])	12 + 13.2 (electrical and non electrical TT + PQ)
Joint	XX [2]) (EQ)	12 + 13.2 (TT + PQ)
Metal enclosed Termination	XX [2]) (EQ)	12 + 13.2 (TT +PQ)
Outdoor Termination	XX [2]) (EQ)	12 + 13.2 (TT + PQ)
The numbers given refer to the respective clauses in IEC 62067 Ed.1 [1]) EQ consists of the bending test, 60 heat cycles without voltage and the electrical type tests [2]) (XX) Clause to be added in the standard		

2.3.1.2 Modification to the cable in a prequalified cable system

In Table 2.3 a guide to the selection of test procedures is presented for the extension of the prequalification tests or of the type tests in case of a modification to the cable in a prequalified cable system.

The selected test procedure depends on the type of modification of the relevant cable component. As far as type tests are concerned, in some cases only the relevant clauses of IEC 62067 Ed.1 type test procedure covering the function of the specific item changed are considered. The origin of the type of modification may be a change in material, manufacturing process, design or design level, as indicated for information in Table 2.3.

2.3.1.3 Modification to an accessory within the same family in a prequalified cable system

In Table 2.4 a guide to the selection of test procedures is presented for the extension of the Prequalification tests or of the Type tests in case of a modification to an accessory (joint and/or termination), within the same accessory family (see Table 2.1) in a prequalified cable system.

The selected test procedure depends on the type of modification of the relevant accessory. The origin of the type of modification may be a change in material, manufacturing process, design or design level, as indicated for information in Table 2.4.

Table 2.3 Guide to the selection of tests because of modifications to a cable in a prequalified EHV cable system

Component	Modification					IEC 62067 Ed.1 Clause number		
	Type of modification	***M****	***P****	***D****	***DL****	**T-test**	**PQ-test**	**EQ-test**
Cable *Conductor*	Larger cross-section		✓	✓	✓	12	13.2[1]	-
	Copper to Aluminium	✓	✓			12	-	-
	Insulated wires (enamelled or oxidized…)	✓	✓	✓		12.5	-	(xx)
	Stranded to solid conductor		✓			12.5	-	(xx)
	Water tightness	✓	✓	✓		12.5.14	-	-
Cable *semi-conductive inner and/or outer screen*	Change of origin (supplier or production plant)	✓	✓			12[3]		
	Transfer extrusion line (see cable insulation)	✓	✓			[2]	[2]	
	Different quality of semicon.	✓				12[3]	-	-
Cable *Insulation*	Change of base resin	✓				12[3]	-	-
	Change in cross linking package (peroxide/antioxidant)	✓				12	-	-
	Nature of polymer (XLPE, LDPE, HDPE, EPR)	✓	✓	✓		12	13.2	-
	Higher conductor stress, no increase of insulation screen stress				✓	12	-	-
	Increase of insulation screen stress				✓	12	13.2	-
	New extrusion line or transfer of extrusion line with earlier experience in-house	✓	✓			12	-	
	New extrusion line, or transfer of extrusion line without earlier experience	✓	✓			12	13.2	
Cable *Bedding (layer over extruded semicon screen)*	Change of laying, material, thickness	✓	✓	✓		12.5.4 12.5.14 (if required)	-	-
Cable *Metallic screen*	Different types of metal screen	✓	✓	✓		12.4.4 + 12.4.10	-	-
Cable *Outer sheath*	Different type of materials	✓	✓			12.5[4]	-	-
	Different processes		✓			12.5[4]	-	-
	Change in bonding material and/or process to metal screen	✓	✓			12.5[4]	-	-

* *M:* change in material; *P:* change in manufacturing process; *D:* change in design (construction); *DL*: change in electrical design stress level

[1] If higher calculated dielectric stresses at the insulation screen, clause 13.1
[2] Same as for insulation
[3] If outside Range of Type Approval, clause 12.2
[4] As appropriate to outer sheath materials
(XX) Clause to be added in the standard
Remark: in type test, only the relevant clauses are applicable

Table 2.4 Guide to the selection of tests because of modifications to an accessory within the same family in a prequalified EHV cable system

Component	Modification					IEC 62067 Ed.1 Clause number		
	Type of modification	*M**	*P**	*D**	*DL**	T-test	PQ-Test	EQ-test
Joints	Higher calculated electrical stress design and construction				✓	-	-	(xx)
	Compound of main insulation body (same base resin)	✓	✓			-	-	(xx)
	Changing nature of polymer, (EPR, Silicone….)	✓	✓	✓		-	13.2	-
	Material of semi-con electrodes	✓				-	-	(xx)
	Fixation of cable ends on either side of the joint			✓		-	-	(xx)
	Screen interruption			✓		Annex D	-	-
	Outer screen and Protection design , (Filling / water tightness), Outlet of bonding leads					Annex D	-	-
Terminations: - *outdoor* - *indoor* - *metal enclosed* + *SF6* + *oil-immersed*	Higher electrical stress design of stress cone (or smaller metal clad for GIS or transformer terminations)				✓	-	-	(xx)[1)]
	Change in nature of Filling medium (e.g. oil to gas….)	✓				-	-	(xx)[1)]
	Change in the formulation of the stress cone compound but with the same base polymer	✓	✓			-	-	(xx)[1)]
	Change of the base polymer (EPR, Silicone, ...) of the stress cone	✓ 2)	✓ 2)	✓		-	-	(xx)
	Change of insulator material for indoor or outdoor terminations.	✓ 2)	✓ 2)			12	-	-
	Change of insulator design or manufacturer of GIS/Transformer insulator			✓		12	-	-

* *M*: change in material; *P*: change in manufacturing process; *D*: change in design (construction); *DL*: change in electrical design stress level

1) When can be demonstrated that the thermo mechanical aspects have no significant influence on the performances of the termination a Type Test may be sufficient.

2) In case of elastomeric insulators ("silicone" or "EPR") climatic and pollution test according to IEC 61109 Annex C should be considered.

(xx) Clause to be added in the standard

2.3.2 Basic principles of the Extension of Prequalification (EQ) test

The Extension of Prequalification consists of a period of 60 days of thermal pre-conditioning without applied voltage, carried out in laboratory conditions, followed by the electrical part of the type test.

The 60 daily heat cycles without voltage plus the 20 heat cycles of the type test applied to the test loop are intended to allow relaxation of most of the mechanical stresses trapped in the cable insulation during manufacture.
This relaxation results in retraction of the XLPE insulation wherever the cable is cut.
The retraction of the cable insulation within an accessory, if not provided with a specific anti-retraction device, can initiate partial discharge activity, leading to failure of the accessory. In fact the considerations made at paragraph 1.3.1 and the TB "Interfaces in accessories for extruded HV and EHV cables" [53], indicate that thermal cycles stressing is the main failure mechanism in accessories, which typically include due to their intrinsic construction a number of interfaces.

As shown by figure 2.1 the retraction of the XLPE insulation is practically completed after about 60-80 heat cycles.

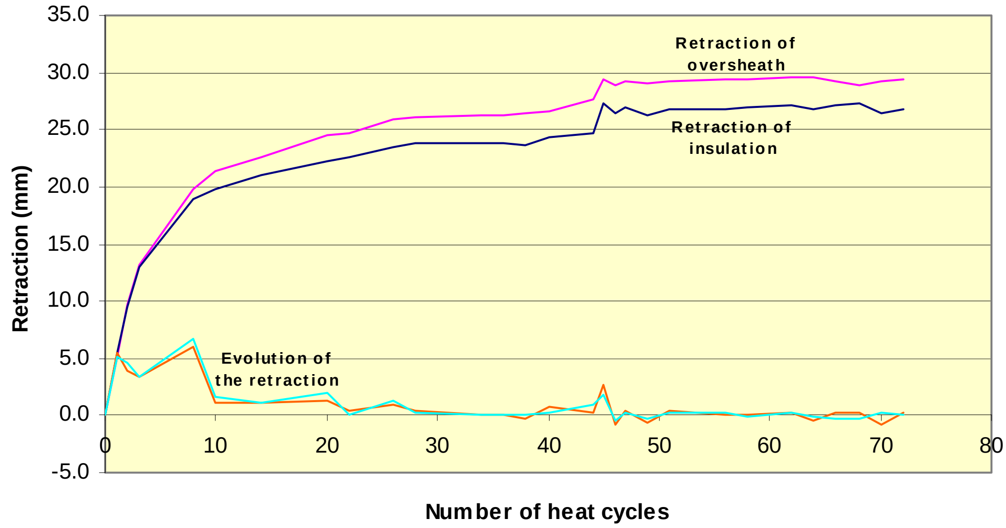

Fig 2.1 Retraction test on a 5-meter long 1000 mm² 500 kV cable with XLPE insulation and PE sheath

In addition the heat cycles are producing a radial expansion and retraction of the cable insulation and of the accessory components that can also influence the interfacial pressure in accessories.

In order to be able to perform the EQ test in a laboratory, limiting the engagement of the HV test equipment, it has been decided to perform these pre-conditioning cycles without applied voltage. Being the EQ test performed in a laboratory, i.e. with well-defined thermal conditions, it is possible to carry out the heat cycles in approximately one day also with very large cross-section cables.

To prove that the heat cycling has not affected the integrity of the test loop a complete electrical type test (as defined in IEC62067 Ed.1) is used.
As the installation design conditions can significantly affect the thermo-mechanical behaviour of the accessories, the test arrangement shall take this into account.
For instance a rigid installation can be simulated by suitably cleating the cable at each side of a joint. In order to comply with this requirement a minimum length of 10 m of free cable between accessories is specified for the EQ test.
To maintain a similar degree of risk for the shorter duration of the EQ test compared to the duration of Prequalification test, at least two accessories of the same type, instead of one, shall be included in the test loop submitted to the extension of prequalification.

2.3.3 Procedure of the Extension of Prequalification test

The sequence of tests for the extension of prequalification is summarized below. The numbers in brackets refer to clause numbers of present tests in IEC 62067 Ed.1.

- Check of the insulation thickness of cable for electrical type test to determine the test voltage values (12.4.1)

- Bending test without final PD test (12.4.4)

- The test assembly may be installed in a laboratory and shall consist of at least 2 accessories of the same type that is to be prequalified. There shall be at least 10m of cable between accessories. The minimum length of the test loop shall be at least 30m. If a joint submitted to EQ has to be used in both flexible and rigid installations, one joint shall be installed in a flexible configuration, the other rigid. Where a joint is designed for use only in rigid installations, then both joints shall be rigidly fixed. Similarly, for a joint intended only for flexible installations, both joints shall be installed in a flexible test configuration. An example of the test loop is shown in figure 2.2.

- The loop shall have a U bend with a diameter specified in 12.4.4

- The partial discharge test defined in 12.4.5 shall be carried out here to check the quality of the assembled accessories.

- The thermal preconditioning test consists of 60 heat cycles with no voltage applied.
  The heat cycles shall be as given in 12.4.7, i.e. a minimum of 8 hours of heating followed by at least 16 hours of natural cooling. The steady state conductor temperature shall be between 5°C and 10°C above the maximum cable operating temperature for at least two hours. At the end of the cooling period the conductor temperature shall be within 15°C of ambient temperature, with a maximum of 45°C.

- Continue with the partial discharge test (12.4.5) followed by the full sequence of electrical type test. No failure shall occur.

NOTE: In case of modification of the cable, in order to cover all the requirements of the type test it is necessary to perform also the non-electrical test on the cable as specified in 12.5.

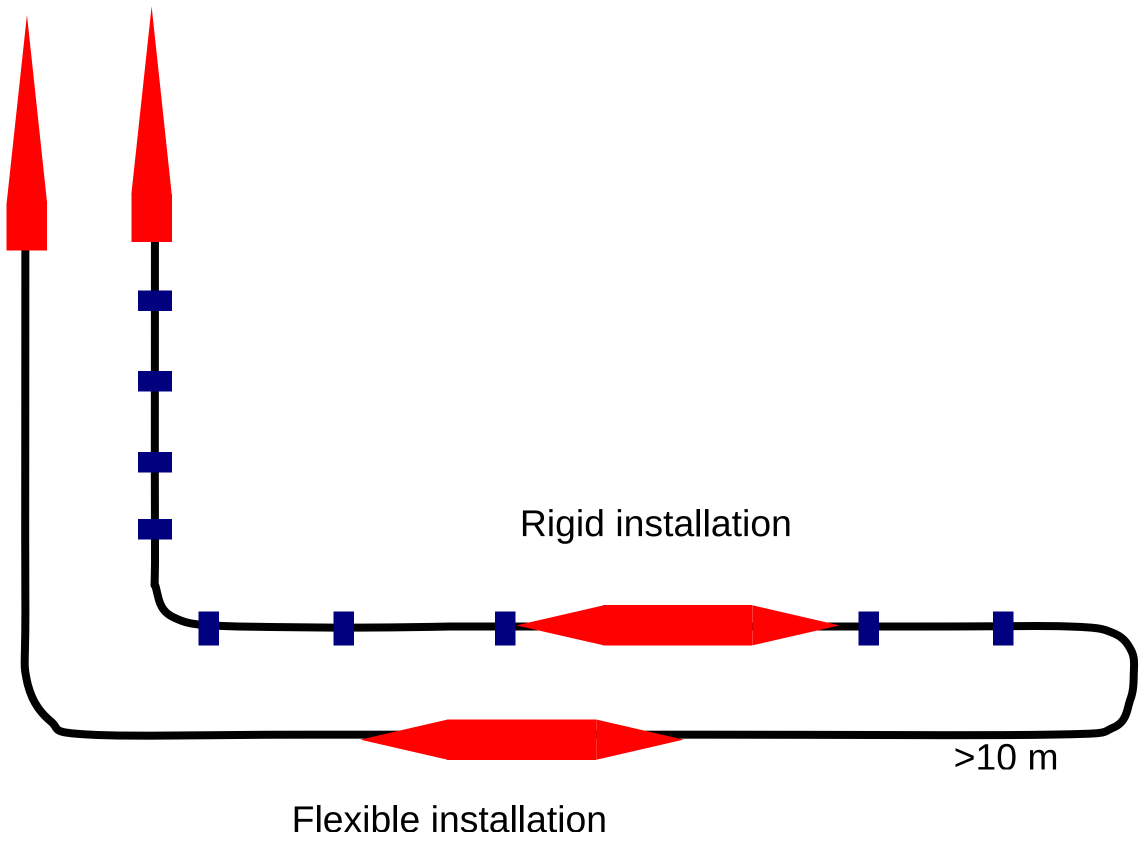

Figure 2.2 Extension of Prequalification test loop for a joint intended for flexible and rigid installations

2.4 Recommendations to IEC 62067

As a summary and conclusion from its reflections WG B1.06 makes the following recommendations to IEC for further consideration in future editions of IEC 62067:

- To maintain unchanged the present one-year Prequalification (PQ) test for the basic prequalification of a new cable system (as a check on e.g. the long-term electrical and thermal-mechanical behaviour).
- To allow in case of a failure of an accessory the continuation and completion of the PQ test for the undisturbed components (cable and other accessories) of the loop.
- To perform partial discharge measurements on the prequalification test assembly during the PQ test to provide an early warning of possible degradation and to enable the possibility of repair before failure.
- 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, on cable samples including

each type of accessory. The intention is to check the insulation properties at the interfaces, in the accessories and in the cable.

- To maintain unchanged the present range of Type and PQ approval, see Annex 5.3.
- To introduce a simplified long-term test (80 cycles) called "Extension of Prequalification (EQ) test" (see 2.3.3) in case of exchange of prequalified components (cable and/or accessories) with other components that are already prequalified in other cable systems with the same or higher calculated electrical stress at the insulation screen of the subjected system or in case of modification of a cable or an accessory within the same family in a prequalified cable system (see 2.3).
- For engineering purposes a "Functional Analysis Method" (see Annex 5.4) is recommended as a mean for a systematic assessment of the significance of changes/modifications at components (cables and accessories) of a cable system and thus for the selection of the appropriate test (PQ or EQ test).
- To introduce guides to the selection of appropriate test procedures, based on the application of that "Functional Analysis Method", to the most important components of actual cable systems, in case of
  - exchange of a cable and/or accessory in a prequalified cable system (table 2.2)
  - modification of a cable in a prequalified cable system (table 2.3)
  - modification of an accessory within the same family in a prequalified cable system (table 2.4)
- To include sample tests on accessories, which are presently "under consideration" within IEC 62067 Ed.1, following the wording of IEC 60840 Ed.3. For accessories, where the main insulation cannot be routine tested, the partial discharge and high voltage test should be introduced, but only on one accessory of each type per contract. These tests are intended to check not only the intrinsic quality of the accessory (design and materials), but also the quality of the installation (equipment and jointers skill), factors that are very important at the EHV level.
- To align the definition of type tests (sub-clause 3.2.3 of IEC 62067 Ed.1) to the definition of the prequalification test to ease the potential use of the tables (2.2, 2.3 and 2.4) as a guide for the selection of test procedures in case of changes on prequalified cable systems.
- It is worth noting that, as a result of the application of the "Functional Analysis Method" (see Annex 5.4), a number of tests have been identified that are not included in IEC 62067 Ed.1. These tests are generally performed as development tests and are summarized in Annex 5.5 for future consideration by IEC.

3. LONG DURATION TEST ON HV CABLE SYSTEMS (36 < $U_m \leq$ 170 kV)

3.1 General

Traditionally EHV cables are working at a significantly higher stress than HV cables (see figure 3.1).
Due to increased competition and good experience with (very) high AC stresses (12-15 kV/mm and even more) on EHV cable systems it becomes more common nowadays to produce cables with reduced insulation thickness [31, 32, 33] at the HV level. This leads to 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.

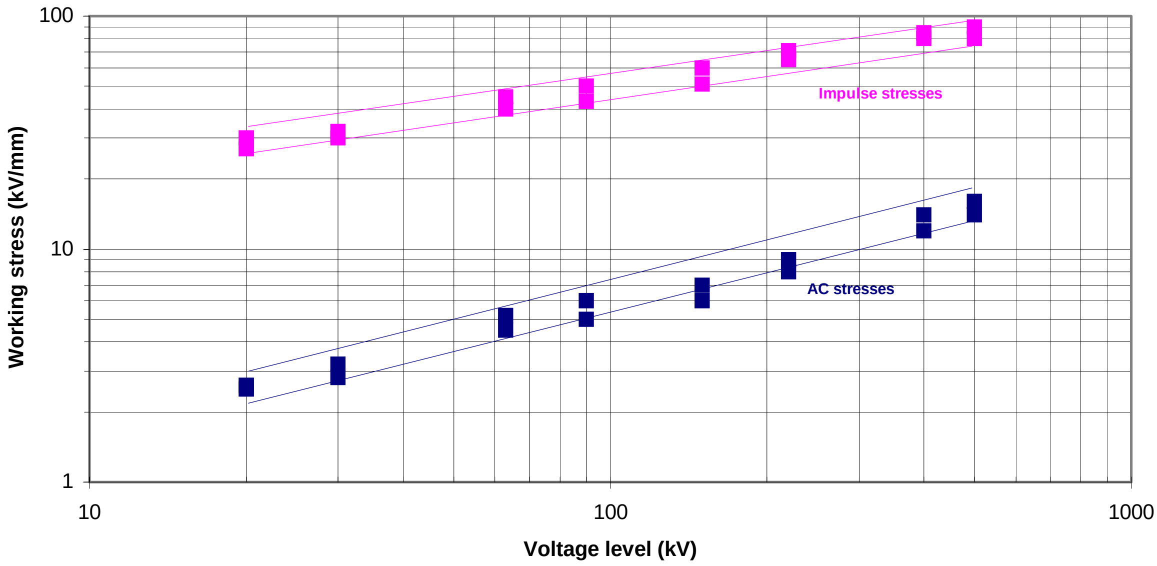

Figure 3.1 AC and impulse conductor stresses of XLPE cables

The development of reduced insulation thickness cables at the HV level was successful due to the experience gained by the major cable makers at the production, testing, installation and good service of EHV cable systems.

Also new types of accessories are appearing on the market, of course with no earlier experience [34-40]. These accessories should be able to fit to the older types of cables with thicker insulation and the newer types of cables with reduced insulation (changes of an existing HV link with a new cable type or repair of an older link).

The following remarks are of major importance:

- The new highly stressed cables with reduced insulation thickness are generally produced by experienced cable makers that are using their know-how from EHV technology: development and production teams, production equipment and process, material handling and control as well as their well trained teams for installation in the field.
- Failures, if any, during type or after installation tests, tend to occur at the interfaces between accessories and cables when new systems are tested [41, 42, 45, 46, 47]. To assess the reliability of a new HV cable system whose working stresses are similar to those of the EHV systems, the experienced cable makers rely on the PQ and type tests they have performed on EHV cable systems.
- For highly stressed cable systems, type tests are not necessarily sufficient [52].

In several countries long-term tests have been performed on new HV cable systems [32, 33, 43, 44, 48].
Working Group members recommend that cable systems should be considered rather than cables or accessories alone, see also [46].

There exist arguments for and against long-term tests on HV cable systems.
For:

- The electrical service stresses and mainly lightning impulse stresses at the core (interface with prefabricated accessories) of HV cables are becoming almost as high as the stresses of EHV cables.
- Practical shrinkage tests on cable lengths of 5 meters or more have shown that cable insulation and over-sheath is only stabilized after around 60 to 80 heat cycles (see Figure 2.1). This is confirmed by experts and by the outcome of PQ tests [23, 28, 49, 50]
- New accessory designs are coming to the market
- The countries that have performed long-term tests on new cable systems before installing them in the network have reported very good service experience
- Test laboratories that conduct type tests for many suppliers have published the results of their experience: the failure rate of MV and HV type tests is growing [45]. The reasons for this could be the lack of experience of some manufacturers with higher dielectric stresses in cables, the lack of experience with new type of accessories or all these combined
- Breakdowns in service are recorded on recently commissioned systems.

Against:

- The good and sometimes long experience of some cable makers with HV cables and cable systems (cables with “reasonable” stresses)
- In some countries where long-term tests are not performed on new cable systems before installing them in the network, service experience is good, as know-how has been gained during many years in the HV field
- The reluctance of some utilities or other end-users to test entire systems if they wish to buy their HV cables and accessories separately

3.2 Prequalification test for HV systems

3.2.1 Range of Prequalification test

As accessories typically include due to their intrinsic construction a number of interfaces, the thermal cycles stressing is their most common failure mechanism (apart from jointing errors). That’s why the critical dielectric stresses in service for which long term testing should be recommended for HV cable systems depend very much on the interface stresses with accessories.

For prefabricated accessories (joints or stress-cones), mainly impulse stresses at the cable insulation screen are most critical. For instance a 400 kV cable has a ratio BIL/U_0 lower than HV cables. That means that HV cables with an AC stress of 4 kV/mm at insulation surface reach an impulse level of 36 kV/mm, as high as a 400 kV system, which has an AC interface stress of 5.5 kV/mm, etc (see table 3.1)

Table 3.1: AC and BIL stresses at the insulation screen for different voltage levels

U_m (kV)	52	72.5	123	145	170	420
U_0 (kV)	26	36	64	76	87	220
BIL (kV)	250	325	550	650	750	1425
Ratio BIL/Uo	9,6	9,0	8,6	8,5	8,6	6,5
Routine Test (kV)	65	90	160	190	218	440
AC-stress for a BIL-stress of 36 kV/mm at insulation surface (kV/mm)	***3,74***	***3,99***	***4,19***	***4,21***	***4,18***	**5,56**
AC-stress for a BIL-stress of 40 kV/mm at insulation surface (kV/mm)	***4,16***	***4,43***	***4,65***	***4,68***	***4,64***	**6,17**

A practical example: A 1600 mm² 400 kV cable with an insulation thickness of 26 mm has a service stress at the insulation surface of 6.5 kV/mm and an impulse stress at the insulation surface of 40 kV/mm. A 1600 mm² 150 kV cable with an insulation thickness of 15 mm has a service stress of 4.7 kV/mm at the insulation screen, i.e. 30% lower than the 400kV cable, but an impulse stress of 40.3 kV/mm at the insulation surface, the same as the 400 kV cable.

Based on the above considerations, a PQ test is recommended for cable systems with insulation screen stresses above 4 kV/mm.

As shown in figure 3.1 HV cables have operated at conductor stresses below 8 kV/mm.
In addition, for joints that are taped or field-molded also the AC and impulse stresses at the conductor screen are critical.

So, if the conductor stresses are higher than 8 kV/mm, it is recommended to perform the long-term test on the system.

These conclusions are also supported by the evaluation of the sensitivity of electric stress to changes in dimensions reported in Annex 5.3. In fact these calculations show that for a reduction of the insulation thickness of 5%, the thickness of a defect between the cable insulation and the premoulded accessory must be reduced of about 21%, in order to avoid partial discharges.

If the operating stresses at the insulation screen and at the conductor screen are below 4 kV/mm and 8 kV/mm respectively, they compare with those found in cable systems already installed for a long time. Even if most of these cables and accessories have only been type tested, service experience is generally considered good.

So the prequalification 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. The prequalification test shall be performed except:

– if cable systems including a cable of similar construction and accessories of the same family have been prequalified for higher rated voltages or

– if an alternative long term test has been carried out on cable systems with the same construction and accessories of the same family and the manufacturer can demonstrate good service experience (*) with cable systems with equal or higher calculated nominal electrical stresses on the conductor and insulator screens, in the main insulation part(s) and in boundaries of the accessories

(*) Unfortunately it is difficult to give a specific rule about the evaluation of a good service experience, but the matter has to be dealt with, case by case, between the supplier and the purchaser.

3.2.2 Prequalification test procedure

As HV cables are less rigid and have generally smaller conductor cross sections than EHV cables, the thermo-mechanical aspects are less critical than for EHV cable systems, so the WG has considered that laboratory conditions, instead of an actual outdoor installation, could be adopted, in this case, for the PQ test.
Being the test performed in a laboratory, i.e. with well defined thermal conditions, it is possible to carry out correctly the heat cycles in approximately one day also with very large conductor cross section cables, so 180 daily cycles instead of one year duration is permissible. This has the advantage of halving the time to market of these new HV cable systems, combined with a reduction of the overall cost of the PQ test. The disadvantage is that the long-term behavior of the electrical insulation of the cable system is checked in only half a year. For these kinds of cable systems, it was judged as acceptable.

The proposed layout of cable system is:

- Length of cable: one length with a minimum of 20 m without accessories and at least 10 m for the other lengths between two accessories. The total length depending on the number of accessories in the system under test
- Number of accessories: at least one of each type
- Test could be performed in a laboratory and not necessarily in a situation simulating the real installation conditions. Where thermo-mechanical aspects have to be considered, special test arrangements could be considered. Figures 3.2 and 3.3 show examples of methods to simulate the thermo-mechanical forces on joints, when a cable is installed in a duct or rigidly fixed.
- The test is to be performed on the cable system (cables and accessories)

The test procedure is:

- Test voltage: 1.7 U_0
- Number of heating cycles: 180 cycles, cycle duration not less than 24 hours. The heating by conductor current shall be applied for at least 8 h. The cable conductor temperature remote from the accessories shall be maintained within the temperature limits of 0 °C to 5 °C above the maximum conductor temperature in normal operation for at least 2 h of each heating period. This shall be followed by at least 16 h of natural cooling to a conductor temperature within 10 °C of the test ambient temperature, with a maximum of 45 °C. No breakdown shall occur.

Note: partial discharge measurements are recommended to provide an early warning of possible degradation.

- Tests after long term testing: hot lightning impulse test on the complete loop
- Examination of the test loop after completion of these tests.

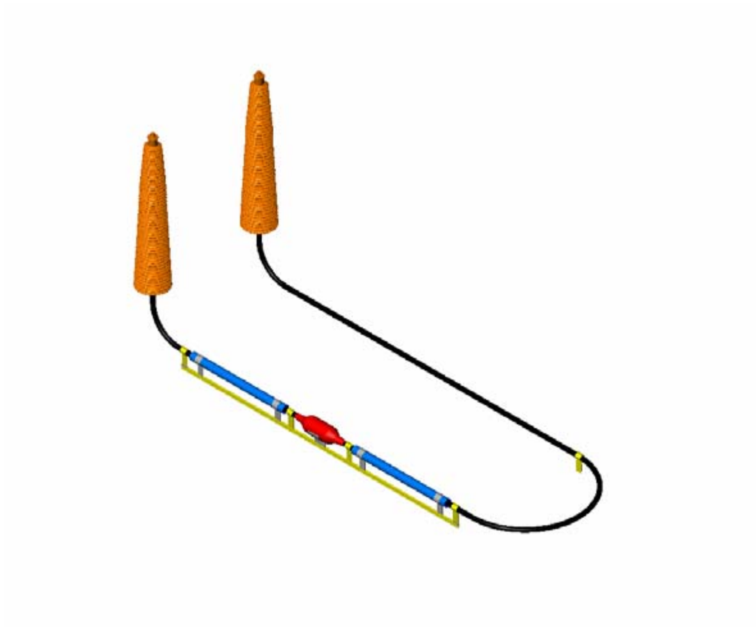

Figure 3.2 Possible test layout for cable installed in a duct

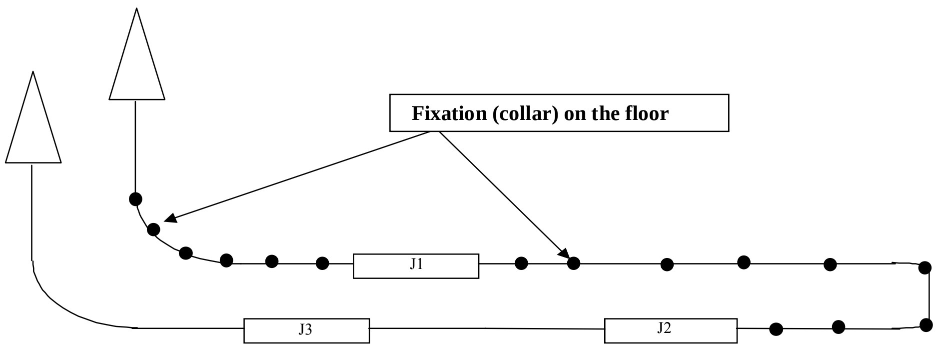

Figure 3.3 Possible test layout for cable anchored on the ground

Note: The replacement/repair of an accessory failed during the heating cycle voltage test is allowed and the test can be continued, because the replaced/repaired accessory cannot influence the behavior of the other ones.
On the contrary it is not allowed to repair a cable failure, unless it is caused by an accidental external damage or the same cable has already been prequalified.

At the end of the 180 loading cycle voltage test and the impulse test, only the successfully tested accessories will be prequalified, while the accessory/ies subjected to repair or replacement will not be prequalified.

However, it is in the option of the cable manufacturer to continue the test on the replaced/repaired accessory/ies until it/they complete the 180 loading cycles voltage test and the impulse test. In this case also these accessories are prequalified.

In the event that during this continued test another component, fully prequalified (including the final impulse test), fails, it is possible to repair it and continue the test until the second run is completed on the replaced accessory/ies.
The failure of the component already prequalified (which in this case acts as a laboratory test component) should not be mentioned in the test report.

3.3 Exchanges and modifications in a prequalified HV cable system

3.3.1 Evaluation of changes and modifications in a prequalified system

As far as the guide to the selection of test procedures in case of an exchange of a cable and/or an accessory with another one or of a modification of a cable and/or an accessory of a prequalified cable system is concerned, the same considerations made at paragraph 2.3 apply.
Also the extension of prequalification test (EQ) is the same as for EHV systems (see 2.3.1.1, 2.3.1.2 and 2.3.1.3), where Tables 2.2, 2.3 and 2.4 (for IEC 62067 Ed.1) have to be replaced by Tables 3.2, 3.3 and 3.4 (for IEC 60840 ED.3).

Table 3.2 – Test procedures in case of an exchange of a cable and/or accessory in a prequalified HV cable system

Cable and/or accessory	Already qualified on another cable system within the ***same or higher*** insulation screen stress	Already qualified on another cable system with a ***lower*** insulation screen stress or ***not qualified***
cable	12.4 + YY [2]) (non electrical TT + EQ [1)])	12 + ZZ [3]) (electrical and non electrical TT + PQ)
Joint	YY [2]) (EQ)	12 + ZZ [3]) (TT + PQ)
Metal enclosed Termination	YY [2]) (EQ)	12 + ZZ [3]) (TT +PQ)
Outdoor Termination	YY [2]) (EQ)	12 + ZZ [3]) (TT + PQ)
The numbers indicate the respective clauses in IEC 60840, Ed.3 [1]) EQ consists of the bending test, 60 heat cycles without voltage and the electrical type tests [2]) (YY) Clause to be added in the standard [3]) (ZZ) Clause to be added in the standard		

Table 3.3 Guide to the selection of tests because of modifications to a cable in a prequalified HV cable system

Component	Modification					IEC 60840 Ed.3 Clause number		
	Type of modification	**M***	**P***	**D***	**DL***	**T-test**	**PQ-test**	**EQ-test**
Cable *Conductor*	Larger cross-section		✓	✓	✓	12	(ZZ)[1)]	-
	Copper to Aluminium	✓	✓			12	-	-
	Insulated wires (enamelled or oxidized…)	✓	✓	✓		12.4	-	(YY)
	Stranded to solid conductor		✓			12.4	-	(YY)
	Water tightness	✓	✓	✓		12.5.14	-	-
Cable *semi-conductive inner and/or outer screen*	Change of origin (supplier or production plant)	✓	✓			12[3)]		
	Transfer extrusion line (see cable insulation)	✓	✓			[2)]	[2)]	
	Different quality of semicon	✓				12[3)]	-	-
Cable *Insulation*	Change of base resin	✓				12[3)]	-	-
	Change in cross linking package (peroxide/antioxidant	✓				12	-	-
	Nature of polymer (XLPE, LDPE, HDPE, EPR)	✓	✓	✓		12	(ZZ)	-
	Higher conductor stress, no increase of insulation screen stress				✓	12	-	-
	Increase of insulation screen stress				✓	12	(ZZ)	-
	New extrusion line or transfer of extrusion line with earlier experience in-house	✓	✓			12	-	
	New extrusion line, or transfer of extrusion line without earlier experience	✓	✓			12	(ZZ)	
Cable *Bedding (layer over extruded semicon screen)*	Change of laying, material, thickness	✓	✓	✓		12.4.4 12.4.18 (if required)	-	-
Cable *Metallic screen*	Different types of metal screen	✓	✓	✓		12.3.3 + 12.3.8	-	-
Cable *Outer sheath*	Different type of materials	✓	✓			12.4[4)]	-	-
	Different processes		✓			12.4[4)]	-	-
	Change in bonding material and/or process to metal screen	✓	✓			12.4[4)]	-	-

* *M:* change in material; *P:* change in manufacturing process; *D:* change in design (construction); *DL*: change in electrical design stress level

[1)] If higher calculated nominal dielectric stresses at the insulation screen, clause 16.1
[2)] Same as for insulation
[3)] If outside Range of Type Approval, clause 12.1
[4)] As appropriate to outer sheath materials
Remark: only the relevant clauses are applicable for type tests
NOTE: (YY) and (ZZ), Clauses to be added in the standard

Table 3.4 Guide to the selection of tests because of modifications to an accessory within the same family in a prequalified HV cable system

Component	Modification					IEC 60840 Clause number		
	Type of modification	***M****	***P****	***D****	***DL****	**T-test**	**PQ-Test**	**EQ-test**
Joints	Higher calculated electrical stress design and construction				✓	-	-	(ZZ)
	Compound of main insulation body (same base resin)	✓	✓			-	-	(ZZ)
	Changing nature of polymer, (EPR, Silicone….)	✓	✓	✓		-	(YY)	-
	Material of semi-con electrodes	✓				-	-	(ZZ)
	Fixation of cable ends on either side of the joint			✓		-	-	(ZZ)
	Screen interruption			✓		Annex D	-	-
	Outer screen and Protection design , (Filling / water tightness), Outlet of bonding leads					Annex D	-	-
Terminations: - *outdoor* - *indoor* - *metal enclosed* + *SF6* + *oil-immersed*	Higher electrical stress design of stress cone (or smaller metal clad for GIS or transformer terminations)				✓	-	-	(ZZ)[1)]
	Change in nature of Filling medium (e.g. oil to gas….)	✓				-	-	(ZZ)[1)]
	Change in the formulation of the stress cone compound but with the same base polymer	✓	✓			-	-	(ZZ)[1)]
	Change of the base polymer (EPR, Silicone, ...) of the stress cone	✓ 2)	✓ 2)	✓		-	-	(ZZ)
	Change of insulator material for indoor or outdoor terminations.	✓ 2)	✓ 2)			12	-	-
	Change of insulator design or manufacturer of GIS/Transformer insulator			✓		12	-	-

* *M*: change in material; *P*: change in manufacturing process; *D*: change in design (construction); *DL*: change in electrical design stress level

1) When can be demonstrated that the thermo mechanical aspects have no significant influence on the performances of the termination a Type Test may be sufficient.

2) In case of elastomeric insulators (“silicone” or”EPR”) climatic and pollution test according to IEC 61109 annex C should be considered.

NOTE: (YY) and (ZZ) Clauses to be added in the standard

3.3.2 Procedure of the Extension of Prequalification (EQ) test for HV cable systems

The basic principles of 2.3.2 apply.

The sequence of tests for the Extension of Prequalification (EQ) test is summarized below. The numbers in brackets refer to clause numbers of IEC 60840 Ed.3.

- Check on the insulation thickness of cable for electrical type test to determine the test voltage values (12.3.1)

- Bending test without final PD test (12.3.3)

- The test assembly may be installed in a laboratory and shall consist of at least 2 accessories of the same type that is to be prequalified. There shall be at least 10m of cable between accessories. The minimum length of the test loop shall be at least 30m. If a joint submitted to EQ has to be used in both flexible and rigid installations, one joint shall be installed in a flexible configuration, the other rigid. Where a joint is designed for use only in rigid installations, then both joints shall be rigidly fixed. Similarly, for a joint intended only for flexible installations, both joints shall be installed in a flexible test configuration. An example of the test loop is shown in figure 2.2.

- The loop shall have a U bend with a diameter specified in 12.3.3

- The partial discharge test defined in 12.3.4 shall be carried out here to check the quality of the assembled accessories.

- The thermal preconditioning test consists of 60 heat cycles with no voltage applied.
  The heat cycles shall be as given in 12.3.6, i.e. a minimum of 8 hours of heating by conductor current followed by at least 16 hours of natural cooling. The steady state conductor temperature shall be between 5°C and 10°C above the maximum cable operating temperature for at least two hours. At the end of the cooling period the conductor temperature shall be within 15 °C of ambient temperature, with a maximum of 45 °C.

- Continue with the partial discharge test (12.3.4) followed by the full sequence of the electrical type test (see 12.3.2 item b to h).). No failure shall occur.

NOTE: In case of modification of the cable, in order to cover all the requirements of the type test it is necessary to perform also the non-electrical test on the cable as specified in 12.4.

3.4 Recommendations to IEC 60840

As a summary and conclusion from its reflections WG B1.06 makes 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 (see 3.2).

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
- if equivalent long term tests have been already successfully carried out on cable systems with the same construction and accessories of the same family and a good service experience at cable systems with equal or higher stresses can be demonstrated

- To allow in case of a failure of an accessory during the test the continuation and the completion of the PQ test for the undisturbed components (cable and other accessories) of the test loop.
- To perform partial discharge measurements on the prequalication test assembly during the PQ test to provide an early warning of possible degradation and to enable the possibility of repair before failure.
- 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, on cable samples including each type of accessory. The intention is to check the insulation properties at the interfaces, in the accessories and in the cable.
- To maintain unchanged the present range of Type and PQ approval, see Annex 5.3
- To introduce a simplified long-term test (80 cycles) called "Extension of prequalification (EQ) test" (see 3.3.2) in case of exchange of prequalified components (cable and/or accessories) with other components that are already prequalified in other cable systems with the same or higher calculated electrical stress at the insulation screen of the subjected system or in case of modification of a cable or an accessory within the same family in a prequalified cable system (see 3.3).
- For engineering purposes a "Functional Analysis Method", see Annex 5.4, is recommended as means for a systematic assessment of the significance of changes/modifications at components of a HV cable system and thus for the choice of the appropriate tests (PQ or EQ) or Type Tests (TT).
- Based on the application of the "Functional Analysis Method" to the most important components of actual HV cable systems (see Annex 5.4), guides to the selection of test procedures are given in case of
  - exchange of a cable and/or accessory in a prequalified cable system (table 3.2)
  - modification of a cable in a prequalified cable system (table 3.3)
  - modification of an accessory within the same family in a prequalified cable system (table 3.4)
- To align the definition of type tests to the definition of the prequalification test (see sub-clause 3.2.3 of IEC 62067) to ease the potential use of the tables (3.2, 3.3 and 3.4) as a guide for the selection of test procedures in case of changes on prequalified HV cable systems.
- To include an electrical sample test as a check on the properties of the insulation of HV cables, see Table 5.5.1, item 25
- It is worth noting that, as a result of the functional analysis exercise (see Annex 5.4), a number of tests that are not included in IEC 60840 Ed.3 have been identified. These tests are generally performed as development tests and are summarized in Annex 5.5 for future consideration by IEC.

4. **CONCLUSIONS**

In this report the testing procedures of HV and EHV extruded cables and related accessories have been reconsidered extensively. Improvements in both effectiveness (can it be done better) and efficiency (can it be done faster) have been proposed. In the final proposals the desirable improvement and its practical feasibility are balanced carefully, resulting in a series of well thought practical propositions to improve extruded cable testing. The main results are summarized below:

- EHV Cable systems: there is no sufficient service experience on EHV cable systems collected so far to change 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 (EQ) 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_0 of the electrical type test.
- 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_0. 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 (EQ) test is proposed to control changes in already prequalified HV cable systems. This new test can be carried out on a laboratory loop and will comprise 60 heating cycles without voltage and followed by the full sequence of the electrical type tests, with 20 heat cycles combined with voltage application at 2 U_0.

- For both EHV and HV cable systems the PQ test will be completed with an impulse test on the full loop to check that no degradation in the system, especially at the interface with accessories, has occurred. (Only in case suitable impulse test equipment is not available at the test site, the impulse test can be carried out in any other test arrangement including each type of accessory taken from the loop).

- For both PQ and EQ tests, PD tests are recommended to provide an early warning of possible degradation and to enable the possibility of a repair before failure.

- Several tables are provided as guides to determine the appropriate test sequence in case of changes or modifications.

- Functional Analysis is a good tool to help engineers to manage a wide range of potential changes. Examples are given in Annex 5.4.

- In Annex 5.5 tests from Functional Analysis, not yet published in IEC standards, are summarized. This list of tests will be handed to IEC TC 20 for further consideration.

5. ANNEXES

ANNEX 5.1 Terms of Reference

Title:
Revision of Qualification Procedures for High Voltage and Extra High Voltage AC Extruded Underground Cable Systems

Scope:
After the official qualification of a cable system, there are possible changes (new cable construction, higher stress, new extrusion line, new process, new type of accessories…) especially if this cable system is manufactured over several years, and the question raised is to examine how it is possible to qualify this new system without making the full set of tests which are presently recommended or specified in standards.

A WG has been launched on this item limited to AC extruded cable systems. All tests, prequalification and type tests will be reviewed, even if the prequalification test should be examined first, as it is the most costly and the longest.

Terms of reference:
For the range of AC extruded underground cable systems for voltages above 30 kV up to 500 kV, review and complete the qualification procedures for the different HV voltage ranges with
the goal to come quickly and economically to the market with innovative solutions but without jeopardizing the reliability of the installed system:

- propose tests where there are lacks e.g. short circuit tests, climatic tests on terminations…
- evaluate whether in high voltage systems up to 150 kV a long term test has to be recommended above given dielectric service stresses or where the innovation is not built on earlier experience
- define what "earlier experience" means
- in case of major innovation in EHV cable systems, evaluate whether long term test can be replaced by shorter ones, which should be defined by the WG

in order to build up a guide of qualification procedures depending on earlier qualification(s) at the same and/or different voltage levels and on field experience.

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ANNEX 5.3 Sensitivity of Partial Discharges in XLPE Cable Insulation to Change of Electrical Stress

Contents

5.3.1. Introduction

In CIGRE WG B1.06, a question was raised whether the range of type approval and of PQ approval could be widened. This annex provides details of the analysis made for this purpose. Dielectric stress level variations specified in relevant sub-clauses of the current IEC standards were used as a starting point in this work.

As a first step of the process, we can determine the rate of change of electric field strength inside a radial cable with respect to:

- the change of the insulation inner radius, without changing the insulation thickness
- the change of the insulation thickness, without a change of the inner radius

The obtained relationships are the so-called sensitivities of field strength to a dimensional change. They can indicate, for example, what effect a 1% change of the insulation thickness has on the field strength at the insulation outer surface.

In the next step, the sensitivity values together with Paschen's curve can be used to calculate the change of the discharge inception voltage in insulation defects. The Paschen curve describes the relationship between breakdown voltage and size of defect together with gas pressure within the defect. In this study we are concerned with discharge free operation of the cable. Therefore, it is more useful that instead of the discharge inception voltage the maximum defect size is determined from the above relationship at a given voltage across the defect and at a given pressure.

Two types of defects are considered in this study: a spherical void located on the conductor screen interface and a fissure located on the outer insulation surface. The former can be seen as a worst-case scenario of a manufacturing fault while the latter can represent a defect at the interface to accessories.

The model calculations presented in this study are first order estimations of the risk of electrical discharge in voids from a change in electric stress at insulation interfaces caused by dimensional changes of insulation. In the practical situation, stresses at the interfaces may be different because of the actual geometry. However the model calculations describe the worst-case situation.

5.3.2. Cable standards and insulation stress

Sub-clauses 12.3.1 of IEC 60840 and 12.4.1 of IEC 62067 state that the test voltage values have to be adjusted if insulation thickness of the tested cable system exceeds 105% of the nominal insulation thickness with the upper limit at which the adjustment is allowed of 115%. The range of type approval sub-clause 12.1 of IEC 60840 and sub-clause 12.2 of IEC 62067 state that the approval is valid for systems in which:

- calculated nominal conductor stress at the conductor screen does not exceed 110% of the tested system
- calculated nominal insulation stress at the insulation screen does not exceed the insulation screen stress of the tested system

In this context, we are considering whether it is possible to widen the range of approval without jeopardizing performance of the cable system.

5.3.3. Sensitivity of insulation stress to change of cable dimensions

Electric field strength at a radial location x in a concentric cable is expressed as

$$E_x = \frac{U_0}{x} \frac{1}{\ln \frac{R}{r}} \qquad (1)$$

where

r is the inner radius of the insulation,
R is the outer radius of the insulation
w is the insulation thickness

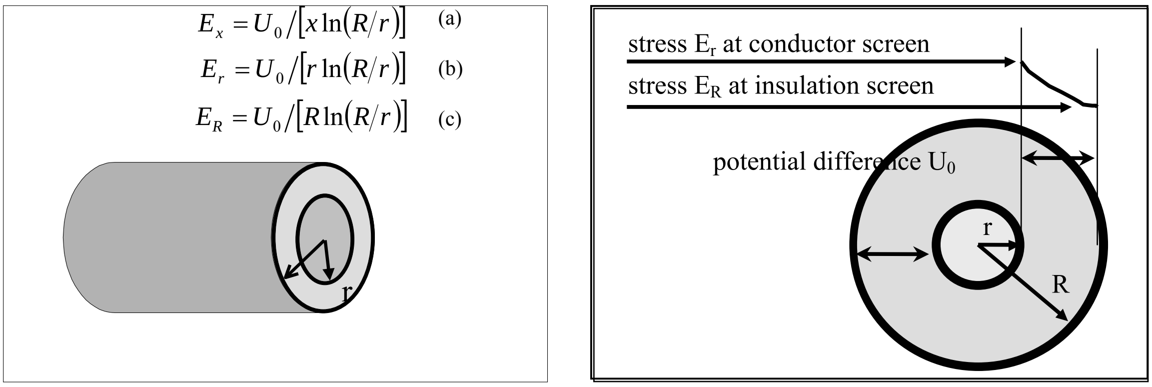


Figure 5.3.1: Electric field strength in a concentric cable

We are interested in the field strength at two locations within insulation, namely, on the inner surface and on the outer surface. Using R = r + w, we get

$$E_r = \frac{U_0}{r} \frac{1}{\ln \frac{r+w}{r}} \qquad (2)$$

$$E_R = \frac{U_0}{r+w} \frac{1}{\ln \frac{r+w}{r}} \qquad (3)$$

which is also shown in Figure 5.3.1

Electrical stress sensitivity is defined as the rate of change of field strength with respect to a given dimension. In this work, we consider the rate of change of field with respect to insulation inner radius, r, and with respect to insulation thickness, w.

Sensitivity to change of inner radius

Sensitivity to change of inner radius only is obtained by differentiating (2) and (3) with respect to r, which gives

$$\frac{dE_r}{dr} = \frac{U_0}{r^2 \ln\frac{r+w}{r}}\left(\frac{w}{(r+w)\ln\frac{r+w}{r}} - 1\right) \quad \frac{\text{kV}}{\text{mm}}\frac{1}{\text{mm}} \qquad (4)$$

and

$$\frac{dE_R}{dr} = \frac{U_0}{(r+w)^2 \ln\frac{r+w}{r}}\left(\frac{w}{r\ln\frac{r+w}{r}} - 1\right) \quad \frac{\text{kV}}{\text{mm}}\frac{1}{\text{mm}} \qquad (5)$$

if U_0 is in kV and all dimensions are in mm.

Sensitivity to change of insulation width

Differentiating (2) and (3) with respect to w gives the following expressions of sensitivity to change of insulation width only

$$\frac{dE_r}{dw} = \frac{-U_0}{r(r+w)\left(\ln\frac{r+w}{r}\right)^2} \quad \frac{\text{kV}}{\text{mm}}\frac{1}{\text{mm}} \qquad (6)$$

$$\frac{dE_R}{dw} = -\frac{U_0\left(\ln\frac{r+w}{r}+1\right)}{\left[(r+w)\ln\frac{r+w}{r}\right]^2} \quad \frac{\text{kV}}{\text{mm}}\frac{1}{\text{mm}} \qquad (7)$$

Sensitivity per unit

The absolute value of sensitivity, as described by equations (4)-(7), is useful only for a specific cable if its operating voltage and relevant dimensions are known. To make sensitivity expressions more general, we can represent them in per unit terms. The per unit base for the field change dEr and dER will be the respective nominal field intensities Er and ER. The per unit base for the dimension change dr and dw will be the respective dimensions r and w. These lead to the following results.

$$\left.\frac{dE_r}{dr}\right|_{PU} = \frac{dE_r/E_r}{dr/r} = \frac{dE_r}{dr}\frac{r}{E_r} = \frac{w}{r+w}\frac{1}{\log\frac{r+w}{r}} - 1 \qquad (8)$$

$$\left.\frac{dE_R}{dr}\right|_{PU} = \frac{dE_R/E_R}{dr/r} = \frac{dE_R}{dr}\frac{r}{E_R} = \frac{r}{r+w}\left(\frac{w}{r}\frac{1}{\log\frac{r+w}{r}} - 1\right) \qquad (9)$$

$$\left.\frac{dE_r}{dw}\right|_{PU} = \frac{dE_r/E_r}{dw/w} = \frac{dE_r}{dr}\frac{w}{E_r} = -\frac{w}{r+w}\frac{1}{\log\frac{r+w}{r}} \quad (10)$$

$$\left.\frac{dE_R}{dw}\right|_{PU} = \frac{dE_R/E_R}{dw/w} = \frac{dE_R}{dr}\frac{w}{E_R} = -\frac{w}{r+w}\left(\frac{1}{\log\frac{r+w}{r}}+1\right) \quad (11)$$

The obtained expressions can now be used to estimate sensitivity values for a range of cable designs. The operating voltage will be reflected in the value of the insulation width, w, while the conductor size will be reflected in the value of the inner radius r.

<u>Numerical example</u>

To provide a more specific numerical example of sensitivity calculations we consider two cables whose dimensions are tabulated in Table 5.3.1These data were applied to sensitivity equations (8)-(11) and the obtained results are shown in Table 5.3.2.

Table 5.3.1: Dimensions of two example cables

Rated voltage Uo/U (kV)	127/220 kV	220/380 kV
Conductor cross-section	2000mm^2	1600mm^2
Conductor radius	28.95 mm	24.4 mm
Insulation inner radius (r)	30.95 mm	27.0 mm
Insulation thickness (w)	20.80 mm	26.6 mm
Insulation outer radius (R)	51.75 mm	53.6 mm

Table 5.3.2: Sensitivity to dimensional change in two example cables

	Rated voltage	dE_r/E_r	dE_R/E_R
Change of *r* only	127/220 kV	- 0.22dr/r	+ 0.18dr/r
Change of *w* only	127/220 kV	- 0.78 dw/w	- 1.18 dw/w
Change of *r* only	220/380 kV	- 0.28 dr/r	+ 0.22 dr/r
Change of *w* only	220/380 kV	- 0.72 dw/w	- 1.22dw/w

Table 5.3.2 results show that a decrease of insulation thickness by 1% leads to an increase of the field strength at the insulation screen by approximately 1.2% in both types of cables. At the same time, an increase of the inner radius by 1% leads to an increase of field intensity at the insulation screen by approximately 0.2%.

Similar calculation results are shown graphically in Figure 5.3.2 (a) and (b) for a range of values of r and w. The obtained plots show that variations of the field strength sensitivity to dimensional change are relatively small within a large range of dimension values. The sensitivity values are also very similar for the two types of cables considered. This is an important observation, which allows the definition of sensitivity to be generalized for the entire range of practical cable designs.

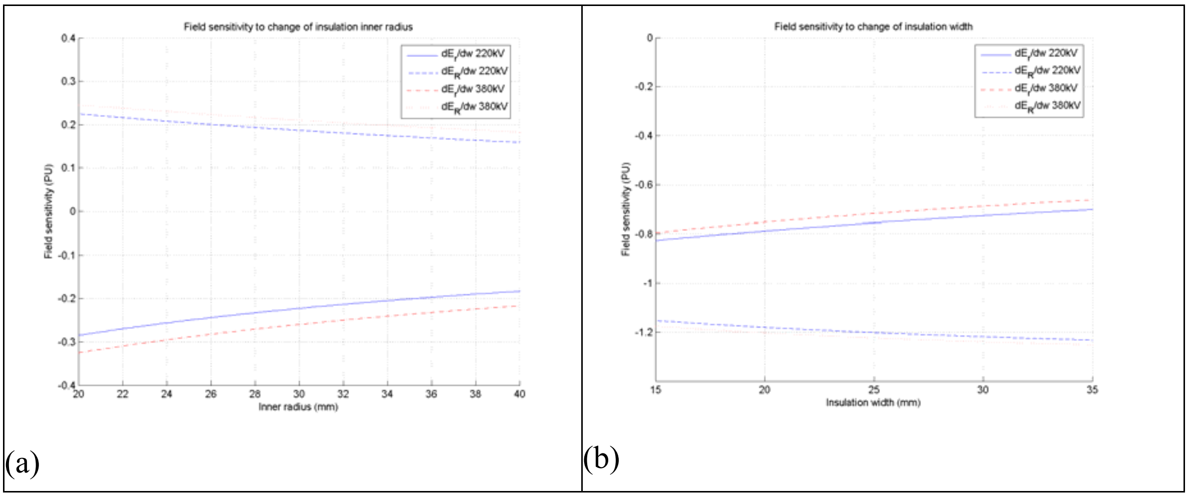


Figure 5.3.2: Field strength sensitivity to change of dimension for a range of values of the insulation inner radius and width.

Now, we will consider how these changes of electric field strength affect the risk of discharge in the interface regions in the presence of voids.

5.3.4. Determination of risk of discharge caused by change of dimensions

<u>Size of discharge-free defects</u>

We consider two types of defects in which discharges can occur

- spherical void located on the conductor screen interface

- fissure located on the insulation screen interface

Spherical defects near the conductor screen usually originate from manufacturing faults and they can be detected by factory quality control tests. Fissure defects at the interface with accessories pose a greater risk because they can be introduced during installation and they are not as easily detected.

Both types of defects are found in most practical cable systems in operation. At a given field strength a discharge free operation is possible if size of defects is sufficiently small. A discharge free operation may be still possible even under increased field strength if the defect size is further reduced. The maximum size of discharge free defects at operating voltage Uo can be estimated from sensitivity of defect size to a relative increase of the field strength in the insulation, dEins/Eins, at the defect location. This is done with the help of Paschen curve shown in Figure 5.3.3

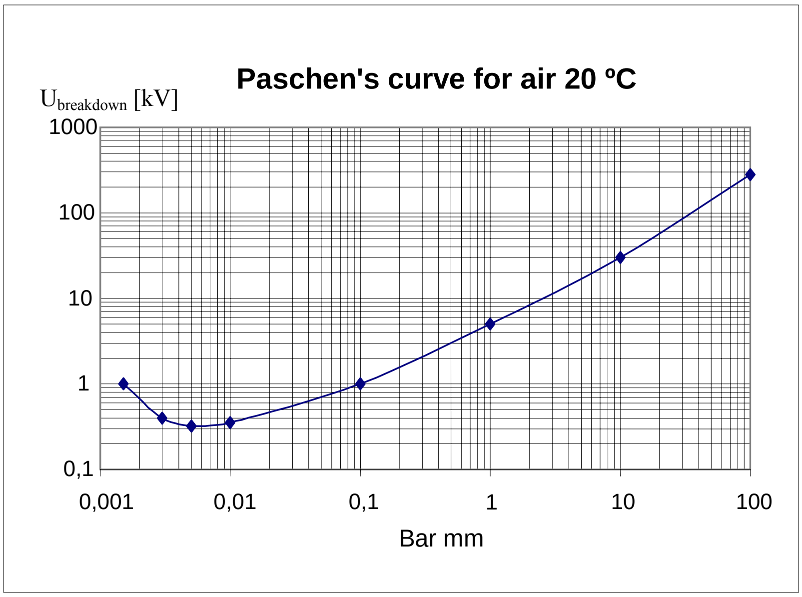


Figure 5.3.3: Paschen's curve for air at 20°C

In the context of this analysis, the Paschen curve can represent relationship between breakdown voltage, Ubd, within a defect of given size at given gas pressure inside the defect (Bar·mm). Instead of breakdown voltage, the breakdown field strength can be obtained from the curve, as shown in Figure 5.3.4.

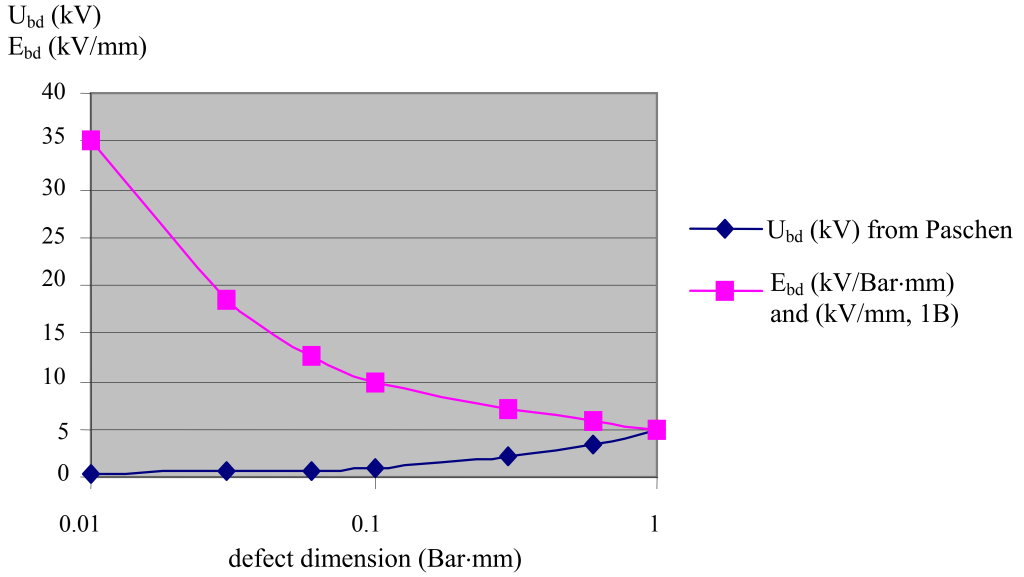


Figure 5.3.4: Breakdown voltage and breakdown field strength as a function of defect dimension in mm from Paschen curve at p = 1 Bar

The field intensity within the defect can be determined from the field strength in the insulation at the defect location considering also permittivity difference between the defect (gas, $\varepsilon = 1$) and surrounding insulation (XLPE, $\varepsilon = 2.26$). In a radial field, such as in the case of fissure at the interface to an accessory, a simple ratio of dielectric permittivity of insulation material and of gas inside the defect gives the field increase factor inside the fissure. This is illustrated in Fig 5.3.5 (a). For a gas filled sphere the field increase factor is equal to 1.23, as shown in Fig 5.3.5 (b).

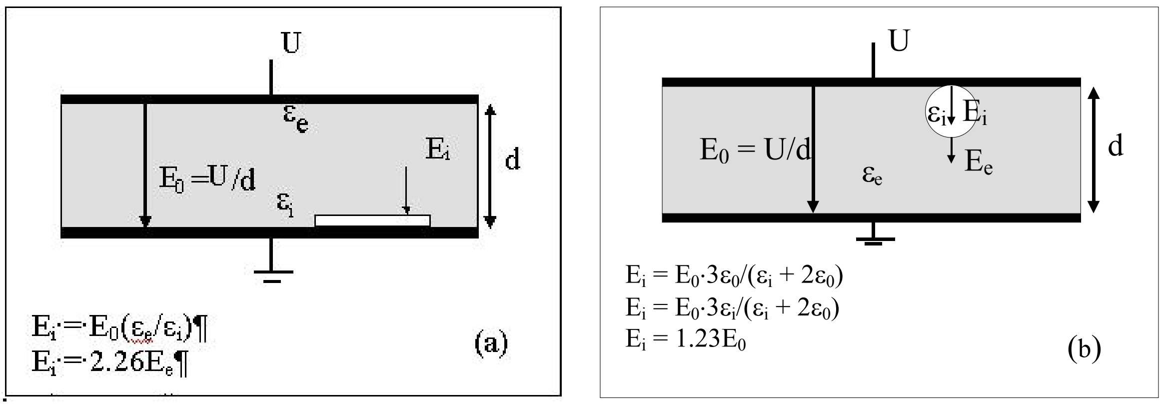


Figure 5.3.5: Electric field calculations inside a fissure (a) and spherical defect (b)

Taking into account the field increase factors from Figure 5.3.5 and the breakdown field strength of the defect from Figure 5.3.4 we can obtain the relationship between the size of a breakdown free defect and the field strength in the surrounding dielectric. It is quite clear that nearly twice stronger field is needed to initiate discharges in a spherical void in comparison with fissure. The related curves are depicted in Figure 5.3.6.

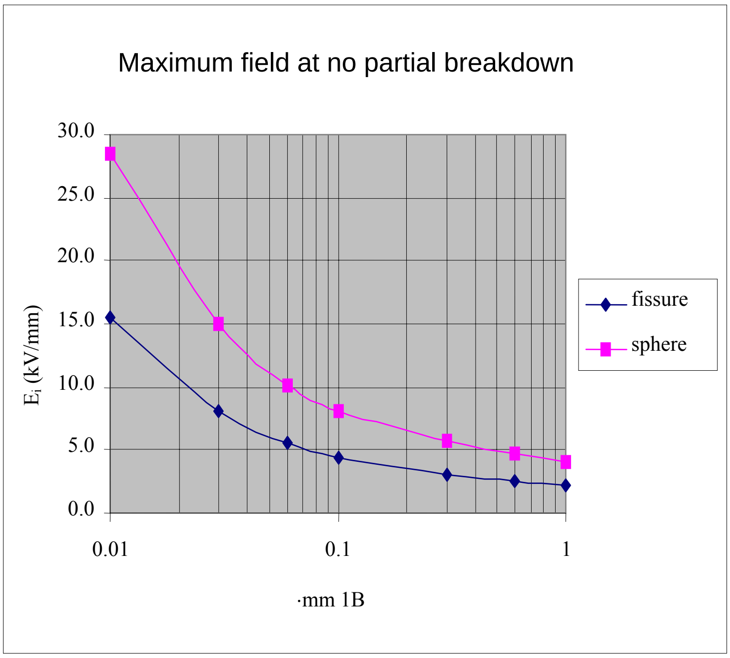


Figure 5.3.6: Maximum field intensity in the surrounding dielectric at p = 1 Bar, with no partial breakdown in the defect

Using equations (2) and (3) we can calculate partial discharge inception voltage from field intensity for a defect located on the conductor screen interface and the insulation screen interface respectively. Typically, we consider a fissure on the insulation screen and a spherical void at the conductor screen interface.

$$U_i^{\mathrm{sphere}} = \frac{1}{\sqrt{2}} E_r r \ln\left(\frac{R}{r}\right) \quad \mathrm{kV_{rms}} \qquad (12)$$

$$U_i^{\mathrm{fissure}} = \frac{1}{\sqrt{2}} E_R R \ln\left(\frac{R}{r}\right) \quad \mathrm{kV_{rms}} \qquad (13)$$

A range of values of inception voltage as a function of defect size can be obtained for the two cables listed in Table 5.3.1by substituting to equations (12) and (13) appropriate field intensity values from Figure 5.3.5together with respective cable dimensions. The obtained results together with the cable nominal voltage are shown in Figure 5.3.7 and 5.3.8

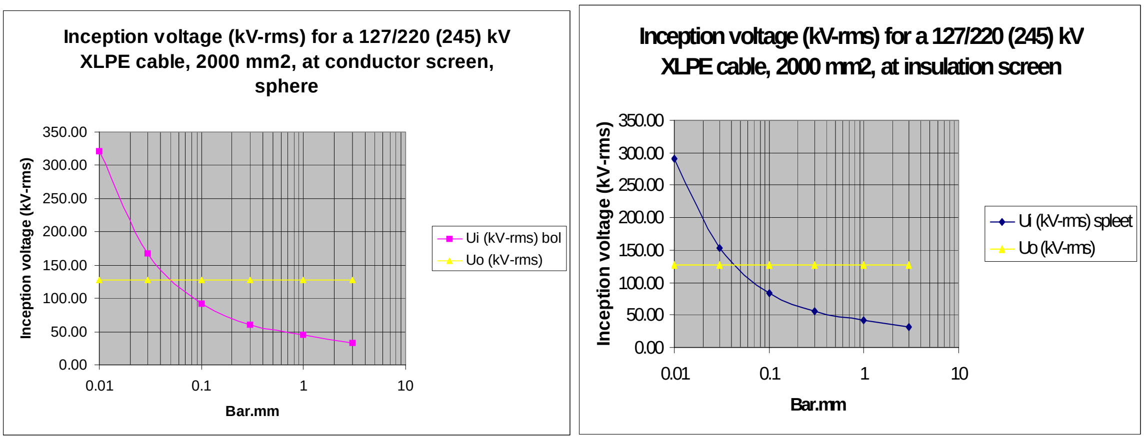


Figure 5.3.7: Partial discharge inception voltage, as a function of the size at p = 1 Bar, in a spherical void at the conductor screen interface and in a fissure at the insulation screen interface in a 127/220 kV, 2000 mm^2 cable

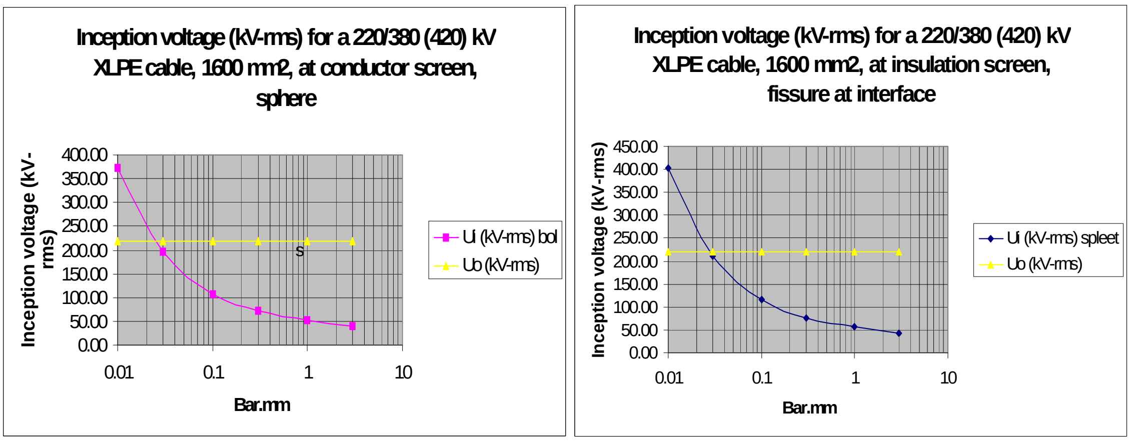


Figure 5.3.8: Partial discharge inception voltage, as a function of the size at p = 1 Bar, in a spherical void at the conductor screen interface and in a fissure at the insulation screen interface in a 220/380 kV, 1600 mm^2 cable

The comparison of the discharge inception voltage Ui with the nominal voltage U0 on these plots gives the maximum size of a discharge free defect of approximately 30 µm (at p = 1 Bar) in the 127/220 kV cable and approximately 20 µm (at p = 1 Bar) in the 220/380 kV cable.

<u>Size sensitivity of discharge free defects to change of field strength</u>

The Paschen curve in the form of field strength vs. defect size, Figure 5.3.4, shows that the higher the field intensity the smaller defect size must be for a discharge free operation of the cable. We are interested in determining the relative rate of change of the defect size with respect to the relative change of field intensity in the dielectric at a given location.

$$\frac{d(Bar \cdot mm)}{Bar \cdot mm} = f\left(\frac{dE_i}{E_i}\right) \qquad (14)$$

These parts of the Paschen curve where Bar·mm > 0.01 (> 0.01 mm at p = 1 Bar) can be modelled in sections as an exponential function of the following form

$$E_{bd} = b(Bar \cdot mm)^a \quad (15)$$

Differentiating both sides of (15) with respect to Bar·mm gives

$$dE_{bd} / d(Bar \cdot mm) = ba(Bar \cdot mm)^{a-1} = a\, E_{bd} / (Bar \cdot mm) \quad (16)$$

At the same time

$$\begin{aligned} E_{bd} &= \varepsilon_i E_i \\ dE_{bd} &= \varepsilon_i dE_i \end{aligned} \quad (17)$$

Substituting (17) to (16) and rearranging gives the desired form of sensitivity

$$\frac{d(Bar \cdot mm)}{Bar \cdot mm} = \frac{1}{a}\frac{dE_i}{E_i} \quad (18)$$

in which a is the exponent coefficient of the exponential function modelling the Paschen curve.

Equation (18) allows us to obtain sensitivity values from estimating the value of exponent a from the Paschen curve. Taking the logarithm of both sides of (15) gives

$$\log E_{bd} = a \log(Bar \cdot mm) + \log(b) \quad (19)$$

Now, the values of a and b can be found from the curve Ebd = f(Bar·mm) in Figure 5.3.4. The obtained results are shown in Table 5.3.3and Table 5.3.4.

Table 5.3.3: Data points from Paschen's curve in Figure 5.5.3

Bar·mm	log(Bar·mm)	U_{bd} (kV)	E_{bd} (kV/mm)	log E_{bd}
0.01	- 2	0.35	35	1.544
0.03	- 1.5228	0.55	18.3	1.262
0.1	- 1	1.00	10	1.000
0.3	- 0.5229	2.10	6.67	0.824
1	0	5.00	5	0.699
3	0.477	11.0	3.67	0.565

Table 5.3.4: Estimated parameters

Bar·mm	a	Log (b)	1/a
0.01 – 0.03	- 0.59	0.34	- 1.7
0.03 – 0.1	- 0.50	0.50	- 2.0
0.1 – 0.3	- 0.26	0.74	- 3.8
0.3 - 1	- 0.30	0.70	- 3.3
1 - 3	- 0.28	0.70	- 3.5

Values of 1/a shown in Table 5.3.4 indicate that within the pd area of 0.03 - 0.1 mm at p = 1 Bar a 1% increase of the electric field strength will require a 2% reduction of the defect size for a discharge free operation of the cable. Within the pd area of 0.1 - 0.3 ·mm at p = 1 Bar the corresponding reduction of the defect size is 3.8%. For the range of 0.1 – 3 mm, the reduction of the defect size is stated to be 3.5% in case of a 1% increase of the electric field strength.

5.3.5. Effect of change of cable dimensions on discharge free operation

A change of insulation dimensions will result with a change of electric field intensity. This was considered in Section 5.3.3 and defined as field strength sensitivity to change of inner radius and to change of width of insulation. We will combine these findings with results of Section 5.3.4 to determine conditions of discharge free operation if dimensions of cable insulation change. There are two main cases that need to be considered

- decreased insulation thickness ("slim" design)
- increased conductor size

At the same time, we concentrate on the case of possible discharges occurring in a fissure located at the insulation screen interface as more important from the practical point of view.

Cable systems with “slim” design

By recalling results from Table 5.3.2 in Section 5.3.3 we know that a 1 % reduction of insulation width will result with a 1.2% increase of the field strength at the insulation screen interface. At the same time, the defect size sensitivity to change of field for a discharge free operation is stated to 3.5, see Table 5.3.4. Therefore, the combined effect will be 1.2% × 3.5 = 4.2% of reduction of permissible size of defects for a discharge free operation. From this, it is straightforward to see that a 5% decrease of insulation width leads to a necessary reduction of the size of contributing defects by 21%.

<u>Cable systems with increased conductor size</u>

Results presented in Table 5.3.2 show that a 1% increase of the conductor radius contributes to a 0.2% increase of the field strength on the insulation screen interface. This gives the total effect of 0.2% × 3.5 = 0.7% decrease of permissible size of contributing defects. An increase of the conductor cross-section from 1600 mm2 to 2000 mm2 results with an approximate increase of the insulation inner radius by 12%. This corresponds to a necessary decrease of permissible size of contributing defects by approximately 8.4%.

5.3.6. Conclusions

The effect of change of insulation dimensions on the size of discharge free defects in high voltage cables was analyzed in this Annex. The following results were obtained for the two types of design considered.

<u>"Slim" design</u>

For each 1% reduction of the insulation width the reduction of fissure radial dimension by approximately 4.2% is necessary for a discharge free operation. Considering reduction of insulation width of 5%, as specified in the current range of type approval, will require a reduction of the fissure size by 21%

<u>Increased conductor size</u>

An increase of the conductor cross-section size from 1600 mm2 to 2000 mm2 without changing the insulation width will result with a necessary decrease of permissible size of contributing defects located on the insulation screen interface by approximately 8.4%.

<u>Conclusion</u>

The above results show that widening the current range of type approval described by IEC 60840 and IEC 62067 will lead to an unacceptable increase of risk of partial discharge in operating cable systems. Therefore, it can be concluded from this study that the range of type approval in relevant IEC standards ought not to be changed.

ANNEX 5.4 Functional Analysis

Use of Functional Analysis in case of Changes in Cable and Accessory Components of HV and EHV Systems

5.4.1. Introduction

International Standards provide plant manufacturers with a consistent set of tests that allows them to demonstrate that their equipment meets certain minimum criteria. For the purchaser, testing to International Standards provides a degree of assurance that the plant or equipment can be operated safely and reliably. Although testing to International Standards is often time consuming and expensive, once a manufacturer and purchaser have agreed that the test requirements have been met, the product is 'approved' and further purchases of the same product are relatively simple. One advantage of testing to International Standards is that many purchasers worldwide will accept the test evidence, without the tests having to be repeated.

A significant disadvantage of International Standards is that once a product is 'approved' there is little incentive to the manufacturer to make incremental improvements to the product, since these would invalidate the 'approval' and require the type approval tests to be repeated.

This Annex sets out a process whereby the significance of any change can be evaluated and the need for further testing agreed.

5.4.2 Functional Analysis method

In principle, it should be possible to classify any change to a cable as a change that might change the performance characteristics ("major" change), requiring a repeat of type testing, or as a "substantial change" requiring a repeat of prequalification testing, or a 'minor' change requiring little or no repeating of testing.

The tests in international cable standards have evolved either to simulate the service conditions experienced by the cable (system) (often in an accelerated manner) or to test for the presence of specific defects and deficiencies. The tests have evolved to ensure that a cable (system) is able to survive the various functions that it has to perform during its lifetime and their resulting stresses (electrical, mechanical and chemical). For example, a cable has to be bent during production, transportation and installation, so the IEC Standards include a bending test. The Working Group has extended this principle to examine how a change to the cable design or manufacture might affect its performance and hence what further testing might be required.

The methodology adopted by the WG was first to perform a functional analysis to consider the functions performed by each part of a cable's and accessories construction and how each function is tested presently in IEC 60840 Ed.3 and IEC 62067 Ed.1.

The WG then considered a number of possible changes a manufacturer might make to the cable system. The functional analysis was then used to determine what further testing might be required.

The result of this exercise is summarized in Table 5.4.1 as far as the constituents of the cable itself are concerned and in Tables 5.4.2 and 5.4.3 for the components of joints and terminations respectively. It must be mentioned that this analysis is based on the present knowledge and could be updated and used as guidance for future work.

For each constituent part, the table identifies;

- The functions performed by that component
- The feature which identifies if the function is being fulfilled or the threat posed if it is not
- Comments that give further details of the threat or alternative test procedures. The tests in IEC 60840 Ed.3 or IEC 62067 Ed.1 which check that the function is being performed satisfactorily
- Some tests described in the Functional Analysis are missing in IEC60840 Ed.3 and 62067 Ed.1 (e.g. short-circuit, side-wall pressure, etc.). The full list of missing tests is given in Annex 5.5

The main changes to cables and accessories in a prequalified cable system, which require the repetition of the type test (or part of it) or of the prequalification tests or of the extension of qualification, are summarized in tables 2.3 and 2.4 of part 2 of this report.

The cable supplier and purchaser may use the functional analysis to discuss if any change to a constituent part might lead to a change in the performance characteristics or reliability of the cable system. This is particularly useful where the change is outside the scope of table 2.3 and 2.4 of part 2.

The process for determining if further testing is required is described in the attached Flowchart.

When a supplier proposes a change to an approved cable system, the functional analysis tables may be used to determine the functions performed by the component of the cable or the accessory that may be changed. The development test evidence is then considered by the supplier and purchaser to see if the change has increased the risk that this cable or accessory will not perform as well as before.

If the development tests prove that there is no or only a “minor” increase in risk, then no further testing is required.

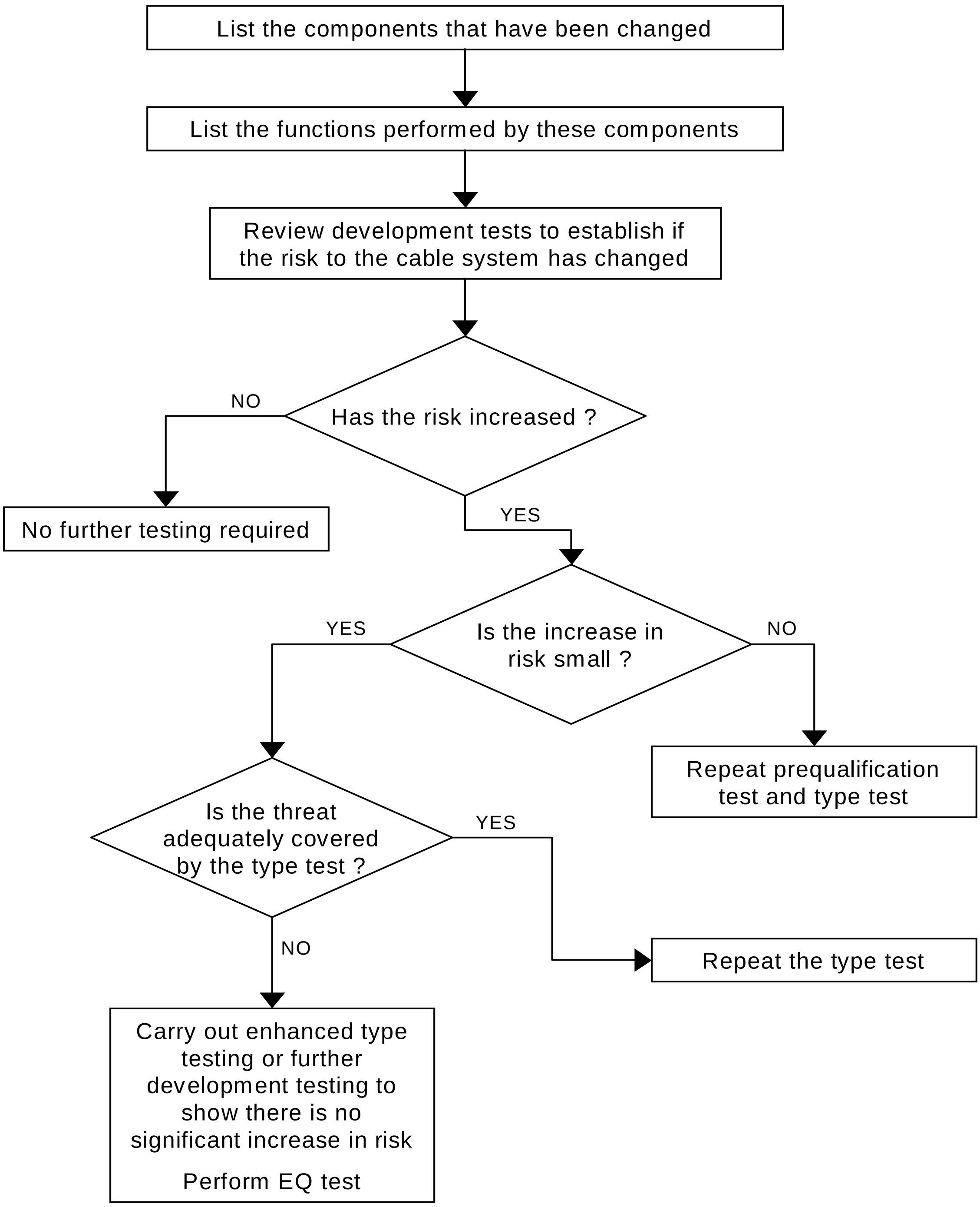
If there is a “major” increase in risk, because of a change in a component of cable or accessory that might change the performance characteristics, then further short-term (type) testing is required but the PQ tests need not to be repeated. The functional analysis table shows which IEC tests are appropriate for each component of cable or accessory that will be changed. In some circumstances a threat may be identified, which is unlikely to be revealed in a normal type test. There are other situations in which other even more efficient tests can be used (for example in the accelerated thermal ageing of accessories). In these circumstances it is appropriate for the supplier and purchaser to agree a further program of development tests rather than repeating the type tests.

If the proposed change introduces a “significant” increase in risk, then both the Type tests and PQ tests should be repeated.

The analysis described above can be extended to cover any components and materials not specifically listed in the functional analysis tables. It must be remembered that a small change in a component of cable and/or accessory does not necessarily mean a small increase in risk. Changing a small component, such as a lubricant or the material used for a wiping cloth can dramatically increase the risk for a cable system failure.

Using a combination of functional analysis and risk assessment should allow the supplier and purchaser to agree on the optimum program of tests to minimize the cost of testing whilst managing the risk of potential future cable system failure.

Flowchart showing how functional analysis can be used to determine the extent of testing required following a change to a component of the cable system



5.4.3 Functional Analysis tables

The functional analyses is divided in the following tables

Table 5.4.1 Cable components
Table 5.4.2 Joint components
Table 5.4.3 Termination components

The tables are structured as follows:

- Column A describes the components from the inner part to the outer part.
- Column B describes per component the functions or properties of the components such as electrical properties, mechanical properties, etc.
- Column C describes per function or property the specification that has to be taken into account in the design of the component or the possible threat during operation.
- Column D describes per function the test to check the functionality. Where possible, reference is made to the relevant paragraphs of IEC 60840 Ed. 3 and IEC 62067 Ed.1. Where tests do not exist in these standards, reference is made to other IEC standards or test recommendations. Distinction has been made between Routine test (R), Type test (T), Sample tests (S), Development tests (D), and Prequalification tests (PQ).
- Column E gives, when necessary, further comments or clarifications

Remark

A number of tests are identified in the functional analysis tables that are neither in IEC 62067 Ed.1 nor in IEC 60840 Ed.3. These tests are considered by the WG as Prequalification tests, Extension of Prequalification tests, Type tests, Sample tests and development or quality control tests. These tests are enumerated in annex 5.5.

Table 5.4.1 Functional Analysis of a High Voltage Cable and cable components

Abbreviations: Routine… R, Sample test… S, Type test….T, Development…. D, Pre-Qualification…. PQ

Cable's component	Function or Property	Specification/Threat	Test to check the functionality **(Relevant paragraphs of IEC 60840 Ed.3/*62067Ed. 1* in brackets –*IEC 62067 Ed.1 in Italics)***	Comments
A	**B**	**C**	**D**	**E**
Conductor	**1** **Electrical conductivity**	-a. No overheating with nominal current -b. Limit temperature with thermal short circuit current	-a. Resistance measurement **(S: §10.5/*§10.5)*** -b. Calculation of thermal short circuit temperaturre	a. Measurement to check design Verification of AC resistance of large conductors with insulated wires or other special properties: See WG B1-03 – Large cross-sections and composite screen designs: For large cross-sections, AC resistance test should be performed as type test (see technical brochure TB 272 of CIGRE WG B1-03 from 2005) b. If temperature rise is considered dangerous, a short circuit test is proposed as a development test. Check that there is no degradation of tapes and extruded semi-con after short circuit test
	2 **Mechanical properties**	-a. Satisfy the minimum bending radius without harmful mechanical deformation -b. Support pulling during installation	-a. Bending before type tests **(S: §12.3.3/*§12.4.4*)** -b. No test	 b. Limitation of pulling force to be given by the manufacturer
	3 **Water blocking**	-a. Prevent longitudinal water penetration	-a. Water penetration test **(T: §12.4.18 / *§12.5.14*)**	a. Test if water blocking properties required
	4 **Chemical properties**	-a .No corrosion when using Al conductor -b. No degradation due to layers over conductor (tape or semi-con)	-a. Examination after type test (IEC60840/ *IEC 62067*) or long term **PQ** test (*IEC 62067*) - b. Compatibility test **(T: §12.4.4/*§124)***	a. If Al conductor avoid: water ingress +chemical species (e.g. contaminations, solvents)
	5 **Interface with other components or accessories**	-a. Low interface resistivity with connectors -b.Thermal-mechanical expansion/deformation (Influence of shape of wires on interface of extruded semi-con with insulation) -c. Avoid water penetration	-a. See accessories -b. Thermal cycles: 20 **(T: §12.3.6/*§12.4.7)*** or 180 **(PQ: *§13.2.3*** on cable system) -c. Water penetration test **(T: §12.4.18/*§12.5*)**	a. Taken into account in accessories part b. **PQ** not in IEC 60840 ed3 c. Water penetration may lead to chemical degradation of the insulation mainly if the conductor metal is aluminum

Cable's component	Function or Property	Specification/Threat	Test to check the functionality **(Relevant paragraphs of IEC 60840 Ed.3/*62067Ed. 1* in brackets –*IEC 62067 Ed.1 in Italics*)**	Comments
A	**B**	**C**	**D**	**E**
Tape over conductor (optional)	**1** **Electrical resistance**	-a. Resistance sufficiently low to avoid PD and to avoid voltage over semicon during fast transients	-a. PD measurement **(R,T; §9.2/*§9.2*-§12.3.4/*§12.4.5)*** +Lightning impulse test **(T; 12.3.7/*§12.4.9*)** **+**examination **(T: §12.3.8/*§12.4.10)***	a. Covered by type tests
	2 **Mechanical properties**	-a. Good mechanical properties	-a. Bending test **(T)§12.3.3/*§12.4.4*)** Examination after completion of the type test **(T: §12.3.8/*§12.4.10*)**	
	3 **Chemical properties**	-a. No degradation of conductor or semi-con -b. Stability of electrical resistivity after heat cycles	-a. Compatibility test on whole cable **(T: §12.4.4/*§12.5.4*)** -b. Resistance measurement after heat cycles	 b. Can be confirmed by test **§12.3.9/ *§12.4.11*** on semicon indirectly and its data should be shown by manufacturer if required
	4 **Interface with other components**	-a. Avoid penetration of semi-con into conductor	-a. Visual examination after manufacturing in hot oil+ impulse test **(S; 12.3.7/*§12.4.9)***	
Inner extruded semi-conducting screen	**1** **Electrical properties**	-a. Smoothening of electrical field at the insulation interface (avoid protrusions, voids, contaminants). -b. Avoid PD at inner surface of insulation -c. Resistivity sufficiently low, to avoid PD, in the whole range of service temperatures and to avoid voltage over semicon during fast transients	-a. AC **(R, T, PQ §9.3/*§9.3*, §12.3.6 */§12.4.7, §13.2.3*** and impulse test **(T, PQ) §12.3.7/*§12.4.9, §13.2.4*** -b. PD tests **(R, T: §9.2/*§9.2*-§12.3.4/*§12.4.5)*** -c. Resistivity measurement **(T: §12.3.9/*§12.4*)**	a. Some standards and customer's specifications prescribe to check on a sample that there are no protrusions, voids or contaminants larger than their permissible level. It is a good tool to check the quality of interfaces–protrusions and contamination. However electrical routine tests are considered necessary to have a view of the quality on the full length of the cable and are still mandatory.
	2 **Thermal- mechanical properties**	-a. Resistance to mechanical bending during manufacturing and installation -b. Stability of form with thermal constrains -c. Shrinkage of semicon	-a. Bending + 20 thermal cycles **(T: §12.3/*§12.4*)** -b. Bending **(T: §12.3.3/*§12.4.4*)** + 20 thermal cycles **(T§12.3.6 /*§12.4.7*)** -c. Heat cycles **(T§12.3.6 */§12.4.7)*** and shrinkage test **(T §12.4.13)**	 b. 20 cycles are considered sufficient by the WG to evaluate this functionality c. For type tests, the shrinkage test acts as a check on the properties of the material. For the long term test, the shrinkage test is not necessary when these long term tests are performed successfully on the cable system

Cable's component	**Function or Property**	**Specification/Threat**	**Test to check the functionality** (Relevant paragraphs of IEC 60840 Ed.3/*62067Ed. 1* in brackets –*IEC 62067 Ed.1 in Italics)*	**Comments**
A	**B**	**C**	**D**	**E**
	3 **Chemical properties**	-a. Stability of electrical properties with ageing -b. Stability of electrical resistivity after heat cycles -c. Compatibility with layers or conductor below and with insulation	-a. Resistivity measurement before and after ageing **(T: §12.3.9/*§12.4.11*)** -b. Resistivity measurement before and after ageing **(T: §12.3.9/*§12.4.11*)** -c. Compatibility test on whole cable **(T: §12.4.4/*§12.5.4)*** +Resistivity measurement of semicon before and after compatibility test **(T: §12.3.9/§*12.4.11)*** .	c. PIXE (Particle induced X-ray Emission) measurements have shown that there is no ionic migration from the semi-con into the insulation during heat cycling tests or in service. However, there is some diffusion of the antioxidant and low molecular weight species during the curing process and afterwards Some customers ask to check the moisture content in the semicon (<1000ppm content) Influence on the dielectric behavior of the insulation system?
	4 **Interface with conductor and insulation**	-a. Compatibility with conductor or layers below and with insulation (See above and underneath) -b. No degradation of insulation by migration of low molecular species -c. Good bonding of extruded semi-conducting screen with insulation -d. No deformation of semicon surface due to penetration of semicon between the conductor's wires	-a. Compatibility test on whole cable **(T: §12.4.4/*§12.5.4)*** -b. Type test **(T: §12.3/*§12.4*)** or long term test **(PQ: *§13.2*)** -c. Bending + heat cycling (min **80** cycles **–D)** + PD**: ((T: §12.3/*§12.4*** -d. Examination of surface in hot oil	b. No PQ long term test in IEC 60840 ed3 c. Good bonding of extruded semi-conducting screen with insulation is generally not a problem but should be checked at least once with a new material. Tests could be performed on model cables. 20 cycles are not considered enough to check whether the bonding with insulation remains correct. When 180 PQ cycles are performed, this property is indirectly checked d. Quality control

Cable's component	Function or Property	Specification/Threat	Test to check the functionality **(Relevant paragraphs of IEC 60840 Ed.3/*62067Ed. 1* in brackets –*IEC 62067 Ed.1 in Italics*)**	Comments
A	**B**	**C**	**D**	**E**
Insulation	**1** **Dielectric properties**	-a. Withstand to AC stresses and lightning/switching impulses	-a. AC: routine test on each length and type test and regular impulse tests: on samples and with type test AC **(R, T, PQ) §9.3/*§9.3*, §12.3.6 /*§12.4.7, §13.2.3*** and Lightning **(S, T, PQ) §12.3.7/*§12.4.9, §13.2.4*** Switching **(T, PQ)** ***§12.4.8*** on EHV system	a. Following a study made in Japan, switching impulse breakdown values on cables are higher than for lightning impulse. For EHV cable systems switching impulse is still relevant Some customers prescribe to check on a sample that there are no protrusions, voids or contaminants larger than their permissible level. WG has considered that protrusions and contamination examination on a small sample is less relevant than an electrical routine test on the whole length of cable (Same as before. See page 2)
		-b. No harmful voids in the bulk or in the interface with semi-conducting screens	-b. PD routine test **(§9.2/*§9.2*)**	b. No PD shall be allowed, as they may be harmful. Good sensitivity
		-c. Stability of dielectric properties with thermal and electrical ageing	-c. Thermal cycles**:** 20 **(T: §12.3.6/*§12.4.7*)** or 180 **(PQ: *§13.2.3*)**	c. **PQ** not in IEC 60840 ed3. Thermal cycles check mainly the possible deformation of the insulation. No thermal or electrical ageing was ever demonstrated under normal service conditions. Some physical-chemical parameters presented changes after pre-qualification tests but they were not correlated to any degradation of the dielectric properties of the insulation. Microscopic defects may, however, lead to local degradation. This possible degradation can be expressed by a power law
		-d. Low dielectric constant	-**d.** Capacitance **(S: §10.10/*§10.10*)**	
		-e. Low dielectric losses,	-e. Tan δ measurement **(T: §12.3.5/*§12.*)**	e. Preliminary test can be performed on insulating material before extruding it on cable

Cable's component	**Function or Property**	**Specification/Threat**	**Test to check the functionality** **(Relevant paragraphs of IEC 60840 Ed.3/*62067Ed. 1* in brackets –*IEC 62067 Ed.1 in Italics)***	**Comments**
A	**B**	**C**	**D**	**E**
	2 **Thermal-mechanical properties**	-a. Resistance to mechanical bending during manufacturing and installation	-a. Bending test followed by PD and dielectric tests +examination after tests (**T: §12.3/*§12.4***)	
		-b. Stability of mechanical and dielectric properties with temperature and thermal ageing	-b. Hot set test **(S: §10.9/*§10.9*, T: §12.4.10/*§12.5.10*)** Ageing and mechanical test on material **(T: §12.4.2/*§12.5.2*)**	
		-c. Stability of form under the pressure of accessories and under the pressure of the thermal-mechanical expansion of the conductor	-c. Heating cycles with bending in test set up **(T: §12.3.6/*§12.4.7*)** Long term test with cable system installed in conditions near reality **(PQ:** 180 cycles ***§13.2.3*)**	c. In IEC 60840 ed3 no long-term **PQ** test is performed on cable systems. (This problem is considered in chapter 3) The experience in the field shows whether the behavior of the cable system is correct. It would be wise to make a long term cycles test also on new cable systems below 220 kV at a relatively high value of electrical stress except if a similar system has been tested for higher voltage
	3 **Chemical properties**	-a. Compatibility with inner and outer semi-con	-a. Compatibility test- **(T:** ageing test on complete cable **§12.4.4/*§12.5.4)***	
		-b. Resistance to oxidation and thermal degradation (see above)	-b**.** 20 cycles **(T) §12.3.6/*§12.4.7*** or 180 cycles **(PQ *§13.2.3***	b. In IEC 60840 ed3 no long-term **PQ** test is performed. Presence of water prohibited avoiding electrochemical (water) treeing. This can be avoided by a metal sheath over the cable core
	4 **Interface with inner and outer semicon and accessories**	-a. Compatibility with inner and outer semi-con: see above	-a. Compatibility test. Ageing test on complete cab le **(T: §12.4.4/*§12.5.4)***	
		-b. Compatibility with accessories interfaces	-b**.** 20 cyc les **(T: §12.3.6/*§12.4.7*)** or 180 cycl es **(PQ: *§13.2.3)***	b. In IEC 60840 ed3 no long-term test PQ is performed on cable systems. Long term tests would be useful as a development test D for new designs on cables or accessories under specific conditions. (This problem is considered in chapter 3)
		-c. Shrinkage of insulation	-c**.** Shrinkage test **(T: §12.4.13/---)** or long term cycling test in presence of accessories **D** or **(PQ: *§13.2.3)***	c**.** No need for a shrinkage test if long-term tests with cycles are performed. For type tests it acts as a test on the material properties
		-d. Smoothness of surfaces and purity of insulation	-d. Test in hot oil as a production test useful	

Cable's component	Function or Property	Specification/Threat	Test to check the functionality **(Relevant paragraphs of IEC 60840 Ed.3/*62067Ed. 1* in brackets –*IEC 62067 Ed.1 in Italics*)**	Comments
A	**B**	**C**	**D**	**E**
Outer extruded semi-conducting screen	**1** **Electrical properties**	Same as inner semicon	See inner semicon	
	2 **Thermal-mechanical properties**	Same as inner semicon	See inner semicon	
	3 **Chemical properties**	-a. Same as inner semi-con, but compatibility with outer layers or (and) metal screen -b. Stability of electrical resistivity after heat cycl	a. See inner semicon b. See inner semicon	a. Some customers ask to check the moisture content in the semicon (<1000ppm content) as for the inner semicon. Influence on the dielectric behaviour of the insulation system?
	4 **Interface with insulation and outer layer or (and) metal screen and accesses**	a. Same as inner semicon, but compatibility with outer layer or (and) metal screen	a. See inner semicon	
Layer over Semicon (optional)	**1** **Electrical properties**	-a. Low resistivity to avoid PD at interface with screen	-a. PD measurement **(R: §9.2/*§9.2*, and T: §12.3.4/*§12.4.5*)**	
	2 **Thermal-mechanical properties**	-a. Resistance to mechanical bending during manufacturing and installatn 16.1.1 - b. Prevent deformation of the semicon and the insulation… -c. Water-blocking tapes possibly avoid the longitudinal water penetration (if required)	-**a.** Bending test before type test **(T: §12.3.3/*§12.4.4*)** Examination after completion of the type tests **(T: §12.3.8/*§12.4.10*)** -b. 20 cycles **(T: § 12.3.6/*§12.4.7*)** + PD test **(§ 12.3.4/*§12.4.5*)** +examination **(§12.3.8/*§12.4.10*)** -c. Water penetration test **(T: §12.4.18/*§12.5.14*)**	
	3 **Chemical properties**	-a. Compatibility with semi-con and screen -b. Stability of electrical resistivity after heat cycles	-a. Compatibility test. Ageing on complete cable **(T: §12.4.4/*§12.5.4)*** -b. 20 cycles (**T**: **§ 12.3.6/*§12.4.7***)+ measurement of resistivity after ageing	

Cable's component	**Function or Property**	**Specification/Threat**	**Test to check the functionality** **(Relevant paragraphs of IEC 60840 Ed.3/*62067Ed. 1* in brackets –*IEC 62067 Ed.1 in Italics*)**	**Comments**
A	**B**	**C**	**D**	**E**
	4 **Interface with semi-con and metal screen**	-a. Compatibility test (see above) -b. Avoid deformation of insulation (see above)	-a. Ageing on complete cable **(T**) but no measurement on tape (see above) -b. 20 cycles **(T: §12.3.6/*§12.4.7***+ examination **§12.3.8/*§12.4.10*)**	
Metal Screen/ Sheath	**1** **Electrical properties**	-a. Satisfy the short-circuit conditions -b. Collects capacitive current and induced currents **-c.** Electrical connection when more than one metallic screen is applied -d. Current sharing in two metal layer constructions -e. Good contact between metal screen/sheath and semicon layer below	-a. Calculation of cross section needed (following IEC 60949 and 61443) -b. Resistance measurement as for conductor **(S, T: §10.5/*§10.5*,)** and dimensions of the screen **(§10.7/*§10.7*)** -b. Calculation of losses (depending on installation conditions – see IEC 60287) **-c. T:** Heat cycling and temperature measurements -d. Current sharing following conductivities. - e. PD test + cycles +PD **(T: §12.3. /*§12.4.*)**	d. Missing in IEC! CIGRE WGB1-03 has made a report TB 272 on this subject in 2005

Cable's component	Function or Property	Specification/Threat	Test to check the functionality (Relevant paragraphs of IEC 60840 Ed.3/*62067Ed. 1* in brackets –*IEC 62067 Ed.1 in Italics)*	Comments
A	B	C	D	E
	2 **Mechanical properties**	-a. Supports mechanical bending	-a. Bending test before type test **(T: §12.3.3/*§12.4.4*)** -Examination after completion of the type tests **(T: §12.3.8/*§12.4.10*)**	
		-b. Limited deformation of insulation and outer semicon in case of short circuit temperature rise	-b. Thermal short-circuit test on screen **(D)**	b. No official thermal short-circuit test in IEC specifications concerning HV cables
		-c. Supports radial pressure during heating	-c. Thermo-mechanical test with heat cycles	c. To be defined: sidewall pressure test as recommended CIGRE in ELECTRA 141 and **IEC 61901 TR** Only to be performed if needed for a special application
		-d. Radial water tightness in case of composite metal foil screen	-d. Technical Report of IEC **(IEC 61901 TR**) recommending a long term test in water (see also CIGRE recommendations from ELECTRA 141): **D**	
		-e. Fatigue in case of lead or lead alloy: possible growth of crystals and fissuring	-e. Check in relevant standards dealing with lead alloys that the chosen alloy is well adapted to the application in the field: EN 12548, EN 50307 or equivalent. Micrographic tests could be useful to evaluate the grain size of the extruded lead (Quality control during extrusion of lead sheath)	e. Other tests like slow elongation (0.1mm/h) or "cone" test could be proposed to check the quality of the lead extrusion?
		-f. Fatigue in case of composite metal foil screen when installed in non buried conditions	-f. A fatigue test (: repeated bending) could be recommended as a development test **D**	f. To be defined: number of bendings, diameter of bending…
		-g. Side wall pressure in case of composite metal foil screen	-g. Technical Report of IEC**(IEC 61901 TR)** recommending a side wall pressure test (see also CIGRE recommendations from ELECTRA 141): **D**	
	3 **Chemical properties**	-a. No corrosion of the metal	-a. Corrosion test following ELECTRA 141 or IEC Technical Report (**IEC 61901 TR**) when using Aluminium foil or IEC 60229, Clause 4.2 for Aluminium metallic layer	
		-b. Compatibility with layers or semi-con	-b. Compatibility test	
	4 **Temperature Monitoring** **(if any)**	-a. Satisfy temperature measurement -b. Satisfy short-circuit conditions -c. Satisfy mechanical conditions	-a.b.c. Short circuit test with the installed sensors (mainly if sensors are optical fibers) would be useful as a development test **D**	Check that the sensor is not destroyed by the short circuit temperature and the electromagnetic forces

Cable's component	Function or Property	Specification/Threat	**Test to check the functionality** (Relevant paragraphs of IEC 60840 Ed.3/*62067Ed. 1* in brackets –*IEC 62067 Ed.1 in Italics*)	Comments
A	**B**	**C**	**D**	**E**
	5 **Interface with semi-con or layer and over-sheath and with accessories**	-a. Compatibility (see above) -b. Correct connection with accessories screens -c. (Especially in case of lead or lead alloy sheath: fatigue problem possible) -d. Radial water tightness in case of metal foil or sheath	-a. Compatibility test**:** -Ageing of complete cable **(T: §12.4.4/*§12.5.4*** with visual examination) -b. Heat cycles: -20 cycles **(T: §12.3.6/*§12.4.7*)** or 180 cycles **(PQ: *§13.2.3*)** And thermal short-circuit test (development test **D**) -c. To make the right choice of lead: see EN 12548 and EN 50307 -d. Corrosion test following ELECTRA or IEC Technical Report (**IEC 61901**)	a. See electric contact properties after compatibility test b. Long term PQ test not in IEC 60840 ed3 c. Fatigue of lead may lead to cracks but may be they do not yet appear during long-term PQ tests
Over sheath	**1** **Electrical properties**	-a. Electrical insulation of screen from earth if required -b. Insulate for AC and impulse voltages in case of cross bonding or single point bonding -c. No degradation of this property -d. Correct behavior in case of short-circuit on outer screen	-a. AC/DC test on sheath **(R: §9.4/*§9.4*)** or a spark test during manufacturing -b. Test combined with test on outer protection of joints **-c.** 20 cycles **(T: §12.3.6/*§12.4.7*)** + AC and impulse test on sheath -d. Short circuit test on screen in network conditions as a development test **D**	
	2 **Thermal-mechanical properties**	-a. Supports mechanical bending during installation -b. Resistance to mechanical impact during and after installation -c. Resistance to abrasion during installation -d. Good mechanical qualities before and after ageing e.g. no cracking of the outer sheath -e. Resistance to fire if required	-a. Bending test **(T: §12.3.3/*§12.4.4)*** -b. Mechanical impact: see ELECTRA 141 for metal foils or IEC Technical Report **(IEC 61901 TR)** and in addition to **§12.4.19** -c. Tests according to IEC 60229, Clause 4.1 -d. See the different tests on the different types of materials in IEC **(§12.4., *§12.5.)*** -e. Tests under fire following the relevant tests in IEC **(§12.4.17, *§12.5.13*)**	

Cable's component	Function or Property	Specification/Threat	**Test to check the functionality** (Relevant paragraphs of IEC 60840 Ed.3/*62067Ed. 1* in brackets –*IEC 62067 Ed.1 in Italics*)	Comments
A	**B**	**C**	**D**	**E**
	3 **Chemical properties**	-a. Compatibility with screen -b. Resistance to UV -c. Resistance to the chemicals in ground -d. Resistance to termites and rodents where needed (special additives or design)	-a. Compatibility test: -Ageing on complete cable **(T: §12.4.4/ *§12.5.4*)** -b. Carbon black content in PE oversheaths: **(T: §12.4.12/*§12.5.12*)** -UV stabilizer in other materials: accelerated weathering test -c. Choice of material depending on the application -d. Special tests depending on type of termites and rodents**: D**	
	4 **Interface with screen, accessories or external aggression**	-a.See above -b. Shrinkage of over-sheath may give problems with accessories	 -b. Long term cycling in presence of accessories: **PQ** or **D** **(T: §12.4.14/ -)**	- **b.** Included in long-term pre-qualification test of IEC 62067 *(§ 13.2.3)* but not in IEC60840 ed3. Shrinkage, if any, is not necessarily finished after 20 cycles.
Complete cable	**1** **Different electrical and mechanical needs**	-a. No degradation because of interactions between all components and of components themselves -b. No ingress of water to avoid insulation degradation and dielectric problems with accessories	-a. Examination after completion of the type tests **(T: §12.3.8/*§12.4.10*)** -b. Short circuit test as **D** depending on the network conditions (to be decided with the network engineers) -b. Water penetration test **(T: §12.4.18/*§12.5.14*)**	

Remarks:

- Long-term tests could be performed where necessary as development tests when not prescribed in specifications. See the recommendation from the WG in this report. (See table 5-7-1)

- The functions are determined by the construction. The construction, the materials applied and the production process applied determine the functional properties. The standards take this into account with the Range of Type Approval

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- A short circuit between conductor and metal screen/shield may influence most of the functions described by thermal effects and mechanical effects (thermal expansion and shrinkage of materials). Adherence of layers/screens is also tested with this test. Should this lead to an extension of the test series with a type test or a development test? After discussion it was concluded that a short circuit test should be recommended as a development test.

- In the IEC 62067 and the IEC 60502-2, there is an electrical Sample test as a check on the properties of the insulation. In the IEC 60840 there is no electrical sample test on the insulation. It would be wise to perform a lightning impulse test as soon as the stress level near the inner semi-conducting screen reaches values as in IEC 62067. This may be the case when reducing the insulation thickness so that the inner AC service stress is becoming as high as 8kV/mm.

- The current standards IEC 60840/Ed3 and IEC 62067/Ed1 cover the most important functions. No tests should be deleted. May be $\tan\delta$ could be performed on materials in stead of being performed on cable insulation (but be careful, as it seems that $\tan\delta$ can be influenced by the diffusion of some products into the insulation)

Table 5.4.2 Functional analysis of High Voltage cable joint and joint components

Abbreviations: Routine… R, Sample test… S, Type test….T, Development…. D, Pre-Qualification…. PQ

Joints components	**Function or Property**	**Specification/Threat**	**Test to check the functionality** (Relevant paragraphs of IEC 60840 Ed.3/*62067 Ed.1* in brackets-*IEC 62067 Ed.1 in Italics)*	**Comments**
A	**B**	**C**	**D**	**E**
Metallic connection and its eventual covering	**1** **Electrical continuity /electrical resistivity**	-a. Transports nominal current without overheating -b. Supports short circuit current and temperature	-a. Heat cycles on connections Use **IEC 61238-1** when appropriate (= not welded): **D** -b. Short circuit test following the network needs: **D** (Such a test is part of **IEC 6121)**	a. No prescription in IEC 60840 ed3 or 62067 ed1 ***IEC61238-1*** *is presently only prescribed for 30 kV connections and below but could be useful for HV connections Short circuit temperature shall not be at 250°C but derived from short circuit currents selected from the data of* ***IEC 61443*** b. No short circuit test prescribed in IEC 60840 ed3 or 62067 ed1
	2 **Mechanical properties**	-a. Supports the compression and extension efforts during cycles from cable conductor (Does not allow wrinkling of conductor during heating cycles)	-a. Heat cycles of cable loop with joint installed: 20 cycles **(T: §12.3.6/*§12.4.7*+** examination **§12.3.8/*§12.4.10*)** Or long term test **(PQ: *§133*)**	a. Are 20 cycles enough to see the effects of longitudinal efforts? In IEC 60840 ed3 long term **PQ** tests are missing to check the long term behavior of joints See tensile strength of welded connectors
	3 **Thermal function**	-a. Dissipates correctly the heat generated in the connection and avoids overheating in the center of the joint	-a. Heat cycles, but without voltage**,** of connections **(D: §12.3.6/*§12.4.7)*** **+**Measurement of temperature of connector versus conductor **+** examination **§12.3.8/*§12.4.10*)**	a. If a reliable program to calculate the temperature profile in a joint is available, it may replace the test on cable system
	4 **Interface with joint semi-con**	-a. Compatibility of the possible used additives with the semi-con of the joint (Grease, mastic, water sealant)	-a. Long- term test **(D or PQ: *§ 13.2.3* +** examination**)**	a. Such a **PQ** test is not prescribed in IEC 60840 ed3 Test is also possible on materials: semi-con plates in air oven exposed to the additives

Joints components	Function or Property	Specification/Threat	Test to check the functionality **(Relevant paragraphs of IEC 60840 Ed.3/*62067 Ed.1* in brackets-*IEC 62067 Ed.1 in Italics*)**	Comments
A	**B**	**C**	**D**	**E**
Possible additives (grease, mastic, water sealant…)	**1** **Electrical function**	-a. No negative influence on the conductivity of the contact	-a. Heat cycles on connections (see above)	
	2 **Thermal properties**	-a. Supports the temperature of the connection during service without degradation	-a. Heat cycles of connections: see above. Examination of the additive after cycling	
	3 **Chemical properties**	-a. Gives some protection against electrical degradation of the contact of the connection	-a. Heat cycles of connections: see above. Examination of the additive after cycling	
	4 **Interface with joint semi-con**	-a. Compatibility of the possible used additives with the semi-con of the joint	-a. Long- term test **(D or PQ*: § 13.2.3* +** examination**)** Or test on semi-conducting materials in air oven exposed to the additives	
Insulation (field grading)	**1** **Dielectric function**	-a.Continuation of the insulation of the cable: Withstand to AC stresses and lightning/switching impulses -b. Reasonably low tan δ, to avoid too high dielectric losses during voltage application -c. Maintenance of the dielectric qualities of the system during the lifetime	-a. Partial discharge test **(R, *S,*: § 9.2 and 11.2.a)**and **(T:§12.3.4/*§12.4.5)*** and voltage tes**t (R, *S:* § 9.3 and11.2.b),** heating cycle test **(T: §12.3.6/*§12.4.7)*** Lightning impulse test during type tests **(T:§12.3.7/§*12.4.9)*** or long term test **(PQ**: **§13.2.4*)*** -b. Tan δ test **(T: §12.3.5/*§12.4.6*)** -c. Long term tests + impulse test on assembly + **(PQ: §13.2.3 + §13.2.4*)* + PD test after after long term test**	c. PQ Test missing in IEC 60840 ed3. Impulse test may be sufficient to detect lack of adherence. PD monitoring during type testing or long term testing would be a good tool to check the evolution of the adherence.

Joints components	Function or Property	Specification/Threat	Test to check the functionality **(Relevant paragraphs of IEC 60840 Ed.3/*62067 Ed.1* in brackets-*IEC 62067 Ed.1 in Italics*)**	Comments
A	**B**	**C**	**D**	**E**
	2 **Thermal-mechanical properties**	-a. Maintenance of good contact with cable insulation (good elasticity and compatible shrinkage of the different layers) with time at ambient and with cycles -b. Maintenance of mechanical quality in case of short circuit -c. Good heat dissipation -d. No slipping on cable with pressure from one side (prefabricated: composite or pre-molded joint)	-a. Long term tests + impulse **(PQ: *§13.2.3 + §13.2.4)*** -b. Short circuit test following the needs of the network would be useful as a development test **D** -c. Development test **D**: check of temperature drop in the insulation during heat cycling -d. Long term test on system installed in a test arrangement representative of installation design **(PQ: *§13.2.3 + §13.2.*:**	a. A long-term **PQ** test is not prescribed in IEC 60840 ed3. A development test: "pressure versus time of contact of joint insulation to cable insulation", would be an alternative for pre-molded type insulation No such test in IEC 62067 ed1 nor in IEC 60840 ed3 d. Long term **PQ** test missing in IEC 60840 ed3
	3 **Interface properties**	-a. Maintenance of good contact with cable insulation (see above) or interface with other joint components -b. Compatibility with cable insulation, lubricants and joint's semi-con -c. Shrinkage of cable materials -d. Compatibility of interface additives (lubricants..) with cable insulation/semicon material and joint insulation/semicon material	-a. Long term tests + impulse +PD **(PQ: §*13.2.3 + §13.2.4)*** -b. Heat cycles **(T: §12.3.6/*§12.4.7*)** Long term tests **(PQ: *§13.2.3 for EHV)*** -c. Long term shrinkage test **as D** on 5m long cable: see French specification for high voltage and extra high voltage cables NFC 32 352 or C 33 253 -d. Development test **D** to check the good behavior of materials in contact with additives: check of mechanical properties of cable materials and joint materials after ageing in airen	a. Long term **PQ** test missing in IEC 60840 ed3 b. Long term **PQ** test missing in IEC 60840 ed3 c. The shrinkage test made following the French specifications shows that the insulation and sheath materials shrink back during a quite long time: **80** cycles or even more are often needed to stabilize the shrink back d. Manufacturers responsibility
	4 **Chemical properties**	-a. No harmful ageing of material	-a. Long term tests + impulse + PD **(PQ: *§13.2.3 + §13.2.4*)**	a. Long term **PQ** tests missing in IEC 60840 ed3
Interface matters including	**1** **Electrical properties**	-a. The materials used to clean or to lubricate the surfaces of the cable or the joint insulation shall not degrade the dielectric properties of the system. The lubricant is also filling up the micro-holes between the two insulating surfaces	-a. Long term tests + impulse +PD **(PQ: *§13.2.3 + §13.2.4***	a. Long term test followed by PD tests will give an indication whether the contact between the the surfaces remain correct Long term **PQ** tests missing in IEC 60840 ed3

Joints components	Function or Property	Specification/Threat	**Test to check the functionality** (Relevant paragraphs of IEC 60840 Ed.3/*62067 Ed.1* in brackets-*IEC 62067 Ed.1 in Italics)*	Comments
A	**B**	**C**	**D**	**E**
cleaning material, lubricants..	**2** **Chemical properties**	-a. No harmful ageing of material	-a. Long term tests + impulse + PD **(PQ: *§13.2.3 + §13.2.4*)**	a. Long term **PQ** tests missing in IEC 60840 ed3
	3 **Thermal-mechanical properties**	**-a.** No slipping on cable with pressure from one side (prefabricated or pre-molded joint)		
	4 **Interface properties**	-a. Compatibility of lubricants with cable and joint's insulation, and cable and joint's semi-con	-a. Development test **D** to check the good behavior of materials in contact with additives: check of mechanical properties of cable materials and joint materials after ageing in air oven	
Metal screening, connection to cable screen	**1** **Electrical function**	-a. Transfers currents circulating in cable screen, transfers short circuit current. -b. Current sharing between double screens if present	-a. Thermal cycles **with current circulating in the screen :D** Thermal short circuit test following the needs of the network would be useful as a development test D (see IEC 61443) -b. Development test **D:** Thermal cycling with current circulating in the screen and temperature measurement in the screen area + examinon	a. Currents in the screen may be important and the ability of the screen connection not to overheat during cycling should be checked (not in cycling tests in IEC) .No such short circuit test in IEC 62067 ed1 nor IEC 60840 ed3
	2 **Mechanical properties**	-a. No hot spot at connection -b. No harmful deformation of cable or joint insulation -c. No cracking near the connection in case of lead or lead alloy sheath of cable	-a. 20 Thermal cycles **(T: §12.3.6/*§12.4.7).*** Thermal short circuit test following the needs of the network would be useful as a development test **D** -b. 20 Thermal cycles **(T: §12.3.6/*§12.4.7).*** + Examination -c. Be sure that the correct lead alloy for the metal sheath of cable has been chosen following EN 50307 and EN 18	a. No short circuit test in IEC 62067 ed1nor in IEC 60840 ed3 c. Cracking may need more than 180 cycles to appear (180 cycles: long term test following IEC 62067 ed1). Severity depends largely on the installation environment and conditions.
	3 **Chemical properties**	-a. Compatibility with cable and joint materials	-a. Thermal cycles **(T: §12.3.6/*§12.4.7*)**	
	4 **Screen disconnection (for cross-bonding)**	-a. Withstands dielectric transients	-a. AC and impulse tests on outer protection of joints **(T Annex H */Annex D)***	
	5 **Water tightness**	-a. Avoid water ingress to the insulation	-a. Water tightness test Long term heat cycles with joint immersed or in ground followed by a sheath voltage test	
(Eventual)	**1** **Filling of housing**	-a. Avoid high thermal resistance		a. Design aspect

Joints components	Function or Property	Specification/Threat	Test to check the functionality **(Relevant paragraphs of IEC 60840 Ed.3/*62067 Ed.1* in brackets-*IEC 62067 Ed.1 in Italics)***	Comments
A	**B**	**C**	**D**	**E**
filling	**2** **Chemical properties**	-a. Compatibility with surrounding material	-a. Development test to check the good behavior of materials in contact with additives: check of mechanical properties of cable materials and joint materials after ageing in air oven	
	3 **Water tightness**	-a. Avoid water ingress to the insulation	-a. Water tightness test Long term heat cycles with joint immersed or in ground followed by a sheath voltage test	
	4 **Thermal-Mechanical properties**	-a. Eventually rigidifies the joint		a. Design aspect
Outer protection	**1** **Electrical function**	-a. Isolation of joint from earth -b. No degradation of dielectric function with ageing and during short circuit	**-a.** Test on outer protection **(T: Annex H */Annex D*)** -b. Long term test **(PQ*: §13.2.3 + §13.2.4*)** Short circuit test on metal screen	 b. Long term **PQ** tests missing in IEC 60840 ed3
	2 **Thermal-Mechanical function**	-a. Mechanical protection of joint		a.. Design aspect of system
	3 **Water tightness**	-a. Avoid water ingress into the cable	-a. Test in water on outer protection **(T: Annex H */Annex D*)**	
	4 **Chemical properties**	-a. Compatibility with inside material, resistance against soil aggression (if cable installed in ground) or other surroundings	-a. Long term test **(PQ: *§13.2.3 for EHV*) +** voltage withstand test on outer protection after long term test	a. Long term **PQ** tests missing in IEC 60840 ed3
	5 **Interface with cable over-sheath**	- a. Possible shrinkage of cable over-sheath and/or shrinkage of joint outer protection to be taken into consideration when designing the outer protection	-a. Check the shrinkage of the cable sheath and joint protection after heat cycling of 20 cycles (T: §**12.3.6**/*§12.4.7*) or 180 cycles (**PQ**: *§13.2.3*)	a. May be 20 cycles are not enough to see the long term behavior of the shrinkage effect Long term **PQ** tests missing in IEC 60840 ed3
Complete joint	**1** **Overall properties**	-a. No degradation because of interactions between all components and of components themselves -b. No water penetration before and after heat cycling into the cable system	-a. Examination after completion of the type tests **(T: §12.3.8/*§12.4.10)*** -b. Test in water on outer protection **(T: Annex H */Annex D)*** or better: Long term test **(PQ: *§13.2.3 for EHV*)** + insulation resistance test on outer protection after long term test	 b. Long term **PQ** tests missing in IEC 60840 ed3

Remarks

- Long-term tests could be performed where necessary as development tests when not prescribed in specifications. See the recommendation from the WG in this report. (See table 5-7-1)

- A short circuit between conductor and metal screen/shield of the cable system may influence most of the functions described by thermal effects and mechanical effects (thermal expansion and shrinkage of materials). Adherence of layers/screens is also tested with this test. Should this lead to an extension of the test series with a type test or a development test? After discussion it was concluded that a short circuit test should be recommended as a development test

- In IEC 60840/Ed.3, sample tests on accessories are included. (In the IEC 62067 yet under consideration). They should be included also in the IEC 62067

General remark: what about checking of skill of the jointers and effectiveness of mounting instructions? People responsible for installation of the accessories shall consider this in their quality assurance and quality control process. CIGRE WG B1-22 is currently working on this issue.

Table 5.4.3 Functional analysis of High Voltage terminations and components of terminations

Abbreviations: Routine… R, Sample test… S, Type test….T, Development…. D, Pre-Qualification…. PQ

component of termination	**Function or Property**	**Specification/Threat**	**Test to check the functionality** **(Relevant paragraphs of IEC 60840 Ed.3/*62067 Ed.1* in brackets *IEC 62067 Ed.1 in Italics)***	**Comments**
A	**B**	**C**	**D**	**E**
Metallic connection of conductor to network	**1** **Electrical continuity /electrical resistivity**	-a. Transfers nominal current without overheating -b. Supports short-circuit current and temperature	-a. Heat cycles on connections Use **IEC 61238-1** when appropriate (= not welded): **D** -b. Short circuit test (D) following the network ds	a. No prescription in IEC 60840 ed3 *or 62067ed1* *Short circuit test values could be selected from the data of IEC 60859* b. No short circuit test prescribed in IEC 60840 ed3or *62067ed1*
	2 **Mechanical properties**	-a. Supports compression/extension efforts during cycling of cable conductor -b. Supports the thermal short circuit efforts	-a. 20 cycles **(T) §12.3.6 / *§12.4.7*** or long term test **(PQ *§13.2.3 for EHV)*** -b. Short circuit test following the needs of the network would be useful as a development te**D**	a. System aspect Long term **PQ** tests missing in IEC 60840 ed3 b. No such test in HV IEC specifications
	3 **Chemical properties**	-a. Resistance to corrosion	a. Humidity and pollution test as a development test **D**	
	4 **Interface with network**	-a. Connection fits with terminal lugs of network interface –(Sliding contacts, bimetallic interfaces…)		-Matter for engineering of network

component of termination	Function or Property	Specification/Threat	Test to check the functionality **(Relevant paragraphs of IEC 60840 Ed.3/*62067 Ed.1* in brackets *IEC 62067 Ed.1 in Italics)***	Comments
A	**B**	**C**	**D**	**E**
Electrical field grading (stress cones, capacitive or non linear grading	**1** **Dielectric function**	-a. Field grading of dielectric stresses in order to pass AC and lightning/switching impulses -b. Maintenance of these qualities with ageing -c. Reasonably low tan δ , to avoid too high dielectric losses during voltage application	-a. Partial discharge **(R §9.2)**and voltage test **(R §9.3)**Lightning impulse **(T §12.3.7 / *§12.4.9)*** Switching impulse on EHV material **(T)*§12.4.8)*** Long term test **(PQ *§13.2.3)*** followed by lightning impulse **(PQ: *13.2.4*) *)*** and PD -b. See above -c. Tan δ test on loop with terminations **(T: §12.3.5/*§12.)***	a. PD after long term test shows that adherence between stress relieve components is still good Long term **PQ** tests missing in IEC 60840 ed3
	2 **Thermal- mechanical properties**	-a. Maintenance of good contact with cable insulation (good elasticity and compatible shrinkage of the different layers) with time at ambient and with cycles -b. Dissipation of thermal losses -c. No harmful cable deformation	-a. Development test: pressure of contact versus time and long term AC test with cycles, Long term test: **(PQ: *§13.2.3)*** and PD*)* after long term test -b. -c. Long term test: **(PQ: *§13.2.3*)** and PD after long term test + examinon	a. PD after long term test shows that adherence between stress relieve components is still good . Long term **PQ** tests missing in IEC 60840 ed3 b. Calculation. Not measurable c. Long term **PQ** tests missing in IEC 60840 ed3
	3 **Chemical properties**	-a. Resistance to thermal ageing	-a**. Long term test: (D: *§13.2.3*)** anD	a. Long term test needed if no earlier experience with a similar product Long term **PQ** tests missing in IEC 60840 ed3
	4 **Interface quality**	-a. Good compatibility with cable insulation system and lubricants (between cable insulation and stress relieve component) if any -b. Resistance to filling medium (oil…)	-**a**. Long term test**:** (PQ: *§13.2.3)* and PD after long term test+ examination -b. Development test **D** on materials in contact with filling medium: check of mechanical, chemical and dielectric properties of cable materials and termination materials after ageing in airen	a. Long term test needed if no earlier experience with a similar product Long term **PQ** tests missing in IEC 60840 ed3 b. Manufacturers responsibility
Interface matters including cleaning material, lubricants…	**1** **Electrical properties**	-a. The materials used to clean or to lubricate the surfaces of the insulation of the cable or the termination shall not degrade the dielectric properties of the system. The lubricant is also filling up the micro-holes between the two insulating surfaces	-a. Long term tests + impulse + PD **(PQ: *§13.2.3 + §13.2.4***	a. Long term test followed by PD tests will give an indication whether the contact between the surfaces remains correct Long term **PQ** tests missing in IEC 60840 ed3
	2 **Chemical properties**	-a. No harmful ageing of material	-a. Long term tests + impulse + PD **(PQ: *§13.2.3 + §13.2.4)***	a. Long term **PQ** tests missing in IEC 60840 ed3

component of termination	**Function or Property**	**Specification/Threat**	**Test to check the functionality** **(Relevant paragraphs of IEC 60840 Ed.3/*62067 Ed.1* in brackets *IEC 62067 Ed.1 in Italics*)**	**Comments**
A	**B**	**C**	**D**	**E**
	3 **Thermal-mechanical properties**	-a . No slipping or restraining on cable due to pressure		
	4 **Interface properties**	-a. Compatibility of lubricants with cable, insulation, semiconductor and termination components	-a. Development test D to check the good behavior of materials in contact with additives: check of mechanical properties of cable materials and terminations materials after ageing in air oven	
Insulator/ Envelope (Porcelain, synthetic insulator, epoxy…)	**1** **Dielectric functions**	-a. Correct creep distance and length in air or gas -b. Resistance to leakage currents and evacuation of these currents	-a. Lightning impulse **(T: §12.3.7/ *§12.4.9*)** Switching impulse **(T: *§ 12.4.8*)** for voltages above 300kV -b. For outdoor terminations, Salt fog test, Climatic test following **IEC 61442**: development tes	a. Switching impulse for voltages of 300kV and above b. Length of creep distance adapted to the degree of pollution
	2 **Thermal- mechanical properties**	-a. Resistance to mechanical forces from the HV connection -b. Resistance to seismic activity -c. Good long term resistance to higher temperatures -d. Resistance to internal arcing in case of breakdown in the termination (no harmful projections) -e. Good heat dissipation	-a. Cantilever test: **D** -b. Calculations according to **IEC 61463** -c. Long term test: **(PQ: *§13.2.3)*** + examination (**PQ**:**§13.2.5)** -d. Short circuit test with internal electrical fault: **D** **Internal overpressure test**:	a. Not prescribed by IEC HV specs; Internal test c. Long term **PQ** tests missing in IEC 60840 ed3, but useful even for this range of voltages d**.** No test in IEC HV specs for cable terminations or similar equipment such as bushings and instrument transformers e. Engineering problem; depends very much on surrounding and protection means
	3 **Interface quality with filling medium and surrounding**	-a. Resistance to climatic and polluting surrounding -b. Compatibility with filling medium	-a. Development test **D**: Climatic tests following IEC 61109 -b. Long term test **(PQ *§13.2.3)* + *examination*(PQ**: **§13.2.5)**	 b. Long term **PQ** tests missing in IEC 60840 ed3
	4 **Chemical properties**	-a. Resistance to UV, climate, water and pollution	-a. Development test: Climatic tests following IEC 61109	

component of termination	**Function or Property**	**Specification/Threat**	**Test to check the functionality** (Relevant paragraphs of IEC 60840 Ed.3/*62067 Ed.1* in brackets *IEC 62067 Ed.1 in Italics)*	**Comments**
A	**B**	**C**	**D**	**E**
Filling medium (if any)	**1** **Electric properties**	-a. Good dielectric breakdown values -b. Low dielectric losses -c. Maintenance of dielectric properties with ageing	-a. Development test on filling material: breakdown tests -b. Long term test **(PQ: *§13.2.3*)** +examination (**PQ**: **§13.2**	a. Manufacturers responsibility b. Long term **PQ** tests missing in IEC 60840 ed3
	2 **Thermal properties**	-a. No harmful degradation of the material with ageing	-a. Long term test **(PQ: *§13.2.3*)** +examination (**PQ**: **§13.2.5)**	a. Long term **PQ** tests missing in IEC 60840 ed3
	3 **Chemical properties and interface**	-a. Good compatibility with cable material in contact (insulation, eventually semi-con) and stress controlling material	-a. Long term test **(PQ *§13.2.3*)** +examination (**PQ**: **§13.2.5)** Development test to check the good behavior of materials in contact with additives: check of mechanical properties of cable materials and joint materials after ageing in airen	a. Long term **PQ** tests missing in IEC 60840 ed3 Responsibility of the manufacturer
Screen/Earth connection	**1** **Electrical functions**	-a. Fixation of earth potential -b. Evacuates short circuit current and circulating currents with both ends earthed -c. In case of disconnection from earth, electrical withstand between earth and screen -d. Suppression of screen currents with single end earthing or special bonding	-b. Short circuit test following the needs of the network would be useful as a development test **D** Thermal cycles with current in the screen (**D**) -c. Impulse and DC/AC test between earth and screen as a type test **T** -	a. Engineering problem, to be considered when installing the system. Bimetallic connections to be considered with special care b. No short circuit test in IEC 60840 ed3 nor in IEC 62067 ed1 Currents in the screen may be important and the ability of the screen connection not to overheat during cycling should be checked (not in cycling tests in IEC) d. Engineering problem: • -Single end earthing • High frequency waves at GIS ends to be solved by coaxial connections to earth
	2 **Thermal-mechanical properties**	-a. No degradation of connection and surrounding with thermal short circuit -b. No cracking near the connection in case of lead or lead alloy sheath of cable	**-a.** Thermal short circuit test of the earth connection following the needs of the network would be useful as a development test **D** With visual examination -b. Be sure that the correct lead alloy for the metal sheath of cable has been chosen following EN 50307 and EN 12548	b. Cracking does not necessarily appear already after long term cycling tests

component of termination	Function or Property	Specification/Threat	Test to check the functionality **(Relevant paragraphs of IEC 60840 Ed.3/*62067 Ed.1* in brackets *IEC 62067 Ed.1 in Italics*)**	Comments
A	**B**	**C**	**D**	**E**
	3 **Interface**	-a. No entry of humidity underneath the outer protection of the cable -b. Possible shrinkage of cable over-sheath and/or shrinkage of joint outer protection to be taken into consideration when designing the outer protection	-a. -b. Check the shrinkage of the cable sheath and joint protection after heat cycling of 20 cycles **(T: §12.3.6/*§12.4.7*)** or 180 cycles **(PQ: *§133*)**	a. Visual inspection on installed system b. May be 20 cycles are not enough to see the long term behavior of the shrinkage effect. Long term **PQ** tests missing in IEC 60840 ed3
	4 **Chemical**	-a. No corrosion of contact points		a. Design: choice of metals and protection
Base plate	**1** **Mechanical properties**	-a. Supports the weight of termination and cantilever forces on termination		a. Design aspect
	2 **Chemical properties**	-a. No corrosion of the base plate	-a. Examination when making climatic tests	a. Design aspect
	3 **Base plate insulators**	-a. Withstand AC/DC/Impulse in specially bonded systems	-a. AC/DC and impulse test on screen connection versus base plate	a. Design aspect
Complete termination	**1** **Overall properties**	-a. No degradation because of interactions between all components and of components themselves -b. Correct sealing and no fluid leakage	-a. Examination of deterioration after completion of the type tests (**T**) §12.3.8/*§12.4.10* and short circuit test	a. Leakage may come up with time in service and, may be, will not be detected during long-term development tests. It needs regular inspection or special protection if no inspection is possible

Remarks

- Long-term tests could be performed where necessary as development tests when not prescribed in specifications. See the recommendation from the WG in this report. See table 5-7-1

- A short circuit between conductor and metal screen/shield of the cable system may influence most of the functions described by thermal effects and mechanical effects (thermal expansion and shrinkage of materials). Adherence of layers/screens is also tested with this test. Should this lead to an extension of the test series with a type test or a development test? After discussion it was concluded that a short circuit test should be recommended as a development test

General remark (same as for joints):
What about checking of skill of the jointers and effectiveness of mounting instructions? People responsible for installation of the accessories shall consider this in their quality assurance and quality control process. CIGRE WG B1-22 is working on this issue

ANNEX 5.5 Tests From Functional Analysis not in IEC

A number of tests are identified in the functional analysis tables, see Annex 5.4, that are neither in IEC 62067 nor in IEC 60840.

Most of these tests are recommended by the WG as development or quality control tests.

One test, the Long Term Heating Cycling Test, is currently not in IEC 60840 Ed.3. For high stress designs it is proposed to include such a test as a Prequalification (PQ) test and as an Extension to Prequalification Test.

Another test (item 24) is considered to be a Sample test, namely the Sample Tests on accessories in the IEC 62067. They are yet under consideration and should follow the regime of the IEC 60840 Ed.3.

Electrical sample test on cable insulation for IEC 60840 (item 25) is recommended, see also Table 5.4.1. It is included in the IEC 62067 and the IEC 60502-2.

All these tests are enumerated in table 5.5.1

Table 5.5.1 Tests from functional analysis not in IEC 60840 or/and IEC 62067 but recommended by WG B1-06.

Item	Test not in IEC 60840 or/and IEC 62067	Function and threat/specification	Comment	Recommendations
1	**Short circuit tests on cable and accessories**	**a) Cable conductor's conductivity**: Limit temperature with thermal short circuit current **b) Electrical properties of the outer metal screen: -** Satisfy the short-circuit conditions **c) Short circuit on outer metal screen. Limited deformation of insulation and outer semi conductive layers in case of short circuit temperature rise** **d) Correct behavior of over-sheath in case of short-circuit on outer screen: influence of temperature or mechanical effort** **e) Short circuit test on screen to check thermal monitoring sensors if any** **f) Short circuit on metal connections (joints and terminations): hot spot?** **g) Check that here is no degradation of dielectric function with ageing and during short circuit on outer protections** (over-sheath, outer protection of joints or terminations **h) No degradation of the conductivity of connections after short circuit tests**	a. If temperature rise is considered dangerous, a short circuit test is proposed as a development test c. Short circuit test on screen in network conditions as a development test d. Check that the sensor is not destroyed by the short circuit temperature and the electromagnetic forces e. Short circuit test following the network needs f. Short circuit test following the network needs (Such a test is part of IEC 6123)	**a. – f. Development test**
2	**Sheath voltage test combined with long term prequalification test on cable**	**a) Check the shrinkage of the cable sheath versus the accessories protection and the absence of water ingress below the outer protection (can be done without voltage application)** b) Check that there is no degradation on outer protections	a. When making pre-qualification long term test this test is indirectly done if after long term test a sheath voltage test is performed	**Development test**

Item	Test not in IEC 60840 or/and IEC 62067	Function and threat/specification	Comment	Recommendations
3	**Long term heat cycling test (not in IEC 60840) on cable or system** (With or without voltage application)	**a) Cable conductor chemical properties:** No corrosion when using Al conductor **b) Cable conductor's interface with insulation and accessories**: -Thermal-mechanical expansion/deformation-Avoid water penetration **c) Semi-con interface with insulation:** -No degradation of insulation by migration of low molecular species **d) Insulation: Stability of dielectric properties with thermal and electrical ageing** **e) Thermal-mechanical properties of insulation**: -Stability of form under the pressure of accessories and under the pressure of the thermal-mechanical expansion of the conductor **f) Chemical properties of insulation and filling media of accessories:** -Resistance to oxidation and thermal degradation of insulation **g) Interface of insulation with inner and outer semicon and accessories**: -Compatibility with accessories interfaces and filling media (joints, terminations) **h) Correct connection of screens with accessories screens** **(Especially in case of lead or lead alloy sheath: fatigue problem possible)** **i) Mechanical properties of connections of joints or terminations**: -Supports the compression and extension efforts during cycles from cable conductor (Does not allow wrinkling of conductor during heating cycles) lead behavior at connection (no cracking,) **j) No slipping of joint on cable with pressure from one side** (prefabricated: composite or pre-molded joint	a. If Al conductor avoid: +water ingress +chemical species (e.g. contaminations, Solvents) b. Water penetration may lead to chemical degradation of the insulation mainly if the conductor metal is aluminum d. Thermal cycles check mainly the possible deformation of the insulation. No thermal or electrical ageing was ever demonstrated under normal service conditions. Some physical-chemical parameters presented changes after pre-qualification tests but they were not correlated to any degradation of the dielectric properties of the insulation. Microscopic defects may, however, lead to local degradation. This degradation can be expressed by a power law f. Long term test with cable system installed in conditions near reality **(PQ: 180 cycles *§13.2.3*):** the behavior of the cable system is correct. It would be wise to make a long term cycles test also on new cable systems below 220 kV at a relatively high value of electrical stress except if a similar system has been tested for higher voltage Presence of water prohibited avoiding electrochemical (water) treeing. This can be avoided by a metal sheath over the cable core Long term tests would be useful as a development test for new designs on cables or accessories in all cases j. Long term test on system installed in a test arrangement representative of installation den	**a.** Part of Development Test b.. We propose a PQ test and an EQ test for the high stress designs c. Part of development test d. We propose a PQ test and an EQ test for the high stress designs e. We propose a PQ test and an EQ test for the high stress designs f. We propose a PQ test and an EQ test for the high stress designs g. We propose a PQ test and an EQ test for the high stress designs h. We propose a PQ test and an EQ test for the high stress dess i. Part of development tests j. We propose a PQ test and an EQ test for the high stress designs

Item	Test not in IEC 60840 or/and IEC 62067	Function and threat/specification	Comment	Recommendations
4	**Climatic and salt fog tests on outdoor terminations (mainly on synthetic and composite terminations)**	**a) Resistance to leakage currents and evacuation of leakage currents (IEC 61109?), Resistance to UV on synthetic insulators**		**Part of development test**
5	**Cantilever test on termination**	**a) Resistance to mechanical forces from the HV connection**		**Part of development test**
6	**Dielectric test on screen disconnections (terminations)**	**a) Withstand the dielectric constraints (Ac and impulse)**		**Part of development test**
7	**Dielectric test on base plate insulators of terminations**	**a) Withstand the dielectric constraints (Ac and impulse)**		**Part of development test**
8	**Measurement of stability of the resistance of semi-conductive tapes on cable**	**a) Chemical properties of semi-conductive tapes- Stability of electrical resistivity after heat cycles**	a. Can be confirmed by test §12.3.9/ *§12.4.11* on semicon indirectly and its data shall be shown by manufacturer if required	**Quality control**
9	**Examination of XLPE cable insulation in hot oil**	**a) Interface of tape over conductor with semicon: - Avoid penetration of semi-con into conductor**		**Quality control**
10	**Examination of protrusions and contaminants on cable**	**a) Smoothness of interface between semicon and insulation and cleanness of insulation**	a. Some customers or standards prescribe to check on a sample that there are no protrusions, voids or contaminants. WG has considered that protrusions and contamination examination on a small sample is less relevant than an electrical routine test on the entire length of cable	**Possibly as quality control**
11	**Moisture content in inner and outer extruded semi-conductive layer on cable**		Some customers ask to check the moisture content in the semi-con (<1000ppm content) Influence on the dielectric behavior of the insulation system?	**Possibly as quality control**
12	**Grain size measurement on lead sheath on cable**	**a) Evaluate the extrusion quality of the lead to have an idea of its fatigue behavior**	a. To make the right choice of lead: see EN 12548 and EN 50307	**Quality control**

Item	Test not in IEC 60840 or/and IEC 62067	Function and threat/specification	Comment	Recommendations
13	**Evaluate Fatigue in case of lead or lead alloy on cable:**	**a) Speed of crystal growth due to heat cycling and vibration**	a. Possible growth of crystals and fissuring -Check in relevant standards dealing with lead alloys that the chosen alloy is well adapted to the application in the field: EN 12548, EN 50307 or equivalent	**Development test where applicable**
14	**Evaluate Fatigue in case of composite metal screen on cable**	**a) Fatigue in case of composite metal foil screen when installed in non buried conditions Test to be defined**		**Development test where applicable**
15	**Side wall pressure test on cable**	**a) Side wall pressure in case of composite metal foil screen**	a. To be defined: sidewall pressure test as recommended CIGRE in ELECTRA 141 (also future IEC 61901TR) Only to be performed if needed for a special application	**Development test where applicable**
16	**Long term thermal cycling test in water on cable**	**a) Radial water tightness in case of metal foil or sheath**	a. Radial water tightness in case of composite metal foil screen A technical specification in IEC recommending a long term test in water (see also CIGRE recommendations from ELECTRA 141) (also IEC 61901TR)	**Development test where applicable**
17	**Mechanical impact on over-sheath**	**a) Check mechanical behavior of over- sheath and metal screen (mainly if metal foil bonded to over-sheath)**	a. Mechanical impact: see ELECTRA 141(also IEC 61901TR) for metal foils	**Development test**
18	**Accelerated weathering test**	**a) Test of UV behavior of over-sheath material**		**Development test**
19	**Test on outer protection to check the resistance to rodents and termites on cable**	**a) Mechanical behavior of over sheath**	a. Special tests depending on type of termites and rodents N.B. There is no international standard dealing with criteria of these kind of resistance.	**Development test where applicable**
20	**Heat cycles on connections (joints and terminations)**	**a) Electrical continuity/electrical resistivity:** -Transports nominal current without overheating **b) Evaluate how currents are distributed when a double screen is applied** **c) Evaluate heat dissipation in the joint**	a. Use IEC 61238-1 when appropriate: D IEC61238-1 is presently only prescribed for 30 kV connections and below but could be useful for HV connections c. Can be replaced by calculation if effective method is available	**Development test**

Item	Test not in IEC 60840 or/and IEC 62067	Function and threat/specification	Comment	Recommendations
21	**Compatibility test of additives and filling material with cable and accessories material**	**a) Check whether the additives do not harm the quality of insulations or semi-con materials of cable and accessories**		**Development test**
22	**PD test on accessories after long term test**	**a) Evaluate whether the cycles have, or not, created a ionizing defect at the interface between the cable insulation and the accessories insulation**		**Development test**
23	**Evaluate heat dissipation in accessories either by calculation or temperature measurement**	**a) Check of temperature drop in the insulation during heat cycling Evaluate heat dissipation in the joint**	a. Can be replaced by calculation if effective method is available	**Development test**
24	**Sample tests on accessories in IEC 62067 are currently “under consideration”**		They are yet in the IEC 60840 ed.3. Thy should also be included in the IEC 62067	**Sample test**
25	**Electrical sample test as a check on the properties of the insulation**	**In IEC 62067 and IEC 60502-2, but not in IEC 60840**	Perform a lightning impulse test as soon as the stress level near the inner semicon screen reaches values as in IEC 62067, meaning higher than 8 kV/mm	**Sample test in IEC 60840 on cable sample**

ANNEX 5.6 Bibliography

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