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

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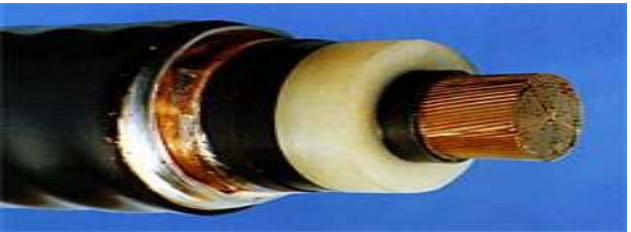
Introduction

- Innovative changes are necessary to improve the product, to remain competitive
- There is little incentive for the manufacturer to make improvements, if the expensive long term testing has to be repeated
- CIGRE WG B1-06 was asked to provide recommendations to qualify a modification to a cable system, without making the full set of tests, which are currently specified in standards
- WG B1-06 has published Technical Brochure 303 in 2006

Terms of reference WG B1-06

- AC extruded cables 30-500 kV
- Review and complete qualification procedures (type tests, PQ tests)
- Prepare innovative solutions, without jeopardizing the system reliability
- Evaluate whether present long term tests can be replaced by shorter ones
- Examine if a modification to a cables system can be qualified without making the full set of tests
- The conclusions have been offered to IEC for further standardisation



Reference standards

- IEC 62067, October 2001,Power cables with extruded insulation and their accessories for rated voltages above 150 kV (Um=170kV) up to 500 kV (Um=550kV)-Test methods and requirements

- IEC 60840, April 2004,Power cables with extruded insulation and their accessories for rated voltages above 30 kV (Um=36kV) up to 150 kV (Um=170 kV)-Test methods and requirements

PQ tests

- Focus on PQ tests, because of costs and time
- PQ test recommended by CIGRE and incorporated in IEC 62067
- Only those manufacturers whose products have passed the PQ tests have been allowed to participate in subsequent EHV cable projects

Experience with HV cable syst.

- In general experience is good
- A new generation HV XLPE cables “slim design” is developed with similar technology and higher operating stresses, as high as EHV XLPE cables
- The experience with slim design HV cables is still limited

Experience with EHV cable syst.

- For more details (see tutorial on service experience)
- XLPE cable is at present preferred transmission type cable (availability, leakage)
- Experience with EHV XLPE cable is still limited, although

  application of EHV XLPE cable is fast growing

  (see next table)

Application of EHV extruded cable systems

Country	Rated Voltage /kV	Conductor size/mm²	Route lengths/ km	Commissionning year
Denmark (Copenhagen:South	400	1600 Cu	22	1997
Denmark (Copenhagen:North	400	1600 Cu	12	1999
Germany (Berlin/ BEWAG	400	1600 Cu	6.3	1998
Germany(Berlin/ BEWAG	400	1600 Cu	5.5	2000
Japan (Tokyo)	500	2500 Cu	39.8	2000
UAE (Abu Dhabi)	400	800 Cu	1.3	2000
Spain (Madrid)	400	2500 Cu	12.8	2004
Denmark (Jutland)	400	1200 Al	14.5	2004
United kingdom (London)	400	2500 Cu	20	2005
The Netherlands (R'dam)	400	1600 Cu	2.25	2005
Austria (Wienstrom)	380	1200 Cu	5.2	2005

Long duration test EHV cable systems

- Long duration test=PQ test was introduced to compensate for lack of experience with EHV XLPE cables
- The PQ tests checks the performance under realistic conditions:
- Design concept
- Long term performance (heat cycling +overvoltage)
- Installation aspects

Long duration test

- PQ test shows in particular critical position of the joints; impulse test at the end of the test
- Although manufacturers are learning from problems in early PQ tests results , PQ test is considered to be necessary

Main items of PQ test to be considered for revision

- Range of approval in relation with calculated nominal stresses
- The duration of heating cycle voltage test
- PD tests
- Procedure in case of component failure during test
- Final control at the end of the test

Range of approval

- New PQ test has to be performed in case of higher system voltage with higher insulation screen stress than in the qualified system

Heating cycle test

- The duration of the voltage application (1.7 Uo) is an important factor because of accessory failures
- At present the duration is 180 heat cycles (8/16) up to 95 gr.C max.(with large conductor and installed in the soil 1 cycle takes more than 1 day)
- The duration of the voltage application should remain 1 year=8760h

PD tests

- Reduction of insulation thickness may result in considerable higher stress at defects, voids, fissures, increasing risk of PD activity
- Consequently the size of defects has to be reduced accordingly
- PD tests are therefore a necessary tool as an early warning for degradation and subsequent failure

System component failure

- Repair/replacement of a failed accessory during test is allowed

- Repair of cable failure is not allowed, unless failure has been caused by external incident or the cable has already been prequalified

Final control test

- After the test has been completed an impulse test has to be performed on the whole test loop
- The whole test loop has to do with the desirability to check the insulating properties at the interfaces in the accessories and the cable.
- An impulse test on the cable only, as was done in the past, is not sufficient

Changes in a prequalified system

- What changes are “substantial” in such a way that the PQ test has to be repeated?
- Functional Analysis Method correlates the function performed by a certain item to the test required to check that function.

Changes in a prequalified syst.(2)

- Some small changes do not require the repetition of a full PQ
- Some major changes require the repetition of the full PQ test
- Some changes require the performance of a simplified long term-test, called Extension of Prequalification test (EQ)

Situations of changes in a prequalified system

- The exchange of components (cable or accessories), already prequalified in systems from different manufactures or from different plants from the same manufacturer
- The modification to cable components
- The modification to accessory components within the same family

Evaluation of changes in a prequalified system

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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 (calculated) or *not qualified*
cable	non electrical Type Test (TT) + Extension of qualification test (EQ)	electrical and non electrical TT + Prequalification Test (PQ)
Joint	EQ	TT + PQ
Metal enclosed Termination	EQ	TT + PQ
Outdoor Termination	EQ	TT+PQ

Tests because of modifications to a cable in a prequalified EHV cable system

Component	Modification	Proposed test
Conductor	▪Copper to Aluminium	**TT** and **PQ**
	▪Larger cross-section	**TT**
Insulation	▪**Change of base resin**	**TT**
	▪**Change in cross linking package (peroxide / antioxidant)**	**TT**
	▪**Nature of polymer (XLPE, LDPE, HDPE, EPR)**	**TT and PQ**
	▪**Higher conductor stress, no increase of insulation screen stress**	**TT**
	▪**Increase of insulation screen stress**	**TT and PQ**
	▪**New extrusion line or transfer of extrusion line with earlier experience in-house**	**TT**
	▪**New extrusion line, or transfer of extrusion line without earlier experience**	**TT and PQ**

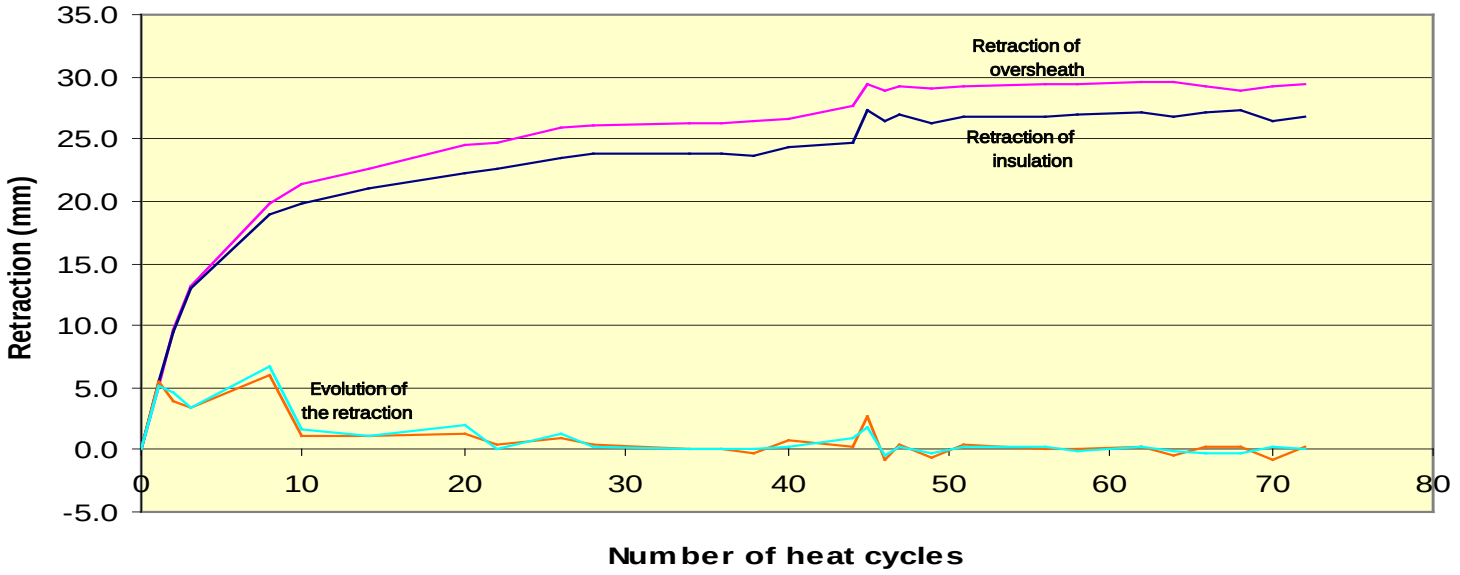
Tests because of modifications to an accessory within the same family in a prequalified EHV cable system

Component	Type of modification	Proposed test
Joint	▪Higher calculated electrical stress design and construction	**EQ**
	▪Compound of main insulation body	**PQ**
	▪Changing nature of polymer, (EPR, Silicone....)	**EQ**
	▪Material of semi-con electrodes	**EQ**
	▪Fixation of cable ends on either side of the joint	**EQ**

Principles of the Extension of PQ test (EQ)

- 60 thermal cycles witout voltage
- 20 cycles with 2Uo+PD+hot impulse test
- The 60 daily cycles + 20 cycles are intended to allow relaxation of mechanical stresses trapped in the cable during manufacture, resulting in retraction of the XLPE insulation
- The retraction of the cable insulation within an accessory can initiate PD activity

Retraction of XLPE insulation and PE oversheath



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.

Recommendations to IEC 62067

- New cable systems:
- Maintain 1 year PQ test
- Allow in case of an accessory failure the continuation and completion of the PQ test for the undisturbed component
- Perform PD tests during PQ test
- Perform impulse test at the end of the test on the complete test loop
- Maintain unchanged present range of TT and PQ approval

Recommendations to IEC 62067

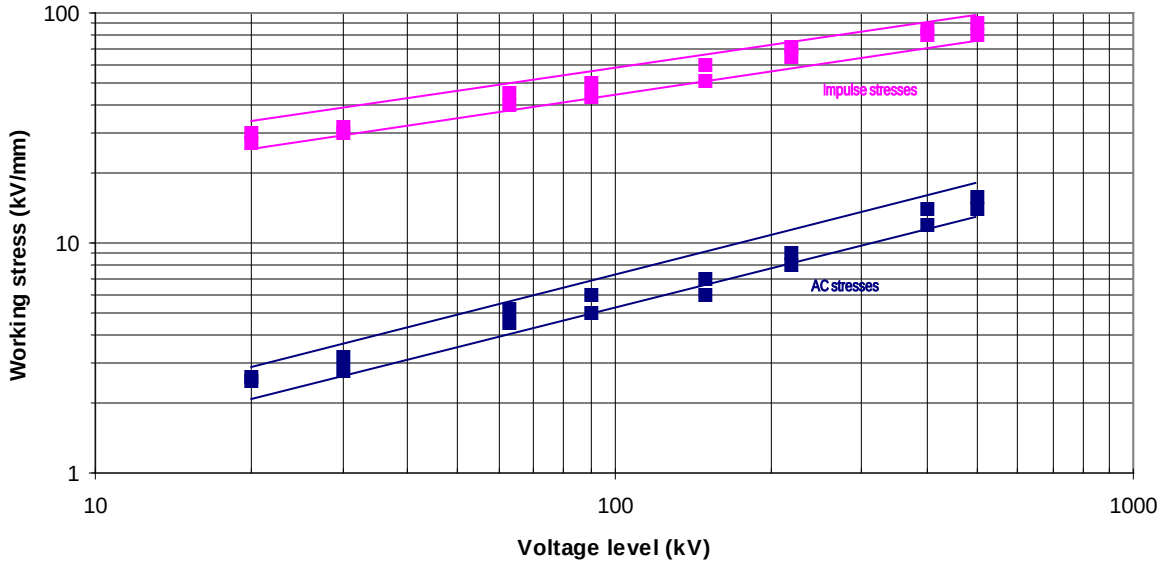
- Exchange of a prequalified component:

- Introduce a simplified long term test of 60+20 cycles in case of exchange of prequalified components with other components or in case of less significant modifications of cable or accessory

Long duration test HV cable systems

- Traditionally EHV cables are operating at higher stresses than HV cables
- Due to good experience with EHV cables, HV cables are being produced with reduced insulation thickness (slim design)
- Higher stresses at main insulation and at interfaces between cables and accessories

Increase of Electric stress with system voltage

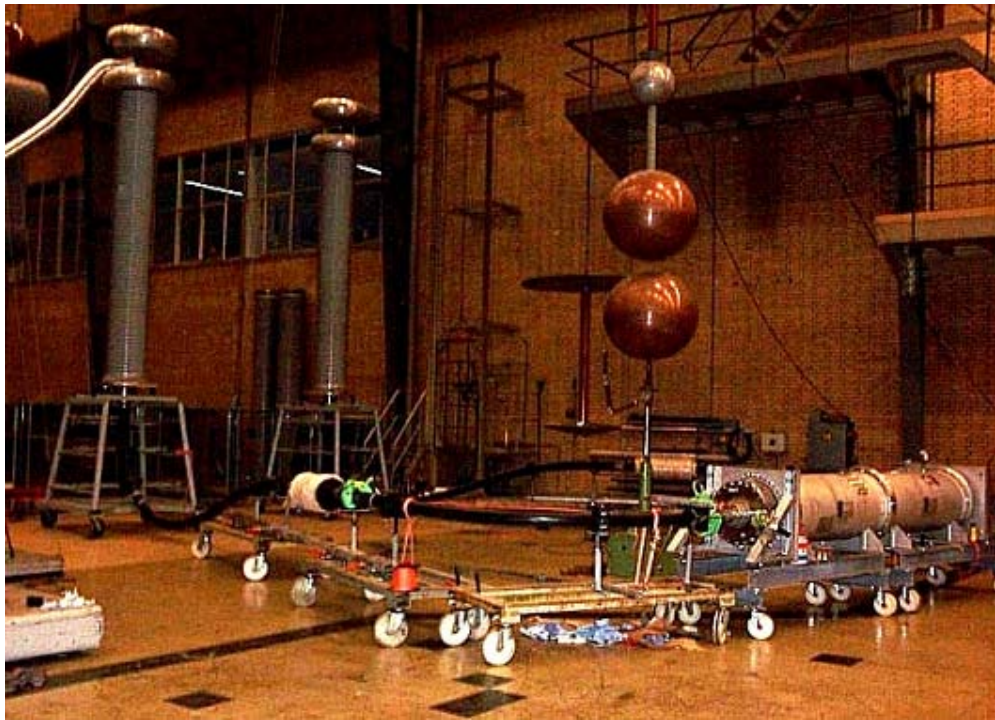


Arguments pro Long term test

- High electric stresses increase failure risk
- Shrinkage is only stabilized after 80 cycles
- New accessory designs are coming
- Failures in high stress cables

Arguments against long term test

- Many manufacturers have good experience so far
- Reluctance of some utilities, to test entire syst. if they buy their HV cables and accessories separately
- Longterm test is costly



Range of PQ test

- For prefabricated joints , mainly impulse stresses at the cable interface are critical
- For taped or field-molded joints also AC and impulse stresses at the conductor are critical
- Therefore the PQ test is recommended for cable systems with conductor stresses higher than 8kV/mm and insulation screen stresses above 4 kV/mm

Recommendations to IEC 60840

Intoduce the following PQ test:

- Voltage, 1.7 Uo
- 180 heating cycles, to max. 95 degr C
- Cooling to ambient
- PD tests
- Impulse test on the complete loop
- Examination of the test loop

Exchanges and modifications

- The procedure and the sequence of EQ tests are the same as for the EHV cable systems

Functional Analysis

- International standards are necessary for both manufacturers and customers
- An advantage of International standards is the world wide acceptance of the test evidence
- A disadvantage of international standards is the limited incentive of manufacturers to make incremental improvements, as this requires a complete repetition of the type testing

Functional Analysis (2)

- According to IEC 62067 the PQ test need to be repeated in case of “substantial” changes
- There is no agreed method to decide what is substantial

Functional Analysis (3)

- In the Functional Analysis method a process is developed, where the significance of a change can be evaluated and the need for further testing agreed:
  - PQ test
  - EQ test
  - Type test
  - Other test

Functional Analysis Method

- Consider the functions performed by each part of a cable or accessory construction and indicate how each function is tested
- Consider a number of possible changes that can be made and indicate what additional testing might be required

Functional Analysis Tables

- Table for cable components
- Table for Joint components
- Table for Termination components

Functional Analysis Table

Structure of the table with 5 columns:

- Component
- Function
- Specification/threat
- Test to ckeck the functionality
- Comments

Cable components

- Conductor
- Inner semiconducting screen
- Insulation
- Outer semiconducting screen
- Longitudinal water tight layer
- Metal screen
- Oversheath

Functions/properties

- Electrical conductivity (conductor, screen)
- Dielectric properties (insulation, oversheath)
- Mechanical properties
- Thermal-mechanical properties
- Chemical properties
- Interfaces with other components
- Watertightness
- Overall properties

Threat for function of conductor

- Overheating
- Mechanical deformation due to bending or pulling during installation
- Corrosion

- High interface resistance with connectors
- Thermal-mechanical expansion
- Water penetration

Functional Analysis

Functional Analysis of a High Voltage Cable and cable components (Example)

Cable component	Function or Property	Specification/ Threat	Test to check the functionality	Comments
A	B	C	D	E
Conductor	Electrical Conduct.	a.No overheating with nominal current -b. Limit temperature with thermal short circuit current	a.Resistance measurement -b. Calculation of thermal short circuit temperature	a For large conductors AC resistance test should be performed as type test b. If temperature rise is considered dangerous, a short circuit test is proposed as a development test.

Tests not in IEC

- Short circuit test
- Examination of XLPE cable insulation in hot oil
- Examination of protrusions and decontaminants
- Moisture content in semicon layers
- Grain size measurement on lead sheath
- Fatigue test of lead sheath
- Side wall pressure test on cable
- Mechanical impact on oversheath
- Compatibility test of additives and filling material with cable and accessory material

Conclusions

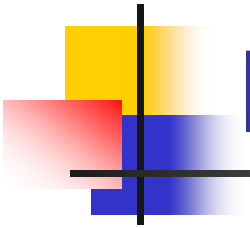
- EHV Cable systems:
- Maintain PQ test of 1 year
- Continuation of PQ test in case of accessory failure
- Impulse test on complete loop
- Introduce EQ test mainly in case of changes of or in accessories: 80 heat cycles, of which 20 will be with 2Uo

Conclusions (2)

- HV cable systems:
  - Introduce PQ test of 0.5 year for high stress cables (8/4 kV/mm)
  - Continue test in case of accessory failure during test
  - Impulse test on complete loop
  - EQ test for changes/modifications at components, the same as for EHV

Conclusions (3)

- Funtional analysis
- FA method is recommended to assess the significance of changes and the selection of related tests
- Lists are made available with appropriate tests in case of changes
- Not only standardized tests but also development tests are being used



End of presentation

- Thank you for your attention