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

Tutorial vor the ICC Educational Session on November 11 2009 in Scottsdale, AZ by Wim Boone
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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

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

<table>
<thead>
<tr>
<th>Cable and/or accessory</th>
<th>Already qualified on another cable system within the <em>same or higher</em> insulation screen stress</th>
<th>Already qualified on another cable system with a <em>lower</em> insulation screen stress (calculated) or <em>not qualified</em></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cable</strong></td>
<td>non electrical Type Test (TT) + Extension of qualification test (EQ)</td>
<td>electrical and non electrical Type Test (TT) + Prequalification Test (PQ)</td>
</tr>
<tr>
<td><strong>Joint</strong></td>
<td>EQ</td>
<td>TT + PQ</td>
</tr>
<tr>
<td><strong>Metal enclosed Termination</strong></td>
<td>EQ</td>
<td>TT + PQ</td>
</tr>
<tr>
<td><strong>Outdoor Termination</strong></td>
<td>EQ</td>
<td>TT + PQ</td>
</tr>
</tbody>
</table>
## Tests because of modifications to a cable in a prequalified EHV cable system

<table>
<thead>
<tr>
<th>Component</th>
<th>Modification</th>
<th>Proposed test</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Conductor</strong></td>
<td></td>
<td>TT and PQ TT</td>
</tr>
<tr>
<td></td>
<td>• Copper to Aluminium</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Larger cross-section</td>
<td></td>
</tr>
<tr>
<td><strong>Insulation</strong></td>
<td></td>
<td>TT TT TT and PQ TT TT TT and PQ TT TT TT and PQ</td>
</tr>
<tr>
<td></td>
<td>• Change of base resin</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Change in cross linking package (peroxide/ antioxidant)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Nature of polymer (XLPE, LDPE, HDPE, EPR)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Higher conductor stress, no increase of insulation screen stress</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Increase of insulation screen stress</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• New extrusion line or transfer of extrusion line with earlier experience in-house</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• New extrusion line, or transfer of extrusion line without earlier experience</td>
<td></td>
</tr>
</tbody>
</table>
Tests because of modifications to an accessory within the same family in a prequalified EHV cable system

<table>
<thead>
<tr>
<th>Component</th>
<th>Type of modification</th>
<th>Proposed test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Joint</td>
<td>- Higher calculated electrical stress design and construction</td>
<td>EQ</td>
</tr>
<tr>
<td></td>
<td>- Compound of main insulation body</td>
<td>PQ EQ</td>
</tr>
<tr>
<td></td>
<td>- Changing nature of polymer, (EPR, Silicone...)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Material of semi-con electrodes</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Fixation of cable ends on either side of the joint</td>
<td></td>
</tr>
</tbody>
</table>
Principles of the Extension of PQ test (EQ)

- 60 thermal cycles without 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
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

Introduce the following PQ test:

- Voltage, 1.7 Uo
- 180 heating cycles, to max. 95 deg 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
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 check 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)*

<table>
<thead>
<tr>
<th>Cable component</th>
<th>Function or Property</th>
<th>Specification/Threat</th>
<th>Test to check the functionality</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conductor</td>
<td>Electrical Conduct.</td>
<td>a. No overheating with nominal current</td>
<td>a. Resistance measurement</td>
<td>a. For large conductors AC resistance test should be performed as type test</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-b. Limit temperature with thermal short circuit current</td>
<td>-b. Calculation of thermal short circuit temperature</td>
<td>b. If temperature rise is considered dangerous, a short circuit test is proposed as a development test.</td>
</tr>
</tbody>
</table>
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)

- Functional 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