SMARTLIFE2: IMPROVING CABLE SYSTEM SPECIFICATIONS

Piet SOEPBOER
Enexis – The Netherlands
piet.soepboer@enexis.nl

Eric DORISON
ErDF - France
eric.dorison@edf.fr

Pieter LEEMANS
Eandis - Belgium
pieter.leemans@eandis.be

ABSTRACT

The "SmartLife" initiative is a European coordination project, relating to the asset management of distribution and transmission networks, gathering multiple partners mainly from utilities, but also from test laboratories, R&D institutes and universities from 9 European countries. The SmartLife project deals with 2 main concerns: On one hand, as significant parts of European networks have been developed in the 60-70s and are now getting close to their expected lifetime, utilities have to plan renewals, requiring significant investment. On the other hand, it is expected that the networks will undergo changes as a result of distributed generation and market changes. The project was intended to gather knowledge and skills of experts to benefit from sharing of resources, efforts, etc. Furthermore, it was intended to define research and development activities needed to prepare for the expected, above mentioned, network changes. In 2008–2010, works were performed within 3 usergroups on components: Underground cables, Overhead lines, and Transformers, and 2 user-groups on asset management practices of Transmission and Distribution System Operators.

The underground cable user-group defined four research activities in 2011-2013 for filling-in knowledge gaps identified in earlier tasks:
1. *Improve cable system specifications.*
2. *Improving the effectiveness of diagnostic techniques.*
3. *Data collection and health index regarding the existing Network.*
4. *Laboratory tests on aged cable samples.*

This paper presents the main findings from the underground cable user-group on their work on improving (technical) cable system specifications.

ISSUES ON CABLE SYSTEM SPECIFICATIONS

Cable system specifications are used to obtain a minimum system quality level in accordance with the maximum permissible fault rate in a certain life time. Requirements for cable systems however are changing over time. Recent changes on the topics of water tightness, cable insulation materials and dimensions, the cable type and the cable's current rating have been reported. Furthermore, also problems and gaps exist applying the current standards and specifications. As a result, the cable user-group concluded that the currently used specifications can be upgraded.

Topics that need to be addressed are:
1. Discuss the completeness of the functional requirements on cable systems.
2. Assess the quality level requested (e.g. raising the quality level over the level offered by standards).
3. Propose relevant tests to ensure that system designs meet the functional requirements.
4. Clarify which tests are necessary to extend the prequalification test if the accessory design changes.
5. Take into account TCO (total cost of ownership) policies, as an evolution compared to initial cost minimization practices.

In January 2012 a workshop on improving cable system specifications was organized, focusing mainly on topics 1, 2 and 3, pinpointed on medium voltage XLPE cables and joints. This because MV-networks have the biggest impact on the network reliability (seen by the customer). Further XLPE is the cable type used by nearly all utilities, and joints is the accessory type having the largest impact on the reliability of MV-cable networks. The goal of the workshop was not to define one ideal set of technical specifications, but to help each other to improve our own specifications for our specific situation and environment by means of discussing the differences between our specifications.

MAIN FAILURE CAUSES IN CABLE SYSTEMS

Because specifications are used to obtain a certain quality level, first it was investigated from which failure causes the participating utilities suffer. Later on it will become clear how they are related to the specifications. All participating utilities confirm that the biggest threats in cable reliability are coming from outside the cable.

The 3 most common cable failures reported are:
1. Damage to the sheath due to third party activities like digging or piling. Such failures may be caused by carelessness of third parties, but also by drawings indicating an imprecise location of cables.
2. Contractors, not respecting the rules of installing cables. Very often damages are observed due to screeping the cable over concrete/tarmac roads during installation, or wrong handling of cable drums. These damages can directly lead to a failure, but more over these damages are observed as leading to a failure after a certain time.
3. External influences (stones, roots of trees). All utilities note however that contractors are required to remove stones from the cable trenches. Some utilities even require a layer of clean sand around the cable before the excavated soil is put back in the trench.

The 3 most common joint failures reported are:

1. Bad workmanship (installation failures).
2. Moisture ingress.
3. Overheating.

CABLE SPECIFICATIONS IN GENERAL

Power cable specifications differ from country to country. Some European utilities refer to IEC standard 60502-2 whereas standard HD 620 in fact is a compilation of each European country's national standard. Some utilities only refer to a standard whereas other utilities use a(n) (inter-) national standard to complement their own specifications. Some utilities require "home-made" additional tests next to the type test requirements in standard. The main reason for this different behaviour in specifications is that there is not one ideal specification. All utilities operate in different geographic situations and environments and are subject to different company policies on standardization.

Next to that, it is shown that many topics seem not to be well addressed in many specifications. Only a few utilities mention a rather complete set of topics in their specifications, while many utilities mention a very short set of topics or refer to the (inter)national standards only. According to the members of the underground cable user-group, a good technical power cable specification at least should pinpoint the following topics:

- Field of application; direct buried or in ducts, depth, soil type and soil conditions, grounding method, etc. This enables manufacturers to advise the utility in selecting the most appropriate cable type.
- Packaging; permissible drum dimensions and weight, required cable length per drum, etc.
- Cable construction and rating.
- Compatibility of the cable with accessories.
- Required type tests to be passed successfully and required routine tests to be done by the manufacturer.
- After installation tests on complete cable systems.
- Supplier Quality Control and sample tests.

Even where utilities agree on which topics need to be addressed in specifications, there still are differences in the details beneath these topics. The most interesting findings and conclusions related to differences in the topics cable construction and type testing are discussed next.

CABLE CONSTRUCTION

Cable type

All utilities have standardized single core cables because of the good flexibility and low weight. The assembly of accessories is also very easy compared to three core cables and a long cable length can be put on a drum. Enexis is the only participating utility having standardized three core XLPE-cables up to a cross-section of $150mm^2$.

The advantage of a three core cable with three cores within one screen can be found in cost reduction and a simpler process of cable laying in crowded areas. Some utilities use triplexed single core cables which in fact are 3 singles twisted together on a drum. Triplexed single core cable is a good compromise between single core and three core cable, applicable for smaller conductor cross-sections. It combines the advantage of laying 3 cores simultaneously (consuming less space) and the easiness of installing accessories. Some utilities mention that they have observed a safer dynamic short-circuit behaviour and better thermo-mechanical behaviour of triplexed cable in comparison with single core cable. To a greater or lesser extent, most utilities have requirements on the water tightness of their cables (not, quasi or fully watertight), based on where the cable is used in the network, the presence of moisture and costs.

Conductor

Nowadays more and more aluminium conductors are used instead of copper. Most utilities use stranded, compacted aluminium conductors. Enexis is the only participating utility having standardized solid aluminium conductors. In the Netherlands, where cables are buried mostly below the groundwater level, a solid conductor is preferred because of its longitudinal water tightness. Furthermore the smaller diameter (compared to a stranded) leads to cost savings. This smaller conductor diameter also leads to a smaller cable diameter. Therefore a cable with solid conductor is hardly stiffer than a cable with a stranded conductor.

During the workshop it became clear that not all utilities set requirements on the conductor. Some specify requirements on the purity of aluminium and conductor diameter whereas others only specify the requirements in IEC 60228. This conductor standard has raised questions at the participating utilities because it looks incomplete. It gives requirements on resistance and tensile strength for stranded and solid aluminium conductors, but no requirements on hardness whilst some utilities do observe differences in the hardness of aluminium conductors. On the other hand IEC 60228 does not give any tensile strength requirements for copper conductors. Some questions related to the compatibility of conductor-connectors and cable conductors were raised. Is it necessary to define better requirements on e.g. aluminium purity, hardness/softness, diameter and tensile strength of as well Cu as Al conductors? This question more or less stayed unanswered. KEMA stated that there indeed is a possibility that there can be a compatibility problem between conductor and conductor-connector, however further investigation on this topic is necessary.

Insulation

Among the participating utilities, the most common required insulation material is XLPE. From studying their national standards it was concluded that the utilities require different XLPE-compounds (DIX 3, 8, 9, 10 and 13).

However not a single utility could answer the question why they have standardized that specific compound and what the differences are compared to other compounds. It was stated by one of the utilities that cable manufacturers probably use only one XLPE-compound to serve all their customers. The question whether or not this would involve risks in reliability could not be answered by the participating utilities because they recognize that they do not check their manufacturers on this item. Another conclusion from studying the national standards is that only a few utilities/countries have requirements on the eccentricity of, irregularities in, and the diameter over the insulation.

Furthermore, to allow/require a reduced insulation thickness or not, is a big difference between the participating utilities. Although more and more common in use, many utilities do not feel confident with a reduced insulation thickness. Despite a reduced insulation thickness is applied to reduce costs, it is thought that it can be more critical for stress control at accessories. Cable preparation has to be performed very accurately to prevent risks of failure. It is supposed that cables with reduced insulation thickness require more severe limits for long-duration-type-testing.

As an alternative for XLPE, it was noticed that utility Iberdrola has standardized HEPR as insulation material. Their choice was based on research resulting in better performance on economical evaluations, breakdown, a higher ampacity, better flexibility and the fact that HEPR is not susceptible to water. Utility ENEL has standardized Prysmian's "P-laser" material next to XLPE, based on advantages at logistics and sustainability. Except Enexis, other participating utilities do not yet study alternative insulation materials.

Semi-conducting screens

In the national standards and specifications there are huge differences in requirements on the semiconducting screens. Where all standards describe the required compounds for insulation and sheathing materials, only France has defined specific semi-conducting compounds for the conductor screen and insulation screen. Next to France, only Belgium has defined requirements for the semi-conducting screens on electrical resistivity, aging and irregularities.

Fig 1. Indentation in/ irregularities on the insulation screen.

The question whether or not such requirements are of importance was answered by studies of Laborelec on the quality of semiconducting materials. Their main conclusions are that the materials for semi-conducting layers are not well known as they are defined by the manufacturer, that low-quality materials can accelerate the formation of water trees and that they see a need for specific requirements and type tests on semi-conducting materials.

Armour and sheath

As noticed in the beginning of this paper, the biggest threats in cable reliability are coming from outside the cable. Knowing that one possible remedy is to add extra specifications on the cable construction, it is remarkable that none of the participating utilities requires an armoured cable. The main reasons for this prove to be that an armour is very costly and does not give enough protection to hitting by excavators. The presence of an armour also makes it more complex to assemble accessories because all metal cable-components must be grounded. According to the utilities an armour only will give good protection to damage by stones. More or less the same arguments are given regarding applying a so called "airbag-cable" with an extra "shock-absorbing" layer over the (normal) outer sheath. To obtain more and probably cheaper protection to external damage it was suggested to improve the characteristics of the cable sheath (thickness and/or material).

TYPE TESTING OF CABLES

Following the differences in cable constructions and requirements it is not surprising that there are a lot of difference in the type testing requirements. All utilities are more or less on the same level on which kind of type tests need to be performed, but there are a lot of differences in how that tests need to be performed. This implies different magnitudes of the applied voltage during voltage tests, different number of heating cycles, testing at different rated temperatures, different pass or fail criteria for PD- and Tan delta tests, etc., etc. Although we will not be able to harmonise all our European cable types, an interesting question is whether or not it will be able to at least harmonise these testing requirements.

All participants of the workshop endorse the following shortcomings at type testing cables:

- Hardness test on conductor materials (in particular for aluminium).
- "Fingerprinting" of semi-conducting materials.
- Short-circuit performance test.

JOINT SPECIFICATIONS

In standardization there is a big difference between cables and accessories. For cables each country refers to its own national part in CENELEC HD 620. Regarding to joints, all participating utilities refer to EN 61442 and HD 629.1 which is not a compilation of national parts but one international (European) standard. So at the joints there is more consensus on requirements. However, there is still some difference because not all utilities refer to the same testing sequences in HD 629. The same also applies to EN 61238-1, the standard with requirements on conductor connectors. Some utilities only require the electrical type tests whereas other utilities require and electrical and mechanical type tests. Most utilities use these standards to complement their own specifications. Some utilities require additional “own” tests next to the mentioned standards.

According to the members of the underground cable user-group, a good technical specification for joints (including connectors) at least should pinpoint the following topics:

- Field of application (e.g. types of cables to be connected).
- Installation (user friendliness, tools, etc.).
- Technology (e.g. heat shrink, cold shrink, etc.)
- Packaging (completeness of component kits).
- Specifications related to the conductor connectors.
- Compatibility of cable, conductor connector and joint.
- Required type tests to be passed successfully.
- Required routine and/or sample tests by the manufacturer.
- After installation tests on complete cable systems.
- Ampacity (equally rated as the ampacity of the cables).
- Health, safety and environment.

TYPE TESTING JOINTS

During discussions on type tests, the usefulness of the mechanical impact test for joints was stated as most doubtful. Damage due to excavation namely is not recognized as a failure mechanism for joints. According to the utilities joints suffer on the one hand more from mechanical forces due to (without any support) hanging of cables and joints during e.g. excavations and remediations. On the other hand joints suffer from thermo-mechanical forces due to expansion and shrinkage of the cable conductors. These types of mechanical impact are way different than the mechanical impact test in EN 61442.

Fig 2. Joint failure caused by thermo-mechanical forces.

HD629 specifies that compliance for one type of joint (for the range of cable conductor cross-sections from 95 mm² to 300 mm²) shall be obtained by successfully completing all the appropriate tests on one conductor cross-section (120, 150 or 185mm^2). Most utilities accept this agreement, but some utilities only accept type testing with the smallest and the largest cross-sections. Because, if therefore different conductor connectors are needed with different dimensions, it can have different (significant) effects on the outcome of the type tests. The cable-user-group has concluded that there is a need to deliberate this topic in future specifications and to bring in this topic in the national and international standardization committees.

It was mentioned by the participating utilities that even correctly installed conductor connectors really can be a hot spot in the joint. Therefore Eandis requires systematically additional thermal testing of joint and connector together. It was claimed that mechanical connectors turn back the usage of compression connectors because of a more stable thermal behaviour due to a man independent installation quality.

Other assumed shortcomings at type testing joints are:

- At type testing joints, not all type tests are performed on the same joint. It would be more reliable and realistic if e.g. and the heating cycles voltage test and the short-circuit tests would be performed on the same joint, instead of on different joints.
- At the heating cycles voltage tests, the cable/conductor ends freely can expand in the open air. Therefore the joint or conductor connector under test is not thermo-mechanically stressed as it is in practice. Conductors and conductor ends should be blocked for a more realistic test situation.
- There is no secured systems approach. Cables, connectors and joints are not systematically type tested together. The only available system tests are the tests performed after installation.

CONCLUSIONS

One conclusion regarding to XLPE-cables and the main causes of cable failure is that we still can improve our cable specifications on preventing risks due to external damages, but this requirements must be in balance with the costs of risks and alternative remedies. Although there are a lot of differences in cable specifications, the outcome of experience on cable reliability is satisfactory which means that, probably, the standard and the test procedures are appropriate to lead to a rather good quality. However that does not mean that there is no need to pay attention to current cable specifications.

One conclusion regarding to joints is that thermal and thermo-mechanical aspects yet seem not to be well enough addressed in our technical specifications and standards.

Due to more and more decentralized sustainable generation and a growing impact of e.g. electric vehicles, the way networks are operated, will change in the future. So there is a need to be aware of the future changes and their implication for our network reliability and cable specifications. As we have seen, there are plenty options for improving our cable system specifications.