STANDARDISATION, PREQUALIFICATION, DIAGNOSTICS, AS PART OF CABLE SYSTEM MANAGEMENT

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KEMA, KEMA, Pirelli Cables and Systems, REMU, TKF Cables, NUON, Essent

Summary

Reducing costs, postponing investments, exceeding common limitations in exploiting the network assets, while still keeping up reliability and power quality standards, these are the key words in a liberalised market.

To be able to operate with less costs, to postpone investments to a later date and even to be able to uprate cable circuits new approaches has been made for

- (pre)qualification of cable and accessory suppliers for low voltage, medium voltage and high voltage has been developed,
- diagnostics as part of CBM on cable circuits,
- making ampacity calculations to be based on the actual installed thermal situation of the cable and
- the role of standardisation.

The (pre)qualification of LV, MV and HV cable and of accessory suppliers has been improved by adding the so-called system approach to the certification process. All aspects related to the operation and the installation of the cable circuits are taken into account, inclusive of the safety, health and environmental aspects.

An important part in the certification is also the characterisation of materials used in type testing the components, followed by requirements regarding traceability of production and processing. By adding this characterisation and traceability, the number of sample tests and the frequency of sampling can be reduced significantly. The result will be less costs, while keeping up the quality level.

The role of diagnostics as part of CBM became even more important. Not only diagnostics for getting insight in the quality of the insulation but also in the actual temperature of the conductor and in the actual thermal conditions of the soil in the cable trench.

The role of standardisation related to cable circuits for a member state of the European Community has been changed significantly. New aspects in standardisation will be making use of “pre-standards” to be able to support and to follow the rapid developments in the liberalised marketplace. Examples are given.
LA STANDARDISATION, LA PRÉQUALIFICATION ET LE DIAGNOSTIQUE COMME PARTIE INTÉGRANTE DE LA GESTION DU SYSTÈME DE CABLES

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RESUME

Réduction des coûts, report des investissements, dépassement des limites communes dans l’exploitation des ressources du réseau, tout en maintenant le niveau de fiabilité et de qualité énergétique, tels sont les mots clé du marché libéralisé.

Afin de permettre une réduction des frais d’exploitation, un report des investissements à une date ultérieure et même une modernisation des circuits de câbles, de nouvelles approches ont été définies pour
• le développement d’un système de (pré)qualification des fournisseurs de câbles de faible, moyenne ou haute tension et de leurs accessoires,
• les diagnostiques en tant que partie de la Maintenance Basée sur la Condition (CBM) sur les circuits de câbles
• un calcul d’établissement de courant admissible basé sur la situation thermique réelle installée du câble et sur
• le rôle de la standardisation.

Le système de (pré)qualification des fournisseurs de câbles BT, MT et HT et de leurs accessoires a été amélioré grâce à l’ajout d’une approche systématique du processus de certification. Tous les aspects relatifs à l’exploitation et à l’installation de circuits de câbles, y compris les aspects liés à la sécurité, à la santé et à la protection de l’environnement, sont pris en compte.

La caractérisation des matériaux utilisés dans les essais type sur les composantes, suivie par les demandes concernant la traçabilité de la production et du traitement constituent également une partie importante du processus de certification. L’ajout de cette caractérisation et de la traçabilité permettent une réduction considérable du nombre d’examens des éprouvettes et de la fréquence de l’échantillonnage, ce qui résultera dans une baisse des frais, tout en maintenant le même niveau de qualité.

Le rôle des diagnostiques en tant que partie la CBM est devenu encore plus important. Par diagnostiques, nous entendons non seulement les diagnostiques permettant une meilleure intelligence de la qualité de l’isolation, mais aussi ceux permettant de mieux se rendre compte de la température réelle du conducteur et des conditions thermiques réelles du sol dans les tranchées des câbles.

Dans les États membres de l’Union Européenne, le rôle de la standardisation relative aux circuits des câbles a connu un changement significatif. Les nouveaux aspects de la standardisation utiliseront des « pré-standards », dont nous donnerons quelques exemples, afin de pouvoir soutenir et suivre les développements rapides du marché libéralisé.
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1 INTRODUCTION

Reducing costs, postponing investments, exceeding common limitations in exploiting the network assets, while still keeping up reliability and power quality standards, these are the key words in a liberalised market.

To be able to operate with less costs, to postpone investments to a later date and even to be able to uprate cable circuits new approaches has been made in the Netherlands for:

- (pre)qualification of cable and accessory suppliers for low voltage, medium voltage and high voltage has been developed,
- diagnostics as part of Condition Based Management (CBM) on power cable circuits,
- making ampacity calculations to be based on the actual installed thermal situation of the cable and
- the role of standardisation.

The different subjects are discussed in the following chapters.

2 (PRE)QUALIFICATION

The (pre)qualification of LV, MV and HV cable and of accessory suppliers has been improved by adding the so-called system approach to the certification process.

For HV cable systems, type testing of cables and accessories in the same test loops and test sequences is common practice. The relevant standards give guidance (1, 2, 3).

For the introduction of new MV cable systems, the same approach was followed. At CIRED 1997 this was reported (4). The total qualification program consisted of the well-known type test program on cables and accessories (5, 6). The ease of assembly and the requested skills for a good assembly were also subject of the system certification program. The test loops consisted of 3 cables of different producers, with the same construction, of 3 different straight-through joints of different producers, of 3 different terminations of different suppliers and of one type of transition joint. An example of the cable construction is given in figure 1. With this (pre)qualification program, the MV system was qualified by the utility. Also the different producers/suppliers of these components were prequalified. Since 1996, this MV XLPE cable system is in use at Dutch electric utilities. With this new MV XLPE cable system, the investment costs were reduced, compared with the existing systems.

Figure 1. The 3 core MV XLPE cable called KUDIKA.

Nowadays, new LV power cable systems are under evaluation. For the introduction of a these new or renewed LV power cable systems, the same approach was followed. Safety, health and environmental aspects were taken into account.

An important part in the certification is also the characterisation of materials used in type testing the components, followed by requirements regarding traceability of production and processing. By adding this characterisation and traceability, the frequency rate of sampling can be reduced significantly. The result will be fewer costs, while keeping up the quality level.

2.1 (Pre)qualification and certification of LV cable systems and components

The new systems will consist of PVC/PVC cables. Systems with XLPE/PE and PP/PP (polypropylene (PP) insulation and PP sheath) are under consideration. Next to the type testing in accordance with the standards (7, 8), aspects related to the operation and the installation of the cable circuits were taken into account, inclusive of safety, health and environmental aspects. These safety, health and environmental aspects were taken into account, both for assembly as well for removal after failure.
The LV system to be (pre)qualified, consisted of PVC/PVC cable (main cable 95 mm² and branched cable 10 mm²), connectors and branched joints (taped and cast resin), all of different producers. A pre-selection program for the joints was made, consisting of:

- assembly on wet cable (VDE 0291-2)
- analysis of toxicity of gases during pyrolysis of all materials used, because of safety and health reasons
- ability to handle at 0 °C
- life test in accordance with VDE 0291-2 or IEC 60216.

Personnel of the utilities involved assembled the test loops in accordance with instructions of the manufacturers. The ease of assembly was judged on several aspects.

The test program consisted of the type tests for cables and for joints (Dutch standards NEN 3616 and NEN 3606, in accordance with the relevant CENELEC Harmonized Documents), with addition of a long life test on test loops, assembled with wet cables.

Outcome of this (pre)qualification program was the qualification of the new LV power cable system and the (pre)qualification of a limited number of components from different producers (cables, joints, connectors). Economic result will be reduction of costs while ensuring the reliability and availability of this new LV system.

Proposals are made for (pre)qualification of XLPE/PE and of PP/PP LV-power cable systems.

2.2 Characterisation of insulation and sheath materials (fingerprinting)

2.2.1 Philosophy. The philosophy in the Netherlands is that for cables and for accessories, to start with low voltage followed by medium voltage and maybe by high voltage, the tests on the final products (for cables only) have to be replaced mostly by tests and checks during production/processing.

Part of the tests and checks during production/processing are functional tests, characterisation (fingerprinting) tests and registration of relevant parameters of the production process. The results of these tests and checks have to be compared with the results of the same tests and checks performed during production of the type-tested component and during type testing. The characterisation tests are a mandatory part of the type test program.

The client may have a look at these data and at the result of the comparison. The manufacturer has to demonstrate to the customer, on his request, those results, for instance making use of his ISO 9000 certified quality system. In simple words: “The intention is that the client will have the certainty that he will receive the same product with the same composition as ordered or as received the previous time or as has been type tested. A certainty to be obtained in a rather easy and reproducible way”.

2.2.2 Characterisation tests; role in type and sample test scheme. In CENELEC, IEC and Dutch standards is stated that type tests need to be repeated when changes are made in the cable or the accessory materials, or design or manufacturing process, which might change the performance characteristics. The question was how do you know as user/buyer, that the components delivered are produced without changes in design, materials or manufacturing process, which might change these performance characteristics.

Characterisation (fingerprinting) tests may act as a tool to identify whether the characteristics of the materials or of the processing used might have been changed or not. When the characteristics have not been changed, type testing needs not to be repeated.

The results of these characterisation tests have to be compared with the results of the same tests performed as part of the type test programme. The results of these characterisation tests in the type test programme act as a reference for future tests, performed as part of the sample test program. When the results of the later tests are in line with the reference results of the characterisation tests as part of the type tests, the functional characteristics of the produced component will be the same as for the type tested one. When these characterisation test results (as part of the sample test program) are not in line with the reference results (from the type tests), some of the type tests have to be repeated to assure that the component will fulfill the requirements of the type test programme. In that case the new results of the characterisation tests will act as the new reference results.

The characterisation tests should be such that they are decisive for the characteristics that will be checked by means of these tests. Quantitative requirements have to be stated, both for the test results, as for the comparison with the reference results.

The characterisation tests may consist of tests to determine the chemical composition or the physical structure of the materials used. For instance infrared spectroscopy for determination
of the chemical composition and of (a part of) the non-electrical tests for determination of mechanical and physical properties (for instance to detect a change in the ratio of different materials used for extrusion).

2.2.3 Infrared Spectroscopy (IR) as a characterisation test. A powerful and rather accurate characterisation test is the so-called infrared spectroscopy (IR). By making use of IR, it is likely that a significant part of the other tests may be deleted.

Infra red light will be sent through a sample of the material to be characterised or reflected on the surface of that sample. A part of the spectrum of the IR light will be absorbed by the sample. The resulting spectrum gives a characteristic view of the molecular composition of the sample. Figure 2 gives an example for the IR spectrum of three different LV cable PVC sheaths. As can be seen, there is a difference in the chemical composition of these 3 materials, they are not the same.

![Figure 2. IR spectrum of 3 different PVC sheath materials](image)

2.3 Characterisation and traceability for LV power PVC/PVC cables

In 2001 utilities and cable makers will start with a pilot project. Elements in this project are the characterisation of the materials used, the traceability of the production/processing and the registration of the most important process parameters.

The insulating and sheathing materials will be characterised by means of an Infra red (IR) measurement, to determine the chemical composition and of the current non-electrical tests in accordance with NEN 3616 (7).

An improved printing on the outer sheath will do the traceability of the location of the production/processing.

The most important process parameters that will be registered are the melt temperatures of the insulating and sheathing materials, by making use of the ISO 9000 quality system.

The type test program will consist of the current type test program and of the registration of the process parameters and of the IR spectrum measurement.

The sample test program will consist of the current sample test program, of the check on the registration of the process parameters and of measurement of the IR spectrum of the insulation and of the outer sheath. The results of the sample tests will be compared with the results of the type tests. The bandwidth of eventual deviations will be determined during the pilot project. The sample test frequency will be reduced from 20 km down to once per 50-km production length.

The routine test program will consist of the current routine test program and of the measurement of the outer diameter of each length.

Result will be that the users will have an improved certainty that they will receive the products as qualified and as ordered, while the manufacturers will not suffer from an increase of the testing costs.

3 DIAGNOSTICS

3.1 Introduction. Diagnostics are well known as a tool for determination of the condition of the insulation, see paragraph 3.2.

However new diagnostic measurements and tools may be used for improved current loading by means of determination of the actual temperature of the conductor or of the actual thermal conditions of the soil in the cable trench, see paragraph 3.3.

Also new diagnostic tools, integrated in cables, are available nowadays for early warning of mechanical damage or moisture ingress, see paragraph 3.4.

3.2 Condition determination. The role of diagnostics is well known for determination of the actual condition of accessories and of cables. However applying diagnostics should be a part of management of cable assets. With diagnostics, repair before failure is possible. Diagnostics as part of a Condition Based Maintenance (CBM) program became even more important (9, 10).

The following diagnostic tests are in use in the Netherlands, see Table 1.
### Table 1. Diagnostic tests used on new and on service aged cable systems.

<table>
<thead>
<tr>
<th>Diagnostic Test</th>
<th>MV paper</th>
<th>MV XLPE</th>
<th>Measuring rate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>New</td>
<td>Old</td>
<td>New</td>
</tr>
<tr>
<td>Withstand test</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- DC insulation test</td>
<td>4Uo</td>
<td>80%</td>
<td></td>
</tr>
<tr>
<td>- DC sheath test</td>
<td></td>
<td></td>
<td>5/10 kV</td>
</tr>
<tr>
<td>- AC insulation test 0.1 Hz</td>
<td>3Uo</td>
<td>80%</td>
<td>3Uo</td>
</tr>
<tr>
<td>- AC insulation test 20-200 Hz</td>
<td>2.5Uo</td>
<td>80%</td>
<td>2.5Uo</td>
</tr>
<tr>
<td>Dielectric measurement</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Tan δ at 0.1 Hz</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>- Tan δ at 50 Hz</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Partial discharge mapping</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- 0.1 Hz mapping, off line</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>- 50 Hz, off line</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>- Oscillating wave (OWTS), off line</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>- CDA, off line</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

Withstand testing is done as commissioning test for new systems and after repair.

New XLPE cable systems will be tested after installation as follows:
1. Withstand test
2. Sheath test
3. Tan δ measurement; as fingerprint measurement; some utilities do not perform this test
4. Partial Discharge measurement to check the accessories; some utilities do this test only if the Tan δ value is too high; some other utilities perform this test instead of the Tan δ measurement

Service aged XLPE cable systems will be tested with the outer sheath test. The Tan δ value is measured upon commissioning, after 10–15 years for the second time and after 5-10 years depending on the results. If the Tan δ value is too high, then PD mapping may be applied to discriminate between defective accessories, if any and deterioration of the polymeric insulation. An advanced Tan δ method, called Dielectric Spectroscopy, is able to discriminate between water-tree deterioration of the cable insulation and defective accessories (12).

New paper cable systems will be withstand tested only. Old paper cable systems will be discharge tested after 2 faults, or before replacement or after 10 years (important circuits only).

Regularly performing diagnostic measurements on a limited number of cable systems with equal properties (age, type, loading, soil etc.) enables the utility to perform statistical analysis, resulting in statements regarding remaining life and reliability. Also the results of the diagnostic measurements, performed because of other reasons, see above, are included in this analysis. This is an important aspect of management of the cable network.

By means of diagnostic measurements and of statistical analysis, service aged cable systems may be used with increased loading (postponement of investments) or may live longer.

#### 3.3 Optimal current loading.

Important part of cable system management is management of the current loading of the cable systems. Cable systems may be better loaded if the actual thermal parameters are known. Diagnostic measurements of the temperature of the outer sheath, either with an optical fibre, or with thermocouples on expected hot spots, together with calculation of the cable conductor temperature will give insight in the possibilities for optimal loading of the system. Not based on the design calculations only, but also on the actual thermal circumstances, see our CIRED 2001 paper (11).

#### 3.4 Early warning for mechanical damage and moisture ingress.

To prevent failures because of damage due to excavation and of damage due to extreme subsidence of cables in peaty soil, optical fibres may be included in the cable design.

An integrated moisture sensor will indicate moisture ingress, long before the insulation properties will be deteriorated.

Soil subsidence will lead to an increased mechanical strain in the cable system or near the accessory. With an optical fibre, the mechanical strain may be detected.
By using optical fibres a low cost system for early warning of mechanically induced failures may be introduced in the cable management system, see our CIRED 2001 paper (11).

4 DEVELOPMENTS IN STANDARDISATION

The role of standardisation for a member state of the European Community has been changed significantly. Leading are the European Standards and the Harmonisation Documents.

However before standardising new developments, experience has to be gained. New developments may use so-called “pre-standards” to be able to support and to follow the rapid developments in the liberalised marketplace. In the Netherlands the “pre-standards” will be used to give guidance to the utilities and the manufacturers. The introduction of new developments will be eased. Result will be less different types, fewer costs for users and cable makers. Standardisation will support new developments in this way.

One example is the inclusion of the characterisation tests, the traceability and the registration of some process parameters in the test regime of LV PVC/PVC cables, as described earlier.

Another example is the pre-standardisation for inclusion of optical fibres in power cables, for instance for distributed temperature measurement or for protection or other purposes. This pre-standardisation is based on the requirements for cables only (NEN 3620/30), of optical fibres (IEC) and on additional requirements. Only those aspects that are not described in the existing standards will be specified, together with the relation between the different elements. The pre-standard will be based on functional requirements. Tests additional to the ones, given in the existing standards, will be specified.

5 CONCLUSION

Management of cable systems consists of management of the existing systems and of the new systems. Management of new systems starts with specifying and qualifying of the new system as a whole, also for LV and for MV systems. Result will be reliable systems with proven performance and prequalification of a limited number of cable and of accessory types and of suppliers. Investment costs may be reduced significantly. For a new LV cable system also requirements based on health, safety and environmental condition were included. Commissioning tests are important to do. They deliver the first data, to be used in the cable system management.

For service aged cable systems, diagnostic measurements are an important tool for optimal usage (loading) of the cable network. Investments may be postponed to a later date. Repair costs will be reduced.

In the Netherlands with a pilot project characterisation tests and traceability will be introduced as part of the test program for LV PVC/PVC cables. This introduction enables reduction of the sample test rate to once per 50 km produced cables. Result is fewer costs and at least the same performance level of LV PVC/PVC cables.

“Pre-standards” are introduced to ease guidance and standardisation of rapid new developments.

6 REFERENCES

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