THE VALUE OF TYPE TESTING CABLES AND ACCESSORIES

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ABSTRACT
In this paper the results of 16 years of type testing MV, HV and EHV cables, accessories and cable systems are presented as general figures and subdivided by cable, the various types of accessories and by standard. This survey is an update of a previous publication [1] and confirms the previously presented data. It shows that 20 % to 50 % of all type tests on accessories result in a change in design or stopping the type test. These results show the necessity of thoroughly testing new designs of cables and accessories. For the user of cable systems, these results indicate the value of purchasing type tested components or even systems. Also, these results may help manufacturers and utilities to define a series of relevant tests. Interfacial problems show the importance of testing the combination of cable and accessories that will be used. Individually type tested components are not a guarantee that the combination will pass the type test. In this view, it is advisable, especially for large cable projects, to type test the envisaged combination of cable and accessories before installation commences.

INTRODUCTION
The use of power cables is steadily increasing. Nowadays mainly extruded cables systems are installed in expanding cities and industrialised areas. These cables are also used for undergrounding overhead lines and as a replacement for paper insulated cables reaching their end-of-life. To ensure proper functioning throughout their entire life-time, various tests are performed from the design phase of a cable or accessory up to the installation phase: prequalification tests, type and routine tests and so-called test after installation. World wide various standards exist, e.g. IEC, CENELEC and national standards for MV, HV and EHV cables, accessories and/or cable systems. During the operation phase of the cable system, diagnostic tests may serve as a basis for condition based maintenance. During the last 20-25 years, KEMA's High-Voltage Laboratory has performed the above mentioned tests for clients world-wide. Utilities and manufacturers may choose between various standards and also have to decide whether to test a complete cable system or the various parts separately (cable and accessories). Figure 1 shows a typical set-up for a type test on (E)HV cable and accessories. The cable is fitted with two outdoor porcelain terminations and a (cross-bonding) joint which is just left of the centre of the figure.

STANDARDS
IEC 60502
This standard is applicable for extruded cables and in the voltage range of 6 to 30 kV it is subdivided in two separate volumes for cables (part 2) and accessories (part 4) [2,3]. The cables-part of this standard describes the construction of cables, either single or three phase and contains guidelines or, where appropriate, restrictions in this respect. The electrical type tests described in both parts are in line with those described in IEC 60840, except for the heating cycles as described in the cables-part: these are surprisingly not performed under voltage application. Naturally, test durations and voltage levels differ from other standards.

IEC 60840
This international standard is dedicated to extruded cables and their accessories in a voltage range from 30 to 150 kV and describes the various tests to be performed for routine, sample and type tests [4]. The electrical type tests comprise a check on insulation thickness, measurement of resistivity of the semiconducting screens, bending test, partial discharge tests at various moments during the complete test procedure, tanδ measurement, heating cycles under voltage application, impulse voltage test and an ac voltage withstand test. The non-electrical type tests are mainly focusing on material characteristics of the various materials in a cable.

Figure 1. Testing of (E)HV cable and accessories
IEC 62067
This standard covers the range of 150 to 500 kV for extruded cable systems (cable and their accessories) and describes the various tests to be performed for routine, sample and type tests [5]. The electrical type tests described in this standard are in line with those in IEC 60840. In addition to type tests, this standard also requires a pre-qualification test. The pre-qualification test enables the system, cable and accessories, to prove it's long-term satisfactory performance.

CENELEC HD 620 and HD 629.1
These standards could be seen as the European counterparts of IEC 60502: they deal with extruded cables and their accessories in the voltage range of 6 to 36 kV [6,7]. The HD 620 (extruded cables) consist of a common part, general requirements, and parts based on the number of cores (1 or 3) and the type of insulation (PVC, XLPE, EPR, HEPR). Except for the common part, all parts are a collation of national sections of the participating countries. With respect to the electrical type tests, the HD 620 contains more or less the same series of tests as the IEC 60502-2. But depending on the submitting country some additional tests can be described, e.g. the 'long term stability test' and 'long duration test' in parts 5-J (single phase XLPE cables) and 6-J (three phase XLPE cables). This 'long duration test' determines the cable's susceptibility for watertrees. As for the non-electrical tests described in e.g. the sections 5-J and 6-J, these tests are basically the same as described in IEC 60502-2, but reference is made to an European standard rather than an IEC standard with respect to the test method.

Unlike the HD 620, the HD 629.1 (accessories for extruded cables) does not contain different national parts. When compared with IEC 60502-4, there is hardly any difference in the kind of tests to be performed for a type test, but test conditions differ.

DATA
General
This paper reviews the results of 16 years of type testing of cables and accessories from 1993 up to and including 2008. In this period slightly more than 470 components have been type tested. The majority has been cable, but terminations and straight joint represent also a significant part. Figure 2 shows the distribution with respect to the various components.

Most of the tests are performed conform IEC 60502 and IEC 60840 as can be seen in figure 3. In the first eight years of this survey, no tests conform IEC 62067 were performed since this standard is only published in 2001. The category 'other' comprise mainly type tests on paper insulated cables, both medium and high voltage.
Accessories

Through the years KEMA High-Voltage Laboratory tests slightly over 15 accessories a year although the first few years show quite some spread (see figure 5). Most of the accessories are terminations and straight joints (figure 2), but also cross-bonding and transition joints have been tested. On an average yearly basis 8 different terminations and 4 straight joints are tested. For crossbonding joints the average is 2, while transition joints are only tested occasionally. The straight joints are normally in the medium voltage range while the cross-bonding joints are in the (extra) high voltage range. The distribution of terminations over MV and (E)HV is roughly equal. The category ‘other’ in figure 5 comprise quite a few IEC 60055 tests (paper insulated medium voltage cables and accessories).

FAILURES

As indicated before, more than 470 components have been type tested in the past 16 years. Because 90 % of all type tests is on cables, terminations and straight joints, the failure statistics are especially meaningful for these three components. The failure rate shows a large variation between the different components: only one out of every six tested cables fails to meet all requirements, while every one out of two tested crossbonding joints fails. In general, accessories show a failure rate between 20 % and 50 %. Figure 6 gives an overview of the average failure rate of each component.

When focusing on cables, figure 7 shows for both IEC and Cenelec standards for medium voltage a more or less equal failure rate of approximately 10 %. There is an increase in failure rate from medium to high voltage cables (IEC 60840). It is well known that electrical stesses in high voltage cables are higher compared to medium voltage. When testing, the heating cycles are combined with voltage application, which is only logical since a type test should simulate (at least) 30 years of service. This results in more severe conditions for high voltage cables and thus testing is more sensitive to improper material handling and processing during manufacturing for this type of cables. Failures related to bad design of HV (extruded) cables are highly unlikely.

On the other hand, figure 7 shows a lower failure rate for high voltage accessories compared to medium voltage, both IEC and Cenelec standards. Despite of the higher stresses that occur in HV cables, the accessories are probably designed more carefully to handle these higher stresses, resulting in a lower failure rate for HV accessories.

Finally, the failure rate of cables and accessories can be displayed as a function of time, as illustrated in figure 8. This shows for both cable and accessory quite some spread through the years. A trendline based on linear regression shows for cable a small decline but due to a very small correlation factor ($r = -0.15$), it should be concluded that no clear trend can be recognised. For cables the average failure rate is around 15 % (see also figure 6) and shows quite some variation.
The trendline for accessories shows some increase, but also a small correlation factor \((r = 0.4)\). Therefore the same conclusion: no clear trend can be recognized.

**DISCUSSION**

As mentioned before, the data presented here confirms the previously published survey [1] and does not show a clear increase or decrease in failure rate regarding type tests. The correlation factor \(r\) gives a measure for linear dependence, this factor is for cables \(r = -0.15\) and for accessories \(r = 0.4\). For cables, this value indicates almost no correlation or, when taking figure 8 into account, a more or less flat trend. The correlation factor for accessories does not give a clear answer; it is too large to say that there is no correlation and on the other hand too small to say that there is a linear trend.

Since the majority of tests is performed according to IEC 60502 and IEC 60840, comparison of these results is sensible. Figure 7 indicates a significant larger failure rate for HV cables as compared to MV cables. A possible explanation for this difference is the larger electrical stress in the insulation of HV cables. Due to the lower stresses in MV cables, these cables are more tolerant to irregularities at the screens or contaminants in the insulation. On the other hand, MV cables are certainly less severe tested: the electrical type tests for both standards differ with respect to the heating cycle test. The IEC 60502-2 range cables are only subjected to heating current without voltage while IEC 60840 range cables are subjected to both heating current and continuous voltage during the heating cycle test. To “compensate” for the absence of voltage during the heating cycle test for MV cables, a 4 hour, 4 \(U_0\) test is to be performed after the lightning impulse test. This 4 hour voltage test is at ambient temperature only. As a consequence, the combination of electrical stress and thermo-mechanical effects are not tested. However, when testing MV accessories, the cable is necessarily part of the testloop and thus subjected to heating cycles under voltage. Since we have so far not experienced failures in the cable during type testing MV accessories, the difference in failure rate between MV and HV cables may be attributed to the lower (design) stresses in MV cables.

The accessories show consistently a higher failure rate compared to cables. One of the main functions of an accessory is to handle the high electrical stresses in the cable insulation, i.e. to avoid a local increase of stress. Also, stresses parallel with the interface should be kept to a minimum. Next to this, accessories have to cope with thermo-mechanical forces exerted by cables. This interaction between cable and accessory might be quite demanding for the accessory as can be seen in figure 6. Especially in the high voltage range (IEC 60840) we have performed quite a few type tests on cable systems of which the individual parts were already type tested but the combination not yet. For these tests, we have seen that a successful type test is not guaranteed, because of this demanding interaction between cable and accessory.

**CONCLUSION**

This survey shows that 20 % to 50 % of all type tests on accessories result in a failure. When compared with the previously published survey [1], the failure data shows only minor changes. Improvements in materials and production techniques are ongoing. Still, these improvements do not result in a noticeable decrease in failure rate. Looking at the competitive market for cables and accessories, the improvements have probably been used to realise lean designs of cable and accessories. In relation to these developments, type testing is definitely valuable. If type testing would be omitted, quite some future problems will be installed today in cable networks.

Interfacial problems show the importance of testing the combination of cable and accessories that will be used. Even when individual components have been type tested before, the combination might fail during a type test. In this respect, it is advisable, especially for large cable projects, to type test a certain combination of cable and accessories before installing these.

**REFERENCES**