ABSTRACT

In this paper the results of 20 years of type testing MV, HV and EHV cables, accessories and cable systems are presented. This survey is an update of a previous publication [1] and confirms the previously presented data. It shows that still 20 % to 50 % of all type tests on accessories result in a failure.

These results show the manufacturer 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. 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. Especially for large cable projects, it is advisable to type test the desired combination of cable and accessories before installation commences.

INTRODUCTION

The use of power cables is steadily increasing, despite the economic downturn of the recent years which may have slowed down the number of cable projects. New cable installations are generally based on extruded insulation systems. These extruded cables are also used for grounding overhead lines and as a replacement for paper insulated cables reaching their end-of-life. To ensure proper functioning throughout their entire lifetime, 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. Worldwide 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 30 years, the KEMA Laboratories have performed these tests for clients worldwide. 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 terminations, two GIS terminations and a cross-bonding joint (behind HV divider).

STANDARDS

IEC 60502

This standard is applicable for extruded cables. 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. For MV cables, the electrical type tests are in line with those described in IEC 60840, except for the heating cycle test: this test is not performed under simultaneous voltage application. To ‘compensate’ for this, a 4 hour voltage test is required after the lightning impulse test. 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]. During the last revision of both IEC 60840 and IEC 62067, these standards have been aligned. Some tests which used to exist only in IEC 62067 have been introduced in IEC 60840, e.g., a prequalification test for cable designs with a high field stress. Also, cables and accessories which fall in this high stress category can now only be tested on the basis of a system approach. Cables and accessories for cables which do not fall in this high stress category, can still be type tested on an individual basis, i.e., as separate items. For both high stressed cable systems and ‘normal’ stressed cables and accessories, 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, tan δ 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.

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]. During the last revision, this standard has been aligned with IEC 60840. Where IEC 60840 differentiates between high stressed cable designs and ‘normal’ stressed cable designs, this standard assumes high stressed cable designs and consequently only accepts testing on a system basis. The electrical type tests described in this standard are in line with those in IEC 60840. In addition to type tests, a pre-qualification test is mandatory. The pre-qualification test enables the system, i.e., cable and accessories, to prove its 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) consists of a common part, general requirements, and parts based on the type of insulation (PVC, XLPE, EPR, HEPR). Except for the common part, all parts are a collection 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 10-J (single phase and three phase XLPE cables). This long duration test determines the cable’s susceptibility for water trees. As for the non-electrical tests described in e.g., the section 10-J, these tests are basically the same as described in IEC 60502-2, but references are 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 20 years of type testing of cables and accessories from 1993 up to and including 2013. In this period almost 700 components have been type tested in the KEMA Laboratories on the basis of one of the above-mentioned standards. For this survey, tests according to IEC 60840 and IEC 62067 have been grouped as ‘HV’ and tests according to IEC 60502, HD 620 and HD 629.1 have been grouped as ‘MV’. The group ‘termination MV’ consists of both indoor and outdoor terminations while the group ‘termination HV’ comprises outdoor and GIS terminations. The group ‘joint HV’ consists of both straight through joints and cross-bonding joints. Roughly 60% of all tests were on medium voltage components and the other 40% on (extra) high voltage components and systems. Nearly half of all tests were on cable, either as a separate component or as part of a system. Terminations represent also a significant part (30%), either tested as a separate component or as part of a system. Figure 2 shows the distribution with respect to the various components.

Most of the tests are performed according to IEC 60502 and IEC 60840 as can be seen in figure 3. In the first eight years of this survey, no tests according to IEC 62067 were performed since this standard was published for the first time in 2001. Type tests on cable and accessories according to European standards represent only a limited number of tests in this survey.
Cables
Over the last 5 to 10 years the KEMA Laboratories test on average almost 20 cables each year, as can be seen in figure 4. This figure shows most of the tests are on extruded medium voltage cables (IEC 60502). Cables in this voltage range can be considered a commodity and consequently many manufacturers world-wide produce such cable. This is why most of the cables tested fall in the medium voltage range. In this medium voltage range only a few cables have been tested based on CENELEC. On average during the last 5 to 10 years, roughly 5 cables each year have been tested according to IEC 60840. Only a limited number of tests according to IEC 62067 have been performed because, as mentioned before, the first edition of this standard was published in 2001.

Accessories
Through the years the KEMA Laboratories test 16 accessories a year although there is quite some spread (see figure 5). The share of tests on accessories belonging to the (extra) high voltage category equals more or less the share of tests on MV accessories. Most of the HV tests are based on testing a project-specific combination of cable and accessories. A typical HV test loop consists of a cable, two outdoor terminations (porcelain and/or composite), two GIS terminations in a back-to-back configuration and a cross-bonding joint. This means three types of accessories against only one cable, which leads to more HV accessories than HV cable. At the same time, the number of manufacturers of MV accessories is smaller than that for MV cable, which might result in fewer tests for MV accessories than for MV cables. This is true if only IEC tests are considered. However, tests according to HD 629.1 and IEC 60502-4 together balance the number of tests on HV accessories.

FAILURES
As indicated before, almost 700 components have been type tested in the past 20 years. These tests have been performed for manufacturers from the whole range of well-established to emerging. It should be no surprise that not every type test results in certification of the test object. One should also realize that failures are not the exclusive ‘domain’ of emerging manufacturers.

The data collected shows that just over 10 % of all type tests on MV cables do not result in certification, while this number increases to 25 % for (E)HV cables. In the high voltage category, the failure rate for terminations is smaller than for joints (just over 10% versus 30%), while in the medium voltage category the converse is the case but the numbers are bigger (roughly 50% versus 40%), see figure 6.

When focusing on cables, the difference in failure rate between medium voltage cables and (extra) high voltage cables seems to be persistent throughout the last 20 years. There is an increase in failure rate from medium to high voltage cables (IEC 60840 and IEC 62067). It is well known that electrical stresses 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 a poor design of high voltage (extruded) cables are highly unlikely.

Figure 6 shows a lower failure rate for (extra) high voltage accessories compared to medium voltage. Despite of the higher stresses that occur in high voltage cables, the accessories are probably designed more carefully to handle these higher stresses, resulting in a lower failure rate for (extra) high voltage accessories.

Finally, the failure rate of cables and accessories can be displayed as a function of time, as illustrated in figures 7 and 8. This shows for cable and accessory in both categories (medium voltage and high voltage) quite some spread through the years. A trend line based on linear regression shows for HV cable a small incline but due to a very small correlation factor ($r = 0.2$), it should be concluded that no clear trend can be recognized. For MV cables the average failure rate is around 10 % (see figures 6 and 8) and although the data shows some variation through the years, the trend line indicates no change in failure rate ($r = 0$).

The trend line for MV accessories shows an increase in failure rate, but also here a small correlation factor ($r = 0.3$) which means that it is difficult to draw conclusions based on this trend line: no clear trend can be recognized. The trend line for HV accessories is rather flat: the average failure rate is around 20% with some spread when looking at individual years. Still, the trend line indicates no change in failure rate ($r = 0$).
DISCUSSION

Figure 6 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 (E)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 and IEC 62067 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 U0 test is to be performed after the lightning impulse test. This 4 hour voltage test is at ambient temperature only. As a consequence, a combination of electrical stress and thermo-mechanical effects are not tested. On the other hand, when testing MV accessories, the cable is necessarily part of the test loop 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.

Medium voltage terminations show a much higher failure rate than HV terminations. These MV terminations must be subjected to additional tests for which the HV terminations do not need to be subjected, such as the salt fog test and humidity test in climatic chambers. Yet, looking at individual failure causes, this higher failure rate cannot be attributed only to these additional tests.

High voltage joints show a much higher failure rate than HV terminations. When a HV joint is claimed to be suitable for direct burying, the so-called Annex G tests, Tests of outer protection for joints, need to be performed. This test, with the joint immersed in water, appears to be quite demanding: roughly 40 – 50% of the test objects fail this particular test. This results in the higher failure rate as compared to HV terminations. For MV joints, heating cycles while immersed in water is part of the test sequence and failures related to this part of testing are already included in the failure rate shown in figure 6.
CONCLUSION

If type testing would be omitted, quite some future problems will be installed today in cable networks. When compared with the previously published survey [1], the failure data shows only minor changes. This survey shows that still 10 % to 50 % of all type tests on accessories result in a failure. Improvements in materials and production techniques are ongoing. The improvements in materials 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 realize lean designs of cable and accessories. In relation to these developments, type testing is definitely valuable to prevent future problems.

In relation to improvements in materials, e.g. components for accessories may have changed in composition and although the change may seem small, it may require a new type test. This means that type testing must be an ongoing process and the validity of a type test approval should be limited not only by voltage or conductor size, but should also be limited in time.

REFERENCES


[2] IEC60502-2, Power cables with extruded insulation and their accessories for rated voltages from 1 kV (Um = 1,2 kV) up to 30 kV (Um = 36 kV) – Part 2: Cables for rated voltages from 6 kV (Um = 7,2 kV) up to 30 kV (Um = 36 kV), third edition, 2014

[3] IEC60502-4, Power cables with extruded insulation and their accessories for rated voltages from 1 kV (Um = 1,2 kV) up to 30 kV (Um = 36 kV) – Part 4: Test requirements on accessories for cables with rated voltages from 6 kV (Um = 7,2 kV) up to 30 kV (Um = 36 kV), third edition, 2010

[4] IEC60840, Power cables with extruded insulation and their accessories for rated voltages above 30 kV (Um = 36 kV) up to 150 kV (Um = 170 kV) – Test methods and requirements, fourth edition, 2011

[5] IEC62067, Power cables with extruded insulation and their accessories for rated voltages above 150 kV (Um = 170 kV) up to 500 kV (Um = 550 kV) – Test methods and requirements, second edition, 2011

[6] HD 620, Distribution cables with extruded insulation for rated voltages from 3,6/6 (7,2) kV up to and including 20,8/36 (42) kV, S2 edition, 2010

[7] HD 629.1, Test requirements on accessories for use on power cables of rated voltage from 3,6/6 (7,2) kV up to 20,8/36 (42) kV – Part 1: Cables with extruded insulation, S2 edition, 2006