INTRODUCTION

The use of power cables is growing very rapidly. In densely populated areas underground cables are virtually the only possibility to distribute the power. 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. the international standards IEC 60502, IEC 60840, IEC62067, CENELEC HD 629 and also national standards, like the Dutch NEN 3620 or German VDE 278. During the operation phase of the cable system, diagnostic tests may serve as a basis for condition based maintenance.

Since the foundation of KEMA's High-Voltage Laboratory in 1927 the above mentioned tests have been performed for Dutch utilities and manufacturers and during the last 15-20 years 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 HV cable accessories. The cable is fitted with two different outdoor terminations and GIS terminations in the tank in the front.

Figure 1. Testing of HV cable accessories

In this paper the statistics of the results of almost 10 years of type testing are presented as general figures and subdivided by cable and the various types of accessories and by standard. This survey is an update of a previous publication [1] and shows that 20-50% of all type tests on accessories result in a change in design or breaking off the type test.

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. 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. The tests mentioned can be those described in a specific standard, with or without additional tests being performed during, in parallel or after a type test.

STANDARDS

IEC60502

This standard is applicable for extruded cables and in the voltage range of 6 to 30kV 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 structure 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 IEC60840, except for the heating cycles as described in the cables-part: these are not performed under voltage application. Naturally, test durations and voltage levels differ from other standards.

IEC60840

This international standard is dedicated to extruded cables and their accessories in a voltage range of 30 to 150kV 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.
IEC62067
The two previous IEC standards for extruded cables only cover the voltage range of 6 to 150kV while presently already quite some extruded cable circuits with system voltages well above 150kV are in operation. This gap is restored with the publication of IEC62067 in 2001 [5], which covers the range of 150 to 500kV for extruded cables and their accessories. The electrical type tests described are in line with those in IEC60840. 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 HD620 and HD629.1
These standards could be seen as the European counterparts of IEC60502: they deal with extruded cables and their accessories in the voltage range of 6 to 36kV [6,7]. The Harmonisation Documents consist generally of a common part (general requirements) and a collation of national sections of the participating countries. With respect to the electrical type tests for cables, the HD620 contains more or less the same series of tests as the IEC60502-2. But depending on the submitting country some additional tests can be described, e.g. the 'long term stability test' and 'watertree long duration test' in parts 5-J (single phase cables) and 6-J (three phase cables). This 'watertree long duration test' determines the cable's susceptibility for watertrees. Based on the 500Hz accelerated aging test, in only 4 months time a complete life-time is simulated. After breakdown tests the watertree susceptibility is known. As for the non-electrical tests described in the sections 5-J and 6-J, these tests are basically the same as described in IEC60502-2, but reference is made to an European standard rather than an IEC standard with respect to the test method. Unlike the HD620, the HD629.1 for accessories for extruded cables does not contain different national parts. When compared with IEC60502-4, there is hardly any difference in the kind of tests to be performed for a type test. Naturally, test conditions differ.

VDE276 and VDE278
As mentioned above, the European Harmonisation Documents are partly collated national standards. The German VDE276 for extruded power cables [8] is similar to HD620, part 5-C (single phase) and 6-C (three phase). Main difference of this VDE276 with respect to IEC60502 is a 2 years accelerated ageing. During this ageing samples are submitted to breakdown tests at specific moments. The statistical distribution of the breakdown voltages (Weibull) must fulfill certain requirements.

The German VDE278 for accessories for extruded cables [9] is similar to HD629.1.

NEN3620 and NEN3608
What can be said for the German standards also holds true for the Dutch situation. The NEN3620 for extruded cables from 6 to 30kV [10] is part of the European HD620. The detailed description is in HD620 parts 5-J and 6-J. Compared to IEC60502 the difference is in long-term testing.

The Dutch NEN3608 for accessories for extruded cables [11] is similar to HD629.1.

DATA
General
This paper reviews the results of 9 years of type testing of cables and accessories from 1993 up to and including 2001. In this period slightly more than 250 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.

Figure 2. Distribution of components
Most of the tests are performed conform IEC60502 and IEC60840 as can be seen in figure 3. In the first six years of this survey, tests conform VDE278 were still performed while this seems to have been taken over by European standards in recent years. The category 'other' comprise these HD-standards and also international standards for paper insulated cables (both medium and high voltage) and the previously mentioned new IEC62067.

Figure 3. Number of tests per standard

Cables
Through the years KEMA High Voltage Laboratory tests approximately 12 cables each year, as can be seen in figure 4. This figure shows especially in the last few years that the majority of the tests are on extruded medium voltage cables (IEC60502). A yearly average of almost 4 cables have been tested conform IEC60840. Unlike accessories, country specific tests like VDE276 have hardly been performed.
The remaining tests ('other') comprise mainly type tests on paper insulated cables, both medium and high voltage.

Figure 4. Cables, number of tests per standard per year

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 1), but also crossbonding and transition joints have been tested. On an average yearly basis almost 7 different terminations and slightly over 5 straight joints are tested. The last few years this number for crossbonding joints is 2, while transition joints are only tested occasionally. Like cables, most of the tested accessories are in the medium voltage range although not exclusively designed for extruded cables. The category 'other' in figure 5 comprise quite a few IEC60055 tests (paper insulated medium voltage cables and accessories).

Figure 5. Accessories, number of tests per standard per year

FAILURES

As indicated before, more than 250 components have been type tested in the past 9 years. Because almost 90% of all type tests is on cables, terminations and 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 five 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 over the last 9 years.

When focusing on cables, figure 7 shows for both IEC standards an increase in failure rate from medium to high voltage cables. 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 bad design of HV (extruded) cables are highly unlikely.

Figure 6. Failure rate per component

On the other hand, figure 7 shows a decrease in failure rate for accessories for both IEC 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.

The failure rates for accessories for both IEC standards and the category 'other' are considerably lower than that for the German VDE278. This standard is definitely demanding with respect to design and installation of accessories. As a type test should adequately simulate many years of service and the corresponding service conditions may vary extremely throughout the world, it's not more than logical that certain national standards are more severe than international ones.

Figure 7. Failure rate per standard

Finally, the failure rate of cables and accessories can be plotted as a function of time, as illustrated in figure 8. This shows for both quite some spread through the years. A trendline based on linear regression shows a small incline but due to a very small correlation factor (r=0.2), it should be concluded that no clear trend can be recognised. For cables the average failure rate is around 20% (see also figure 6) and shows especially the last few years quite some
variation. The accessories showed an increase in failure rate through the years up to 2000 and a remarkable sharp decrease in 2001. The number of accessories tested in 2001 can not be the reason for this decrease. Neither a maldistribution between the various standards can serve as a plausible explanation for this, because both in 2000 and 2001 almost all tests in the category 'other' consist of IEC60055 type tests. The only reasonable explanation seems to be: coincidence.

Figure 8. Failure rate through the years

DISCUSSION

As previously mentioned, the data presented 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 $r=0.2$ 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.

As mentioned before, the design of a cable (extruded) is not too difficult, but keeping control of the manufacturing process and handling of materials is the main issue. If certain aspects in this process are not controlled properly, this will show up in the type test as a failure. That is, provided the type test reflects practice properly. Based on figure 7, one could conclude that IEC60502-2 tests cables too weak: both IEC60840 and other standards for cable type testing result in a failure rate above 20%, while IEC’s standard for MV extruded cables results in 16%. A difference between IEC60840 and IEC60502-2 is the absence of voltage application during the heating cycles in the latter. This omission in IEC60502-2 should be rectified.

The accessories show consistently a higher failure rate compared to cables. One of the main functions of an accessory is to handle the high stresses in the cable insulation, i.e. to avoid a local increase of field stress. Also stresses in the direction of interfaces should be kept to a minimum. Altogether, this is quite demanding for joints, as can be seen in figures 6 and 7. Minor differences between corresponding cables from various manufacturers might result in slightly different stresses in interfaces in joints and consequently it might affect the long-term behaviour. From this point of view it could be sensible to test a certain intended combination of cable and accessories.

CONCLUSION

This survey shows that 20-50% of all type tests on accessories result in a change in design or breaking off the type test. The HV-range shows a lower failure rate for accessories compared to the MV-range. Despite of the higher stresses that occur in HV cables, the accessories are probably designed more carefully to handle these higher stresses.

When comparing the heat cycle tests described in IEC60502-2 and IEC60840, the latter combines these heat cycles with voltage application. This seems to be only a proper reflection of real life and therefore this should be rectified in IEC60502-2.

Naturally, there has been an improvement in materials and production techniques over the years. However, this survey shows that these improvements have not been utilised for a reduction in failure rate during type testing, since there is hardly any change. It is well known that today’s market for cables and accessories, especially medium voltage, is very competitive. The improvements have probably been used to realise lean designs of cable and accessory. 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. The tests mentioned can be those described in a specific standard, with or without additional tests being performed during, in parallel of after a type test. For specific situations, these results may help manufacturers and utilities to define a series of relevant tests.

REFERENCES

[7] CENELEC HD629.1 S1, 1996
[10] NEN3620