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NEW APPROACH TO MEASURE CONDUCTOR TEMPERATURE DURING TYPE TEST

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ABSTRACT

The latest edition of IEC 60840 gives guidance how to measure the conductor temperature during the heating cycle voltage test as part of the type test sequence. Although that method is very practical, sometimes a heating cycle test has to be interrupted because one of the thermocouples gives a too high or low temperature. To overcome the problem of biased temperature measurements, we slightly changed the way the thermocouple is in contact with the conductor. The new approach is described in detail as well as our experience. Also, recommendations are given to improve IEC 60840.

KEYWORDS

Type test, Heating cycle, Temperature measurement

INTRODUCTION

A heating cycle test is an essential part of type test procedures for medium voltage, high voltage and extra high voltage cables and their accessories, usually combined with voltage application. The latest edition of IEC 60840 gives some possible methods how to determine the conductor temperature during the heating cycle test as part of the type test sequence. Before it was published, KEMA High Voltage Laboratory utilised already the method using a reference cable and we have seen that this method is very practical. Nevertheless, sometimes a heating cycle test has to be interrupted because one of the thermocouples measures incorrect and has to be re-installed.
To overcome the problem of biased temperature measurements, we have slightly changed the way the thermocouple is in contact with the conductor. The concept of two separate loops, one test loop and a reference cable, is maintained. Instead of drilling a hole through the insulation and inserting a sping-loaded thermocouple rod, a small section of the insulation is carefully taken out and some thermocouples are fixed between the wires of the stranded conductor or in the interface between a solid conductor and conductor screen. The insulation taken out is then inserted back which restores the thermal characteristics.
This IEC 60840 also advises to use thermocouples a certain distance apart to demonstrate minimum heat transfer in axial direction. Experience has learned that the heat transfer from the middle to the ends of the reference cable is negligible when this cable is of sufficient length.

GENERAL

A heating cycle test is an essential part of type test procedures for medium voltage, high voltage and extra high voltage cables and their accessories, usually combined with voltage application. During the heating phase, the cable conductor is heated by means of current until a certain temperatue is reached and subsequently this temperature is maintained for some time. Based on IEC standards, this temperature is 5 to 10 K above the maximum conductor temperature during normal operation and is to be maintained for 2 hours. After these 2 hours, the cable is allowed to cool down to ambient, or close to ambient. This heating cycle test is to simulate expansion and contraction during operation and to thermally stress the insulation.
Since the cable under test is to be subjected to various voltage stresses, if not during the heating cycle test then after this test, a direct measurement of the conductor temperature is not possible. The procedure preferred by KEMA High Voltage Laboratory to perform this heating cycle test is by using two identical cables: one test loop and a so-called reference cable of sufficient length. The test loop contains the cable with or without accessories to be tested and is laid out on the floor of the laboratory. The reference cable is also laid out on the floor, near the test loop but avoiding thermal influence. Thermocouples are used to measure the conductor temperature of the reference cable. Small holes are drilled through the insulation and outer layers of the reference cable to allow small stainless steel rods containing the thermocouples to touch the conductor. By means of springs, sufficient contact pressure between rod and conductor is maintained throughout the whole test period. Figures 1 and 2 show the thermocouple and the mounting device. This contact pressure and the fact that the thermocouple is at the bottom of the rod ensures that the correct temperature of the conductor of the reference cable can be measured. The reference cable is heated by means of (induced) current through the conductor and this current is measured using a CT. As long as the (induced) current through the conductor of the test loop is kept on the same level as that of the reference cable, the conductor temperature of the test loop is the same as the reference cable. A small correction may be applicable for (extra) high voltage cables to compensate for dielectric losses.

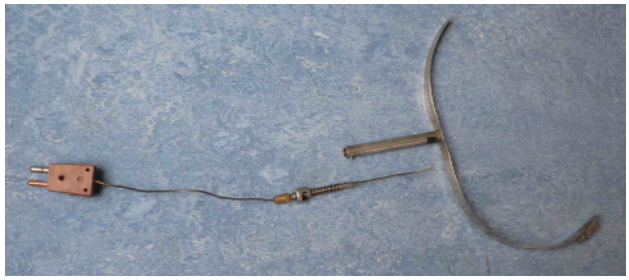

Figure 1 Thermocouple rod (left) and mounting device (right)

Figure 2 Detail of thermocouple (below) and mounting device (top)

PRACTICAL ASPECTS

Based on the above description, KEMA High Voltage Laboratory has performed heating cycle tests on cables and accessories for many years. Although the method of using a reference cable for measuring the conductor temperature is superior, some practical aspects require a high level of attention. These aspects are mainly related to the contact of the thermocouple-rod to the conductor and contact of the thermocouple-rod to the metal screen.

As a consequence of thermal cycling, some parts of the cable, e.g. insulation or outer sheath, may move. This may cause the metal thermocouple rod to make contact to both the conductor (intentionally) and the metal screen (unintentionally) even though the metal rod is originally insulated by means of tape. The friction of the lead sheath or copper wire screen will damage this tape and the contact to the metal screen results in an additional loop. Current will be induced in this loop and consequently the thermocouple will experience additional heating. The temperature recorder will show a sudden increase in temperature for that channel and is an indication for such unintentional contact. The remedy is to restore the insulation between the thermocouple-rod and the metal screen.

This movement of individual layers in the cable may also cause the thermocouple to loose contact with the conductor. When the thermocouple-rod is no longer in contact with the conductor, a lower temperature than the actual conductor temperature will be measured. Since the temperature measurement relies on three thermocouples, the lack of contact for one thermocouple can be seen on the recorder: one trace is lower than the other two. The remedy is usually to drill a new hole for the particular thermocouple.

As long as more than two thermocouples are used for measurement of the conductor temperature, any malfunctioning of one of the thermocouples can be recognised and it can be repaired. However, this usually requires an interruption of the test, since the test bay has to be entered and the reference cable has to be touched physically. Because the aim is to perform tests without interruption, KEMA High Voltage Laboratory investigated the possibilities to overcome above mentioned problems.

SOLUTION

In search for alternatives which guarantee good contact between the thermocouples and the conductor of the reference cable throughout the entire test, the solution has been found to fix a tiny thermocouple between two wires of the outer layer of a stranded condcutor or, in case of a solid conductor, in the interface between the conductor and the conductor screen.

In order to reach the conductor, a small 'hatch' is to be made in the cable. A small part of the outer sheath, about 5 to 10 cm in length, is carefully taken out after which, layer by layer, the underlying parts are removed (metallic layers) or taken out (insulating layers). Once the conductor is exposed, three thermocouples are fixed between the wires of the conductor. These steps are illustrated in figure 3. Some redundancy for the temperature measurement is thought to be necessary although, so far, no thermocouple lost contact with the conductor during thermal cycling. To avoid tension on the thermocouple wire during expansion and contraction of the cable, the wire is laid down on the conductor in a S-curve. After the thermocouples are installed, the insulating parts that have been taken out, are put back in place to restore the thermal behaviour of the cable at the measurement location, see figure 4. One or two layers of tape are applied over the whole to prevent ventilation in the tiny gaps that remain.

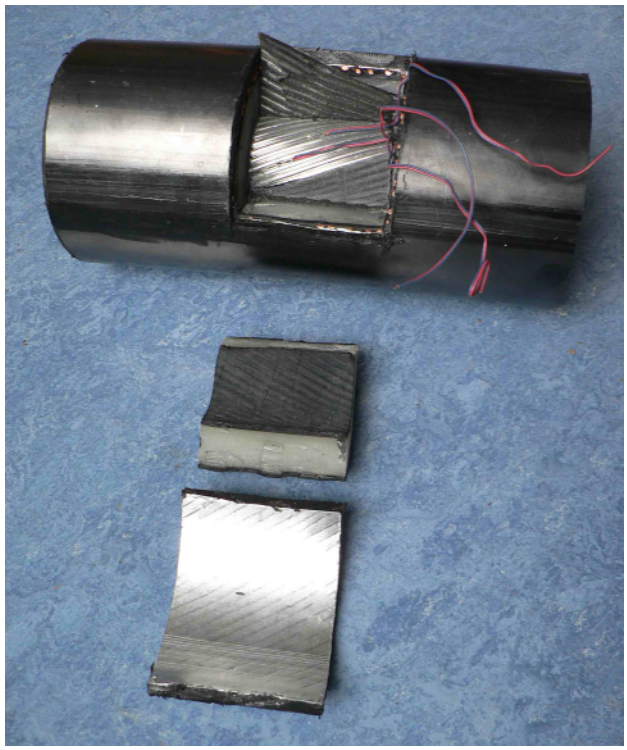

Figure 3 Conductor of cable exposed to insert thermocouples

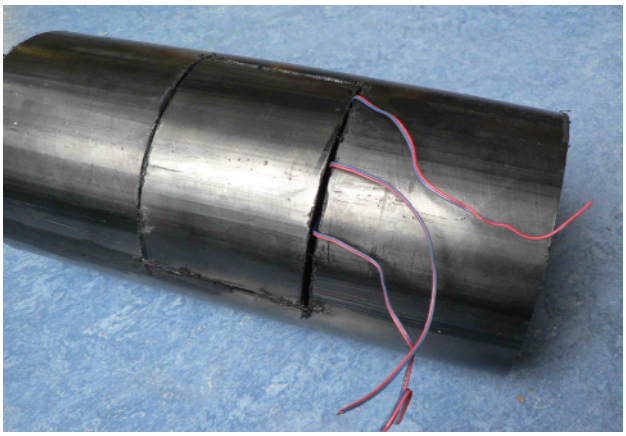

Figure 4 Isolating layers replaced

EXPERIENCE

This improved method to measure the conductor temperature of power cables during thermal cycling is being used by us since the end of 2005. Since the first test with this method, the difference in temperature between the thermocouples on the conductor is typically less than 1 K, see figure 5. Moreover, when removing the thermocouples after finishing the tests, all thermocouples were still in place. This has given us the confidence that this procedure to measure the conductor temperature is more reliable than the previously applied technique from a measurement point of view. Next to that, the main advantage is that the need to interrupt a test for adjustment of the thermocouples has now disappeared. This also makes this new method more reliable.

As mentioned before, the reference cable is laid out on the floor in the same manner at the test loop and near this test loop but avoiding thermal influence. The reference cable is heated by means of (induced) current through the conductor and this current is measured using a CT. As long as the (induced) current through the conductor of the test loop is kept on the same level as that of the reference cable, the conductor temperature of the test loop is the same as the reference cable. That is provided that the heat transfer from the middle of the reference cable to the ends is negligible. Based on our experience, this requirement is met when the reference cable has a length of at least 10 m. This means that in case of a reference cable of at least 10 m, temperature measurement in the middle of the reference cable is sufficient in most cases, avoiding the need to install thermocouples at two other locations (middle + 0,5 m and middle + 1 m).

RECOMMENDATION

To avoid incorrect measurement of the conductor temperature of reference cables during heating cycle tests, it is recommended to fix the thermocouples, which measure this temperature, between the wires of the stranded conductor or, in case of a solid conductor, between the conductor and the conductor screen. It is also recommended to append the existing annex A of IEC 60840 to give more specific information regarding the way the thermocouple is to be installed on the conductor.

It is recommended to use a reference cable of at least 10 m length. This prevents heat transfer from the middle of the cable (where the conductor temperature is measured) to the ends and hence avoids the need to install thermocouples at 0,5 m and 1 m from the middle. It is also recommended to append the existing annex A of IEC 60840 likewise.

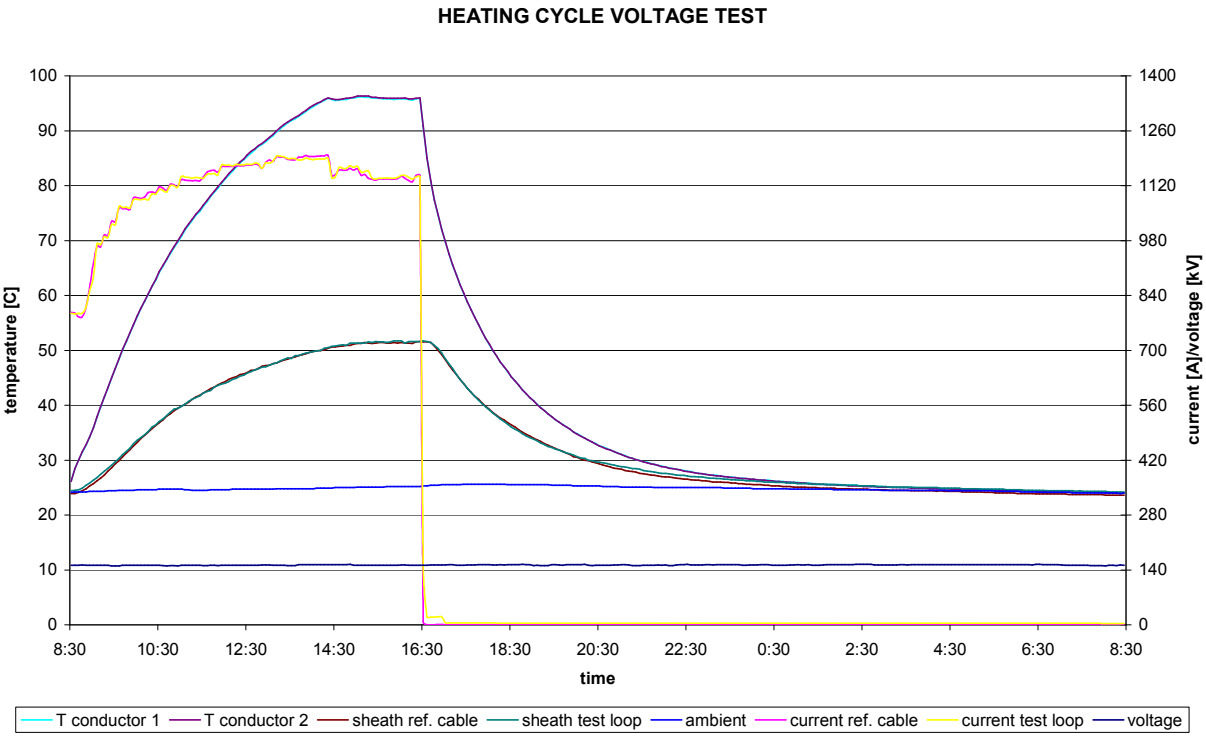

Figure 5 Temperature, current and voltage as function of time during one 24 hour heating cycle