# THERMAL BEHAVIOR OF CONNECTORS IN JOINTS

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## *ABSTRACT*

*One of the main failure causes of MV joints is related to thermal ageing of the joint. The European Standards [1] for MV joints for cables describe heat cycle tests in air and water to evaluate the compatibility of the joint with a specific cable. The connectors used in combination with the joints are tested separately in free air (according to [2]).*

*Investigation on several failures that occurred on qualified joints, mounted with qualified connectors, revealed that the compatibility between the connector and the joint needs also to be tested.*
*Electrical tests have demonstrated that, when a joint and a connector are not compatible, while the cable reaches 110°C during emergency regimes the connectors can reach temperatures in excess of 145°C.*

*Therefore several DGO's in Belgium started a research program to develop test methods that take into account the thermal behavior of connectors inside the joints. Two test methods are described in this paper.*

## INTRODUCTION

Due to negative results of joints tested according to [1] and failures of MV joints in the MV network a Belgian group of experts started to examine the thermal behavior of connectors in joints in detail. The goal of this study was to find out:

- Can the heat dissipation of a connector be simulated with an artificial connector?
- Can the thermal behavior of different MV joints be compared?
- Can the thermal interaction of a connector and a joint be quantified in pass / fail test criteria supposed it passed the test criteria according to [1] and [2] successfully?

## TEST METHOD 1: SIMULATION OF HEAT LOSSES BY AN ARTIFICIAL CONNECTOR

### Goal of the test method and test set-up

The goal of this test is to evaluate the capacity of a joint to evacuate heat generated by an artificial connector. The intention is to quantify the heat losses absorbed and dissipated by the joint in free air and to compare the thermal behavior of different types of joint.

To eliminate the influence of type, manufacturer, tolerance of dimensions and tolerance due to the installation, the joint is installed on a cable where the conductor has not been cut. The heat losses of a real connector are simulated by an artificial connector with the same external dimensions and with controllable heat losses.

In order to create this artificial connector two metal shells are placed above an electric wire which is wound around a cable conductor. The shells are thermally (but not electrically) connected to the conductor. Three thermocouples are placed on the surface in order to measure the temperature of the outer surface of the artificial connector. The practical realization is shown in Figure 1.

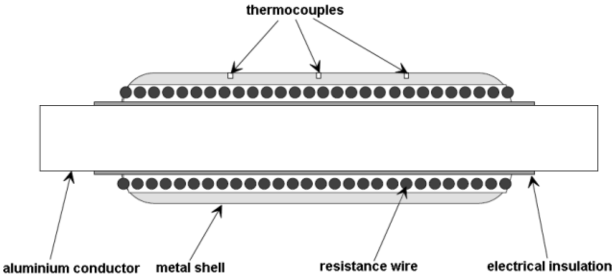
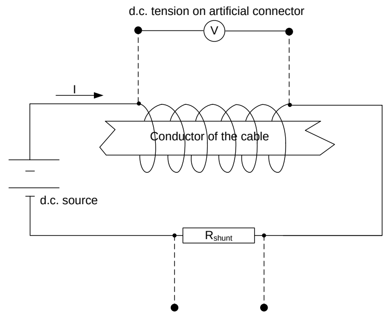


**Figure 1: practical realization of an artificial connector**

After the installation of the artificial connector the complete joint is installed around it. The test method starts with the injection of a d.c. current in a first test circuit to raise the conductor to a constant temperature of 90°C and of 110°C. Next, the losses of a real connector are simulated with a d.c. source in a second test circuit (Figure 2). The d.c. losses in the connector are injected until the surface of the connector reaches 90°C and 110°C.



Shunt: 75 mV – 10 A

**Figure 2: second circuit with artificial connector**

The total losses of the artificial connector are equal to the Joule losses generated by the part of the cable conductor under the resistance wire and the extra heat losses injected with the d.c. source and generated by the resistance wire:

$$P_{heat,tot} = P_{heat,conductor} + P_{heat,injected}$$

The losses $P_{heat,tot}$ are compared with the losses of a real connector. The contact resistance of the real connector can be determined with the *k*-factor ([2]).

This test method has limitations:

- It is impossible to simulate a connector with a very good electric contact ($k < 1$) because the losses of the artificial connector are always present.
- This method cannot be used on joints where it is necessary to cut the conductor of the cable to install the different components of the joint.

This test method also allows to compare different types of joints in combination with connectors with different dimensions and to determine the influence of the type of cable and the cross section on the thermal behavior.

## Performance & reproducibility

### Control of losses of artificial connector

To control the losses of the artificial connector the test method is performed two identical joints: one with a real connector with *k*-factor > 1 and the other with an artificial connector. The measured heat losses are almost equal (17 W vs. 19 W). The little difference can be explained by:

- the precision of the measurement equipment;
- the fact that in reality the heat losses of a connector are dependent of its surroundings;
- the unequal distribution of the wires on the surface of the artificial connector.

### Control of the reproducibility of the test method

The relationship of the temperature and the losses were measured for 3 identical joints with artificial connectors installed on the same type of cable. For the same temperature a difference of 1 W was measured. This means an accuracy of < 10%. All the tests were performed at an ambient temperature of 20-22°C.

### Results of simulated heat losses by artificial connector

Figure 3 shows the total losses ($P_{heat,tot}$) of the artificial connector in function of the connector temperature for different joints and connectors.

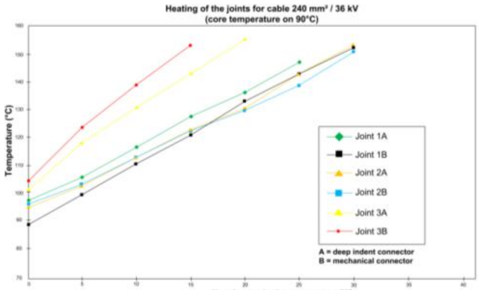


**Figure 3: total heat losses for different connector temperatures**

For all tested joints the heat losses were also calculated for different *k*-factors (Figure 4). With this information the maximum *k*-factor of a real connector, used in combination with the tested joint, can be evaluated.

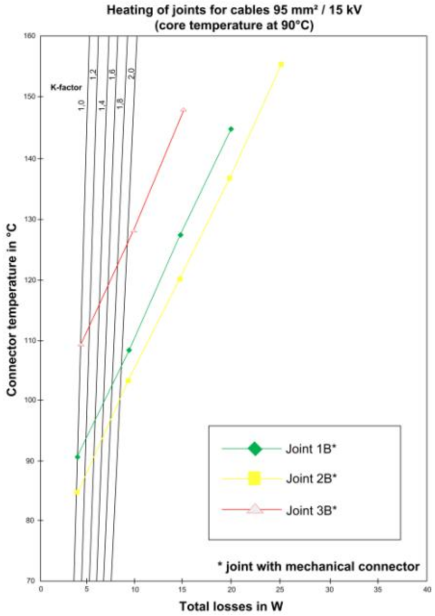


**Figure 4: heat losses for different *k*-factors**

## Conclusions for tests method 1

The temperature in a joint, installed with a connector with the same quality and injected with the same current, can be very different (up to 30 K). Joints with a better thermal behavior are more tolerant for temperature variations that could follow from the decreasing quality of the connector (e.g. due to short-circuits).

For 36 kV joints it is more critical to use emergency temperatures up to 110°C. There was a difference (up to 15 K) in temperature for the tested 15 kV and 36 kV joints.

It is more critical to use emergency temperatures for lower cross-sections. A difference of 15 K was measured in a joint installed on cable with a cross section of 95 mm² and 240 mm² for the same insulation level and connector quality.

For the same *k*-factor a connector with the same length but with a larger diameter shows lower temperatures (up to 3-5 K). The tested mechanical connectors gave in general lower temperatures in comparison to the tested deep indent compression connectors.

## Pass / fail criteria

The $\lambda$-factor ([2]) of a connector multiplied with the initial "cold resistance" ($R_{j0}$) of the connector allows to calculate the resistance of the connector at a temperature of 20°C with the following formulas in [2]:

$$\lambda = \frac{k}{k_0} \qquad R_{j0} = \frac{k_0.R_r.l_j}{l_r}$$

This resistance is recalculated for temperatures of 90°C and 110°C with the following formula:

$$R_{conn}(X\,°C) = \frac{R_{conn}(20°C).(225 + X)}{245}$$

The connector passes the test if:

- $R_{conn}$ (90°C) $I^2 < P_{heat,tot}$ at 90°C with artificial connector
- $R_{conn}$ (110°C) $I^2 < P_{heat,tot}$ at 110°C with artificial connector

With I = the current in the first test circuit.

## TEST METHOD 2: EVALUATION OF THERMAL BEHAVIOR OF CABLE SYSTEM

### Goal of the test method and test set-up

The goal of the test method is to evaluate the thermal behavior of the entire cable system (combination cable, joint and connector) in real conditions.
The test is performed on two standard cables, used by the DGO, with the same cross-section.

The cables that are connected to the joints under test and their cable lugs/terminations can be rigidly fixed on e.g. a wooden floor by means of cable clamps, preventing the cable from bending/snaking. In this way the joints under test are fully exposed to thermo-mechanical behavior caused by the heating and expansion of cable conductors.

From experiments [3] it is deduced that a total cable length of 10 m is sufficient. A cable length > 10 m will not add to the force due to the thermal expansion, which force is theoretically not function of the length of the sample. The complete set-up is shown in Figure 5.

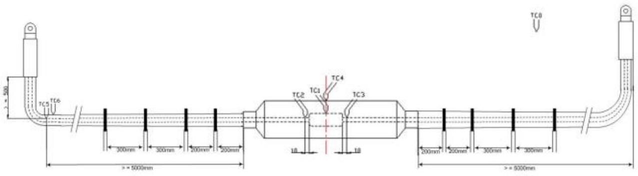


**Figure 5: test set-up for the thermal behavior of cable systems**

The test loop is short-circuited and using current transformers a 50 Hz "heating current" is induced in the test loop in order to stress the cable system with a heating cycle based on IEC 61442 [4]. During each heating period the cable first must be heated to the desired conductor temperature ($TC_5$) within max. 3 hours, and then kept constant for min. 2 hours.

Measurements are noted when the temperature of the cable conductor is raised up to 80°C, 95°C, 110°C and 125°C at the same room temperature.

For the test set-up the following temperatures are measured and logged by a computer:

- $TC_0$: Ambient temperature
- $TC_5$: Undisturbed conductor temperature (not disturbed by the thermal behavior of the connector)
- $TC_6$: Undisturbed temperature of the outer sheath of the cable

For each joint under test the following temperatures are measured and logged by a computer:

- $TC_1$: Temperature of the connector surface
- $TC_2$/$TC_3$: Temperature of the 2 conductors on both sides of the connector at 10 mm
- $TC_4$: Temperature on the outside of the joint body

During the stabilization period of the 4 temperatures, punctual measurements are performed from the outer surface of the joint and the outer sheath of the cable by a thermal imager to locate the hot spot.

### Pass / fail criteria

The result of the test is positive when the following requirements are fulfilled:

- The temperature of the surface of the connector is lower ($TC_1$) than the conductor temperature outside the influence of the joint ($TC_5$).
- The temperatures of the conductor of the cable, measured at 10 mm from the extremities of the connector ($TC_2$ and $TC_3$), is lower than the conductor temperature of the temperature of the cable outside the influence of the joint ($TC_5$).

### Performance & reproducibility

The test methods were developed end of '90 and after more than 10 years of experience we can correlate test results to problems which occurred in the field.

**Results in laboratory**

In a laboratory two types of joint (type X and Y) were tested with different connectors. In the test both mechanical connectors, deep indent compression connectors as well as an artificial connector were installed on a cable type EAXeCWB 8,7/15 kV 1x400 mm² - 3,6 mm insulation thickness. The artificial connector was installed to validate test program 1. The results for a conductor temperature of 90°C are listed below:

| Joint | Connector | TC1 (°C) | TC2 (°C) | TC4 (°C) | TC5 (°C) |
|---|---|---|---|---|---|
| Type X<br>Ø 71 mm | Ø 40 mm<br>l = 218 mm<br>Mechanical | 90,7 | 84,4 | 54,6 | 91,2 |
| Type X<br>Ø 68 mm | Ø 40 mm<br>l = 270 mm<br>Deep indent | 91,0 | 82,9 | 58,6 | 90,7 |
| Type Y<br>Ø 75 mm | Ø 42 mm<br>l = 166 mm<br>Mechanical | 97,8 | 90,5 | 56,3 | 93,0 |
| Type Y<br>Ø 76 mm | Ø 42 mm<br>l = 210 mm<br>Mechanical | 97,7 | 92,1 | 59,8 | 89,4 |
| Type Y<br>Ø 75 mm | Ø 40 mm<br>l = 218 mm<br>Deep indent | 91,2 | 91,7 | 54,6 | 89,5 |
| Type Y<br>Ø 75 mm | Ø 42 mm<br>l = 166 mm<br>Artificial connector | 97,8<br>(with injection of 4,7 W) | 95,4 | 59,5 | 94,1 |

**Figure 6 : table with results by conductor temperature 90°C**

The injected current to reach a conductor temperature of 90°C was 940 A.

| Joint | Connector | TC1 (°C) | TC2 (°C) | TC4 (°C) | TC5 (°C) |
|---|---|---|---|---|---|
| Type X<br>Ø 71 mm | Ø 40 mm<br>l = 218 mm<br>Mechanical | 113,3 | 104,3 | 65,1 | 113,8 |
| Type X<br>Ø 68 mm | Ø 40 mm<br>l = 270 mm<br>Deep indent | 113,1 | 102,2 | 69,4 | 112,9 |
| Type Y<br>Ø 75 mm | Ø 42 mm<br>l = 166 mm<br>Mechanical | 121,4 | 114,6 | 70,9 | 109,6 |
| Type Y<br>Ø 76 mm | Ø 42 mm<br>l = 210 mm<br>Mechanical | 113,6 | 114,2 | 63,7 | 113,4 |
| Type Y<br>Ø 75 mm | Ø 40 mm<br>l = 218 mm<br>Deep indent | 113,1 | 102,2 | 69,4 | 112,9 |
| Type Y<br>Ø 75 mm | Ø 42 mm<br>l = 166 mm<br>Artificial connector | 122,0<br>(with injection of 5,4 W) | 118,5 | 70,6 | 114,9 |

**Figure 7: tabel with results by conductor temperature 110°C**

The injected current to reach a conductor temperature of 110°C was 1040 A.

The underlined temperatures in Figure 6 and 7 indicate a higher connector temperature than the conductor temperature of the cable (result of the test = fail).

## EXPERIENCE FROM THE FIELD

Before the development of the test methods to evaluate the thermal behavior, different joints of type Y in combination with a connector (Ø 42 mm, l = 166 mm) were installed in the field. In 2009 two MV joints failed and after visual examination is was clear that inside the joint an overheating of the connector occurred. Figure 8 and Figure 9 show thermal problems which occurred in the two joints.

**Figure 8: thermal problems in joint 1**

**Figure 9: thermal problems in joint 2**

The connector, used in joint 1 and 2, also gave also bad results when tested by the laboratory test methods.

## GENERAL CONCLUSIONS

Most cable systems installed in distribution networks are not subjected to permanent and high current load profiles and therefore should not suffer from the thermal problems discussed in this paper. Due to more and more decentralized sustainable energy generation there is an evolution of the average load and of the load profiles that could lead to dramatic failures of cable systems in the future.

In reality it is not only the choice of the combination MV cable-joint-connector which allows DGO's to avoid thermal problems. The simulation of the real thermal behavior of a joint must also take into account the thermal resistivity of the soil, where the cooling of the accessories is slowed. Considering the compaction of the soil and the different types of soil around the joints, the average thermal resistivity of the soil can reach high values.

Based on this research it is very clear that the thermal aspects of connectors inside joints are currently not sufficiently covered by the test programs in the international standards. For the DGO's and other industrial clients it is necessary to develop a test program allowing to make a good decision in the combination cable-connector-joint and avoiding thermal problems in present and in future cable networks.

## REFERENCES

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[2] EN 61238-1:2003, *Compression and mechanical connectors for power cables for rated voltages up to 36 kV (Um = 42 kV) - Part 1: Test methods and requirements*

[3] B. Hennuy, E.F. Steennis, B. Aerns, P. Soepboer, P. Buys, P. Leemans, P. Oosterlee, T. Van Rijn, E. De Ridder, H. Grandjean, M. Vandenberg, L. Bokma and R. Meier, 2011, "*Measurement of the force induced by thermal expansion of conductor of MV cables and impact on MV joints*", CIRED, 22nd International Conference on Electricity Distribution, Stockholm, June 10 to 13, 2013, Paper 0128

[4] IEC 61442: *Test methods for accessories for power cables with rated voltages from 6kV (Um=7,2kV) up to 30kV (Um=36 kV).*