THE EFFECT OF HIGH CURRENT LOADS ON JOINTS IN MV CABLE SYSTEMS

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ABSTRACT

Breakdowns in joints in medium voltage cable networks were reason for the Dutch network owners to investigate their background. It was found that a large part of the breakdowns was in one or another way related to high current loads and especially high cycling current loads. In many different ways such high loads cause joints to degrade and the dominant degradation mechanism is the fact that under a high load the mechanical forces from the cable conductor in the joint body become considerable, with sometimes unexpected consequences. In this paper the theoretical background of thermo-mechanical forces in cables and joints will be summarized and also the first results of laboratory experiments will be given, showing that the degradation as observed in service conditions can be reproduced in the laboratory.

INTRODUCTION

Various breakdowns of joints in medium voltage networks prompted network owners in the Netherlands to search for their causes of breakdown. These Dutch network owners, together with KEMA and in a later stage also the Dutch manufacturer of cable joints, Lovink Enertech, decided to investigate the possible causes and possible remedies.

It was found that a considerable percentage of the breakdowns was in one or another way related to problems that have a mechanical background. And in this category it was found that these mechanical problems were enhanced a lot in case of networks operated at a high load, especially in case of a high cycling current load.

Such high (cycling) loads will become more and more common in networks operated to their limits because of economical reasons and because of wind mill parks and other sources of power generation or demand. Therefore, it became clear that certain questions needed to be answered. These questions are:

1 How sensitive are the various types of joints existing already for a long time in the networks?
2 How sensitive are the new types of joints that are being applied in recent years and which will be used in future years as well?
3 In case also new types of joints suffer from these high (cycling) loads, why did type tests carried out in the past not find their susceptibility for high current (cycling) loads?
4 And in case even present type tests do not sufficiently represent high current (cycling) loads, what could be a possible recommendation for an update of these tests?

So far, a study is made of the first two questions.

In this paper, in the first place a summary will be given of the possible degradation mechanisms that can be foreseen under high load (cycling) conditions, with a focus on the thermo-mechanical performance of joints.

The paper will also show the theoretical mechanical forces that might be the result of high loads. Especially the forces that come with the expansion of a conductor will be shown to be considerable.

After these desk study related matters, the focus will go to some laboratory tests that show that indeed certain types of joints are quite susceptible for the above mentioned forces and moreover that these forces are close to those foreseen from a theoretical point of view.

The laboratory tests so far have been carried out on joints for Paper Insulated Lead Covered (PILC, in Dutch: GPLK) cables as mastic (bitumen) filled joints and oil-filled joints. Apart from that, attention is given to conductor connectors that have been and are being applied in all types of joints for all types of cables. The paper will show in what way such joints (or joint parts) are indeed susceptible for the expanding and contracting forces that come with load and load cycling.

JOINT PROBLEMS AS EXPERIENCED

The fact that high current loads cause more joint failures is shown in Figure 1. This is a result from one of the network owners in the Netherlands, created from a database with almost 42.000 joints. Similar experiences were found for other network owners in the Netherlands. Moreover, the network owners in the Netherlands know that a cycling load is more detrimental than a constant load. It was concluded that this fact happened as well for older types of joints (bitumen, oil, silicone or resin insulated), as for the newer types of joints (with an insulation of oil, silicone or heat-/cold shrink material). Also it became clear that joints connected to all types of possible cables and all possible types of conductors were suffering from this degradation, i.e. PILC or XLPE cable with copper stranded or aluminium solid or stranded conductor.

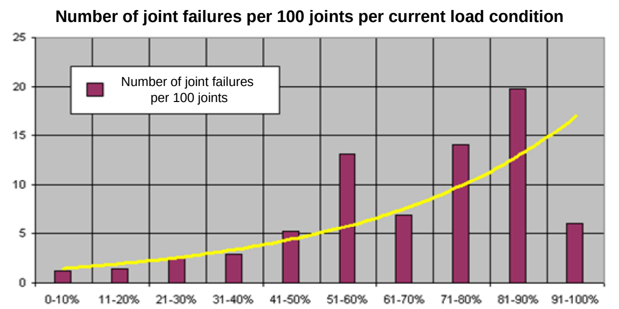

Figure 1 The number of failing joints in relation to the cable load.

In 2007, KEMA and the Dutch network owners involved in this project already studied what the potential mechanisms are that could lead to a higher failure rate of joints at high current loads. A full report on this will be published in a later stage, but in summary the thermo-mechanical mechanisms look like what is shown in Figure 2.

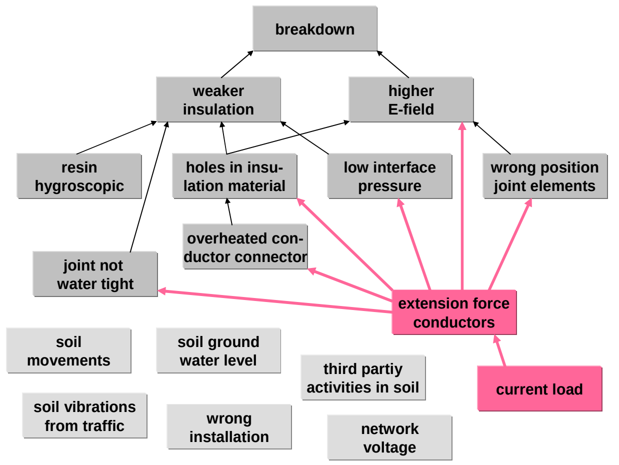

Figure 2 Degradation mechanisms, the high current load is found to be dominant.

For instance, a high cycling current will give large extension and contraction forces on the conductor connector and certainly if the connector is not fully suitable for the cable conductor, the connector will come loose from the conductor. At these high currents and high interface resistance there will be a lot of heat produced, resulting in voids in the surrounding insulation and on its turn this will give high electrical fields in the gas filled voids which already are a weaker insulation material compared to a solid insulation. In the end, the joint will fail. An example of such a conductor connector applied in an XLPE cable joint that caused the degradation of the surrounding joint material is shown in Figure 3. Of course one can claim that we are dealing here with a wrong connector or with a wrong installation. True. But in practice this is a real risk and in the end, the ageing comes with the high current load.

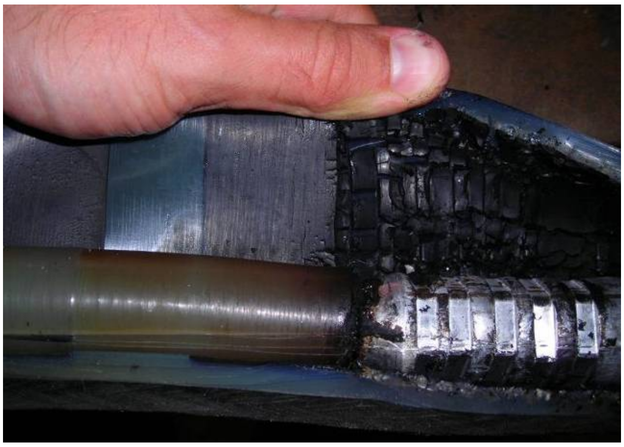

Figure 3 Conductor connector that came loose and thus started to heat its surrounding joint material.

Another example is that the conductors under a high load tend to extend. In an iron cast joint with an insulation of bitumen, oil or silicone, the cable cores can move sideward in the joint through the insulation material and touch the iron casting. When there are bare conductor connectors, a failure will follow. In case the conductor connectors are covered with an extra insulation material, there will not be an immediate breakdown, but during cyclic load the cores will move constantly and multiple bending will in the end lead to mechanical degradation of the insulation (especially in the case of PILC), followed by a failure. An example of a joint that failed in this way is shown in Figure 4.

Figure 4 Joint of the type with a bitumen insulation, where the conductor extension was such that the insulation got damaged in the bend of the cores and the joint failed.

MECHANICAL FORCES IN THEORY

One can calculate the conductor forces and extension. In fact there are two extremes possible and everything in between. The extremes are easy to calculate and this will be done below. These are the following situations a and b:

a There is no conductor extension possible because the conductors are blocked. This might happen if the conductor can't move longitudinally nor sideward, not in the cable nor in the joint, for instance in a cable with a solid conductor and with a resin joint or cold shrink joint, all blocked in the soil. In this case there will be a maximum force in the conductor and no conductor extension. This force, as will be shown, is NOT depending on the cable length involved. The force [Newton] is $F = E \cdot A \cdot \alpha \cdot \Delta T$ in which E = the Young's modulus of the conductor material [N/m^2], A = the conductor cross-section [m^2], α = the coefficient of thermal expansion [ºC^{-1}] and ΔT = the difference of the temperatures of an unloaded cable and the conductor temperature at a certain current load [ºC].

b There is a maximum conductor extension possible because the conductors can move freely and without friction forces. In this case, the forces in the conductor drop to zero. The conductor extension ΔL is depending on the cable length involved. $\Delta L = \alpha \cdot \Delta T \cdot L_o$ in which L_o is the conductor length that is contributing to the extension.

Both situations a and b were calculated for a PILC and XLPE cable with cross-sections of 150 mm^2 and 240 mm^2 under the following conditions

- for aluminium $E = 7 \cdot 10^{10}$ N/m^2; $\alpha = 24 \cdot 10\text{-}6$ ºC^{-1}
- for copper $E = 12.5 \cdot 10^{10}$ N/m^2; $\alpha = 19 \cdot 10\text{-}6$ ºC^{-1}
- the maximum operating temperature for PILC and XLPE cable are respectively 50 ºC and 90 ºC
- the undisturbed soil temperature is 15 ºC
- the cable length contributing to the conductor extension is 10 m.

The results are plotted in Figure 5 for the force and Figure 6 for the conductor extension.

It is interesting to see that the forces and/or extension of a conductor are 4 times higher when the current is doubled. Moreover, forces at highly loaded cable can become considerable, depending on the cable type and conductor cross-section. For example, a fully loaded XLPE cable with a cross-section of 240 mm^2 develops forces per single conductor of 30 kN, assuming there is no conductor extension possible. And in case the conductor of this cable would be able to move freely over a length of 10 m, then the extension would be almost 2 cm. Please realize that these figures are theoretical outcomes, in fact a worst-case approximation. Certainly in case of a stranded conductor where the individual strands / wires might move a bit outwards under the large extension force, the total extension forces in the conductor might be more reduced.

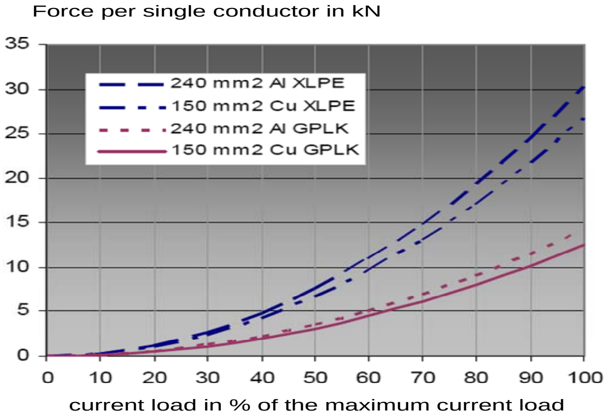

Figure 5 Calculated forces per single conductor in kN as a function of the current load situation for PILC and XLPE insulated cables with a conductor cross-section of 150 mm^2 or 240 mm^2.

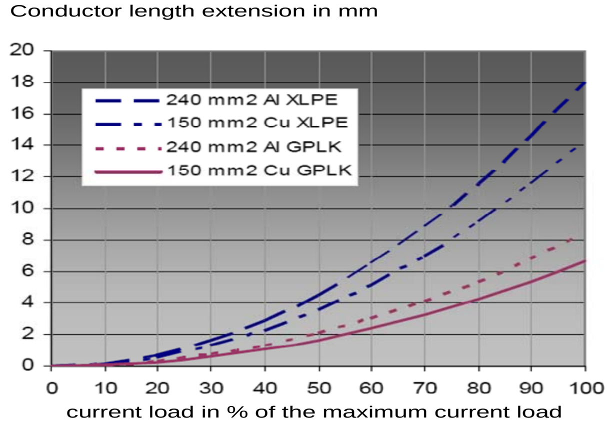

Figure 6 Calculated conductor length extensions as a function of the current load situation for PILC and XLPE insulated cables with a conductor cross-section of 150 mm^2 or 240 mm^2.

LABORATORY EXPERIMENTS

The first experiments in the laboratory were made to check whether it was possible to simulate the "real-life" phenomena as experienced by network owners in many of their failed joints. For that purpose a test set-up was made (shown in Figure 7) where the joint was connected to short cable sections only. On one side the cable is blocked. On the other side a hydraulic cylinder could realize the calculated pressure on the cable conductor and in this way the effect of the mechanical force (up to 50 kN maximum) could be made visible.

Figure 7 Test set-up where the mechanical forces applied to the conductor can be created by oil pressure.

For instance, what could be made visible in this test set-up is the conductor extension where the conductor bends itself sideward, as is illustrated in Figure 8 and Figure 10. Compare this result with a failure as seen in service as shown in Figure 4, Figure 9 and Figure 11.

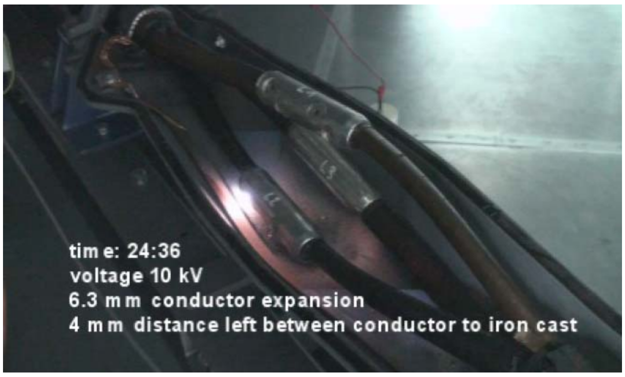

Figure 8 Laboratory result: a conductor extension of 6.3 mm causes a failure in a 10 kV joint (insulation material replaced by air, no upper iron case).

Figure 9 Field result: a similar joint as shown in Figure 8, but failed in service due to conductor extension.

Figure 10 Conductor extension when the force is about 6 kN. The potential degradation of the paper insulation is very likely in case of a cyclic load.

Figure 11 Field result: a similar joint as shown in Figure 10, but failed in service due to conductor extension.

CONCLUSIONS / DISCUSSION

Despite the figures and test outcomes are partly based on theoretical outcomes, it became clear that high and cycling current loads can have a devastating effect on joints. One can question why the present type tests do not show these thermo-mechanical phenomena as can be seen in practice and in the performed laboratory tests. In fact it is concluded that the relevant standards are not fully in accordance with service conditions in distribution networks. For instance: during the "heating cycles voltages type-tests" [1] the conductors freely can expand in the open air, where under service conditions the cable ends always are blocked by mounted terminations or buried joints.

FUTURE WORK PLANNED

The final objective of this research work, will be to derive better testing procedures in which the mechanical stresses from high current loads are better reflected, if needed indeed. Therefore, among others, the following research items are planned:

- Finish comparable tests on bare conductor connectors.
- Perform tests to find the friction, the extension forces and extension length of solid and stranded cable conductors.
- If needed: define a test that is unequivocally definable and feasible and to offer this to get incorporated in the relevant standards.

REFERENCES

[1] IEC 611442, 2nd edition 2005-03, 2005, Test methods for accessories for power cables with rated voltages from 6 kV (U_m = 7.2 kV) up to 30 kV (U_m = 36 kV).