Contact Resistance and Temperature Rise of Cable Connections in Cable Distribution Cabinets

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Contact Resistance and Temperature Rise of Cable Connections in Cable Distribution Cabinets

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Abstract— **Initiated by a number of fire accidents in the low voltage switchgear in cable distribution cabinets, investigations have been performed to identify the cause of these fires. The results indicate that the cable connection was likely to be the cause of the problems, rather than overheating of the fuse links accommodated in the fuse switch disconnector modules. In the relevant equipment, the cable is connected with a cable clamp tightened with a specified torque. However, it was found that by mechanically stressing the cable (moving the cable in order to connect another phase), the individual strands of the cable conductor might be displaced and the contact pressure reduced. Based on these findings, laboratory testing have been done, investigating how contact resistance and temperature rise of the cable connection might vary with the practical execution. The results seems to indicate that applying a cable lug connection could be a more reliable solution. Finally, measurement of temperature rise of properly installed cable connections in the field are made by applying miniature wireless sensor elements. The findings show that during a relatively mild Norwegian winter (ambient temperatures between -5–5ºC) the temperature rise of the cable connection is far below the relevant temperature limits of such contacts set by the IEC 60439-1.**

Keywords—cable, connection, resistance, temperature, distribution, cabinet, low voltage.

I. INTRODUCTION

Our society depends on electricity, and the energy supply needs to be safe and reliable. Heat is always developed when the current flows through electrical equipment and an excessively high heat generation may constitute a fire risk and pose a threat to the safety and reliability of the power supply.

Due to the high portion of electric heating in Norway, the highest load normally occurs on the coldest days. This is favorable since the equipment then experience the lowest ambient temperature, which will limit the temperature of the equipment. However, the increasing use of high power consuming equipment, such as the charging of electric vehicles, means that the energy consumption pattern is changing and one might experience high power peaks at times when the ambient temperature is higher.

In addition, the focus on personnel safety is growing, and requirements that equipment should be "safe to touch" has led to an increased use of encapsulated equipment. Together with the desire to have compact designs, this will reduce the cooling condition of the equipment.

This might be the background for a number of fire accidents occurring in low voltage switchgear in Norway in recent years [1]. The development towards increased use of high power demanding equipment together with the reduced cooling conditions will increasingly challenge the thermal loadability of our electric grid. To reduce the probability of fire in electrical equipment located near the consumers, it is important to map how the utilization of the grid affects components and equipment.

The work presented in this paper focuses on the possible cause of fire in the low voltage (LV) cable distribution cabinets. An inquiry to several utilities in Norway, showed that they mainly suspect a poor cable connection to be the problem for the fire accidents. In this work, investigations are performed to verify if this is a reasonable assumption. This includes laboratory measurements of the contact resistance with focus on parameters affecting the resistance. Especially factors that depend on the installer, as the applied torque, the use of wire brush and grease and mechanically stressing the cable (e.g. moving the cables in order to connect the other phases).

In addition, temperature measurements of cable contact resistances in the field are performed using miniature wireless sensor elements to compare the temperature rise with the relevant limits of such contacts set by the IEC 60439-1 [2].

II. THE NORWEGIAN LV CABLE DISTRIBUTION GRID

Fuses are applied throughout the distribution grid to protect against overloads and short-circuit currents. In the low voltage part of the cable distribution grid, fuses are applied at three different levels, illustrated in Fig. 1:

1. In the LV switchgear in the secondary substations.
   Typical rated fuse currents: 315 – 400 A
2. In the cable distribution cabinets.
   Typical rated fuse currents: 80 – 125 – 160 A
3. At the intake to the customer building.
   Typical rated fuse current: 50 or 63 A

In the secondary substation, due to the diversity factor, the rating of the fuse is much lower than the sum of the fuses connected to it. Here, overloading of the fuses is possible, and therefore also overheating, with subsequent melting, of the fuses.

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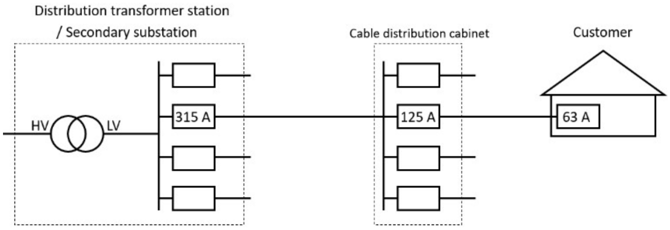


Fig. 1. Simplified overview of the Norwegian cable distribution grid with typical fuse ratings indicated.

For the cable distribution cabinets, the most common situation is that one outgoing branch is feeding one customer with an intake fuse of a lower rating. In this case, the fuse in the cable distribution cabinet only function as a short-circuit protection of the cable, and not as an overload protection. Overheating of the fuse rail due to heating of the fuse is therefore not likely, and the cause of the fires must be faulty installation or malfunctioning contacts/connections. This is also supported by investigations showing that as long as the fuse is working properly, the temperature of any fuse part will not exceed the ignition temperature of the plastic material in the fuse switch module [3].

There are several contacts and connections in the cable distribution cabinet. Most of them factory assembled and to some extent quality controlled, except for the cable connection. Guidelines for connecting the cable properly are normally provided. REN is a Norwegian company providing norms for equipment and installation methods in the Norwegian utilities. In [4] REN has given recommendations for how the connection of the cable should be performed. This involves treating the aluminum cable conductor with a wire brush to remove the oxide layer and apply grease before mounting with a torque wrench, and readjusting the torque after mounting all phases.

In practice, however, these recommendations are not always followed. As part of this study, the authors performed an inquiry to a selection of utilities. The inquiry showed that the cable is not always brushed or lubricated with grease before connected and a torque wrench is not always applied. In addition, there is no systematic post check of the connection. This means that the reliability of the connection is to a large extent dependent on the installer.

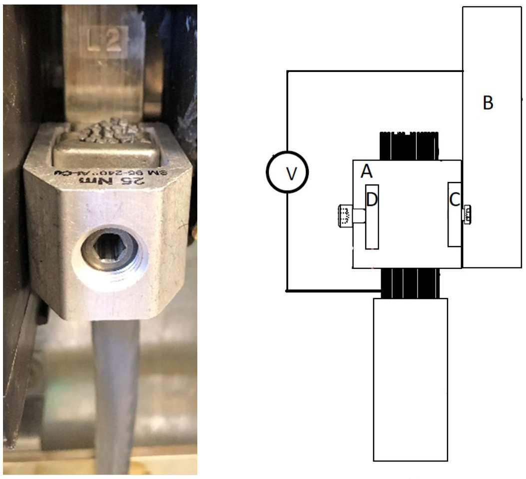
In the following, laboratory investigations of the contact resistance are presented, with focus on the impact of installer dependent factors, such as the influence of different torques, the use of a wire brush and grease, and mechanically stressing the cables (e.g. to fit all three phases).

III. RESISTANCE MEASUREMENTS

Laboratory measurements of the contact resistance of the cable connection was performed on two different cable clamps:

1. Cable cross-section: 10-95 mm^2
   Recommended torque: 15 Nm
2. Cable cross-section: 95-240 mm^2
   Recommended torque: 25 Nm

The cable used for the experiments was a stranded 95mm^2 sector-shaped aluminum conductor, which implies that the cable was in the upper range for the smallest clamp and in the lower range for the larger clamp.



(a) *(b)*

Fig. 2. A stranded 95 mm^2 aluminum conductor fastened in a cable clamp.

One of the cable clamps is shown in Fig. 2. The cable clamps consist of one fixed part (A) that is bolted to the connection bar (B) on the fuse rail by an intermediate piece (C). When tightening the clamp, a movable part of the clamp (D) fastens the cable conductor.

The contact resistance was measured by applying the four-wire method. A DC current of 50 A was feed through the contact, and a voltmeter was used to measure the voltage drop across the cable connection, as illustrated in Fig. 2 (b).

A. *Influence of the applied torque*

In the first test the contact resistance was measured for different torques. In this test, the cable conductor was not brushed or lubricated with grease (except for the grease included in the clamp by the manufacturer). For the cable clamp with 15 Nm recommended torque, the following torques were tested: 11, 13, 15, and 20 Nm. For the cable clamp with 25 Nm recommended torque, the following torques were tested: 21, 23, 25, and 30 Nm. These ranges are assumed to represent approximately the deviation from the recommended torque to be expected when mounting the cable without a torque wrench.

Before each test, the cable was cut so measurements were always performed on a “fresh” cable end, to avoid any possible “memory effect”. The results are shown in Fig. 3. Five tests were performed for each torque, and maximum and minimum value registered is also indicated in the figure.

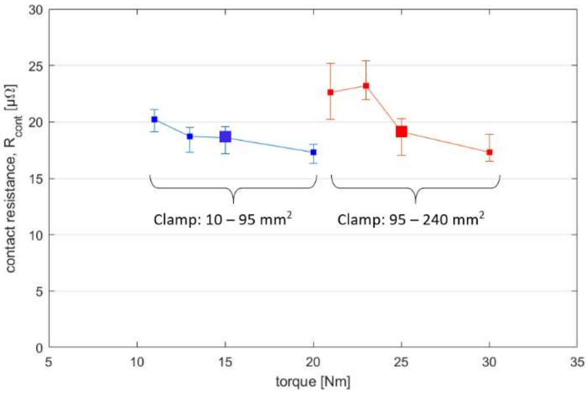


Fig. 3. Average contact resistance for the cable connection as a function of the applied torque for two different cable clamps. The recommended torque is indicated with the largest square marker. The bars indicate the maximum and minimum values of five measurements.

The first thing to notice from Fig. 3 is the relatively high overall contact resistances, around 20 μΩ. Further investigations showed that about 30 % of this contact resistance was the resistance across the bolted contact between the clamp and the connection piece (B and C in Fig. 2), which does not depend on the applied torque.

The second thing to notice, is that the resistance seems to fall with increasing torque, as expected and documented in [5]. It should be noted that for some of the tests, the deviations between identical tests are larger than the deviations caused by changed torque. The deviations between identical measurements seems to be larger for the largest clamp.

The resistances observed exceeding the resistance at the recommended torque, are not believed to cause significant differences in the temperature rise of the connection during normal operation. More tests are needed to get better indication of the repeatability of the measurements.

B. Effect of wire brush and grease

Lubricant or grease is widely used in most types of contacting devices to slow down contact degradation by preventing dust, corrosive gases, humidity, and other damaging agents to reach the small contact spots [6]. Grease is therefore recommended for outdoor equipment, but also recommended by REN for cable connections in cable cabinets. Some cable clamps are pre-greased by the manufacturer.

For this test, three different "treatments" of the cable conductor were compared:

1. Untreated, i.e. not brushed nor greased.
2. Wire brushed, but not greased.
3. Wire brushed and greased.

One would normally expect the resistance to drop when wire brushing the cable end due to the removal of the oxide layers. Applying grease might result in smaller metal-to-metal contact area and therefore higher contact resistance. However, based in the findings in [7], one might also expect a decreased contact resistance when applying grease as it will increase the portion of the applied torque being converted to the axial compressive force.

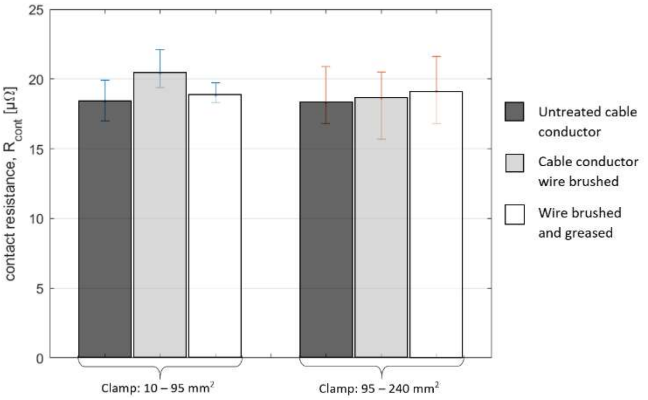


Fig. 4. Contact resistance for different treatments of the cable conductor and two different cable clamp sizes. Average of five measurements. Maximum and minmium values measured are indicated.

The results of five measurements are showed in Fig. 4 where the column heights represents the average of five measurements, while the bars indicate the lowest and highest values measured. It can be seen that only small differences in contact resistance was found for the different cable treatments. The difference was in general smaller than the variation between identical tests. Also here, more tests have to be performed to verify the results.

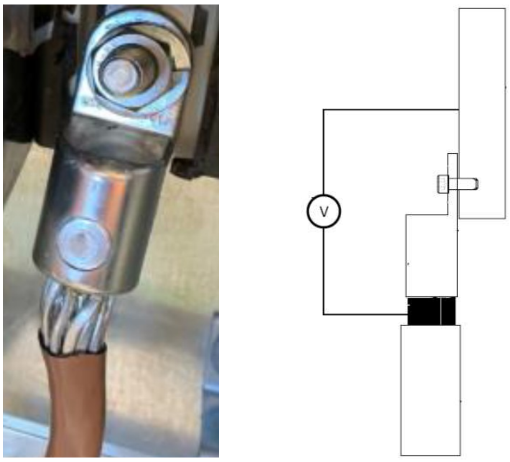
C. Influence of mechanically stressing the cable

In this test, the effect of mechanically stressing the cable was investigated. First, the contact resistance was measured directly after mounting the cable in the clamp with the recommended torque. Then the cable was slightly moved in order to fit the other phases. Then the contact resistance was measured again without readjusting the torque.

The same test was then repeated, but with the cable clamp replaced with a cable lug to see if that would give a more reliable connection. The cable was connected in the cable lug by tightening bolts going through the lug (not mechanically compressing and deforming the lug as for crimping cable lugs), see Fig. 5 (a). Such bolted lugs are often used because they are easier to assemble, as only a socket wrench is required (as opposed to the bulky hydraulic or electrical compression tools). The contact resistance was measured between the cable strands and the connection piece; see Fig. 5 (b).

The results are plotted in Fig. 6. For this test, only one measurement has been performed pr test, giving very uncertain results. For the cable clamp, it can be seen an increase in the resistance after mechanically stressing the cable. This might be caused by displacement of the individual strands of the cable conductor and hence reduced contact pressure. The increase is most significant for the largest clamp where the cable cross section was in the lowest range.

From Fig. 6 it can also be seen that the change in resistance before and after stressing the cable is less when using a cable lug. This might be because the cable clamp is made to fit a relatively wide range of cross-sections, while the lug is designed for one specific cross-section. The results implies that applying a cable lug connection could represent a more reliable solution, less dependent on the installer.



(a) *(b)*

Fig. 5. Cable connection with cable lug.

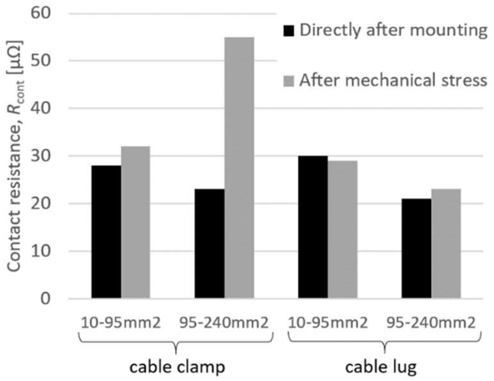


Fig. 6. Contact resistance directly after mounting and after mechanically stressing the cable, for two different sizes of cable clamp and cable lug. Tightened with the recommended torque. Only one measurement pr test.

IV. TEMPERATURE MEASUREMENTS CABLE CONNECTION

Temperature measurements were performed on cable connections in a cable distribution cabinet operating in the grid. The inside of the cabinet is shown in Fig. 7. The left module is the power supply to a so-called cloud connector for the wireless temperature sensors. The next four modules (numbered 5-8 in the figure) are outgoing branches to consumers. The two modules to the right is the incoming cable, and outgoing cable to another cable distribution cabinet. These modules can be connected without being connected to the busbars, enabling disconnecting all customers directly supplied from this cabinet, while still supplying the next cabinet.

The miniature wireless sensors were placed on the upper side of the cable clamp of phase L2 in the four outgoing branches, as indicated in the right hand part of Fig. 7. The outgoing cable was a stranded 16 mm^2 copper conductor. The cable clamp correspond to the smallest one tested in the laboratory (10-95 mm^2).

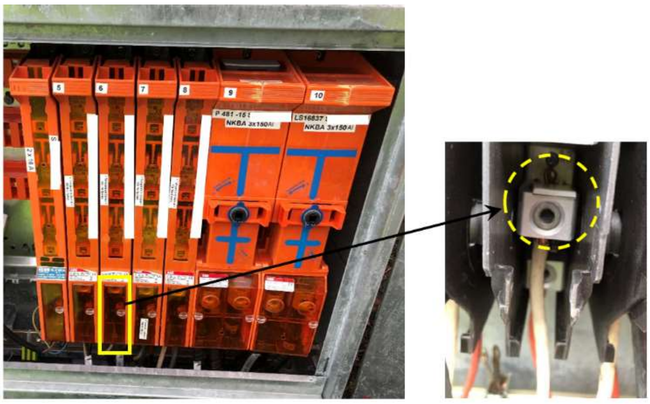


Fig. 7. Left: Cable distribution cabinet with four outgoing branches (module 5-8). Right: Miniature wireless sensor placed on top of the cable connection clamp in phase L2.

The ambient temperature on the day to be analyzed (2020.02.27) varied between -5 – 0°C, as illustrated in Fig. 8. The air temperature measured inside the cabinet (sensor located above the modules) are plotted in the same figure. It is clear that the temperature of the air inside the cabinet follow the ambient temperature, but about 5°C higher.

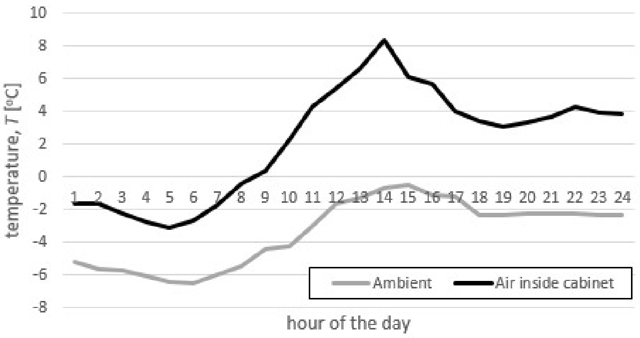


Fig. 8. Ambient temperature and air temperature inside cabinet during the day analyzed.

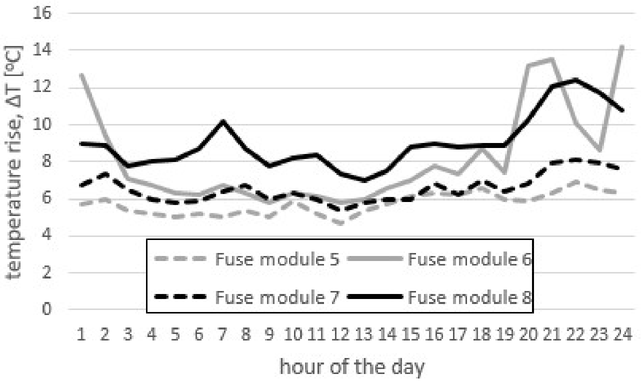


Fig. 9. Temperature rise of the cable connection for the four fuse modules shown in Fig. 7.

The measured temperature rise, ΔT (measured temperature minus ambient temperature) of the cable connections is plotted in Fig. 9. The temperature rise of the cable connection of fuse module 8 is around 8°C, while the other three are around 6°C. This is far below the maximum allowable temperature rise of these connections, which is 80°C according to IEC 60947. This is mainly because of the low load current (around 5-15 A) compared to the current carrying capacity of the conductor, but it also indicates that the cable connection does not represent a critical heat source in this cabinet. The situation might be different in another cabinet with different cable cross-sections, load patterns, cooling conditions and quality of the cable connection.

The situation might also be different on a very cold winter day where the ambient temperature might approach -20°C and the average load might be up to 2 times higher. A warm summer day where the ambient temperature might be 30-35°C, might also give higher temperatures in the cabinet. Then the average load is normally low, but charging of electric vehicles might give high load peaks of shorter duration.

The temperature rise of the connections is a result of the heat generation and heat dissipation (cooling). The heat generation depends on the contact resistance and the load current squared ($P = RI^2$). The average value of the current during each hour could be deduced from the automatic metering modules installed at each consumer. The load current squared for each outgoing branch is given in Fig. 10.

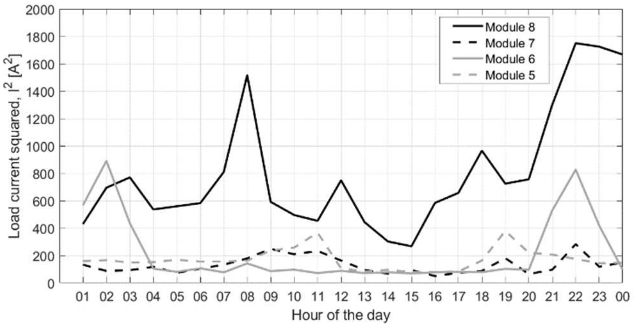


Fig. 10. Load current squared for each of the fuse switch modules in Fig. 6.

Some interesting observations could be made by comparing the temperature rise in Fig. 9 with the load current squared in Fig. 10. By considering the duration 10:00 – 18:00, branches 5-7 had a current square value of about 100-200A^2, while branch 8 was about 600A^2, i.e. a value at least 3 times higher than the other branches. By considering the temperature rise for the same duration, branch 8 had a value only about 1.3 times higher than the other branches. By considering the peaks occurring at 08:00 and 22:00, the difference is even higher.

This might indicate that the resistance of the cable connection for branch 8 is significantly lower than the other three. However, this is not supported by considering the temperature rise of the fuse bodies for each branch. For the fuse bodies, the difference in temperature rise between branch 8 and the rest, is about the same as the difference in temperature rise for the cable connections.

One possible explanation might be that the time constant for the system is in the order of 1 hour or longer, which means the temperature rise is not able to keep up with the rapid changes in the load.

In addition, a dampening effect of the temperature is caused by the effective heat conduction along the current path and heat dissipation to the surroundings (maybe especially to the right hand side for branch 8, where the neighboring modules are generating very little heat because there are no fuses in these modules).

V. CONCLUSION

In this study, installer-dependent factors affecting the quality of the cable connection in cable distribution cabinet were investigated. Environmental factors like temperature, humidity, pollution and the effect over time was not studied.

The investigation presented is relatively limited, and more tests are planned to check the reproducibility of the laboratory results and to observe the situation in the field at more “extreme” ambient conditions. Despite these limitations, a few interesting observations can be made.

Based on the results, it is not believed that the small differences in applied torque (which might happen due to the lack of applying a torque wrench) will cause significant differences in the temperature rise of the cable connections in operation.

The probability of an increased contact resistance if the cable is mechanically stressed after connection, seems to be more important. If the cable is not re-tightened after mounting all phases, a significant increase in contact resistance, and hence increased temperature rise might result. This is believed to be especially relevant if the cross-section of the cable conductor is in the lower range of the cable clamp. Applying a cable lug connection, with the correct dimensions, instead of a cable clamp, seems to be a more reliable solution, less dependent on the installer.

The investigation did not show a significant change in the contact resistance when applying wire brush and greasing. In the long run however, grease has previously proved to contribute extensively to a more stable and sufficiently low contact resistance.

The temperature measurements of the cable connection in cable distribution cabinets in service, showed limited variations in temperature rise, despite significant differences in the load. This is believed to be a result of the relatively long time constants and effective heat conduction along the current path. The temperature rise was well within the temperature limits set by IEC.

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