EXPERIENCES WITH CABLE FAULTS LOCATED AT METALLIC SCREEN CONNECTIONS

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ABSTRACT

Overheating of metallic ground screen connections at accessories of single core cables are the root cause of severe insulation failures in the distribution network. The overheating is due to a high transition resistance of the connections combined with high induced currents in the ground screens during operation. For copper screened cables equipped with a metallic laminate, overheating causing failures are also observed randomly along the cables often at locations close to cable straps or cleats. Currently there are no international standards with complete tests to determine the ampacity of ground screen connections for different cable system designs making future installations more reliable. Furthermore, product information from the suppliers indicates that basis for design and test criteria is not uniform, and tests are not performed concerning relevant operation and fault scenarios. A research project is launched in Norway, to test different ground screen connections and then to provide guidelines to ensure proper future installations. A new CIRED working group is proposed to provide recommendations for complete tests of ground screen connections lacking in current international standards and brochures.

INTRODUCTION

For medium voltage (MV) single core cables it is common to earth the metallic ground screens at both ends. During normal operation (symmetrical current load), currents are induced in the screens due the magnetic field resulting from the conductor currents, in addition to the capacitive charging currents. The magnitude of the induced currents are dependent on the installation geometry (flat or trefoil), magnitude of the conductor currents, and the metallic screen design (i.e. geometry and electrical conductance of the screen elements) [1]. In addition to normal operation, the cable ground screens must be able to carry transient currents originating from induced voltages during short circuit and ground fault conditions, and voltage build up due to transients related to switching and lightening impulses.

The ground screen connections for terminations or joints to the ground screen of the cable should be designed to ensure a reliable service operation. Essentially, there are two different ground screen connection scenarios between the cable and accessory dependent on the cable design: 1) The cable screen consists of copper wires only, and 2) A watertight cable design with an outer metallic sheath laminate in parallel to the copper wires.

The main purpose of this paper is to present some results from analysis of severe cable failures in the Norwegian distribution grid where the breakdown site is located close to the cable accessory. Secondly, to present a review of international standards with respect to testing of ground screen connection designs and compare this with the root cause analysis of the service failures.

CABLE FAILURES AND EVALUATIONS

After about 25 years of experience with watertight cable designs, a number of severe failures have occurred at metallic screen connections. These failures are likely not many, but very costly when they occur. Since service failures of this type are still occurring after many years, it could be suspected that knowledge of the issue is not well known among cable system installers and owners. Grounding of the watertight laminate is normal practice at 145 kV level and above. For medium voltage cable systems, the practice is diverse. Reasons for this could be:

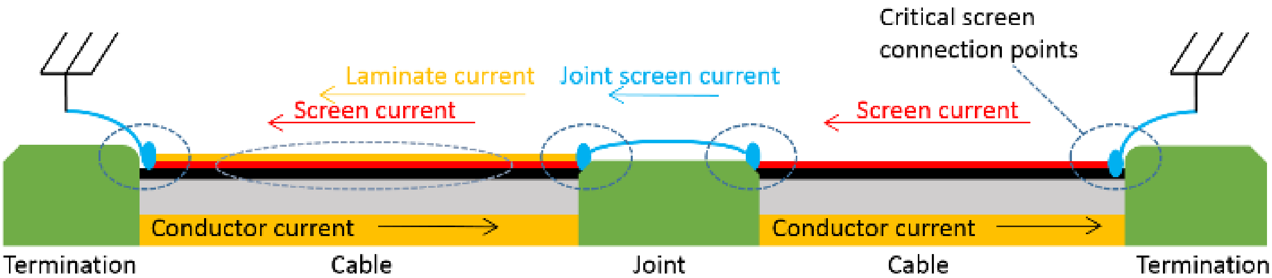

Figure 1. Critical metallic screen connection points at termination, joint and along cable with screen wires and metallic laminate.

- No standard testing regime for screen connections
- Bad design
- Less clear or misleading installation procedure
- Lack of information from supplier of cable and accessories
- Unskilled engineering/installers
- Relative large currents in cable screens for particular installation geometries.

For watertight cable constructions, the cable screen design includes screen wires and a metallic laminate. Currents will therefore be induced in both metallic layers. The size of the current in the screen wire and laminate can be as large as 27 % and 14 % (respectively) of the conductor current [1]. This means that metallic screen connections may have to carry several hundreds of amperes. In addition to normal operation, the cable ground screens must be able to carry transient currents. Thus, the laminate shall be properly connected to the cable ground screen wires at the accessory, especially if there is no direct contact between the wires and the laminate in the cable design.

Some examples of service failures located at metallic screen connections are described in the following paragraphs.

In [2] it was reported that a cable system was installed with screen wires grounded at all terminations, but leaving the aluminium laminate ungrounded. It was detected that arbitrary metallic contact spots were created between the screen and laminate causing overheating due to ohmic losses and finally cable insulation failure. After many costly repairs, it was decided that the laminate should be connected to earth at both cable ends and across all repair joints. A soldering method was applied but unfortunately the work was not properly performed. The final solution was to replace all soldered laminate connections with abrasive plates. The cable screens were grounded at one end only resulting in no induced currents. The induced voltage at the end terminal was less than 20 V. Neither of the screen connection methods were tested according to international or national standards since no relevant standard was available. The customer had to trust the manufacturers internal test results and recommendations.

Cable joints with overheating at the screen connections has also been observed [3]. The cable was watertight and equipped with a copper screen and an aluminium laminate. At the cable joints, the copper wires of the cable and copper mesh of the joint kit were not interconnected directly, but was instead interlaced by two layers of spring clamps. The roll-spring was made from stainless steel that has a significantly lower electrical conductivity than copper. Close to the roll-springs, there had been severe heating as significant discoloration of the exposed XLPE was visible. In addition, the copper ground wires of the cable had been forced into the (soft) insulation screen resulting in an uneven interphase between the layers. Better understanding of the screen connection criticality for such installation with high load currents would probably have avoided the incorrect use of roll-springs.

Prior to use, screen connection systems are only subjected to a thermal short circuit test (2 times the short circuit, no breakdown) according to the standards [4 - 7]. At present, it is left to the manufacturers to test their own designs and decide the ampacity limits. Improper design of the metallic connection between laminate and screen wires will lead to hot spots, resulting in ageing and melting of the polymer materials involved. Material deterioration by overheating can typically be caused by ohmic losses in the connection point, induced losses in metallic elements of the screen connection kit, or due to bad installations. It is important to consider (moderate) overheating conditions where no immediate or rapid service failure occurs. High temperatures subjected to the polymer materials in the cable joints cause thermal expansion and thermal oxidation. Both these two phenomena can induce partial discharges in the insulation system. By time, this will cause service breakdown as the polymer materials involved are susceptible to degradation by partial discharges.

Some cable designs allow direct contact between the laminate and the ground screen wires along the cable. The contact resistance may increase over time, due to oxidation of the aluminium surface [8], making it challenging to make good electrical connections along the cable. The main reason of the reported service failure is due to poor performance of the contact between these two elements, as faults occur mainly close to cable joints and at the end terminations. However, faults also occur close to cable straps where the cable is compressed and the copper screen may be in contact with the laminate. Essential information why and how to carry out the screen terminations may not always be sufficiently emphasized.

Large currents

For some cable system configurations (typically large cross sections, flat formation, grounded metallic screens at both ends), the screen and laminate current can become very large (hundreds of amps). Lack of understanding of the phenomenon of screen and laminate current in the engineering phase may lead to design of cable systems using wrong equipment. The engineers need simple but robust calculation tools to estimate the screen currents, thus enabling them to plan long lasting cable systems.

Defining the screen area

Many failures could probably been avoided with the correct knowledge of the different cable types and accessories qualities. For example, there is different practice among countries and manufacturers whether the metallic laminate is considered as a current carrying part of the screen circuit. This is further complicated by a diversity of manufacturers for accessories. The data sheets provided by the manufacturers do not always give sufficient information of the laminate and copper screen cross section. The copper screen may be specified as e.g. 35 mm^2 for a 12 kV cable with 240 mm^2 cross section, but the laminate (typical 0.2 mm thick) may also be included giving a reduced copper screen cross section. This implies that the effective equivalent copper screen cross section e.g. is 25 mm^2 and equivalent laminate copper cross section is 10 mm^2 [1].

Methods for screen and laminate connection

The most common methods for connection at the accessories are:

- Abrasive plate over/under laminate, fastened by roll-springs/collar-ties/or similar
- Clamping rings
- Welding

Generally, cables are made with either an "open" or a "closed" design. Closed design means that a semi conductive tape is installed with an overlap. Open design means that the semi-conductive tape is helically wound with a distance between each layer. The wires and laminate are then in electrical contact with each other in the sections between the layers.

Regardless of the cable design (open or closed design), it is recommended to maintain a good electrical contact between screen wires and metallic laminate during the complete life of the cable [9]. This can be achieved either at accessories or by design along the cable length. Further, it is also advised to avoid designs with roll-springs or pressed contacts for currents above 200 A, and no bunching of screen wires. Pressed contacts perform satisfactory when single point grounding is used. For voltages equal to or higher than 150 kV, due the expected high short circuit current and time duration, pressed contacts are anyhow not recommended.

Little or no work is reported on the dynamic performance (expansion due to temperature variations) of cable screen connections. Some national standards have been proposed and are currently being reviewed [10].

A "best practice" for the installation of medium voltage cable accessories has been published [11]. According to the report, the installer carries the responsibility for checking whether the earth bonds provided with the accessory are adequate, and to stop if in doubt. This is a difficult (if not impossible) task as none of the international standards gives adequate test recommendations.

AVAILABLE STANDARDS AND RECOMMENDATIONS

Requirements to metallic screen connections are not well covered in current standards. The type test sequences of both IEC and CENELEC miss a complete test of equipment for ground screen connections to determine their ampacity. For many utilities the in-house competence and knowledge on these details is lacking, and the compatibility with respect to this issue for the cable and cable accessories are often not known. This could also include a lacking estimation of ground screen currents for the actual installed cable system.

CENELEC and IEC

The CENELEC cable standard [12] part K (Norway) states that: "Provided there is electrical contact between the wire screen and the metallic tape its conductance may be regarded as part of the metallic screen". The standard does not define the quality of the electrical contact between the layers. If the metallic tape is of aluminium, the effect of the aluminium oxide layer should not be disregarded. Aluminium oxide is an insulator, with electrical resistivity 10^{14} Ωcm [8]. The practical consequence of a thin layer of aluminium oxide will therefore be that the electrical contact resistance between two layers of aluminium could be very high. A sufficient electrical contact will only be made if this layer is breached (by force).

The accessories standard [4] and [5] states that the required test for accessories equipped with a connection to, or adaptor for, the metallic screen of the cable is the thermal short circuit test. The test requirements: two short circuits at I_{sc} with no breakdown.

The test methods are described in [6] and states that the current I_{sc} and duration t shall be agreed between manufacturer and customer taking account the actual short-circuit conditions in the network. The cable conductor shall be heat conditioned 5 K to 10 K above normal operation temperature before carrying out the test. Between the two short-circuits, the cable screen shall be allowed to cool to a temperature less than 10 K above its temperature prior to the first short-circuit.

In [7] a description of a short circuit test and an earth fail short circuit (spike test) for the cable screen can be found, but it does not include any test of the metallic screen connection.

The present CENELEC and IEC tests does not verify the thermal ampacity limit or the long-time quality of the cable screen connections, and thus has limited value for normal service performance.

CIGRÉ

Historically CIGRÉ has considered cable systems above 36 kV, however many aspects may be applicable for medium voltage systems. Recommendations and user experience with laminated cables and screen connections have been presented [9]. It is recommended to perform a test in which the single-phase short circuit current can flow through the metal screen, the metal screen / accessory connection, the ground lead of the joint or the termination. The test is performed simultaneously on cable, the connection to accessories, the accessories, the grounding connection, and the grounding cables. There shall be five short circuits with conductor temperature stable at 90 to 95 °C for 2 hours prior. The cable screen shall cool down within 5 K of initial temperature between tests. A visual examination shall conclude the test. The recommendations have not yet been adopted by the high voltage standards [13, 14]. According to [9], thermal cycle test and thermo-mechanical tests are already addressed in the high voltage standards for cable systems. Type test, routine tests and after installation, tests beyond the high voltage standards are not considered useful by the technical brochure. However, neither [9] nor [13, 14] verify the screen connections continuous thermal ampacity limit through tests.

TB476 Cable Accessory Workmanship on Extruded High Voltage Cables [15] have some practical recommendations on work with screen connections.

National standards

French medium voltage XLPE cables are designed with a longitudinally applied aluminium foil screen bonded to the oversheath. A specific device, called "screen plate" has been developed to interconnect the screens. EDF in France has worked on upgrading their national standard for aluminium laminate screen connections based on laboratory tests and results. The work has been ongoing for several years [10].

More national standards may exist, but with naturally limited benefit for other countries with no national norms on the subject.

Summary of standards and recommandations

Table 1 summarises the metallic screen connections pre-qualification and type-tests included in the standards.

Table 1. Summary of standards and recommendations

Standard	Test	Comment
CENELEC HD620	N/A	Describes the general design requirements applicable to the cables
CENELEC HD629	Short Circuit Test ($2xI_{sc}$) + Visual examination	Accessories. Only fault condition tested.
CENELEC HD605	Short circuit test + spike test	Cables alone. Only fault condition tested.
IEC 60502-4	Requirements for short circuit test ($2xI_{sc}$) + visual examination	Accessories. Only fault condition tested.
IEC 61442	Method for short circuit test	Accessories
CIGRÉ TB446	Short circuit test ($5xI_{sc}$) + visual examination	For cable systems > 36 kV. MV cable systems not considered
National Standards	Uncharted	Relevant tests may be described in national standards.

FURTHER WORK

A project with partners from Norwegian utilities, international cable and cable accessories manufacturers was started in 2017 and is planned to be completed during 2019. The main objective is to establish a guideline for testing and installation of ground screen connections in power cables to avoid future service breakdowns and to increase the reliability of distribution and transmission cable networks. Some of the activities are mentioned below.

Laboratory test of screen connections

The project plans to test commercially available cable screen connections. The connections will be examined by applying constant and dynamic current loading as well as overvoltages and transients. The tests will examine the ampacity limit and endurance for the screen connections. The relation between the contact pressure and the viscoelastic properties of the polymers involved will be studied in detail. Known root causes for service failures will be reproduced in the laboratory to confirm failure mechanisms.

The standards for testing compression and mechanical connectors [16] may be useful since the aspect of testing the connections with thermal heat cycles, short circuits and resulting contact resistance before and after tests imitate relevant operation and fault scenarios for metallic cable screen connections.

Establishment of CIRED working group and international standards

The project aims to establish a joint working group within CIRED. The goal is to survey failure types and recommend test procedures for ground screen connections for power cables to determine their ampacity. The specific activities will be as follows:

- Survey different cable and cable accessory designs and connection types
- Provide an overview of failure types in MV (and HV) cable system components related to overheating in ground screen connections
- Propose a qualification test for power cable ground screen connections
- Issue a report with test recommendations for ground screen connections

CONCLUSIONS

Service failures associated with metallic cable screen connections still occur after being in the market and used for many years. The reasons for this are probably a combination of several factors:

- Missing international standard for testing to determine the ampacity of the connections
- Lack of understanding of the physical and electrical phenomenon ongoing in cable screens and accessories
- Misleading or difficult installations procedures
- A diversity of manufacturers for accessories and cable with different solutions

A CIRED working group will hopefully find solutions and give recommendations to this problem, with help from national representatives and ongoing projects.

MISCELLANEOUS

Acknowledgments

The project behind the findings in this paper is partly funded by the Norwegian Research Council and partly by the members of the industry research project *Reliable Power Cable Screen Connections* lead by REN AS.

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