Science.
Applied to Life.™

Splice reliability:
an assessment of five factors affecting the life expectancy of a medium voltage electrical splice

George Fofeldea
Power Engineer, 3M Canada

August 2019

Abstract

How long can a medium voltage splice last?

There are many parameters that help to determine the overall life expectancy of a splice. Of these parameters, there are five key reliability identifiers that give us great insight when estimating the overall life expectancy of an electrical splice. Those five identifiers are:

1. **Technology**
2. **Materials**
3. **Design**
4. **Workmanship**
5. **Testing procedures**

Table of contents

Introduction	4
Materials and methods	4
Discussion	4-5
1. Technology	5
1.1. Disadvantages of heat shrink splice technology	*5*
1.2. Disadvantages of push-on splice technology	*5*
1.3. Advantages of cold shrink splice technology	*5*
2. Materials	6
3. Design	6-9
3.1. Electrical stress inside the splice	*6*
3.2. Complete continuation of all cable layers	*8*
3.3. Margin of error in installation	*8*
3.4. BIL voltage	*8*
3.5. Quality and reliability in manufacturing	*9*
4. Workmanship	9
5. Testing procedures	9
Conclusion	10
Tables and graphs	10
Figure 1: Temperature profile for a 15 kV splice configuration	*10*
Figure 2: 15 kV stress plot	*11*
References	12
Important notice	12

Introduction

3M™ Cold Shrink QS-III Splice was designed for easy cable splice installation and high reliability. It was introduced to the North American market in 1996.

The silicone rubber QS-III design revolutionized power cable splicing by addressing the installation pitfalls of traditional splices, which required pushing, pulling or heat. By eliminating the need to apply heat and force, 3M™ Cold Shrink QS-III Splice offered the market a safer and more reliable solution to splicing medium voltage power cables.

Our over 23 years of field experience with 3M™ Cold Shrink QS-III Splice and over 40 years of field experience with 3M™ Cold Shrink QT-II and 3M™ Cold Shrink QT-III Terminations (Fofeldea G. 2018) helps us formulate a more robust understanding regarding the life expectancy of medium voltage cable accessories.

Did you know?

3M invented cold shrink technology over 50 years ago!

Materials and methods

Medium voltage electrical splice life expectancy was determined using five critical reliability factors: **technology, materials, design, workmanship and testing procedures.**

The evaluation: an examination based on 3M™ Cold Shrink QS-III Splice's 23 years in the field, failure investigation reports, and 50 years of cold shrink materials and design experience.

Discussion

By looking at the five reliability factors that affect the life expectancy of a medium voltage cable splice, this paper aims to identify the product with the highest reliability.

1 Technology

1.1. Disadvantages of heat shrink splice technology

In general, heat shrink splices require more installation steps compared to cold shrink splices (e.g., applying heat so the splice can conform to the cables) – leaving more room for installation error.

Uneven heat application can result in burning different heat shrink layers and uneven wall thickness. If such mistakes are made during the installation process, the life expectancy of a heat shrink splice can be reduced.

1.2. Disadvantages of push-on splice technology

Aside from the more cumbersome installation steps (i.e., greasing cables, pushing splice body back and forth, asymmetrical cable preparation cutbacks, etc.), one significant disadvantage of push-on splices is the limited tolerance during installation. The push-on splice design only allows for a minimal semi-con overlap of ½ inch and a freshly installed splice can easily move, reducing this critical overlap.

For optimal life expectancy, a push-on splice must provide enough initial pressure so that it does not electrically fail. Additionally, the initial installation pressure must be low enough to allow for pushing the splice body onto the cable. However, research shows that for push-on splices, up to 90% of the initial pressure is lost during heat cycles (Amyot, N., et al. 2001), which reduces the overall life expectancy of the splice. **Comparatively, the initial pressure in 3M™ Cold Shrink QS-III Splice is much higher and thermal cycles do not lower the pressure, which results in improved cable splice reliability.**

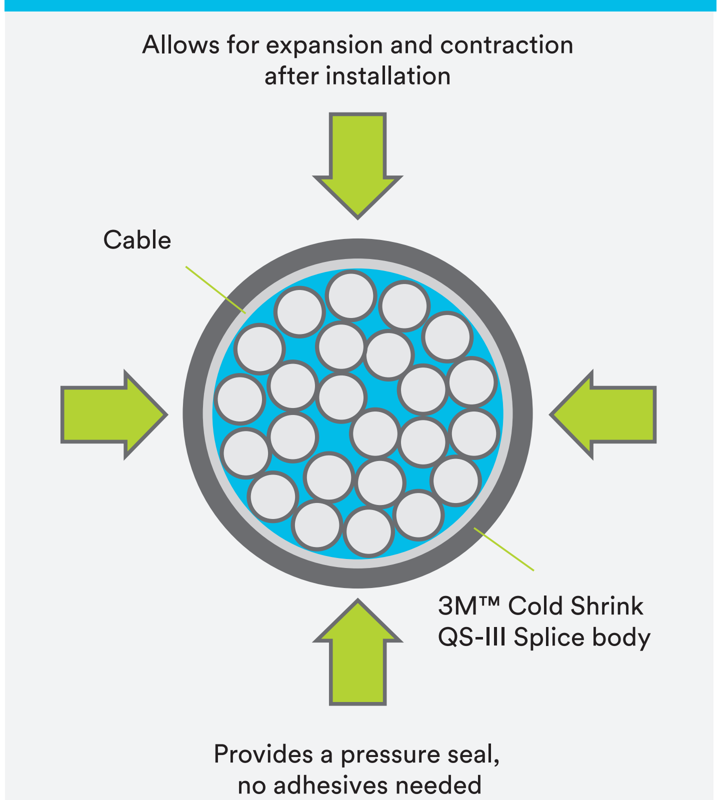
1.3. Advantages of cold shrink splice technology

None of the disadvantages highlighted above apply to 3M Cold Shrink Technology. 3M designed this technology for long-term reliability – **to last the life of the cable while helping to ensure excellent electrical performance**. The dynamic "living" seal expands and contracts with variations in temperature and load on the cable.

The 3M™ Cold Shrink QS-III Splice firmly shrinks onto the cable insulation – **providing an active seal, without loss of pressure due to cable heat cycling.** Additionally, 3M™ Cold Shrink QS-III Splice has a wide application range, and the overall splice body design (i.e., length of semi-conductive inner electrode or outer shell) is designed to help minimize potential installation errors.

3M™ Cold Shrink QS-III Splice provides constant inward pressure

A "living" seal



② Materials

When considering cable splice life expectancy, we also must evaluate the various materials used to manufacture cold shrink splices. There are two main types of materials used to manufacture cold shrink splices: **ethylene propylene diene monomer (EPDM) rubber** and **silicone rubber.**

The splices made from EPDM rubber have a lower elasticity coefficient, making them more difficult to install in cold weather. As a result, this material sometimes requires heat to shrink onto the cable.

130°C or 140°C

There are two types of silicone rubber materials used to manufacture cold shrink splices:

1. a clear, "unfilled" liquid silicone rubber
2. one that is "filled" with thermally conductive additives

The heat dissipating additives used in the 3M™Cold Shrink QS-III Splice enables us to meet the 130°C or 140°C cable emergency overload temperature requirements of IEEE 404, on both aluminum and copper conductors. (IEEE 404 requires that heat cycling testing be done at cable emergency overload temperature.)

3M™ Cold Shrink QS-III designs are tested to the worst-case scenarios on aluminum (AL) conductors with AL compression connectors, and cross-linked polyethylene (XLPE) insulation. Because of the unique silicone material used for the 3M™ Cold Shrink QS-III Splice the connector area in a 15 kV 3M™ Cold Shrink QS-III Splice typically runs 10°C – 15°C cooler than the conductor itself ***(see Figure 1 on page 10)***. This is important because a good thermal heat dissipation by the splice body helps prolong life expectancy of an installed splice.

③ Design

Splice body design has an important influence over the long-term reliability of a medium voltage cable splice – directly impacting the life expectancy. Since we learned above that the material used for 3M™ Cold Shrink QS-III Splice **helps to prolong** life expectancy of an installed splice, we will now evaluate the design of 3M™ Cold Shrink QS-III Splice.

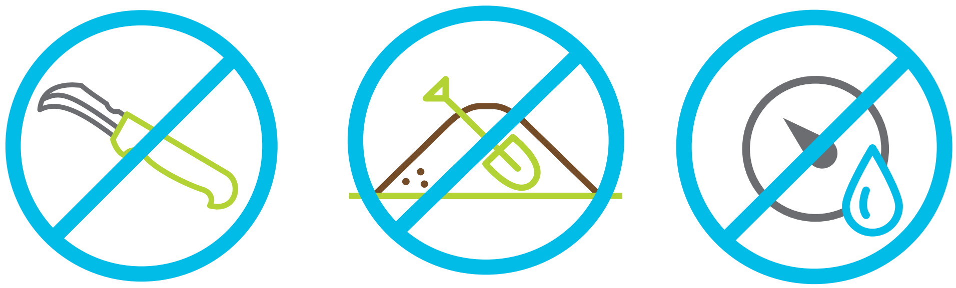
3.1. Electrical stress inside the splice

The electrode design of the 3M™ Cold Shrink QS-III Splice is unique. It is designed to help provide precise control and management of the electrical stress along the cable-insulation interface and over the connector shield within the splice insulation. The precision geometry incorporates rounded inner electrode ends with an undercut inner electrode design and rounded outer semi-conductive shell to help reduce electrical stresses.

The 3M™ Cold Shrink QS-III Splice design requirements call for the maximum interfacial stress to be no greater than half of the stress over the connector shield and the maximum stress over the connector shield to be approximately equal to two-thirds of the maximum stress in the cable ***(see Figure 2 on page 11)***.

Due to 3M™ Cold Shrink QS-III Splice's precise geometry, the electrical stresses within the splice are less than those experienced by the cable insulation. E4 in **Figure 2** is the highest electrical stress for a 15 kV cable and is approximately 72 V/mil. The maximum stress in the 3M™ Cold Shrink QS-III Splice Body for a 15 kV cable is E2 and is approximately 36 V/mil – about half of E4. The installer cannot interfere in any way with E2 since it is inside the splice body (in other words, 3M manufacturing controlled). T**his low E2 stress enhances the safety and reliability of the splice body**.

Furthermore, E3 in **Figure 2** is situated at the cable insulation-splice body interface. E3 is an extremely important point since any cable preparation inconsistencies (e.g., potential knife cuts, dirt, humidity, etc., on the insulation) will increase the stress in this area.



With 3M™ Cold Shrink QS-III Splice's unique undercut inner electrode design, E3 is only 12.7 V/mil and allows for enhanced safety and long-term performance.

To help demonstrate the positive impact of this intricate and precise geometric stress control design, we must look at the basic impulse levels (BIL) of the 3M™ Cold Shrink QS-III Splice.

The 3M™ Cold Shrink QS-III Splice is rated one BIL higher than the corresponding splice classification; e.g., 25 kV splices meet the BIL requirements of 35 kV splices. This superior BIL classification is testimony to the low stresses inside the splice bodies, **thus enhancing long-term reliability and improving the overall life expectancy**.

In a correctly installed 3M™ Cold Shrink QS-III Splice, the electrical stress in the splice is less than the stress in the cable.

E1, E2, E3 < E4

A well-designed splice combined with high-quality manufacturing, and a correct installation can remove the traditional splice weak link in a cable and increase life expectancy of the cable splice installation.

There are some cold applied splices, manufactured using EPDM rubber. In some designs, the manufacturing process of the EPDM-cold applied splices requires the grinding out of the inner conductive layer to provide the insulation interface. This provides a sharp point on the end of the electrode and a step between the insulation and the electrode, which is why a large amount of grease is required to lower electrical stress at these points.

In contrast, the 3M™ Cold Shrink QS-III Splice electrode is molded and designed so that the electrode has a round shape, to help minimize the electrical stress. **Minimizing electrical stress helps provide better long-term performance**.

Furthermore, some EPDM-cold applied splices have a separate cold applied insulation shield as part of the manufacturing process. As a result the complete splice body cannot be tested to the two production test requirements as requested by the IEEE 404 – the standard allows for different material and subcomponent tests in exchange.

3M™ Cold Shrink QS-III Splice is one molded splice body and each body is tested according to the production test requirements of the IEEE 404, which help enhance safety and reliability.

3.2. Complete continuation of all cable layers

3M™ Cold Shrink QS-III Splice continues all the layers of the cable. The outer shell of the splice consists of a thick 3-4 mm layer of semi-conductive material, with short-term short circuit current initiating capacity. This layer overlaps the cable semi-conductive layer with a firm grip, and forms a solid shield of semi-conductive material, from one side to the other of the splice.

This helps provide long-term reliability insurance, as it does not rely on a copper mesh for semi-conductive layer continuity, as seen with other cold applied designs.

The 3M™ Cold Shrink QS-III Splice bodies comply with the requirements of the IEEE 592 (also known as the "nail test"). This is because of the thick, molded outer semi-conductive shell. Other cold applied designs use a thinner painted outer semi-conductive layer and cannot comply with the IEEE 592 requirements.

While compliance to IEEE 592 is not mandatory as per IEEE 404, **3M™ Cold Shrink QS-III Splice does comply with the IEEE 592 test, offering a superior and more reliable product**.

3.3. Margin of error in installation

The length of the 3M™ Cold Shrink QS-III Splice allows the outside semi-conductive layer to extend over the cable semi-conductive layer, past the minimum ½ inch requirement. This makes the splice more forgiving when it comes to mispositioning errors.

Similarly, the inner semi-conductive electrode is quite long, allowing for use of any long or short connectors and minimizes mistakes in insulation length removal.

Therefore, the design of 3M™ Cold Shrink QS-III Splice helps decrease the margin of error during installation.

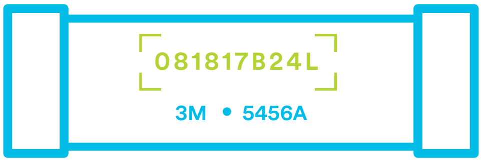
3.4. BIL voltage

As described in **Section 3.1**, 3M™ Cold Shrink QS-III Splice is tested for a normal AC voltage level (e.g., 15 kV, 25 kV, 28 kV, etc.) and exceeds the BIL requirements of the next AC voltage level. This is due to the low electrical stress design criteria that 3M employs and the many design features that are incorporated in the 3M™ Cold Shrink QS-III Splice body.

Basic Insulations Levels (BIL) reveal the safety and reliability of a given design, which is why successive BIL test rounds are done in the IEEE 404. It should also be noted that 3M conducts other internal tests, exceeding IEEE 404 requirements. For example, a 25 kV AC splice is required to pass a 150 kV BIL.

Our data sheets report that the 3M™ Cold Shrink QS-III Splice passes 200 kV BIL levels, and in some instances where we tested BIL to destruction, it achieved levels of up to 260 kV BIL.

3.5 Quality and reliability in manufacturing



Each individual 3M splice body is factory tested – two production tests (PD and AC withstand) are performed. A manufacturing date stamp on a 3M™ Cold Shrink QS-III Splice indicates that the splice body has passed both production tests and are defect-free. As a result, it is unlikely for a customer to receive a defective product.

4 Workmanship

Workmanship is a key component in every power cable accessory installation.

Although 3M™ Cold Shrink QS-III Splice is designed to help mitigate many installation errors through design, proper cable preparation techniques must be employed.

The same cable preparation techniques are to be used regardless if the cable will be spliced or terminated on a pole or terminated through an elbow or deadbreak.

3M application engineers conduct failure investigations and provide end users with analysis reports that identify root causes for failures and make suggestions for improving installations. The majority of these laboratory investigations pinpoint poor workmanship in cable preparation techniques as the leading root cause for the failures, in conjunction with/or separate from other types of mistakes (e.g., mispositioning of the splice body, wrong cutbacks, connector related installation mistakes, incorrect use of certain tapes, etc.).

Did you know?

3M offers online training modules to help our customers improve their cable preparation skills and medium voltage splice installation techniques. Ask your 3M sales rep to learn more.

5 Testing procedures

Many different cable testing procedures are available and used in the field. The IEEE 400 describes the test methods and procedures. Not all test methods are equal in the sense that the cables are stressed differently. The IEEE 400 also lists the advantages and disadvantages of the given test methods. For example, over the years many utilities have moved away from Direct Current High Potential (DC Hi-Pot) testing due to the many drawbacks that this type of testing presents and since it ages and speeds time to failure of an existing cable with incipient defects before testing. Type testing done in 3M laboratories both on new and aged splices removed from the field help us understand long-term performance and help better predict life expectancy.

Field cable testing depending on the exact test method employed can negatively impact the remaining cable life and the estimated life of the splices in that loop. The testing conditions, the test method, the number of tests done over the life of the cable with splices included in the circuits, are all factors that must be considered when estimating life expectancy of cables and splices. Many of these factors are within the unique control of the utility.

Conclusion

The life expectancy of the 3M™ Cold Shrink QS-III Splice helps meet or exceed the life expectancy of the cable because 3M employs the best materials, design and manufacturing techniques available, to make the most reliable splice possible.

Over 23 years of excellent 3M™ Cold Shrink QS-III Splice track record in conjunction with over 50 years of cold shrink technology innovation have led to the development of cold shrink splice and termination products for applications up to 69/72.5 kV (3M Company. 2012) that have helped enhance the safety, reliability and life expectancy of cable accessories.

For more information about 3M electrical products and solutions, contact us at **3Menergysolutions@mmm.com**.

Tables and graphs

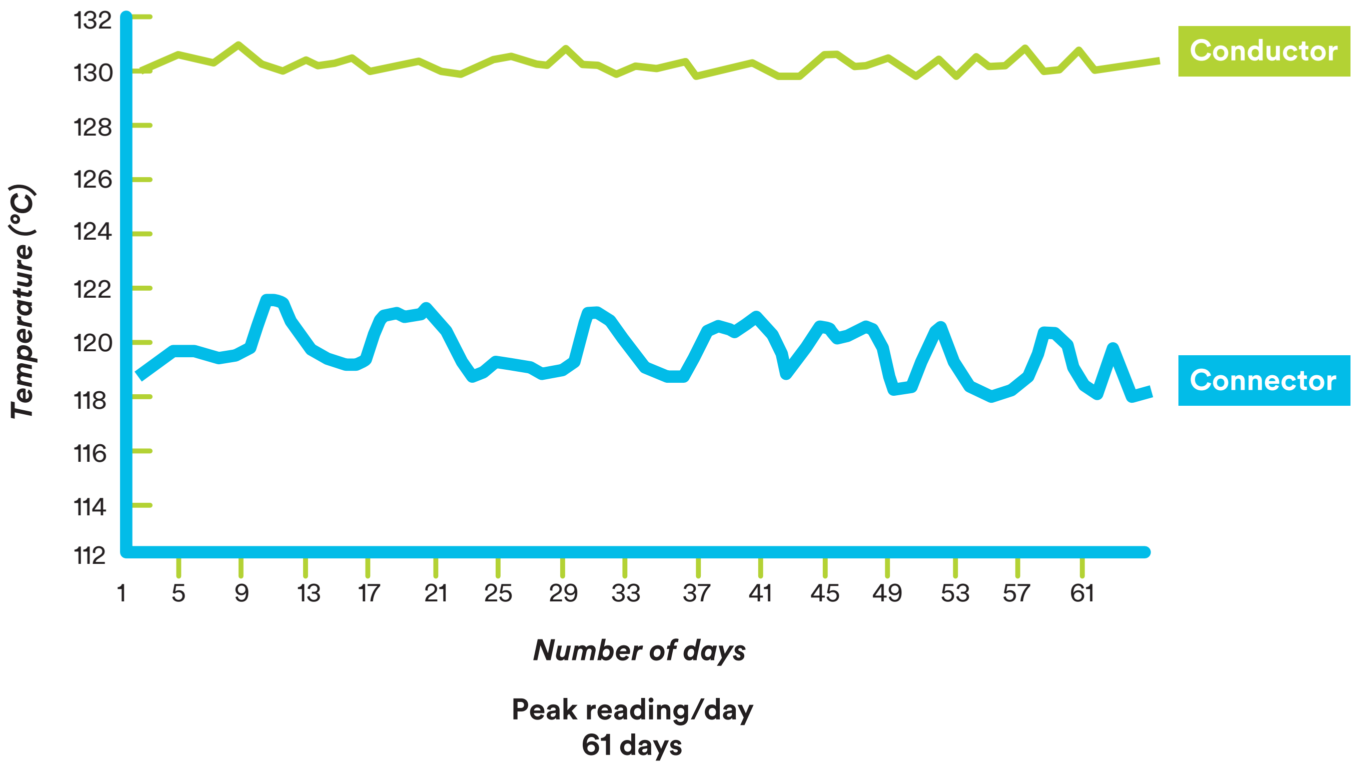


Figure 1: Temperature profile for a 15 kV splice configuration

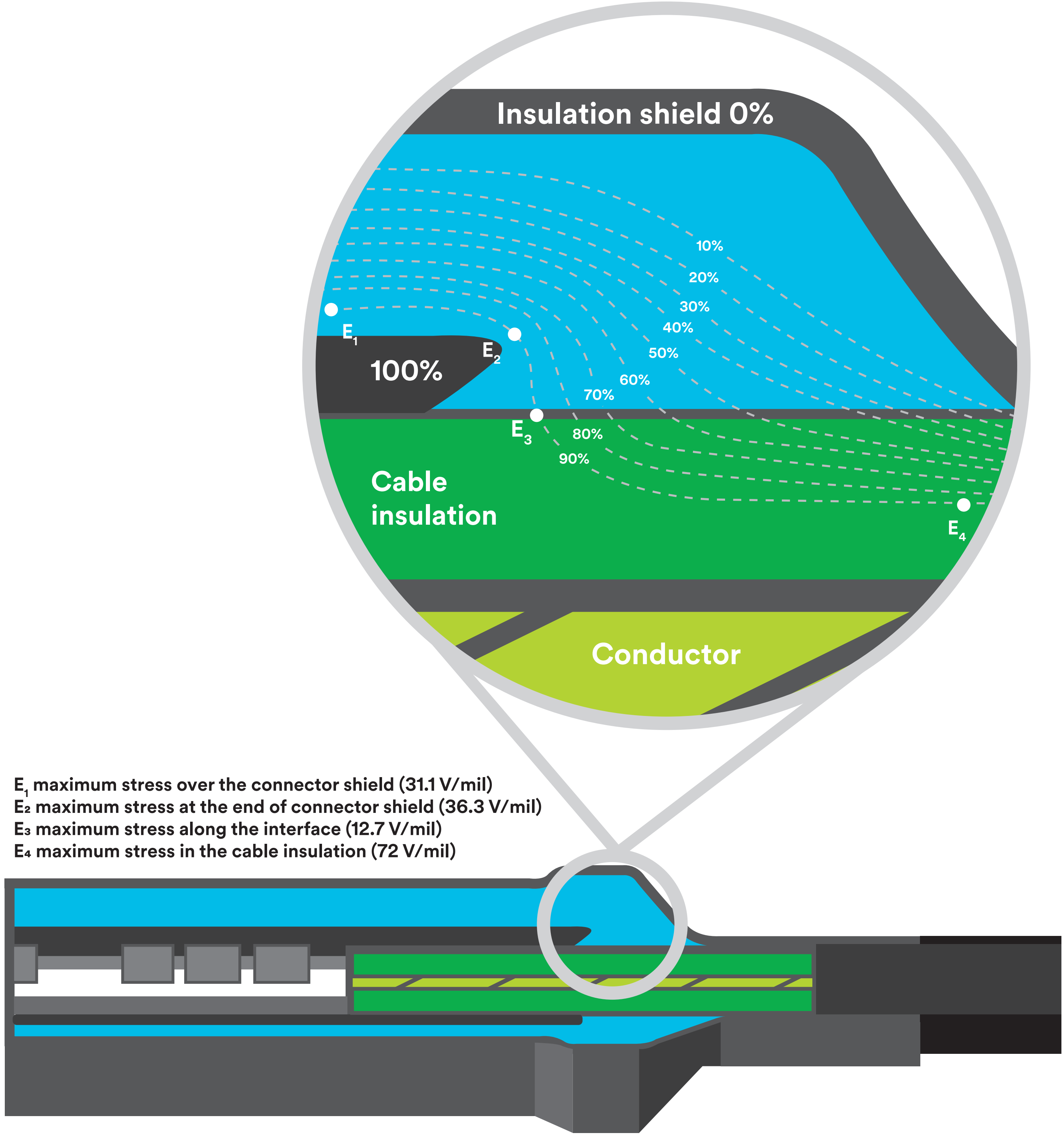


Figure 2: 15 kV stress plot

References

3M Company. 2012. 3M™ Cold Shrink Joints and Terminations for high voltage applications. P 1-4.

Amyot, N., et al. 2001. The Effect of Thermal Cycling on the Cable Joint Interfacial Pressure. P 1-4.

Fofeldea, G. 2018. Geometric vs. Capacitive Stress Control: choosing cable termination accessories to help reduce electrical stress. P 1-12.

Fofeldea, G. 2015. How do you take your splice? Integrated or not. P 1-7.

Important notice

Technical information: The technical information, guidance, and other statements contained in this document or otherwise provided by 3M are based upon records, tests, or experience that 3M believes to be reliable, but the accuracy, completeness, and representative nature of such information is not guaranteed. Such information is intended for people with knowledge and technical skills sufficient to assess and apply their own informed judgment to the information. No license under any 3M or third-party intellectual property rights is granted or implied with this information.

3M Electrical Markets Division
3M Canada
P.O. Box 5757
London, ON N6A 4T1
1-800-364-3577
3M.ca/Electrical