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Geometric vs. Capacitive Stress Control:

Choosing cable termination accessories to help reduce electrical stress.

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Abstract

3M invented cold shrink technology in 1968.

3M engineers used Ethylene propylene diene monomer (EPDM) rubber, which was a new rubber at the time, and developed a unique formulation that paved the way for 3M™ Cold Shrink Technology - a live seal to help manage electrical stress. These specially formulated rubber tubes also offered installation benefits; with no source of heat or extra tools required, 3M™ Cold Shrink Technology became a vastly simplified solution to cable termination.

Realizing the benefits of this cable termination method (i.e., ease of installation, living seal, etc.), other manufacturers have introduced similar-looking designs.

But if they look the same, does it mean that they perform the same?

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Table of contents

Introduction

The goal of this study is to answer: are all cold shrink medium voltage terminations equal? One would think the answer is "yes" since the industry follows the same IEEE 48 type test standard.
However, test results indicate this may not always be the case.

Materials and Methods

It's important to understand what happens to the electric field when a cable termination is installed.

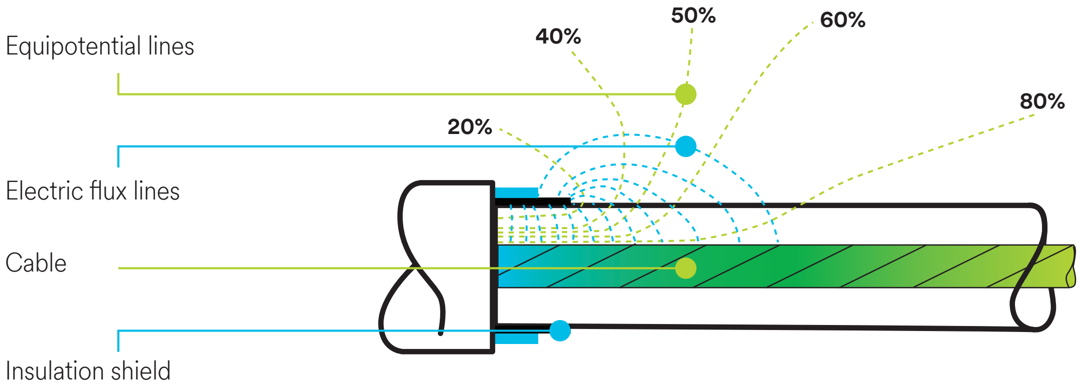
In a typical shielded, medium voltage cable (5-46 kV) with a continuous insulation shield, the electric field is uniform along the cable axis, but the field itself varies in a radial direction.

When a termination is installed on a cable, removing the insulation shield causes a discontinuity in the axial direction of the cable, resulting in a field that is no longer uniform along the axis. This process produces a high concentration of electrical stress closer to the insulation shield end.

Figure 1 shows a field plot without stress control. These electrical stresses at the end of the insulation shield must be reduced to avoid cable insulation failure. This reduction is referred to as **electrical stress control.**

The removal of the insulation shield results in a discontinuity in the axial direction of the cable → The field is no longer axially uniform along the cable → Shield removal produces a high concentration of stresses → Steps must be taken to avoid cable insulation failure

Field plot without stress control



Stress control methods

1. Traditional geometric stress cone

This method reduces the stress at the shield discontinuity by extending the shield and gradually increasing the thickness of insulation under the shield. The areas where there is higher electrical stress receive additional insulation, as shown in **Figure 2**, below.

2. High dielectric constant (Hi K) stress control

This method lowers the electrical stress at the point of shield discontinuity by refracting the electrical stress. This allows the equipotential lines to spread out along the cable insulation interface. By doing this, the surface stress of the termination is greatly reduced, which improves cable termination performance and life expectancy shown in **Figure 3**, below.[1,3]

Geometric Stress Control

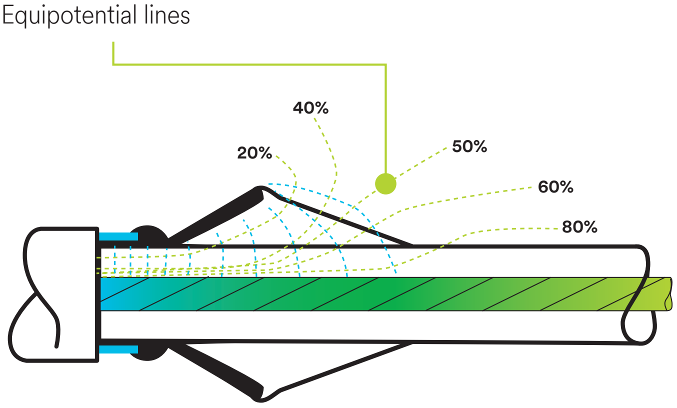


Figure 2

High Dielectric Constant (Hi K) Stress Control

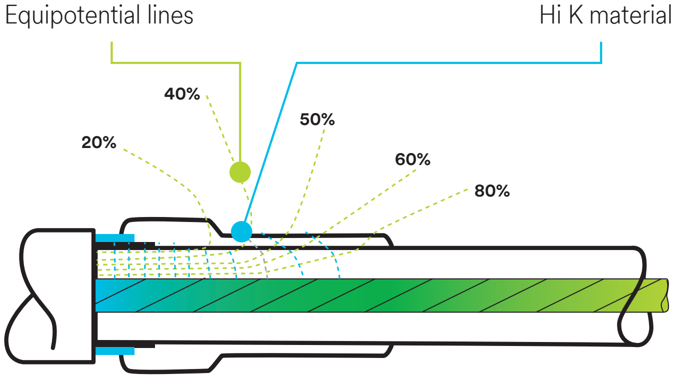


Figure 3

Study methodology

A test was conducted in a controlled laboratory environment to determine which method is most effective at controlling electrical stress.
The comparison: 3M™ Cold Shrink Products that use Hi-K capacitive stress control versus competitive cold shrink products that use geometric stress control.

1. Competitive cold shrink geometric stress cone termination testing

- Competitive 15 kV and 25/28 kV cold shrink geometric stress cone terminations were tested in compliance with the IEEE 48-2009 short-term testing sequence
- 15 kV terminations were installed on 350 Kcmil/15 kV cables
- 25/28 kV terminations were installed on 4/0/25 kV cables
- Partial discharge (PD) testing was conducted using a 3pC threshold

2. 3M™ Cold Shrink Hi-K capacitive termination testing

- 3M™ Cold Shrink Termination 7695-S-4 (test report: CRQTIII-7695-S-4) rated for 25/28 kV applications, tested to 28 kV levels, according to IEEE 48-2009, on a 750 Kcmil/25 kV cable
- 3M™ Cold Shrink Termination 7655-T-150 (test report: CRQTIII-7655-T-150) rated for 25/28 kV applications tested to 35 kV levels for indoor applications (150 kV BIL), according to IEEE 48-2009, installed on a 500 Kcmil/35 kV cable

Results

The presented test results are a reflection of the performance of the stress control method.
Table 1: testing results

Pass: ● Fail: ● Not tested: ●

Competitive Cold shrink stress cone termination	**Voltage Class**	**PD** (CSV/CEV)	**1 Minute AC Withstand**	**15 Minute DC Withstand**	**BIL** (10+/- Surges)	**HOT BIL** (10+/- Surges)	**PD** (CSV/CEV)	**5 Hour AC Withstand**	**5 Hour AC Withstand**	**BIL** (10+/- Surges)	**PD** (CSV/CEV)
Sample 1	15 kV	DF at 31 kV(Pass) ●	50 kV (Pass) ●	-75 kV (Pass) ●	110 kV (Pass) ●	110 kV (Pass) ●	DF at 31 kV (Pass) ●	31 kV (Pass) ●	39 kV (Pass) ●	110 kV (Pass) ●	DF at 31 kV (Pass) ●
Sample 2	28 kV (tested at 28 kV levels)	17.3/ 14.2 kV (Fail) ●	73 kV (Fail) ●	●	●	●	●	●	●	●	●
Sample 3	28 kV (tested at 28 kV levels)	21.0/ 18.5 kV (Fail) ●	73 kV (Fail) ●	●	●	●	●	●	●	●	●
Sample 4	28 kV (tested at 28 kV levels)	15.4/ 13.9 kV (Fail) ●	65 kV (Fail) ●	●	●	●	●	●	●	●	●
Sample 5	28 kV (tested at 28 kV levels)	DF at 50 kV (Pass) ●	65 kV (Pass) ●	-105 kV (Pass) ●	150 kV (Pass) ●	150 kV (Pass) ●	34.7/33.3 KV (Pass) ●	50 kV (Fail) ●	●	●	●
Sample 6	28 kV (tested at 28 kV levels)	15.9/ 14.6 kV (Fail) ●	73 kV (Pass) ●	-116 kV (Pass) ●	165 kV (Pass) ●	165 kV (Pass) ●	16.6/15.6 kV (Fail) ●	56 kV (Fail) ●	●	●	●
3M™ Cold Shrink Hi-K Termination 7695-S-4, Specimen 1*	25/28 kV (tested at 28 kV levels)	44.6 kV/44 kV (Pass) ●	73 kV (Pass) ●	-116 kV (Pass) ●	165 kV (Pass) ●	165 kV (Pass) ●	DF at 56 kV (Pass) ●	56 kV (Pass) ●	73 kV (Pass) ●	165 kV (Pass) ●	DF at 56 kV (Pass) ●
3M™ Cold Shrink Hi-K Termination 7695-S-4, Specimen 2*	25/28 kV (tested at 28 kV levels)	46.3 kV/45.5 kV (Pass) ●	73 kV (Pass) ●	-116 kV (Pass) ●	165 kV (Pass) ●	165 kV (Pass) ●	DF at 56 kV (Pass) ●	56 kV (Pass) ●	73 kV (Pass) ●	165 kV (Pass) ●	DF at 56 kV (Pass) ●
3M™ Cold Shrink Hi-K Termination 7655-T-150, Specimen 1*	25/28 kV (tested at 35 kV levels)	62.4 kV/ 59.5 kV (Pass) ●	90 kV (Pass) ●	-140 kV (Pass) ●	150 kV (Pass) ●	150 kV (Pass) ●	DF at 71 kV (Pass) ●	71 kV (Pass) ●	91 kV (Pass) ●	150 kV (Pass) ●	DF at 71 kV (Pass) ●
3M™ Cold Shrink Hi-K Termination 7655-T-150, Specimen 2*	25/28 kV (tested at 35 kV levels)	DF free at 71 kV (Pass) ●	90 kV (Pass) ●	-140 kV (Pass) ●	150 kV (Pass) ●	150 kV (Pass) ●	DF at 71 kV (Pass) ●	71 kV (Pass) ●	91 kV (Pass) ●	150 kV (Pass) ●	DF at 71 kV (Pass) ●

Legend:
AC: Alternating current
BIL: Basic lightning impulse insulation level
CSV/CEV: Corona starting voltage/corona extinction voltage
DC: Direct current
DF: Discharge free
HOT BIL: Basic insulation level at cable emergency temperature
PD: Partial discharge

**Each specimen consists of a piece of cable with terminations at each end. A total of 4 terminations were tested.*

Observations

3M™ Cold Shrink Products with high dielectric constant (Hi-K) capacitive stress control proved to be more effective in controlling electrical stress than the competitive products with geometric stress control.

Both 3M™ Cold Shrink Termination 7695-S-4 specimens and 3M™ Cold Shrink Termination 7655-T-150 specimens passed each test for their voltage class.

The results of the competitive cold shrink geometric stress cone termination testing did not have the same success:

- **Sample 1** of the cold shrink stress cone design 15 kV termination passed the short-term test sequence based on the IEEE 48-2009 design test requirements.

- **Samples 2, 3, 4, 5** and **6** of the cold shrink stress cone design 25/28 kV terminations did not pass the IEEE 48-2009 design test requirements.

- **Samples 2** and **3** failed the initial PD test (17.3 kV inception voltage, 14.2 kV extinction voltage, 21 kV inception, and 18.5 kV extinction voltage respectively). Additionally, internal failure of the terminations occurred at the end of the void-filling mastic during the 1-minute AC withstand test at 73 kV, which resulted in the breakdown of the cable insulation at that location.

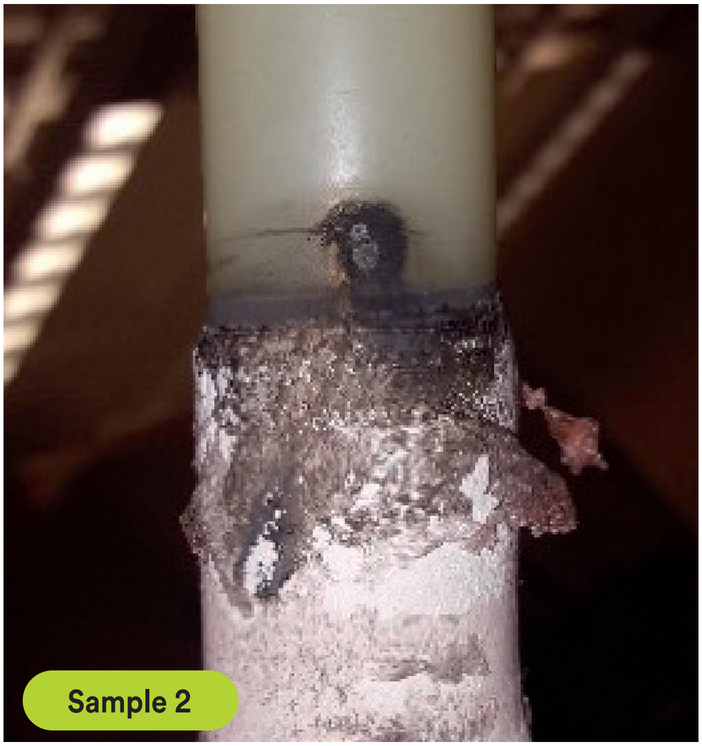
- **Sample 4** failed the initial PD test (inception voltage at 15.4 kV and extinction voltage of 13.9 kV). Internal failure of the termination also occurred at the end of the geometric stress cone during the 1-minute AC withstand test at 65 kV, which also resulted in cable failure.

- **Sample 5** passed PD testing both initially and after the HOT BIL test, but failed at 50 kV, 19 minutes into the 5-hour AC withstand test. The failure was located at a certain distance away from the cable semi-conductive edge, within the length of the void-filling mastic.

- **Sample 6** failed the initial PD test (15.9 kV inception and 14.6 kV extinction voltage). It also failed PD testing after the HOT BIL (16.6 kV inception and 15.5 kV extinction voltage) and ultimately failed 95 minutes into the 5-hour AC withstand test at 56 kV. Failure location was in the vicinity of the cable semi-conductive step down layer.

Research Samples

**The pictures below show a failed cable after termination removal, typical of Samples 2, 3, 5 and 6.*



Sample 2

Sample 3

Sample 4

Sample 5

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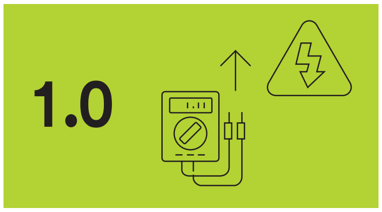
Discussion

The results of this study demonstrate the following three key benefits to choosing 3M™ Cold Shrink Terminations with high dielectric constant (Hi-K) capacitive stress control:

High withstand capabilities and greater reliability

This can be easily demonstrated by gradually raising the voltage on two types of terminations - one with geometric and one with Hi-K capacitive stress control - until leakage currents become visible. At a certain voltage, the geometric stress cone will develop intense stresses, followed by surface discharges, while the Hi-K capacitive stress control termination remains free of visible discharges.[2]



A more uniform distribution of electrical field

A uniform electric field distribution lowers surface stress and improves track resistance. The plots in **Figure 4** below, drawn to scale, illustrate how the equipotential lines are more agglomerated (closer together) over a shorter distance for a geometric stress cone, compared to a Hi-K capacitive stress cone, where the equipotential lines are spread more uniformly and over a longer termination surface distance.[2]

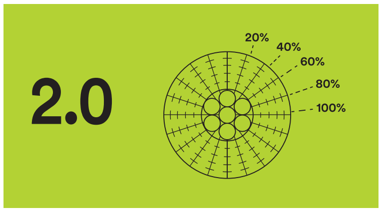
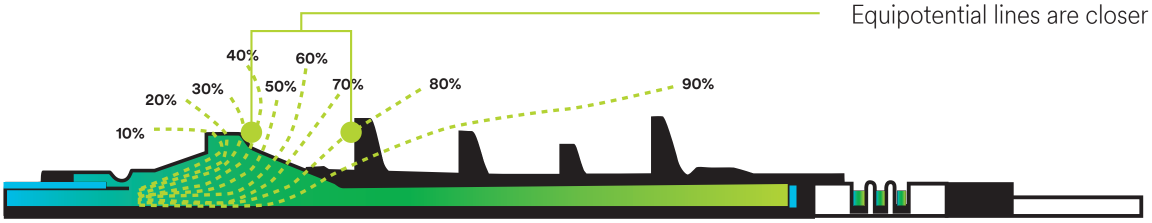
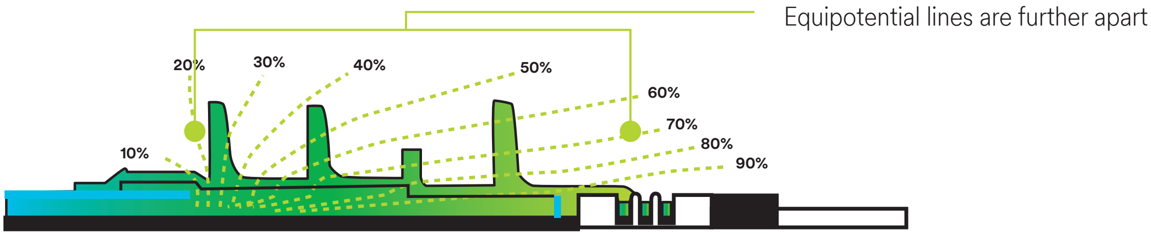


Figure 4

Geometric



High Dielectric Constant

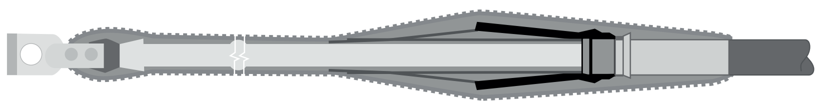
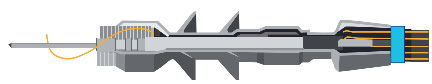
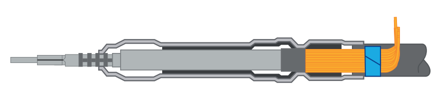
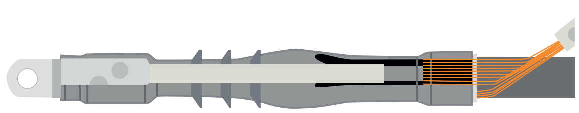


Shorter overall Hi-K termination

A shorter termination improves safety and overall reliability because it lowers the risk of cable preparation errors associated with longer insulation interfaces. It can also be an installation benefit in tight spaces, such as inside switchgear.

Table 2 shows the approximate lengths of an installed 15 kV tape stress cone termination, 3M™ QT-III Silicone Rubber Hi-K Indoor and Outdoor Terminations and a competitive stress cone silicone termination. As shown, the 3M™ Cold Shrink Hi-K Capacitive Terminations are the shortest.

Table 2: approximate lengths of installed 15 kV terminations

Termination type	Picture	Installed length*
3M 15 kV tape stress cone		50.8 cm (20 in)
3M 15 kV outdoor QT III Hi-K termination		25.4 cm (10 in)
3M 15 kV indoor QT III Hi-K termination		25.4 cm (10 in)
Competitive 15 kV cold shrink stress cone termination		33.02 cm (13 in)

**Installed lengths are approximate because for cold shrink terminations the actual installed length depends on the cable insulation diameter.*

Conclusion

Testing shows that the 3M™ Cold Shrink Terminations with Hi-K capacitive stress control meet and exceed the requirement of the IEEE 48 standard. The tested competitive cold shrink geometric stress control terminations rated for 25/28 kV voltage levels do not meet the requirements of the standard, although the 15 kV terminations comply with the standard requirements.

3M™ Cold Shrink QT-III Termination's Hi-K capacitive stress control termination design enables uniform distribution of the electric field - resulting in lower surface stress and improved track resistance.

In closing, 3M™ Cold Shrink QT-III Termination's Hi-K capacitive stress control tested is a more reliable technology for medium voltage cable terminations.

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2 H.C Hervig, P.N. Nelson, IEEE Transaction on Power Apparatus and Systems, Vol. PAS-103, No. 11, November 1984, "High dielectric constant materials for primary voltage cable terminations"

3 R. A. Wandmacher, J.D. Heyer, John Morris, IEEE T&D Conference Los Angeles, September 1996, "New Silicone Cold Shrink Termination"

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