



# High Temperature Operation of Extruded Distribution Cable Systems

**White Paper**

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- Any references to this paper must remain in context, consistent with the paper conclusions.

## INTRODUCTION / SUMMARY

Operating temperatures for underground extruded power cables commonly installed across North America are specified in standards prepared by the Insulated Cable Engineers Association (ICEA) or Underwriters Laboratories (UL). These standards rate medium voltage cables made with polymeric insulations i.e. tree retardant cross-linked polyethylene (TRXLPE) or ethylene propylene rubber (EPR) at conductor temperatures up to 140 °C under emergency operating conditions. The implication is that complete cable systems (cables, joints and terminations) have the same ratings and that the relevant standards require test programs that verify reliable operation at these temperatures.

A number of NEETRAC members have questioned the ability of cable systems to operate at elevated temperatures and tests conducted at NEETRAC support this concern. To better understand the topic, NEETRAC members initiated a project to provide an overview of high temperature operation issues for extruded underground distribution cable systems.

To prepare the overview, NEETRAC gathered or developed information on the following:

- a) Operating temperatures specified in relevant cable and cable accessory standards
- b) Utility and manufacturer cable system operating temperature expectations (survey)
- c) Tests outlined in relevant standards to verify elevated temperature operation
- d) Extruded cable material properties as a function of temperature
- e) Risks associated with elevated temperature operation
- f) Potential options for mitigating the risk of high temperature operation.

The information collected shows that while cable and cable accessory standards and specifications rate cable system components for highly elevated temperature operation, they do not provide for comprehensive test programs that verify reliable system operation at these temperatures. That is, there are gaps between what cable and accessory standards allow and what they actually verify.

These gaps point out a number of reasons to be cautious about operating extruded distribution cables at elevated temperatures:

- 1) Polymeric material properties change demonstrably as a function of temperature
- 2) Cable accessory connector performance is problematic at elevated temperatures
- 3) Cable system thermal environments are uncertain, at best, making it difficult to accurately calculate cable system temperature rise as a function of system loading.

From the available information, cable system operating conductor temperatures can be classified into three zones, each with a different level of operational risk as shown in Table 1. Details of how these zones were developed appear in body of this paper.

In summary, operating an extruded distribution cable system at elevated conductor temperatures carries a risk of reduced system reliability (increase in failure rates). Risk mitigation entails operating within lower temperature zones or conducting comprehensive test programs to verify reliable operation at elevated temperatures.

**Table 1: Operating Temperature Zones with Associated Operating Risks**

Zone	Temperature Range °C	Operating Risk
1	40 to 70	Data is available to support operating in this zone with no known issues with field operations.
2	70 to 90	Some data is available to support operating in this zone, but it is not comprehensive and some problems have been observed in lab tests. Polymeric insulation properties begin to change.
3	90 to 140	Polymeric insulation properties experience significant changes. Laboratory data shows joint connectors (primarily on Al conductor) often overheat. Little data is available to support operating in this zone. Field problems have been reported, particularly with windfarms.

Surveys show that utilities expect that their cable systems will operate reliably at the rated emergency temperature, although they rarely operate them at these temperatures. The concern is that if they ever chose to operate them at their rated temperature, evidence indicates that such operation will degrade the cable system thereby reducing reliability an indeterminable amount.

## **OPERATING TEMPERATURES – WHAT IS ALLOWED AND WHAT IS TESTED**

Performance requirements for extruded distribution cable systems are not covered by one standard. As mentioned earlier, in North America, cable conductor operating temperature ratings are specified in ICEA and UL standards. However, ratings for cable accessories (splices, terminations and separable connectors) are covered in separate component standards that are prepared and published by the Institute of Electrical and Electronic Engineers (IEEE). The IEEE standard for cable joints (splices) also references an ANSI standard for evaluating the connectors used to join cable conductors inside joint housings. In addition, cable specifications prepared by the Association for Edison Illuminating Companies (AEIC) were reviewed because they provide supplemental test requirements to the ICEA documents. A summary of the temperature ratings outlined in relevant extruded distribution cable standards appears in Table 2.

While cable standards clearly specify emergency operating temperature ratings as high as 140 °C, accessory standards are somewhat less specific. Termination and joint standards specify that the rating shall be equal to or greater than the cable for which they are designed. The separable connector standard only specifies current ratings,

though various test requirements used to evaluate the performance of these devices are conducted at a variety of temperatures. It is particularly notable that joint connectors are required to pass ANSI C119.4, which has a maximum conductor operating temperature of 93 °C for aluminum conductors or 100 °C for copper conductors. This implies that all cable systems with joints are limited to a maximum operating temperature of 93 °C or 100 °C depending on the conductor type, though this fact is not generally recognized.

The test procedures outlined in these documents are quite detailed and far too extensive to discuss in their entirety in this paper. Therefore, NEETRAC focused on basic design/qualification test parameters relevant for qualifying cable systems.

**Table 2: Allowable Extruded Power Cable System Conductor Operating Temperatures**

Device	Relevant Standard	Insulation Material	Normal Operation	Emergency Operation	Short Circuit
Cable	ICEA S-94-649, AEIC CS8	XLPE, TRXLPE, EPR (Classes I, II, and IV)	90 °C	130 °C	250 °C
		XLPE, TRXLPE, EPR (Class III)	105 °C	140 °C	250 °C
Joint Housing	IEEE 404	All	Rating not specified. Testing is based on Cable Emergency Operating Temperature		Not Addressed
Joint Connector	ANSI C119.4	None (tested on bare wire)	≤ 93°C for Al-Cu or Al-Al, ≤ 100°C for Cu-Cu		Not Addressed
Terminations	IEEE 48	All	Rating not specified. Testing is based on Cable Emergency Operating Temperature		Not Addressed
Separable Connectors	IEEE 386	All	Temperature rating not specified. Devices have a current rating of 200A, 600A, or 900A		3,500 to 10,000 A

To assure that cable systems will perform reliably at their rated temperature in a representative service environment, the expectation is that cable system component standards would require multifactor accelerated aging tests that include the simultaneous application of high temperature, moisture, lightning impulses and elevated ac voltage – with specified performance requirements.

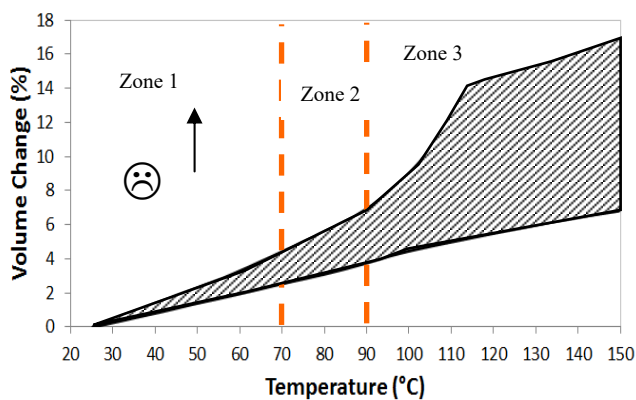
A review of all relevant ICEA, UL, IEEE, AEIC and ANSI standards/specifications shows that no test or set of tests outlined in these cable and accessory standards and specifications adequately evaluates elevated temperature performance in a manner that accurately reflects service in the field. The gaps between what the standards allow and what they test for are provided for cables rated 90/130 °C in the Appendix. Similar gaps exist for cables rated 105 °C /140 °C.

## PERFORMANCE RISK

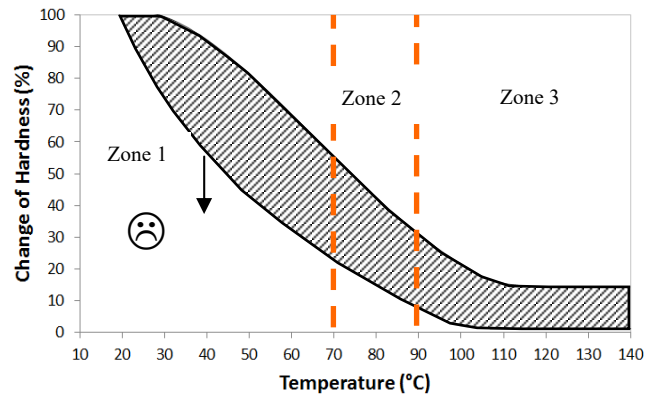
### Material Physical and Electrical Characteristics as a Function of Temperature

As mentioned in the introduction, the polymers that make up the extruded cable structure have physical and electrical characteristics that change as a function of temperature.

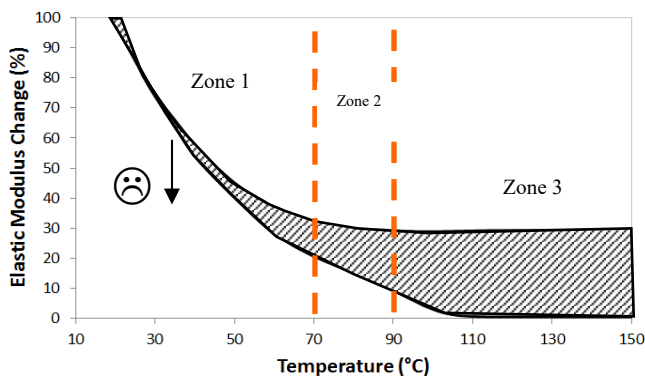
Detailed physical and electrical characteristics of polymeric cable insulation materials appear in EPRI Project Report EL-938, 1978, "Research to Determine the Acceptable Emergency Operating Temperatures for Extruded Dielectric Cables". Figures 1 – 4 summarize the range of data encompassing common extruded cable insulation materials. Note that each material property characteristic has reduced performance (frowny face) characteristics as the material temperature increases, particularly at temperatures above 90 °C. The vertical dashed lines shown in each figure represent three cable conductor operating temperature zones (See Figure 1) that will be discussed later in this paper.



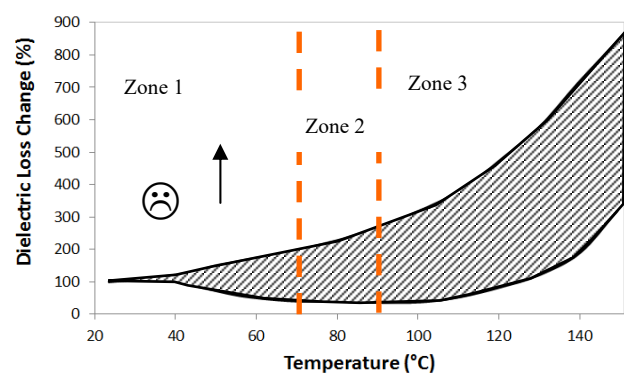
**Figure 1: Polymeric Insulation Volume**



**Figure 2: Polymeric Insulation Hardness**



**Figure 3: Polymeric Insulation Elastic Modulus**



**Figure 4: Polymeric Dielectric Loss**

## **Consequences**

The implications of the physical changes shown in Figures 1 – 4 are demonstrated by laboratory tests conducted on samples of XLPE insulated cables. Figure 5 shows a cable with a concentric wire neutral operated at 130 °C in a conduit. The “scalloped” deformation occurred as the cable insulation expanded and pressed into the surrounding wires, which were removed before taking the photo. Figure 6 shows a cable with a flat strap copper neutral operated at a conductor temperature of 130 °C. In this case, the flat straps “choked” the cable. The jacket also deformed because of the high temperature operation.

In both of cases, the cables did not fail electrically. However, it is obvious that the deformation changed the cable geometry thereby increasing local voltage stresses that over time accelerate aging. The hoop stress on a cable from an accessory such as a splice, termination or elbow could cause even greater deformation, which would further compromise the integrity of the cable/accessory interface.



**Figure 5: Cable Deformation Due to Elevated Temperature Operation**



**Figure 6: Cable Deformation Due to Elevated Temperature Operation**

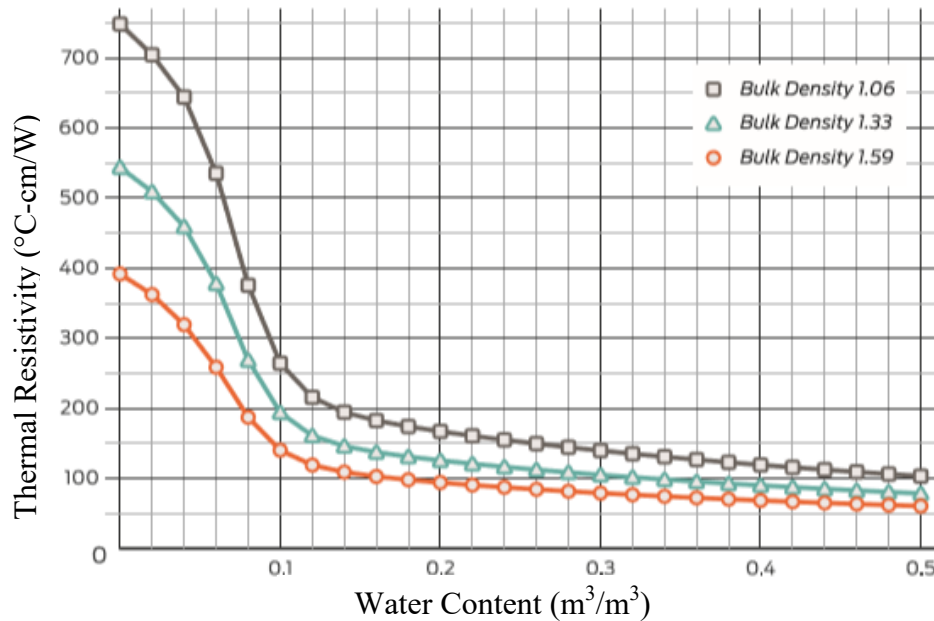
## **Temperature Calculation Uncertainty**

Establishing the operating temperature of a cable system requires performing a heat transfer calculation often referred to as a Neher-McGrath ampacity calculation. The heat generated by

$I^2R$  losses in the conductor and metallic shield (and to a lesser degree the heat generated from dielectric losses) must flow from the cable into its surroundings, typically the earth.

The thermal properties of the cable components and the earth must be known with reasonable accuracy to achieve an accurate estimate of the cable conductor temperature at a given conductor current. The thermal properties of the cable components are fairly well established. However, it is difficult to accurately establish soil thermal properties. They can vary as a function of soil type, soil moisture content and soil density. Soil thermal properties can also vary as a function of depth and they can vary along the cable system route.

An example of this variability appears in Figure 7, which shows that the thermal resistivity for the soil tested is strongly dependent on moisture content and soil density.



**Figure 7: Earth Thermal Resistivity of Loam Soil as a Function of Moisture Content and Density. From: *Don't Guess, Measure, A Guide for Soil Thermal Resistivity*, Distributed by Decagon Thermal Devices.**

### **Accessory Connector Performance at Elevated Temperatures**

Laboratory testing at NEETRAC has shown that the performance of joints installed on medium voltage cables with 1/0 AWG and 750 kcmil aluminum conductors and subjected to a test patterned after the IEEE 404 test protocol can be problematic. The test was conducted at a cable conductor temperature of 40 °C, 70 °C, 90 °C, 105 °C and 120 °C for the 1/0 AWG samples and at a cable conductor temperature of 90 °C, 105 °C and 120 °C for the 750 kcmil samples.



However, for both the 1/0 AWG and 750 kcmil samples, the connector temperature exceeds the conductor temperature when the conductor is operated at 90 °C and far exceeds the conductor temperature when the conductor is operated at 105 °C or 120 °C. Polymeric joint housings will readily degrade and fail at these highly elevated connector temperatures.

Table 3 summarizes the test results, showing the median of the connector temperatures at each cable conductor temperature. The circled temperatures indicate operating temperature zones that will be discussed later. For the joints tested on 1/0 AWG cable, the joint connectors operate at a temperature that is close to the conductor temperature when the conductor is at 40 °C or 70 °C. This reasonable condition should not cause harm to the joint housings.

However, for both the 1/0 AWG and 750 kcmil samples, the connector temperature exceeds the conductor temperature when the conductor is operated at 90 °C and far exceeds the conductor temperature when the conductor is operated at 105 °C or 120 °C. Polymeric joint housings will readily degrade and fail at these highly elevated connector temperatures.

**Table 3: Median of Connector Temperatures at Each Cable Conductor Temperature (Aluminum Conductors)**

Connectors	Conductor Temperature				
	40 °C	70 °C	90 °C	105 °C	120 °C
Connectors for 750 kcmil conductors	-	-	104	122	141
Connectors for 1/0 AWG conductors	45	71	140	194	400+

Note:

- 10% of 1/0 samples were removed during 90 °C cycles as a result of severe overheating
- 30% of 1/0 samples were removed by the end of the 105 °C cycles as a result of severe overheating

**Risk Zones**

From the previous information provided in Figures 1 – 4 and Table 3, cable system conductor operating temperatures can be classified into three temperature “risk” zones:

- **Zone 1: 40 to 70 Deg. C**
  - Data is available to support operating in this zone
  - No known issues with field operations
- **Zone 2: 70 to 90 Deg. C**
  - Some data is available to support operating in this zone, but it is not comprehensive and some problems have been observed in lab tests
  - Polymeric insulation properties begin to change (See Figures 1-4)
- **Zone 3: 90 to 140 Deg. C (Elevated Temperature Operation)**

- Polymeric insulation properties experience significant changes (See Figures 1-4)
- Laboratory data shows joint connectors (primarily on aluminum conductor) often overheat
- Little data is available to support operating in this zone
- Field issues reported (wind farms, highly loaded circuits with a high load factor)

To establish a sense of how each temperature zone can potentially affect cable life, they are overlaid on a cable life curve in Figure 8. This “natural” cable loss-of-life curve was established in another NEETRAC project based on collated accelerated cable life tests (ACLT). The risks associated with each temperature zone are discussed below:

- In Zone 1, the maximum temperature in the cable system (i.e. connector temperature) is similar to conductor temperature. The additional risk is low. The life curve in Zone 1 (dashed green line) is overlapping with life curve from ACLT.
- In Zone 2, the connector temperature is higher than the conductor operating temperature is. For example, the connector temperature can be 104 °C or higher when the conductor is operated at 90 °C. Thus, the life curve is driven by connector temperature (dashed yellow line). The resulting additional risk is medium/high.
- In Zone 3, the connector temperature can be much higher than the conductor operating temperature. Thus, expected life is significantly reduced (dashed dark red line). The resulting additional risk is high when a cable system is operated in this temperature zone.

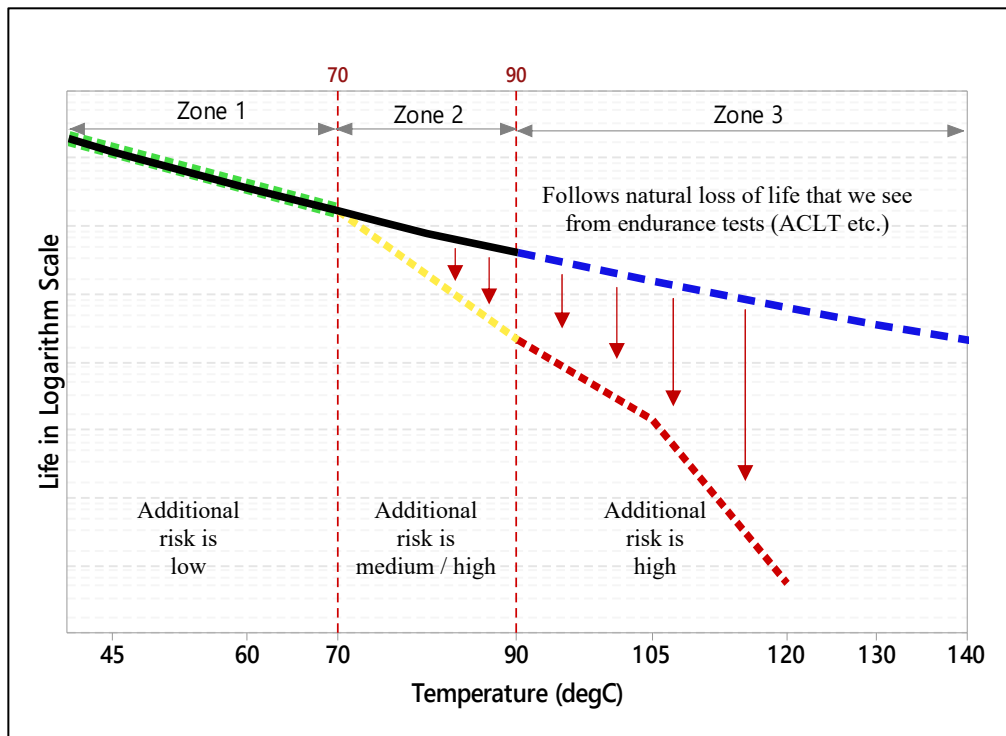


Figure 8: Cable System Loss of Life as a Function of Temperature

Naturally, there are likely specific combinations of cable, accessory housing and accessory connector that can perform reliably when the cable conductor is at temperatures as high as 140 °C. However, to assure a low risk of premature failure, extensive testing of the entire cable system at elevated temperatures should be performed.

**RISK MITIGATION**

The preceding sections identified the potential risks of operating extruded distribution cable systems at elevated temperatures; it is now worthwhile to review how a utility might minimize these risks. The most obvious risk mitigation approach is to avoid operating cable systems at conductor temperatures approaching 90 °C. However, there can be times when, to avoid service outages, a utility needs to operate a cable system at 90 °C or higher. Furthermore, they would like to be assured that the elevated temperature operation would not cause a reduction in the life of the cable system over and above the natural reduction in life resulting from operating a system at elevated temperatures.

A number of test protocols can assess the performance of cable systems at elevated operating temperatures. The tests suggested in Table 4 do this by building on test programs outlined in current cable and accessory standards and specifications. As an example, operation in the temperature Zone 1 does not require testing over and above standard test programs. Zones 2 and 3, however, require progressively more comprehensive tests to help assure that a given cable system made up of a specific set of cable and accessory designs will perform with only the normal loss of life expected for elevated temperature operation.

*Note that the test protocols presented are suggestions. In some cases, the specific test requirements are provided in general, not specific terms.*

**Table 4: Enhanced Testing for Minimizing Risk of Operating at Elevated Temperatures**

Enhanced Testing to Minimize Risk			
Component	Zone 1 (40 – 70 °C)	Zone 2 (70 up to 90 °C)	Zone 3 <sup>1</sup> (90 – 140 °C)
<b>Connectors</b>	Existing C119.4 Appear to be Adequate	Run IEEE 404 & 48 Style <sup>2</sup> Test (or Proven Alternative) on <u>Your</u> Connectors Connector Temperature Must be ≤ Conductor Temp. + 5 °C	Run IEEE 404 & 48 Style <sup>2</sup> Test (or Proven Alternative) on <u>Your</u> Connectors Connector Temp. Must be ≤ Conductor Temp.
<b>Housings</b>	Existing IEEE 404 & 48 Tests Appear to be Adequate	Existing IEEE 404 & 48 Tests Appear to be Adequate	Run Extended Duration <sup>3</sup> IEEE 404 & 48 Tests

<b>Cable</b>	Existing AWTT Tests Appear to be Adequate	Run 44 or 34 ACLT & Require no Failures within a Year	Run Enhanced <sup>4</sup> Thermomechanical Test & Run 45 or 36 <sup>5</sup> ACLT Require no Failures within a Year
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Notes for Table 4:

1. The cable used for this application should have a conductor that blocks moisture (solid or strandfilled). Otherwise any moisture that might enter the conductor can turn to steam at temperatures above 100 °C, which can penetrate the cable structure and damage accessories.
2. To assess connector performance, the IEEE 404/48 test should be run in the usual manner with thermocouples (or other temperature sensing devices) applied to monitor the temperature of the accessory connector. No voltage is applied during this test.

Note that conductor design can also impact connector performance. There are many different stranding technologies used for power cable conductors. They can have a different number of strands, strand shapes and levels of compression and hardness. In addition, mastic, water swellable tapes, water swellable powders or combinations of these materials are often applied within the interstices of stranded conductors to prevent axial moisture migration. If low resistance strand-to-strand contact is required for a connector to perform reliably, these materials can impact connector performance, particularly under heavy loading (high current) conduction. Thus connectors should be tested on the specific conductor technology expected for use at elevated temperature operation.

3. Extended = a test duration of six months or longer
4. Enhanced = more rigorous performance requirements such as an ac breakdown strength test at the end of the load cycling period and elevated voltage applied during the test. Note: If a water blocked conductor strand is part of a given cable design, it should be included.
5. In ACLT tests, the primary test conditions are described by a set of two numbers (41, 32, etc.) The first number represents a multiple of the cable operating voltage (1 - 4) and the second number represents the conductor test temperature (1 = 45 °C, 2 = 60 °C, 3 = 75°C, 4 = 90 °C). In Table 4, the suggested second number temperature aging conditions are:

- 5 = 90 °C conductor temperature with periodic excursions to 130 °C
- 6 = 105 °C conductor temperature with periodic excursions to 140 °C

Periodic is not specifically defined, but should represent a total accumulated time at the emergency operating temperature outlined in relevant AEIC and ICEA cable specifications and standards, which is 1500 hours.

The risk mitigation options provided in Table 4 are applicable for new cable systems. Options for minimizing elevated temperature operation risks for existing cable systems are much more limited. However, a potential approach is to gather as much information as possible on the elevated temperature performance of the existing circuit components.

It is also important to know the thermal characteristics of the cable circuit surroundings and conduct circuit ampacity calculations with the best available information. One way to maximize the accuracy of ampacity calculations is to use a controlled thermal backfill along the buried portion of the cable circuit to assure that the soil thermal properties are known and are stable. When performing ampacity calculations, it is also important to take into account the portion of the circuit that is in air, particularly at pole riser locations, where solar radiation and riser design (vented or non-vented) can significantly impact the cable temperature.

If the thermal characteristics of the cable surroundings are unknown, utilities should consider lowering the cable circuit emergency operating temperature. How much they should be lowered is difficult to establish. AEIC CS8-13 Specification for Extruded Dielectric, Shield Power Cables Rated 5 Through 46 kV-4<sup>th</sup> Edition states: "In the absence of [adequate information], the permissible conductor temperatures should be reduced by 10 °C or in accordance with available data."

## CONCLUSION

Current extruded distribution cable and cable accessory standards allow for normal operation of cable systems at conductor temperatures as high as 105 °C with emergency operating temperatures as high as 140 °C. However, they do not provide for comprehensive test programs that verify reliable operation at these elevated temperatures under typical field conditions. Thus, there are gaps between what cable and accessory standards allow and what they actually verify.

There are a number of reasons to be cautious about operating extruded distribution cable systems at elevated temperatures including:

- 1) Material property changes
  - Polymeric materials soften as their temperature increases, with a resulting loss in hardness and mechanical strength.
  - Dielectric strength of polymeric insulations decreases as temperature increases.
- 2) Problematic performance of accessory connectors
  - Laboratory tests show that many joint connectors overheat significantly when the cable conductor temperature is operated at 90 °C and above.
- 3) Thermal environment uncertainty
  - Soil thermal properties are often unknown and can vary along the cable system route, so the actual operating temperature of a cable system is extremely difficult to predict (calculate).

As a result, operating an extruded distribution cable system at elevated conductor temperature carries a risk of reduced system reliability (increase in failure rate) and it is difficult to predict the degree of risk for several reasons:

- a) The consequences are likely not immediate.
- b) The risk magnitude is impossible to predict.
- c) Elevated temperature operation likely accelerates the degradation of localized “weak spots” in the system, which is virtually impossible to replicate in a laboratory test.
- d) Higher temperature operation (and longer periods at elevated temperature) equals higher risk.
- e) Actual temperature operation is difficult to predict.

Naturally, the easiest and most reliable method of minimizing risk is to avoid elevated temperature operation, that is, operate the cable system within the zone 1 temperature range shown in Table 4. However, if elevated temperature operation is a required, the risk can be minimized for new cable systems by doing the following:

- a) Select cables and accessory designs known to perform well at elevated temperatures.
- b) Verify high temperature operation performance for all components installed on a given cable system. This can be done by following the enhanced testing suggestions outlined for each temperature **risk zone** shown in Table 4.
- c) Establish the thermal conditions of the cable system environment (usually soil thermal properties) along the entire cable route.
- d) Perform comprehensive ampacity calculations to maximize knowledge of the relationship between the cable current and the cable operating temperature. The calculations should include load factors that reflect expected variations in conductor current as a function of time.

For existing cable systems, the best option is to follow the recommendations in (d) above and obtain any available information on the elevated temperature performance of the components used in the system.

Note that utilities are not reporting significant failures due to elevated temperature operation and there is a good reason for this. While utilities purchase cables rated at a conductor temperature of 90/130 °C or 105/140 °C, they reported in the survey that their most common maximum conductor operating temperature is between 45 °C and 60 °C for URD cable systems and between 75 °C and 90 °C for feeder cable systems. Utilities anticipate that their cable systems will operate reliably at the rated emergency temperature even though they rarely operate them at these temperatures. The concern is that if they ever chose to operate them at their rated temperature, there is evidence that such operation will degrade the cable system, with a subsequent reduction in reliability that is impossible to predict.

## REVIEWED STANDARDS

- [1] Specification for Extruded Dielectric, Shielded Power Cables Rated 5 through 46 kV, AEIC CS8, 2013.
- [2] Specifications for Extruded Insulation Power Cables and their Accessories Rated Above 46 kV through 345 kV ac, AEIC CS9, 2006.

- [3] Guide for Establishing the Maximum Operating Temperatures of Extruded Dielectric Insulated Shielded Power Cables, AEIC CG6, 2014.
- [4] Extruded Insulation Power Cables Rated Above 46 Through 345 kV, ICEA S-108-720, 2012.
- [5] Test Methods for Extruded Dielectric Cables, ICEA T27-581, 2008.
- [6] Concentric Neutral Cables Rated 5 Through 46 kV, ICEA S-94-649, 2013.
- [7] Guide for Establishing Stability of Volume Resistivity for Conducting Polymeric Compounds of Power Cables, ICEA T-25-425, 2003.
- [8] IEEE Guide for Accelerated Aging Tests for Medium-Voltage (5 kV-35 kV) Extruded Electric Power Cables Using Water-Filled Tanks, IEEE 1407, 2007.
- [9] IEEE Standard for Test Procedures and Requirements for Alternating-Current Cable Terminations Used on Shielded Cables Having Laminated Insulation Rated 2.5 kV through 765 kV or Extruded Insulation Rated 2.5 kV through 500 kV, IEEE 48, 2009.
- [10] IEEE Standard for Extruded and Laminated Dielectric Shielded Cable Joints Rated 2.5 kV -500 kV, IEEE 404, 2012.
- [11] IEEE Standard for Separable Insulated Connector Systems for Power Distribution Systems above 600 V, IEEE 386, 2006.
- [12] Power Cables with Extruded Insulation and their Accessories for rated voltages from 1 kV up to 30 kV, IEC 60502-2, 2014.
- [13] American national standard for electric connectors, ANSI C119.4, 2011.
- [14] Shielded and concentric neutral power cable for distribution utilities, CSA 68.5, 2013.
- [15] Performance based Standard for Electric Utility Extruded Dielectric Shielded Power Cables rated 5 through 46 kV, ICEA S-113-684-2016.
- [16] Standard for Medium-Voltage Power Cables, UL 1072, 2013.

APPENDIX A

Standard	Component Tested	Test	Conductor Temperature (°C) Score			Voltage (U <sub>0</sub> )		Time		Environment (wet/dry)		Performance	
			Actual Use	Normal Rated	Emergency Rated	Specified	Score	Specified	Score	Specified	Score	Requirement	Score
Utility Expectation	Cable System	Field	45-70	90	130	1X		40 years		wet		Very high level of survival expected	
ICEA	Cable Core	AWTT Conditioning	-	-	✓	0	-	14 days	-	dry	-	No failure	-
ICEA		AWTT	✓	-	-	3x	✓+	360 days	✓	wet in & out	✓+	Breakdown test (ac& Impulse), tan δ. PD	✓
ICEA	Cable Core	Tan δ Stability	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
ICEA	Cable	Thermo-mechanical	-	-	✓	0	-	14 days	-	dry	-	Tan δ, PD, physical dimensions ( test is optional)	✓-
IEEE ACLT	Cable Core	33 Test	✓	-	-	3x	✓+	run to failure	✓+	wet out	✓	Survival expected, but no requirements specified	-
IEEE ACLT		44 Test	-	✓	-	4x	✓+	run to failure	✓+	wet out	✓	Survival expected, but no requirements specified	-
IEEE 48	Termination Housing	Cyclic aging	-	-	✓	3x	✓+	30 days	-	wet for tracking	-	BIL (amb. & hot), ac withstand, PD	✓+
IEEE 404	Joint Housing	Cyclic aging	-	-	✓	3x	✓+	30 days	-	wet out	-	BIL (amb. & hot), ac withstand, PD	✓+
ANSI C119.4	Joint Connector	500 cycle	-	-	✓	N/A	N/A	45-60 days	✓	N/A	N/A	Resistance and temperature stability	✓
IEEE 386	Separable Connector	Accelerated thermal test (200 Amp)	-	-	✓	0	-	13 days	-	dry	-	Resistance and temperature stability	✓
IEEE 386	Separable Connector	Current cycling test (600 & 900 A)	-	✓	-	0	-	25 days	-	dry	-	Device temp < control conductor temp.	✓
IEEE 386	Separable Connector	Accelerated sealing life test (200, 600 & 900 A)	-	✓	-	0	-	4-13 days	-	short term wet	-	Impulse withstand	✓

- ⇒ does not address the indicated operating condition (i.e. this is a gap in the test standards)  
 ✓ ⇒ addresses indicated operating condition  
 ✓+ ⇒ accelerates indicated operating condition  
 ✓- ⇒ address indicated operating condition, but in a limited manner  
 Blank = test does not focus on this operating condition