IMPACT OF FILLED-STRAND CONDUCTOR ON CONNECTOR TEMPERATURES FOR MEDIUM VOLTAGE JOINTS

Thomas **PARKER**, Nigel **HAMPTON**, School of ECE / NEETRAC – Georgia Institute of Technology, (USA),
thomas.parker@neetrac.gatech.edu, nigel.hampton@neetrac.gatech.edu

ABSTRACT

The authors have investigated issues with connectors installed in medium voltage joints that were reportedly attributed to the use of conductors with different methods of water blocking and / or strand fill materials. Tests completed on connectors for 1/0 AWG conductor indicate that the currently used test for evaluating connectors for use in joints is insufficient. Therefore, some connectors installed on joints in underground cable systems are likely to reduce the ability of the system to operate at rated temperature, even for short periods of time.

KEYWORDS

Cable, Accessory, Connector, Reliability

INTRODUCTION

In recent years, reports have surfaced from both the field and laboratories in the US indicating possible problems with conductor connectors within medium voltage underground cable joints. The reported problems appear to be particularly severe in applications such as feeders that are heavily load cycled from low load to full load on a regular basis, especially when using conductor containing water blocking strand fill materials.

The impact of installing a compression connector on strand-filled conductor is not easily determined in a controlled and reproducible manner. There are many other additional factors that may influence the connector performance including size of connector, die and tool used to install the connector, wire brushing the conductor prior to connector installation, inhibitor, fill material used in the conductor strands, and skill of the installer.

In order to address these concerns, two connector / joint combinations were subjected to an in-air IEEE 404™ style load cycle test with the connectors installed in joints. Additional factors investigated in this test program included the issue of wire-brushing the conductor, and connector installation on conductor without a fill material and on conductors with two different fill materials. The same connectors were also evaluated using the ANSI C119.4 CCST (connector only) currently used to qualify connectors for use in medium voltage joints in the USA.

IMPACT OF FILLED STRAND CONDUCTOR

Test Materials

The components used to construct the test samples consist of two different compression connectors for 1/0 AWG (53.49 mm^2) aluminum conductor, three different conductors and cable, and two different joint installation kits. The “small” connector was approximately 55 mm in length and had an approximate diameter of 18 mm. The “large” connector was approximately 75 mm in length and had an approximate diameter of 24 mm. The 25 kV joint kits were obtained from two different manufacturers. One of the kits used a cold-shrink joint /small connector, and the other used a molded joint / large connector.

The medium voltage cable was a 25 kV class cable with a 1/0 AWG aluminum conductor, 260 mils (6.6 mm) of TRXLPE insulation, sixteen #14 AWG (2.08 mm^2) concentric neutrals, and an extruded LLDPE jacket. The cable was obtained from three different cable manufacturers resulting in cable samples that contained conductor having no strand fill material, and two different strand fill materials. Manufacturers of the medium voltage cable also supplied uninsulated (bare) lengths of the same conductor for use in the ANSI C119.4 tests.

ANSI C119.4 Connector Tests

Samples including cable & connector were prepared according to the ANSI Standard and assembled into test loops. Due to the large number of connectors, the test samples were constructed in two loops that were tested separately. Welded equalizers were installed on the conductor between connectors as required by the ANSI standard. Sample resistance was measured between the equalizers on each side of the connector during the test. Changes in the conductor type were also made at the equalizers. A non-filled conductor was used for the control conductor.

In order to monitor the temperature of the connectors, probe-type thermocouples were installed in holes drilled into the center of each connector after the connector was crimped. Figure 1 shows a completed loop ready for test. Figure 2 shows a typical connector installed in the loop with the probe-type thermocouples in place.

Figure 1: ANSI C119.4 Test Setup – Current Cycle Submersion Test (CCST)

The test program consisted of 100 cycles of load current passed through the test loop to achieve a 100 °C rise over

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ambient temperature. Each 1-½ hour load cycle was divided into 1 hour with "current on" followed by ½ hour with the "current off" and the connectors submerged in chilled water. The connector temperatures were monitored and recorded during each load cycle. The resistance of each connector was measured between the equalizers on each side of the connector every ten cycles. Resistances measured were then corrected to 20 °C prior to analyzing any resistance data.

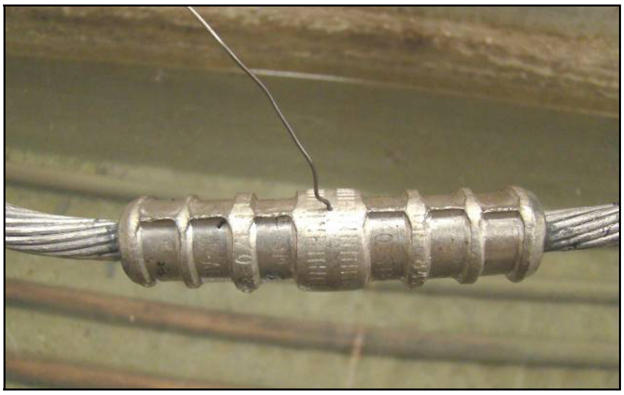

Figure 2: Typical Installed Large Connector

Figure 3 compares the connector temperatures of the individual connector samples in both loops by each conductor fill type at the end of the 100 cycle ANSI C119.4 CCST. Each dot represents the temperature of a single connector relative to the non-filled control conductor temperature. At first glance, there does not appear to be much difference between the three sets of data in general. All of the samples except one on Fill-2 conductor are significantly cooler than the control conductor temperature represented by the zero relative temperature line. The connector that is running hotter than the control conductor is classed as a failure according to the maximum temperature requirements of the ANSI C119.4 Standard.

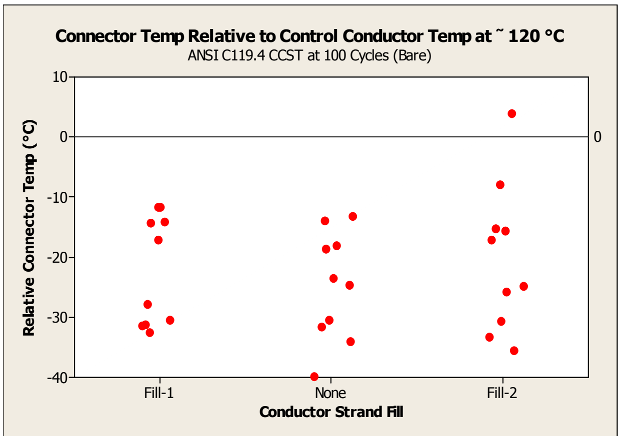

Figure 3: ANSI C119.4 CCST – Relative Connector Temperature (connector-control) at 100 Cycles by Conductor Strand Fill

There are three acceptance criteria in the ANSI C119.4 Standard:

- Connector Temperature, connector temperature must be ≤ conductor temperature
- Connector Temperature Stability, temperature difference between a connector and the conductor must be ≤ 10 °C of the average temperature difference between the connectors and conductor
- Connector Resistance, connector resistance must be ≤ 5% of average connector resistance

For the data obtained, the impact of each variable on these three criteria was investigated.

The effect that each factor studied has on the connector temperatures is summarized in Figure 4. The points plotted here are the mean values for the data in each set as it pertains to the factors studied. The factor that affects the connector temperature most is the connector itself. The strand fill material used in the conductor has the least effect on the connector temperature.

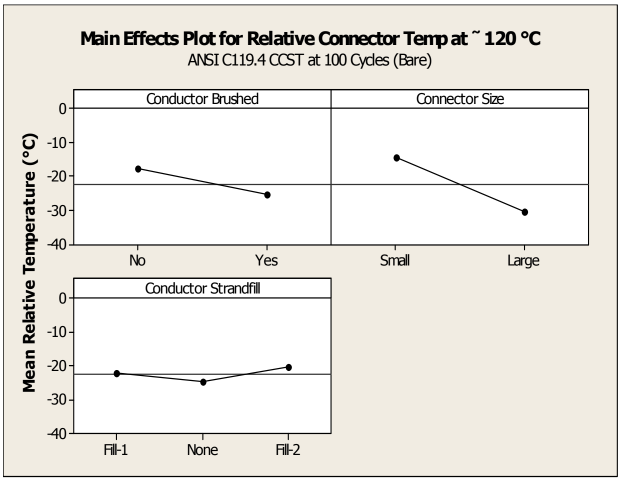

Figure 4: ANSI C119.4 CCST - Main Effects for Relative Conductor Temperature at 100 Cycles

None of the connectors failed the temperature stability requirement of the ANSI C119.4 Standard. Figure 5 summarizes the effect that each factor studied has on the connector temperature stability. Again, the points plotted here are the mean values for the data in each set as it pertains to the factors studied. The factor that affects the connector temperature stability most is the conductor strand fill. The connector itself has the least effect on the connector temperature stability.

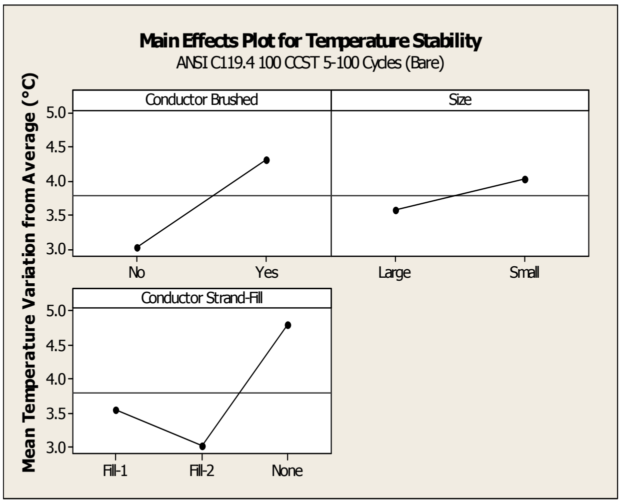

Figure 5: ANSI C119.4 CCST – Main Effects for Temperature Stability

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The ANSI C119.4 Standard also has a requirement for resistance stability of connectors. Figure 6 shows the effect that each factor has on the resistance stability of the tested connectors. As expected, the factor that affects the resistance stability most is the wire brushing of the conductor prior to installing each connector. The connector and the strandfill material have a lesser and almost equal effect on the resistance stability.

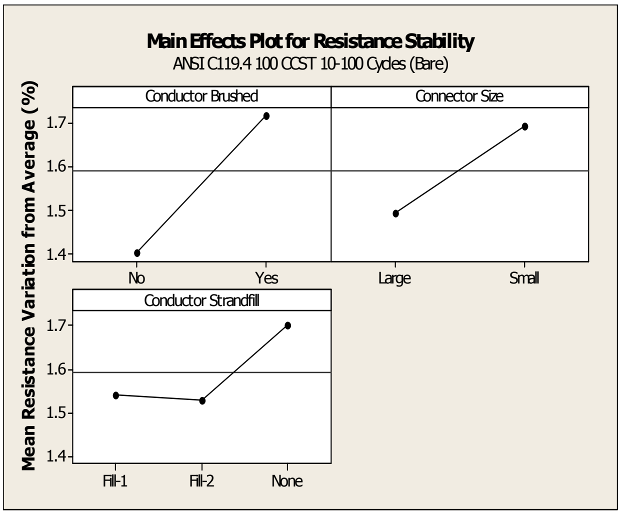

Figure 6: ANSI C119.4 CCST - Main Effects for Sample Resistance Stability at 100 Cycles

IEEE 404 Style Joint Connector Tests

The IEEE 404 Standard contains a design test for joints that does not address the issue of connectors other than to say that the connector used in joints must, as a minimum, pass the ANSI C119.4 test requirements. The IEEE Standard does not place a limit on the temperature of the connector inside a joint but rather relies on the absence of a dielectric / electrical failure of the joints when exposed to voltages specified in the Standard. The load cycle test within the IEEE Standard requires test samples of joints to be exposed to current sufficient to elevate the conductor temperature to 130 °C for six hours of each twenty-four hour cycle of a thirty cycle test. During the entire time of the load cycle test, the samples are exposed to approximately three times the rated voltage on the joint.

When these connectors are installed in underground medium voltage joints, they are not used in the same manner as they are tested in the ANSI test procedure i.e. they are used insulated (cable and joint) but tested in air (wire and connector). Therefore, sample connectors were also installed in joints and load cycled in an IEEE 404 style test. An IEEE 404 test sample consists of a joint installed in a length of medium voltage cable with terminations on each end. Since voltage was not necessary during these tests which measure connector temperature, terminations are not needed on the samples. Holes were drilled through the joint housings and into the center portion of each joint connector and a thermocouple probe was installed in each. Thermocouple probes were also installed in the same manner on the cable containing each of the three conductor types used.

There were two samples of each of the two joints on each conductor type that was wire brushed prior to installing the joint connectors and one of each of the two joints on each conductor type without wire brushing the connector. The component sections were suspended in air and bolted together in one zigzagged test loop for the cyclic aging. The completed test setup is shown in Figure 7.

The samples were exposed to load cycles consisting of eight hours with current on and sixteen hours with current off for thirty cycles at each target conductor temperature. The target conductor temperatures were 90, 105 and 130 °C in that sequence. These temperatures were selected because they are the operating temperatures specified in the AEIC / ICEA Standards for cable. During this time, the exterior joint housing temperatures and the joint connector temperatures were monitored and recorded.

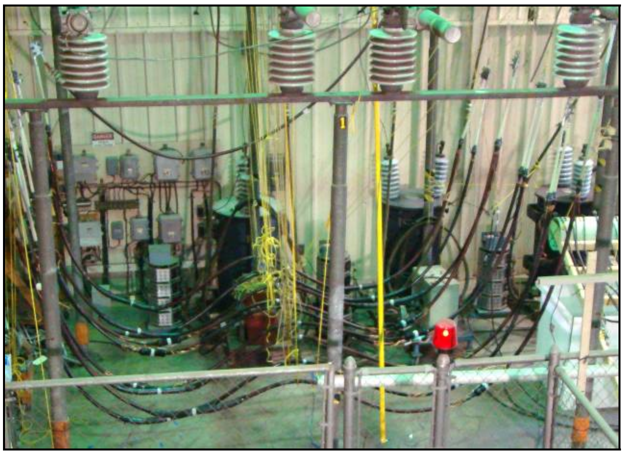

Figure 7: IEEE 404 Style Load Cycle Test

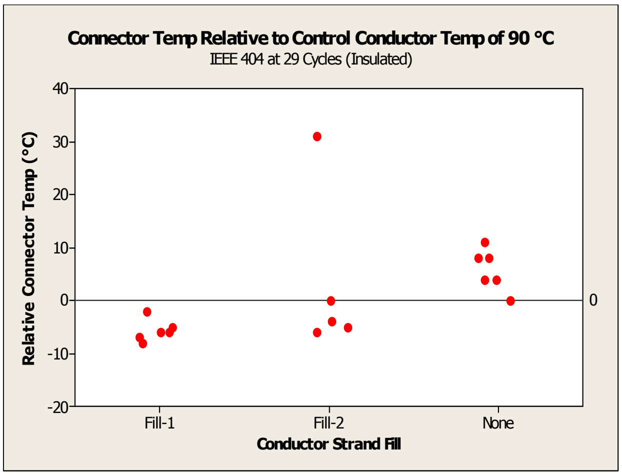

Figure 8: IEEE 404 Cyclic Aging – Relative Connector Temperature (connector-control) with Control Conductor at 90 °C by Conductor Strand Fill

The connector temperatures are compared, Figure 8, after 29 cycles of IEEE 404 type cyclic aging at 90 °C, the normal conductor temperature rating. The connectors in this configuration are much hotter than during the ANSI C119.4 cyclic aging. One of the connectors on conductor with Fill-2 appears to be approaching thermal runaway because it is over 30°C higher than the other connectors on the same conductor type. There is also a more noticeable difference between the data for each conductor fill type than with the ANSI C119.4 data. Connectors on the non-filled conductor have the highest temperatures while those installed on conductor with Fill-1 material have the lowest.

Figure 9 shows the effect that each of the factors studied has on the connector temperature at the rated operating temperature of the cable. The conductor condition, wire brushed or not, has the least effect while the conductor strand fill material has the greatest effect on connector temperature.

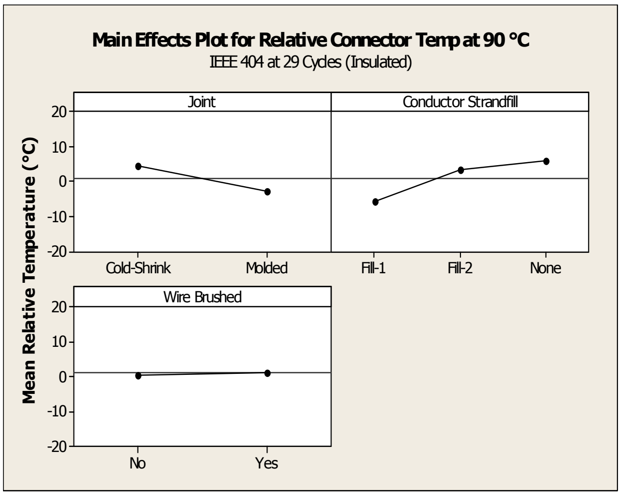

Figure 9: IEEE 404 Cyclic Aging - Main Effects for Relative Conductor Temperature at 90 °C

Discussion

Although this investigation only looked at two connectors and two joints, the IEEE 404 load cycle data in Table 1 gives some idea of the difference that can be expected in connector temperature due to operating an underground cable system at normal rating versus emergency operating temperatures. The operation of an underground system using these components would cause a connector to run at a significantly higher temperature with the conductor at emergency operating temperature than operation at the normal rating of 90 °C.

It is clear from Table 1 that the factor having the largest impact on connector temperature during the ANSI test is the joint/connector. The strand fill material in the conductor has the least impact for those tests. However, the conductor strand fill material is the most influential factor once the connector is installed in a joint.

ADDITIONAL TESTING IN PROGRESS

Additional work is underway in the author's laboratory to investigate how the selection of tools / dies used to crimp connectors impacts the temperature at which these same connectors operate inside joints. Data from this work will also be used to determine if changes in the test procedure or acceptance criteria of the ANSI C119.4 Standard can bring the pass / fail results of that test more in line with data from connectors installed in medium voltage cable joints.

For this new test program, the same two connectors used in the previous test program were installed using two different manufacturer suggested dies for each connector. One of the dies has a narrow width, the other has a wide

Table 1
Magnitude of Factors on Relative Conductor Temperature – Segregated by Test Program

Test Program	Difference in the Factor Means for ANOVA of relative temperatures(°C)		
	Joint / Connector	Wire Brushed Conductor	Conductor Strand Fill Material
ANSI C119.4 CCST	Large & Small Connector	Brushed & Not Brushed	Fill1, Fill2 & None
≈120 °C	16	8	5
IEEE 404 Load Cycle	Molded / Large Connector & Cold-shrink / Small Connector	Brushed & Not Brushed	Fill1, Fill2 & None
Load Cycle @ 90 °C	7	2	12
Load Cycle @ 105 °C	10	6	17
Load Cycle @ 130 °C	17	8	29

ANSI C119.4 CCST and an IEEE 404 style load cycle test in which the temperature of each connector is being measured using thermocouples that were installed in the joint as the joint was assembled. The number of joints in which the connectors have been installed has been expanded to include three different cold-shrink joints and one heat shrink joint. Since the conductor strand fill seemed to have the largest impact on conductor temperature, only one conductor having strand fill material was selected for these tests.

The target conductor temperature for the IEEE style load cycle tests was set at 120 °C and the number of cycles extended to one-hundred for these tests. After much discussion, the decision was made to consider a connector failed if the temperature exceeded 130 °C. This temperature was selected because it was felt to represent the temperature at which damage would begin to occur within the joint.

The preliminary results of the 1/0 AWG connector tests are somewhat surprising. Table 2 shows a summary of the sample failures as defined by the set connector temperature limit. Most of the samples exceeded the connector temperature limit during the first cycle prior to ever reaching the target conductor temperature of 120 °C. One of the connectors "failed" during the first load cycle prior to reaching the connector's rated conductor temperature rating of 90 °C. A few of the large connectors installed using a narrow die were the only ones to reach 100 cycles of aging at 120 °C without exceeding the set connector temperature limit. It is interesting to reflect that the qualification of these connectors to ANSI meant that all of these connectors were expected to comply with these tests.

Table 2
Summary Results
1/0 AWG IEEE 404 Style Joint Tests

Joint	Connector	Die	No. of Non Compliant [1] End of Cycle 1	No. of Non Compliant [1] Cycles 2-100	No. of Survivors
Cold-Shrink Design A	Small	Narrow	3	-	0
		Wide	3	-	0
	Large	Narrow	0	1	2
		Wide	3	-	0
Cold-Shrink Design B	Small	Narrow	3	-	0
		Wide	3	-	0
	Large	Narrow	0	-	3
		Wide	0	2	1
Cold-Shrink Design C	Small	Narrow	3	-	0
		Wide	3	-	0
	Large	Narrow	0	2	1
		Wide	3	-	0
Heat-Shrink	Small	Narrow	3	-	0
		Wide	3	-	0
	Large	Narrow	0	1	2
		Wide	2	1	0

1 – Non Compliant is defined as connector temperature exceeding 130 °C.

Table 3 shows a summary of the pass / fail results for both the ANSI test with bare conductor and connectors, and the IEEE 404 style test with connectors in joints installed on medium voltage cable. The ANSI result is an overall result for the ANSI test even though there are three individual criteria that must be met for a connector to pass. The IEEE 404 style test result is much simpler with a connector passing if it does not exceed the specified temperature. The results of the ANSI test do not agree with those of the IEEE style load cycle test.

It is interesting to reflect that at first sight the temperature selected for "failure" of the connector in the IEEE test is too low at 120 °C. However, the "failures" began to occur when the conductor temperature was less than the rated temperature of 90°C and had yet to reach equilibrium. Thus they would have readily exceeded the emergency temperature of 130 °C which is itself limited to a few thousands of hours. Furthermore, most all of the "failures" occurred during the first load cycle.

Table 3
Connector Pass / Fail Summary
Both Inside Joint and Bare Connector Test Programs

Connector	Die	Connectors Passing (%): ANSI C119.4 CCST (Bare) Conductor ≈ 130 °C (Overall)	Connectors Passing (%): IEEE 404 Style[1] (Inside Joint) Conductor ≈ 120 °C
Small	Narrow	100 %	0 %
Small	Wide	0 %	0 %
Large	Narrow	100 %	67 %
Large	Wide	75 %	8 %

1 – Non Compliant is defined as connector temperature exceeding 130 °C.

If the failure data is further investigated (Figure 10), it shows that none of the smaller connectors could be expected to operate inside a joint at the rated conductor temperature of 90 °C, even though the ANSI test indicates that the connector would perform acceptably if the narrow die is used to install it. The threshold temperatures for good operation are 84 and 77 °C for the small connector installed with the narrow and wide dies respectively.

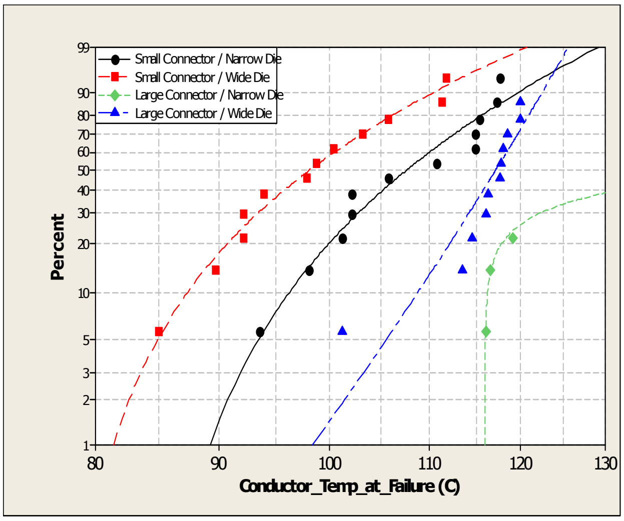

Figure 10: Failures by Conductor Temperature

Conclusions / Future Work

Tests have been conducted on 1/0 AWG connectors to evaluate the effectiveness of the ANSI C119.4 test protocol and acceptance criteria to evaluate connectors for use in medium voltage underground cable system joints. A fully randomized factorial experiment and procedure employing replicates was used. This rigorous experimental approach enabled the statistical significance and the magnitude of the effects to be established un ambiguously. Significances in the range of 90% to >99.9% were identified.

Compliance with ANSI C119.4, which is reported as a pass/fail test, is not a guarantee of good thermal performance when the connectors are installed in joints as in IEEE 404: two combinations which provided 100% compliance with the ANSI test yielded between 0% and 67% compliance with the IEEE 404 test environment.

The data shows that connectors that comply with ANSI C119.4 have unacceptably poor performance resulting in very elevated temperatures at cable system operating temperatures when transferred to the underground environment. The data indicate that the cable system operating temperature is likely to be considerably below the 105 °C anticipated for modern cables on their own.

Since many joints have been installed over the years using connectors that were evaluated using the ANSI test procedure, the operation of cable systems at emergency operating temperatures should only be considered after much study and consideration. The data from these tests have shown that even the ability to operate existing cable systems at rated temperature is questionable in at least some cases.

This work has shown that when determining which connector to select, utilities should consider:

- Size of connector – larger connectors would be preferred
- Die Size – multiple applications of a narrow die would be preferred
- Wire Brushing – wires (irrespective of age or condition) should be wire brushed
- Water Blocking – the performance should be assessed on the technology / materials used in the cable

Tests to confirm the performance of larger cable systems are planned as the next step in the test program.

REFERENCES

[1] NEMA, "American National Standard for Electric Connectors – Connectors for Use Between Aluminum-to-Aluminum or Aluminum-to-Copper Conductors", NEMA/ANSI Standard C119.4-2004

[2] IEEE Power and Energy Society, "IEEE Standard for Extruded and Laminated Dielectric Shielded Cable joints rated 2500 V to 500 000 V", IEEE Std. 404™-2006

GLOSSARY

CCST: Current Cycle Submersion Test