The Need to Update / Upgrade Test Procedures for Connectors Used in MV Underground Joints

Barry **Fairley**, Nigel **Hampton,** Thomas **Parker;** NEETRAC, Atlanta, USA, barry.fairley@neetrac.gatech.edu, nigel.hampton@neetrac.gatech.edu, thomas.parker@neetrac.gatech.edu

ABSTRACT

The authors have investigated factors that contribute to overheating of connectors installed in medium voltage joints. Tests completed on connectors for 1/0 AWG and 750 kcmil conductors confirm that the currently used test for evaluating connectors for use in joints is insufficient. Furthermore, the Success Criteria for these tests cannot be modified to better align the results with connector performance within joints. Therefore, a new test procedure is required to ensure that connectors installed in joints on underground cable systems are better able to operate at their rated temperature.

KEYWORDS

Cable, Accessory, Connector, Reliability

INTRODUCTION

Although medium voltage (MV) cable systems are rated for operation at temperatures in the range of 90 to 105 °C, the vast majority operate at temperatures much lower than this (in the range 35 to 45 °C for North America). As a result, reports of problems / failures with overheating connectors are very rare. However, the authors have noted that overheating problems are more regularly being reported when the cable systems are operated above the normal 30 to 45 °C range, yet puzzlingly below the rated temperatures. The causes of this phenomenon were not clear though a number of hypotheses are being discussed. Consequently, it was decided to conduct a number of designed experiments to try and bring some clarity to this issue.

Initial work reported in Jicable11 [3] focused on reported problems that appeared to be particularly severe in applications such as feeders that were more heavily loaded and used conductor containing strand fill materials. Yet, the load did not exceed the cable design rating. This work confirmed that issues did indeed exist and indicated that there was a minimal impact of the strand fill material commonly used in North America. Thus, additional work was undertaken on a wider population of test samples.

The tests employed in the study reported here was patterned on the load cycle test of IEEE Standard 404™ [2] and the ANSI C119.4 [1] protocols. Both of the tests considered a range of cases with a large number of replicates and thereby provided a good level of confidence. The results indicated that, contrary to expectation, the connector inside many MV underground cable joints will overheat when the current is increased to achieve a cable conductor temperature of 90 °C, the rated temperature for typical cable systems. This implies that there is an increased risk that those cable joints may fail prematurely in the field if they are loaded up to or near their design rating.

The IEEE 404 test program is designed to be a design qualification test for the dielectric system of cable joints only, the connectors are not explicitly considered. It obliquely addresses the current carrying capability of connectors by requiring that connectors used for MV underground cable joints be qualified using the ANSI C119.4 test protocol. The ANSI standard is widely used to evaluate connectors in the overhead environment and tests bare connectors (without the splice housing) on bare conductors. It is important that the most recent embodiment [1, 2] of the ANSI standard is limited to temperatures below 93°C or 100°C for copper. Available data from the tests conducted by the authors indicate that the ANSI test protocol is likely not adequate for evaluating the performance of connectors installed in MV joint housings.

TEST MATERIALS

The components used to construct the test samples consist of different connectors (compression and bolted) for two conductor sizes 1/0 AWG (53.49 mm^2) and 750 kcmil (380 mm^2) Aluminium conductors employing the extruded mastic strand fill method common in North America. The test samples are described in Table 1.

Table 1: Cable Conductor Size, Connector & Connector Die used in the ANSI and IEEE style tests

Size	Connector	Die	Set ID
1/0 AWG 53.49 mm^2	Compression A (5/8 size)	Narrow	111
	Compression A (5/8 size)	Wide	112
	Compression B (840 size)	Narrow	121
	Compression B (840 size)	Wide	122
750 kcmil 380 mm^2	Compression C	1	711
	Compression C	2	712
	Compression D	1	721
	Compression D	2	722
	Shearbolt E	N/A	73
	Shearbolt F	N/A	74

All connections and joint installations were prepared strictly in accord with the manufacturers instructions. Where these instructions were unclear, the manufacturers were contacted for clarification. Heatshrink and Coldshrink joint bodies (7 types) and 25 kV jacketed cables with strandfilled Aluminium conductors (2 types) were used in the IEEE 404 style tests. All of the cables, connectors, and joint bodies were represented to have passed all of the relevant standards and are / could be used on North American cable systems.

TEST PROTOCOLS

Testing was undertaken in such a way that it was possible to compare the thermal performance (temperature achieved and the temperature stability) of connectors in tests patterned after the IEEE 404 load cycle test protocol with results of the ANSI C119.4 Current Cycle Submersion Test (CCST). All connectors that were tested bare using the ANSI protocol were also tested within a joint using the IEEE 404 protocol.

ANSI C119.4 Connector Tests

Cable conductor and connector samples 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 to facilitate resistance measurements as required by the ANSI standard.

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 a probe-type thermocouple in place.

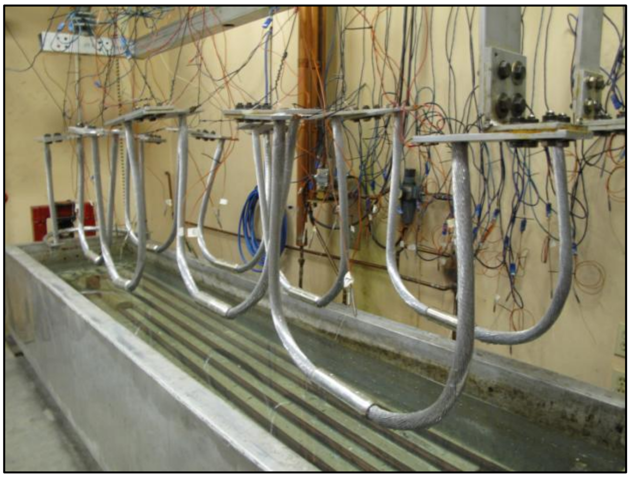

Figure 1: ANSI C119.4 Current Cycle Submersion Test (CCST) for 750 kcmil Connectors

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

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 mean temperature difference between the connectors and conductor
- Connector Resistance, connector resistance must be ≤ 5% of mean connector resistance

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

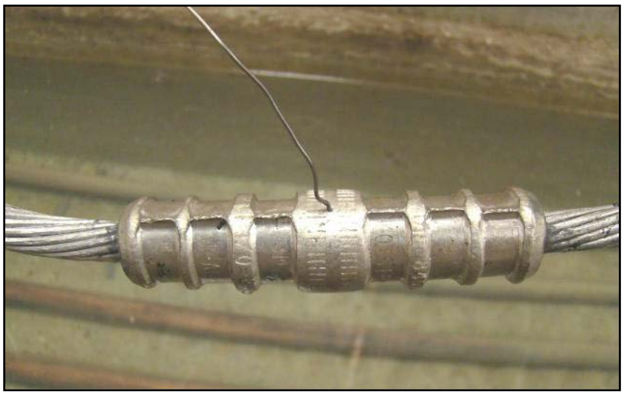

Figure 2: Typical Installed Connector

IEEE 404 Style Joint Connector Tests

The IEEE 404 Standard contains design tests for joint bodies but 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 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 cable conductor temperature to 130 °C for six hours of each twenty-four hour cycle for all thirty cycles of the test. During the entire duration of the load cycle test, the samples are exposed to approximately three times the rated voltage of the joint.

When connectors are installed in underground medium voltage joints, they are used in a different manner than they are tested in the ANSI test procedure. The connectors are insulated by the joint housing and are installed on conductor that is insulated by the cable insulation. 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 were not needed and thermocouples could be placed directly onto the connectors inside the joints. Holes were drilled through the cable of joint samples allowing thermocouples to measure the cable conductor temperature as well.

There were multiple samples of each of the joints on each conductor type. 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 3.

The samples were exposed to load cycles consisting of eight hours with current on and sixteen hours with current off for 100 cycles at each target conductor temperature. The target conductor temperatures were 90, 105 and

120 °C, in that sequence. These temperatures were selected because they are the operating temperatures specified in the AEIC / ICEA Standards for cable. During load cycles, the joint connector and cable conductor temperatures were measured and recorded.

Figure 3: IEEE 404 Style Load Cycle Test for Complete Joints on 1/0 AWG Conductor Cable

ANALYSIS OF ANSI & IEEE TEST RESULTS

Typically the results of ANSI Qualifications are reported in a Pass / Fail format. In most applications this is not that beneficial in that it's not possible to assess the margin of performance. In this work we chose to consider all of the three categories separately (Table 2), such that the source of a non conformance can be seen. At first sight, Table 2 is surprising in that all of the Overall Scores should be 100% (or close to it) as these were connectors sold as compliant with ANSI. In addition, the non compliance is due to all of the elements. Finally, it is clear that which of the approved dies are used has a profound effect on the performance: compare 111 & 112, and, 711 & 712. Nevertheless 5 out of the 10 met the current ANSI Criteria.

Table 2: Results of the ANSI CCST for Samples described in Table 1 – 4 samples tested per condition

Set ID	Temp Limit	Temp Stability	Resistance Stability	Final Outcome (% of tested)
111	100 %	100 %	100 %	100 %
112	0 %	50 %	50 %	0 %
121	100 %	100 %	100 %	100 %
122	100 %	100 %	75 %	75 %
711	100 %	50 %	100 %	50 %
712	100 %	100 %	100 %	100 %
721	100 %	100 %	100 %	100 %
722	100 %	100 %	100 %	100 %
73	100 %	75 %	100 %	75 %
74	0 %	50 %	100 %	0 %

The reporting of the IEEE style tests is somewhat more straightforward as the only metric employed was the temperature of the connector. However to compare with Table 2 we wanted to compare against some broadly acceptable criteria. In this case the experts involved in this project determined that a connector within a joint would not be expected to run hotter than the conductor upon which it was installed. However, as an absolute upper limit, it should not exceed 130 °C which is the limited time Emergency Operating Temperature for the cable. Thus remaining <130 °C was determined as the Success Criteria in advance of the testing.

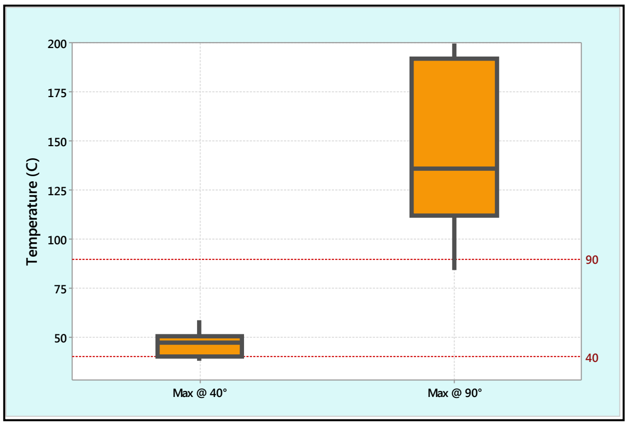

Figure 4: Maximum Temperatures Achieved by 1/0 AWG Connectors Inside Joints at 40 and 90 ˚C in a Box and Whisker Format

Table 3: Results of the IEEE 404 Style Joint Test for Samples described in Table 1

Set ID	# Tested	Outcome of Connectors ≤ 130 °C (% of tested)
111	12	0 %
112		0 %
121		67 %
122		8 %
711	9	0 %
712		0 %
721		22 %
722		11 %
73		67 %
74		0 %

Contrary to expectations, the connectors within the joint very rapidly achieved temperatures in excess of the conductor (Figure 4) and continued to rise such that they exceeded the 130 °C limit. It is also noteworthy that most of the connectors that exceeded 130 °C did so prior to the completion of Cycle 1. As the conductor temperature was being raised to 120 °C, the connectors exceeded 130 °C. The first 1/0 AWG connector exceeded 130 °C at a conductor temperature of 85 °C; the first 750 kcmil connector exceeded 130 °C at a conductor temperature of 94 °C.

The performance of the connectors within joints against the 130 °C Success Criteria is shown in Table 3. Like the ANSI tests, the results were somewhat surprising because it was anticipated that most of the joints would meet the <130 °C criteria.

As noted earlier, many of the connectors within the joints exceeded the agreed to criteria before Cycle 1 of the 100 cycle test. Consequently, it is very instructive to examine the distribution of the conductor temperatures resulting in these large temperature rises. Before this analysis was completed, the temperature data were inspected to determine if the joint bodies played a large and / or significant role in achieving the elevated temperatures. The analysis did not show any large effects; thus, the analysis proceeded without segmentation for joint bodies. The analysis is shown in Figure 5. The curves for the different conductor sizes are of the same form (curved distributions indicating threshold performance and two mechanisms for temperature increase as evidenced by the low and high temperature portion of each curve) but displaced.

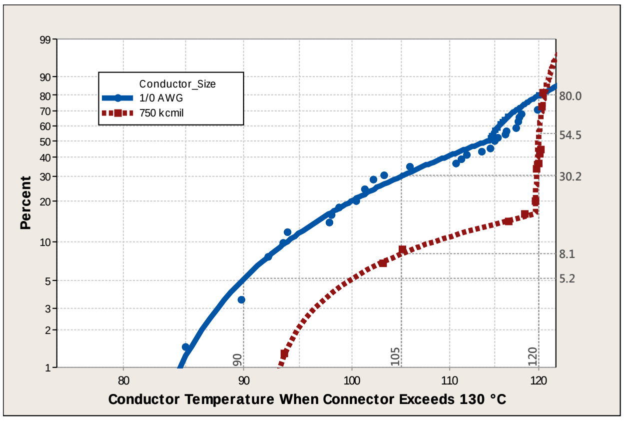

Figure 5: Conductor Temperatures when the Connector within the Joint exceeded 130 °C (multiple Weibull distributions)

If the samples selected in Table 1 are representative of MV joints installed in North America with correctly installed connectors and joints on new Aluminium conductor cable, these curves indicate that:

- There is a threshold temperature below which connector temperature > 130 °C are vanishingly small
- If tested at a conductor temperature of 105 °C, 30% of 1/0 AWG and 8% of 750 kcmil combinations would exceed 130 °C.

It is difficult to directly relate these results from qualification style tests to Service Experience as the installation conditions in the laboratory are different from those in Service. Also, load currents in the field will constantly vary and are likely to be significantly different from those used in lab tests. Nevertheless, lab tests with samples in air are the basis for qualification and such analysis does promote discussion and awareness.

MAXIMUM CONNECTOR TEMPERATURES WITHIN JOINTS

As noted earlier, once joints exceeded 130 °C, they were removed from the test. Thus, the maximum temperatures that they would have achieved were not determined. In a separate experiment, these samples were tested again with suitable fire precautions in place and not removed until an equilibrium was established. The results of this work are shown in Table 4 & Figure 6. Figure 6 shows the familiar connector temperature curves for the 750 kcmil conductor samples suggesting a minimum temperature. Interestingly, the same shape is shown for all conductor temperatures and the minimum temperature achieved within the joint is always in excess of that of the conductor.

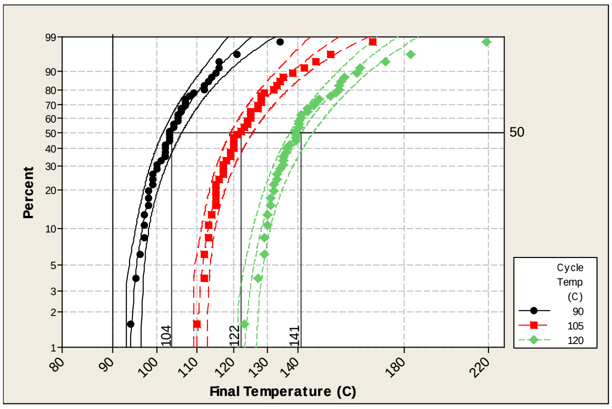

Figure 6: Maximum Connector Temperatures by Cycle Temperature Conductor (750 kcmil Conductor)

The results for the 1/0 AWG conductor show the same pattern as Figure 6; however, the curves are shifted to significantly higher temperatures. In some cases the connectors exceeded the 400 °C operational rating of the thermocouples used (10% exceeded 400 °C with 90 °C conductor temperatures & 30% exceeded 400 °C with 105 °C conductor temperatures).

Summarizing, the Median connector temperatures achieved in the IEEE style tests are shown in Table 4 for all conductor temperatures and conductor sizes. In these experiments there was no conductor / connector / die / joint body combination where all combinations did not exceed the conductor temperature of the cable.

Table 4: Median Value of the Maximum Connector Temperatures in the IEEE style tests by Selected Conductor Temperatures

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

ANALYSIS TO MAXIMISE AGREEMENT BETWEEN ANSI & IEEE

Initial inspection shows that using a simple Pass / Fail approach (Table 2 & Table 3) does not yield the expected agreement between the ANSI and IEEE Standards. However, it was conjectured that better agreement might be achieved if the 'degree of Pass' is considered. This would lead to a ranking approach where it would be expected that the poorest and best performers in each test would agree and thus some improvement in correlation could be obtained. This correlation analysis was undertaken and is shown in Figure 7. The diagonal line indicates perfect agreement between the two test programs. There is rarely perfect agreement with real data and misplacement by a rank or so would be acceptable. However, for this data, improvement only occurs within the mid portion and there is poor agreement at the extremes.

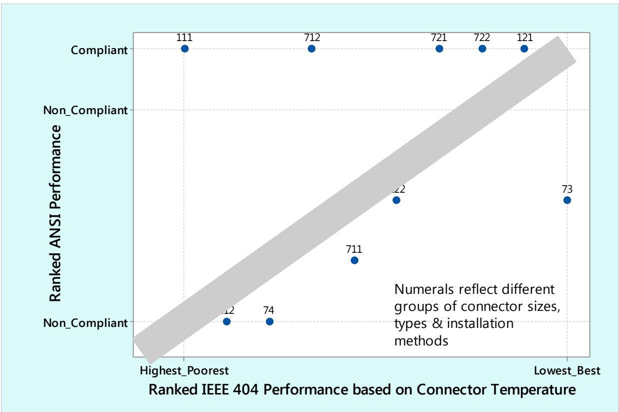

Figure 7: Correlation of Rank Order from IEEE 404 Style Tests and ANSI Tests

Consequently, it was recognised that the ANSI Success Criteria (Temperature, Temperature Stability, Resistance Stability) were based on those of bare overhead lines and that these may be sub-optimal for the underground environment. Thus, it was determined that the criteria should be adjusted and compared with the IEEE data to identify new ANSI Success Criteria that will provide a better and hopefully acceptable agreement. It did not seem practical to adjust the temperature criteria due to the known uncertainties in the measurement of absolute temperature, and the concern with accelerating mechanisms that are unlikely to occur in service (see high temperature mode in Figure 5).

The outcome of this Criteria Optimisation is shown in Figure 8 & Figure 9. In this analysis, contours closer to 1 indicate an improved agreement between ANSI & IEEE. Thus common areas of dark green would indicate a set of new and robust Success Criteria within the current ANSI test that would be appropriate for use with underground connectors. The current ANSI Criteria are represented by the top right corner of these plots.

Unfortunately, inspection shows that no such region exists. Thus we conclude that there is not a practical way in which the mode of analysis (Ranking) or the Success Criteria (Pass / Fail) can be modified that enables the current ANSI C119.4 CCST to replicate the observed performance of connectors in currently used MV joints.

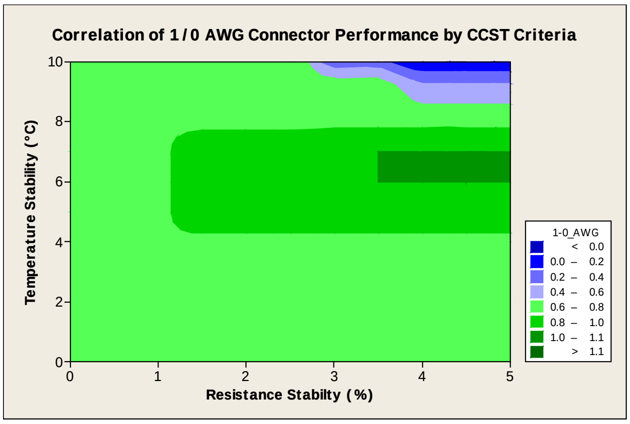

Figure 8: Test Correlation Plot for 1/0 AWG Conductor

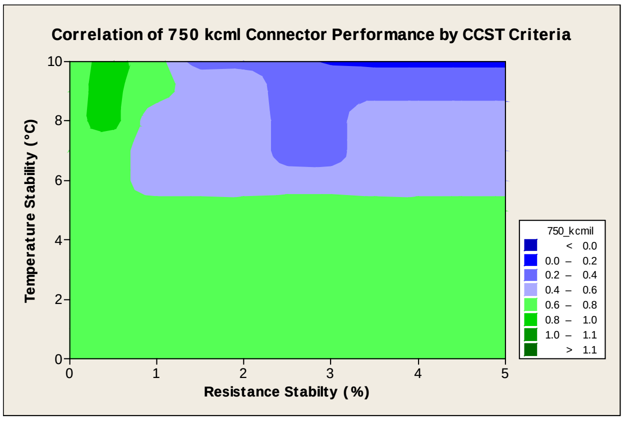

Figure 9: Test Correlation Plot for 750 kcmil Conductor

CONCLUSIONS

The work reported here suggests that, for the cable accessories currently being installed in North America:

- Most connectors (>90%) will operate at temperatures higher than the cable conductor. This is contrary to the perception within the utility sphere.
- Continual operation of the cable conductor close to or above 90 °C is likely to result in a larger risk of thermal runaway than previously thought .
- The expedient approach in IEEE 404 of using the ANSI tests for overhead connectors to demonstrate that connectors may perform well for MV cable joints is likely not robust.
- There does not appear to be a practical way by which the ANSI C119.4 criteria (compliant / non compliant) can be made to correlate with the real connector thermal performance seen in the IEEE 404 style load cycle tests, which better represent how the connectors are used.
- The use of models of the cable accessory to qualify connectors in cable joints is believed to be practical and attractive as it would provide information on the particular architecture of interest.

REFERENCES

[1] ANSI Standard C119.4-2004, *American National Standard for Electric Connectors – Connectors for Use between Aluminum-to-Aluminum or Aluminum-to-Copper Conductors*

[2] ANSI Standard C119.4-2011, *American National Standard for Electric Connectors – Connectors for Use Between Aluminum-to-Aluminum and Aluminum-to-Copper Conductors Designed for Normal Operation at or Below 93 °C and Copper-to-Copper Conductors Designed for Normal Operation at or Below 100 °C*

[3] IEEE Standard 404-2012, *IEEE Standard for Extruded and Laminated Dielectric Shielded Cable Joints Rated 2.5 kV to 500 kV*

[4] T Parker & N Hampton, "Impact of filled-strand conductor on Connector Temperatures for Medium Voltage Joints", *JICABLE11*, Versailles France, June 2011