POWERTECH LABS INC.

TEST REPORT
CABLEMATE TDD0/TDD1 DEADBREAK 600A, 15kV/25kV CONNECTORS

Prepared for
Ardry Trading Company Inc.

PROJECT No. PL-01263

December 2016

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1.0 SUMMARY

A design of CableMate TDD0/TDD1 600 Amp Deadbreak 15kV/25kV connectors manufactured by Taimold Electrical Ltd. and supplied by Ardry Trading Company successfully passed a series of selected IEEE 386-2006 design tests listed in Table 2 of this report.

2.0 TEST STANDARD

The requested tests were performed in accordance with the following standard:

- IEEE 386-2006 Standard for Separable Insulated Connector Systems for Power Distribution Systems Above 600V

3.0 TEST SAMPLES

Connector test samples were CableMate TDD0/TDD1 600 Amp Deadbreak 15kV/25kV connectors. The connectors in combination with the corresponding CableMate insulating plugs (catalog number TDPA), cable adapters (catalog number TDAH08), crimp connector (catalog number TDCA21) and bushings (catalog number TDBAS) were assembled onto 750 kcmil insulated cables according to manufacturer instructions. Test sample ratings are listed in Table 1.

For tests of Clause 7.9, "Current-cycling of uninsulated components", the connector samples were assembled onto bare 750 kcmil aluminum conductor with CableMate crimp connector catalog number TDCA21.

4.0 TEST SEQUENCE

The tests were performed according to Table 5 of IEEE standard 386, Design Tests. The applicable tests and the corresponding number of samples that were tested as part of this program are listed in Table 2 of this report.

5.0 TEST DATE & LOCATION

The tests were performed at the Powertech Labs in Surrey, British Columbia during the period of June 21, 2016 and October 17, 2016.

6.0 TEST PROGRAM

6.1 Partial Discharge Test

6.1.1 Test Procedure

The 60 Hz test voltage was applied to the conductor of the cable termination of each sample while the connector was terminated with two insulating plugs. Test setup diagram is shown in Figure 1. The test voltage was increased to 20% above the partial discharge minimum extinction voltage of 31.2kV (20% of 26kV as per Table 1 of IEEE standard 386. If the partial discharge measurement exceeded 3pC, the test voltage was lowered to the manufacturer specified minimum extinction voltage of 21.5kV.

6.1.2 Acceptance Criteria

Partial discharge reading taken during 3 to 60 seconds interval must not exceed 3 pC.

6.1.3 Test Results

Test samples from test sequence A and test sequence B successfully passed the test. Summary of results are provided in Table 3.

6.2 AC Withstand Test

6.2.1 Test Procedure

The 60 Hz test voltage of $45kV_{rms}$ was applied to the conductor of the cable termination of each sample while the connector was terminated with two insulating plugs. The test voltage was maintained for 1 minute. Test setup diagram can be seen in Figure 1.

6.2.2 Acceptance Criteria

The test samples are considered to have met the acceptance criteria if the voltage is sustained for 1 minute without occurrence of any flashover or puncture through insulation.

6.2.3 Test Results

Test samples from test sequence A and test sequence B successfully passed the test. Summary of results are provided in Table 4.

6.3 DC Withstand Test

6.3.1 Test Procedure

DC test voltage of 84 kV (negative polarity) was applied to the conductor of the cable termination of each sample while the connector was terminated with two insulating plugs. The test voltage was maintained for 15 minute. Test setup is shown in Figure 1.

6.3.2 Acceptance Criteria

The test samples meet the criteria if the voltage is sustained for 15 minutes without occurrence of any flashover or puncture.

6.3.3 Test Results

Test samples from test sequence A have successfully passed the test. Summary of results are provided in Table 5.

6.4 Impulse Test

6.4.1 Test Procedure

Samples were subjected to 3 positive and 3 negative, 1.2/50 μs full wave impulses of 140 kV crest magnitude. Each sequence of impulses was preceded by a 50% reduced conditioning impulse. The wave shape parameters were in accordance with IEEE standard 4. The impulse was applied to the conductor at the cable termination while the connector was terminated with insulating plugs. Connector was grounded as per manufacturer instructions.

6.4.2 Acceptance Criteria

The samples must withstand all applied impulses without flashover or puncture.

6.4.3 Test Results

Test samples from test sequence A and test sequence B successfully passed the test.

6.5 Short-time Current Test

6.5.1 Test Procedure

The test samples were subjected to test current of 25 kA_{rms} for the duration of 0.17 seconds, followed by a subsequent test at 10 kA_{rms} for 3.0 seconds. Following the tests samples were examined for damage, DC resistance measurements were made and compared to those prior to the test and insulation was tested with a high voltage test at 45 kV AC. The test circuit diagram is shown in Figure 4.

6.5.2 Acceptance Criteria

The test samples are considered to have passed the test if no separation of interfaces occurs during the test and if there is no damage or significant increase in resistance measurements and the samples pass the withstand test.

6.5.3 Test Results

Test samples from test sequence C successfully passed the short-time current test. The resistance measurement results are provided in Table 6.

6.6 Current Cycling of Uninsulated Components

6.6.1 Test Procedure

The test samples were tested in accordance with ANSI C119.4-2011, "Standard for Electrical Connectors for Use between Aluminum-to-Aluminum and Aluminum-to-Copper Conductors Designed for Normal Operation at or Below 93 ºC" for class A connectors.

Samples consisted of 750 kcmil uninsulated aluminium conductors assembled with corresponding aluminium crimp connector lugs that are part of the T-body Connector kit. Samples were subjected to 500 current cycles using Current Cycle Test Method (CCT) in

accordance with ANSI C119.4-2011. Temperature and resistance measurements were made according to Table 2 of the standard.

6.6.2 Acceptance Criteria

The samples are considered to pass the test if the following criteria are met:

a. The resistance of tested connections shall be stable
b. The temperature difference between the control conductor and each connector shall be stable
c. The temperature of each connector shall be stable

The resistance and temperature stability criteria are defined in clause 4.3 and clause 4.4 of ANSI C119.4-2011.

6.6.3 Test Results

Test samples from test sequence E successfully passed the uninsulated current cycling test. The stability graphs of temperature and resistance are shown in Figure 6 to Figure 12.

6.7 Current Cycling of Insulated Connectors

6.7.1 Test Procedure

The test samples were subjected to 50 current cycles, with the current on 6 hours and off 6 hours for each cycle. The current was adjusted to maintain a steady state temperature of 90 ºC on the surface of the conductor of the control cable in accordance with IEEE 386-2006, Clause 7.11. The temperature of the barrel of the crimp lug of each sample connectors was measured during the test.

6.7.2 Acceptance Criteria

The temperature of the connector should not exceed the temperature of the conductor of the control cable.

6.7.3 Test Results

Test samples from test sequence D successfully passed the insulated current cycling test. The results of temperature measurement are provided in Figure 13.

6.8 Accelerated Sealing Life Test

6.8.1 Test Procedure

The test connector assemblies were placed in an oven having 121 °C temperature and remained there for three weeks. After this time has elapsed, the samples were removed from the oven and each operated once by using the operating eye or an appropriate location on the axis of the separable interface.Then, the test samples were subjected to 50 current cycles, with the current on 4 hours and off 2 hours for each cycle. The assemblies were heated in air during on period with a current adjusted to maintain a steady state temperature of 90 C on the surface of the conductor of the control cable and were submerged in conductive water (5000 Ω-cm maximum) of 25 °C ± 10 °C during the off period in accordance with IEEE 386-2006, Clause 7.12.

6.8.2 Acceptance Criteria

After the 50th cycle, each tested connector and cable assembly shall withstand a design impulse test as described in section 6.12 of this report. Also, the test point shall be capable of passing the voltage test described in section 6.10 of this report.

6.8.3 Test Results

Test samples from test sequence B successfully passed the accelerated sealing life test.

6.9 Cable Pull out Test

6.9.1 Test Procedure

The test samples were subjected to 200 lbs tensile force between the cable conductor and the compression lug of the connector.

6.9.2 Acceptance Criteria

The connection shall withstand the applied force for 1 minute without deformation or slippage of the conductor from the connector.

6.9.3 Test Results

Test samples from test sequence E successfully passed the cable pull out test.

6.10 Test Point Test

6.10.1 Test Procedure

The test samples were energized at the nominal operating voltage of 15 kV. The test point was checked using DVI-100T Digital Voltage Indicator for the presence of voltage. The samples were then de-energized and the capacitance between the test point and cable conductor, and test point and shield were measured for each sample. The test circuit diagrams are shown in Figure 2 and Figure 3.

6.10.2 Acceptance Criteria

The samples are considered to have passed the test if the capacitance between the test point and the conductor is ≥ 1pF. The ratio of the capacitance between the test point to shield and test point to conductor shall not exceed 12.0. While samples are energized, voltage indicator shall produce a positive response when applied to the test point.

6.10.3 Test Results

Four samples that were previously tested and passed the test sequence A were used for this test under test sequence E and successfully passed the test. Summary of results are provided in Tables 6 to 8.

6.11 Shielding Test

6.11.1 Test Procedure

The test samples were tested in accordance with IEEE 592-2007, Standard for Exposed Semiconducting Shield on High-Voltage Cable Joints and Separable Connectors. Shield

resistance of the test specimens was measured before and after specimens were oven aged for 504 hours at 121 ºC.

The test specimens were then assembled onto cables and faulting rods were installed at the furthest possible extremity of the shield. The specimens were then subjected to two consecutive fault current initiation tests with short circuit current of 10 kA_{rms} symmetrical. The test circuit diagram is shown in Figure 5.

6.11.2 Acceptance Criteria

Shield resistance test: measured shield resistance of the specimens from cable entrance to the furthest shield extremity should be less than or equal to 5000 Ohm.

Fault-current initiation test: The shield should be capable of initiating and sustaining two consecutive fault-current arcs.

6.11.3 Test Results

Test samples from test sequence E successfully passed the shielding test. Summary of results are provided in Table 9.

6.12 Impulse Test (post accelerated life)

6.12.1 Test Procedure

The test procedures are the same as Impulse Test described in section 6.4 of this report.

6.12.2 Acceptance Criteria

The samples must withstand all applied impulses without flashover or puncture.

6.12.3 Test Results

Test samples from test sequence B successfully passed the test.

7.0 TEST CIRCUITS

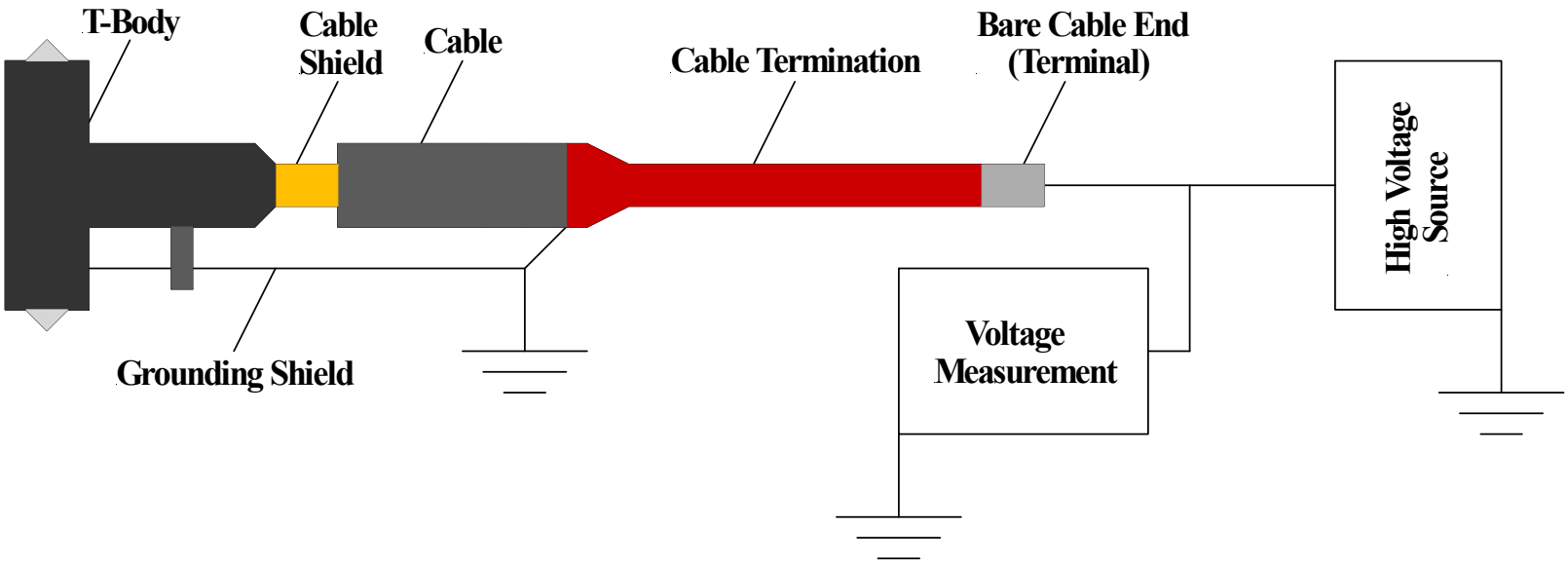

Figure 1: Partial discharge, AC and DC Withstand test circuit

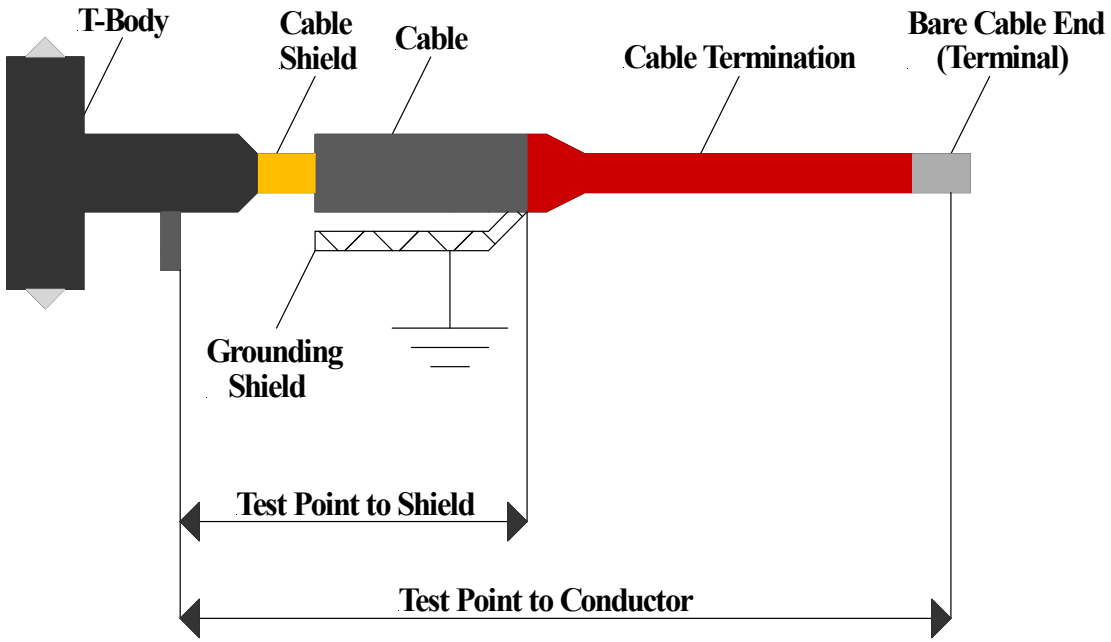

Figure 2: Test point capacitance test circuit

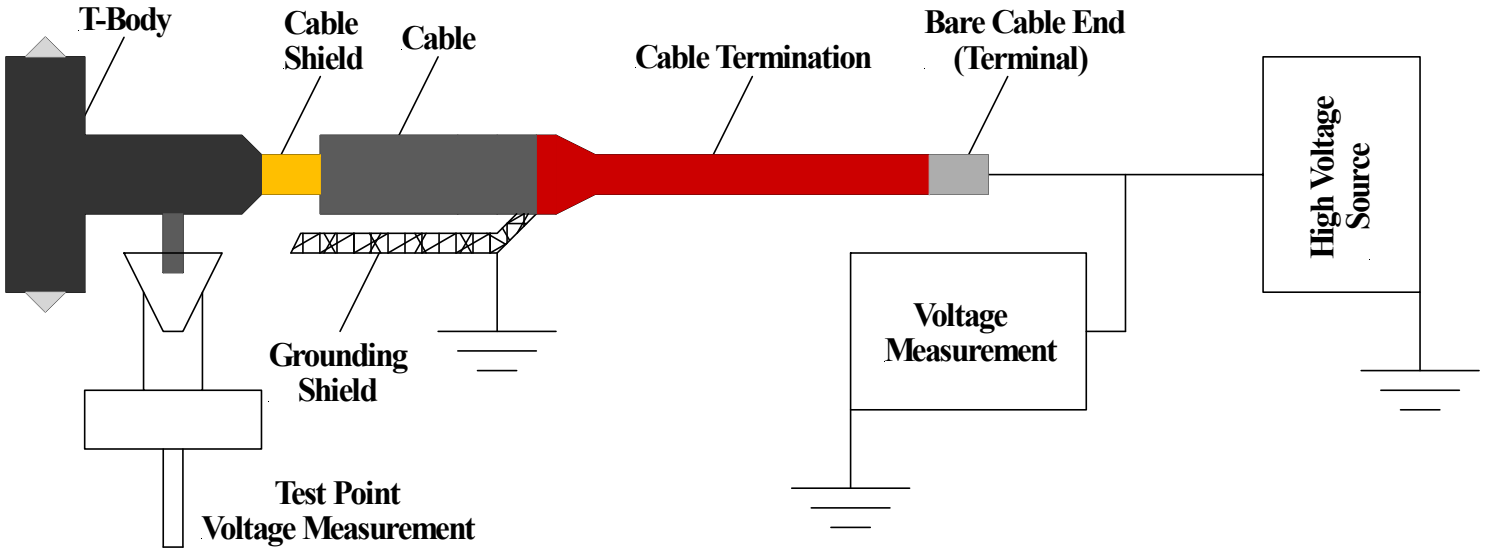

Figure 3: Test point voltage test circuit

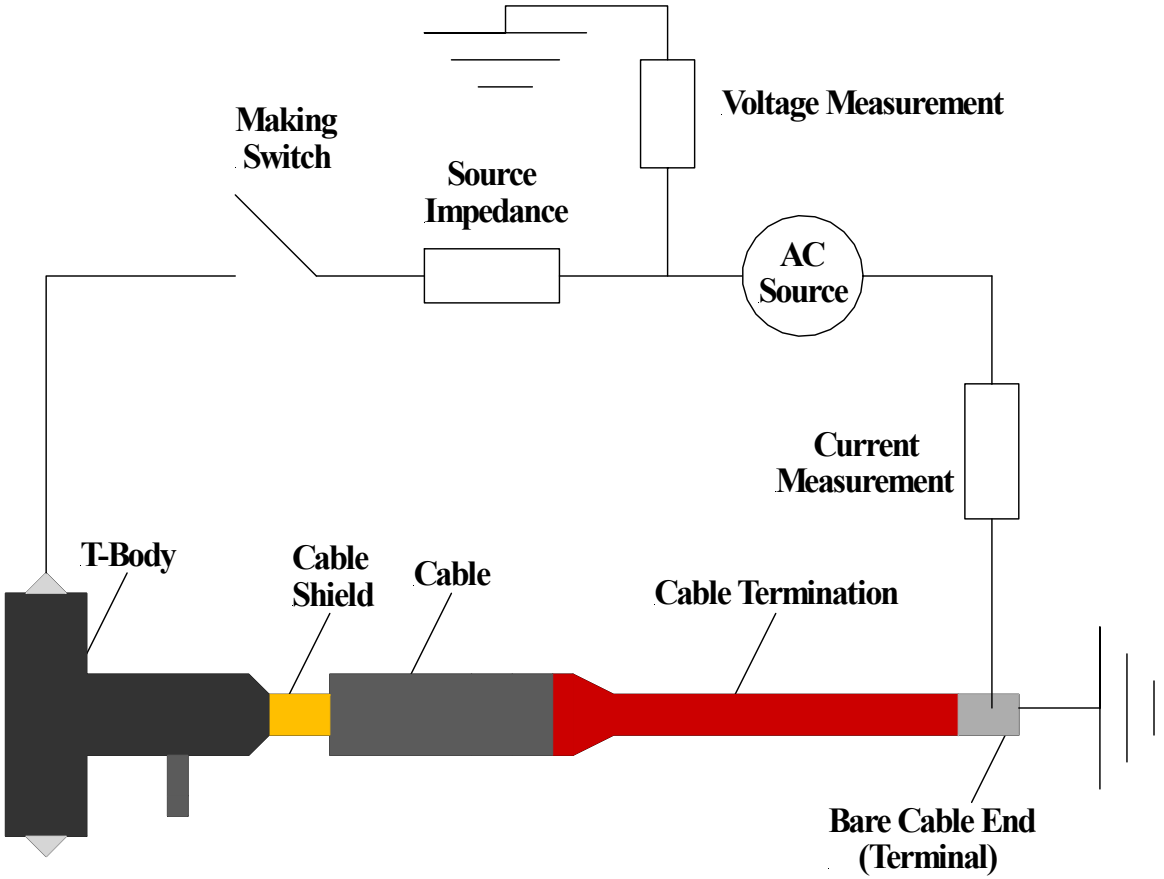

Figure 4: Short time test circuit

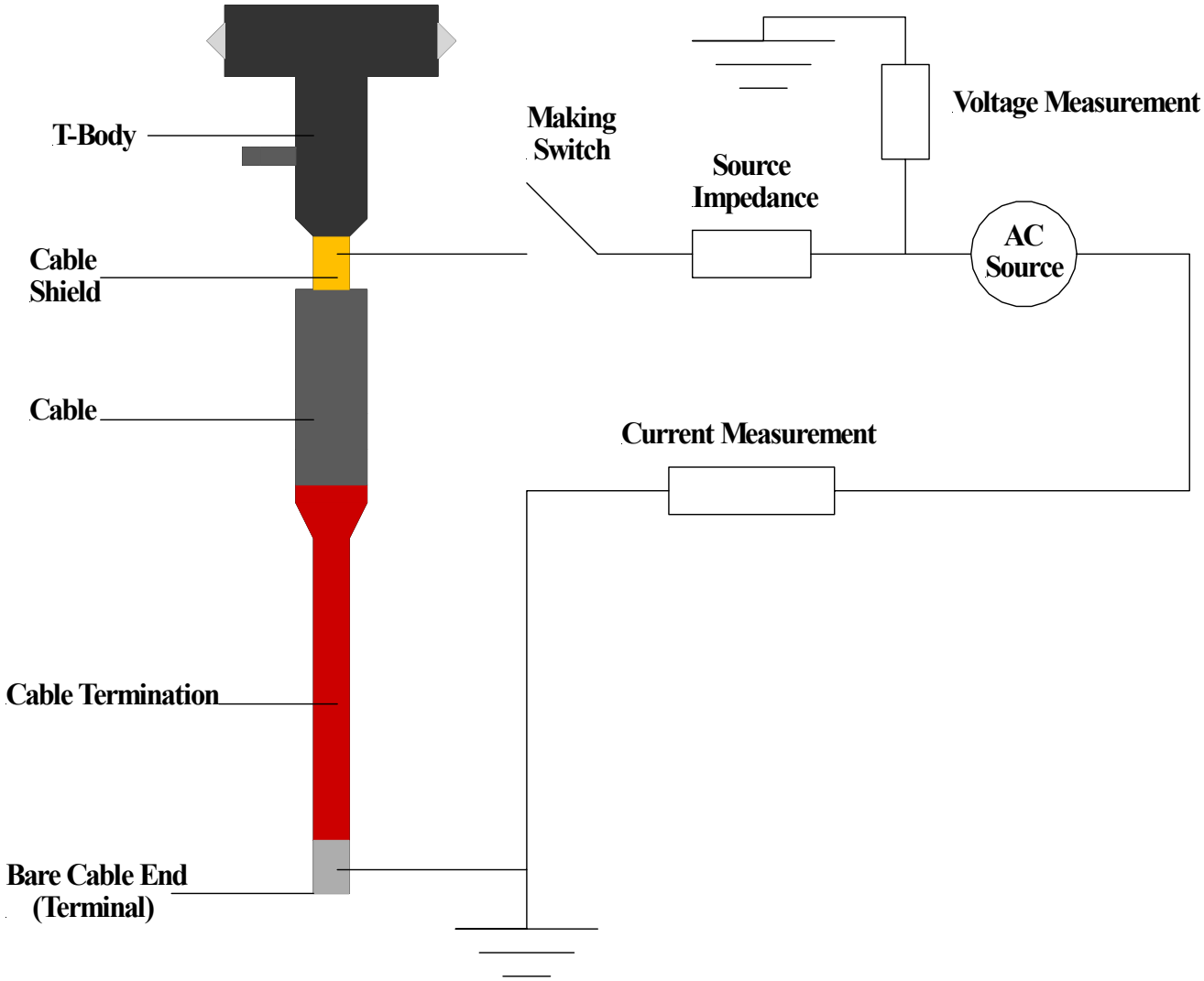

Figure 5: Fault current initiation test circuit

8.0 TABLES

Table 1: Test sample details

Connector		**Cable**	
Maximum voltage rating	16.2kV L-N, 28 kV L-L	Manufacturer	Nexans
Impulse withstand (BIL)	140 kV	Nom. voltage rating	25 kV
AC 1 min. withstand	45 kV	Insulation	TR-XLPE
DC 15 min. withstand	84 kV	Metal shield	Corrugated Cu. tape
PD extinction below 3pC	21.5 kV	Conductor	750 kcmil, Al.
Continuous current	600 A	Overlaying jacket	PVC
Short-time current	25 kA		

Table 2: Test sequences performed and numbers of samples tested

		Test Sequences				
		A	B	C	D	E
	No. of Samples	10	4	4	4	4 ea.
Design Test	**Clause Ref.**					
Partial discharge test	7.40	■	■			
AC withstand voltage	7.5.1	■	■			
DC withstand voltage	7.5.2	■				
Impulse withstand voltage	7.5.3	■	■			
Short-time current	7.60			■		
Current cycling - uninsulated comp	7.90					■
Current cycling - 600 A connectors	7.11				■	
Accelerated sealing life test	7.12		■			
Cable pull-out (tensile strength)	7.13					■
Test point	7.17					■
Shielding	7.18					■
Impulse test (post accelerated life)	7.5.3		■			

Table 3: Results of partial discharge test

Test Voltage (kV)	Test Sample	Discharge (PC)
21.5	1A	< 2.5
21.5	2A	1-2
21.5	3A	1-2
21.5	4A	1-2
21.5	5A	1-2.5
21.5	6A	1-2.5
21.5	7A	1-2.5
21.5	8A	1-2.5
21.5	9A	1-2.5
21.5	10A	1-2.5
21.5	1B	1-2.5
21.5	2B	1-2.5
21.5	3B	1-2.5
21.5	4B	1-2.5

Table 4: Results of AC withstand test

Test Voltage (kV)	Test Sample	1 min withstand results
45	1A	Pass
45	2A	Pass
45	3A	Pass
45	4A	Pass
45	5A	Pass
45	6A	Pass
45	7A	Pass
45	8A	Pass
45	9A	Pass
45	10A	Pass
45	1B	Pass
45	2B	Pass
45	3B	Pass
45	4B	Pass

Table 5: Results of DC withstand test

Test Voltage (kV)	Test Sample	Withstand Time (min)	Leakage Current (μA)	15 min Withstand Results
84	1A	15	69	Pass
84	2A	15	55	Pass
84	3A	15	63	Pass
84	4A	15	55	Pass
84	5A	15	63	Pass
84	6A	15	52	Pass
84	7A	15	63	Pass
84	8A	15	55	Pass
84	9A	15	69	Pass
84	10A	15	69	Pass
84	1B	15	52	Pass
84	2B	15	52	Pass
84	3B	15	42	Pass
84	4B	15	42	Pass

Table 6: DC resistance measurements before and after short time test

Test Sample	Initial Resistance (μΩ)	Resistance After Test (μΩ)	Result
1C	79.5	76.6	Pass
2C	80.4	75.8	Pass
3C	73.3	75.9	Pass
4C	80.3	76.1	Pass

Table 7: Test point capacitance results

Test Sample	Test Point to Shield/Ground (pF)	Test Point to Conductor (pF)	Result
7A	10.5	9.5	Pass
8A	4.5	9	Pass
9A	5	9.5	Pass
10A	12	8.5	Pass

Table 8: Test point voltage results

Test Voltage (kV)	Test Sample	Test Point Reading on Device (kV)	Reading Device shows energized condition	Result
16	7A	10	Yes	Pass
16	8A	10	Yes	Pass
16	9A	11	Yes	Pass
16	10A	11	Yes	Pass

Table 9: Shielding Test- shield resistance measurements before and after oven aging

Unaged Samples			
Temperature: 22.4 ºC			
Sample No.	Voltage @ 1mA	Resistance (Ω)	Result
1E	1.17	1170	Pass
2E	1.03	1030	Pass
3E	0.84	840	Pass
4E	1.32	1320	Pass
Temperature: 88 ºC			
1E	2.1	2100	Pass
2E	1.6	1600	Pass
3E	0.89	890	Pass
4E	2.54	2540	Pass
After Oven Aging			
Temperature: 22.2 ºC			
1E	2.17	2170	Pass
2E	2.19	2190	Pass
3E	2.86	2860	Pass
4E	2.34	2340	Pass
Temperature: 94 ºC			
1E	3.98	3980	Pass
2E	1.7	1700	Pass
3E	2.45	2450	Pass
4E	4.8	4800	Pass

9.0 GRAPHS

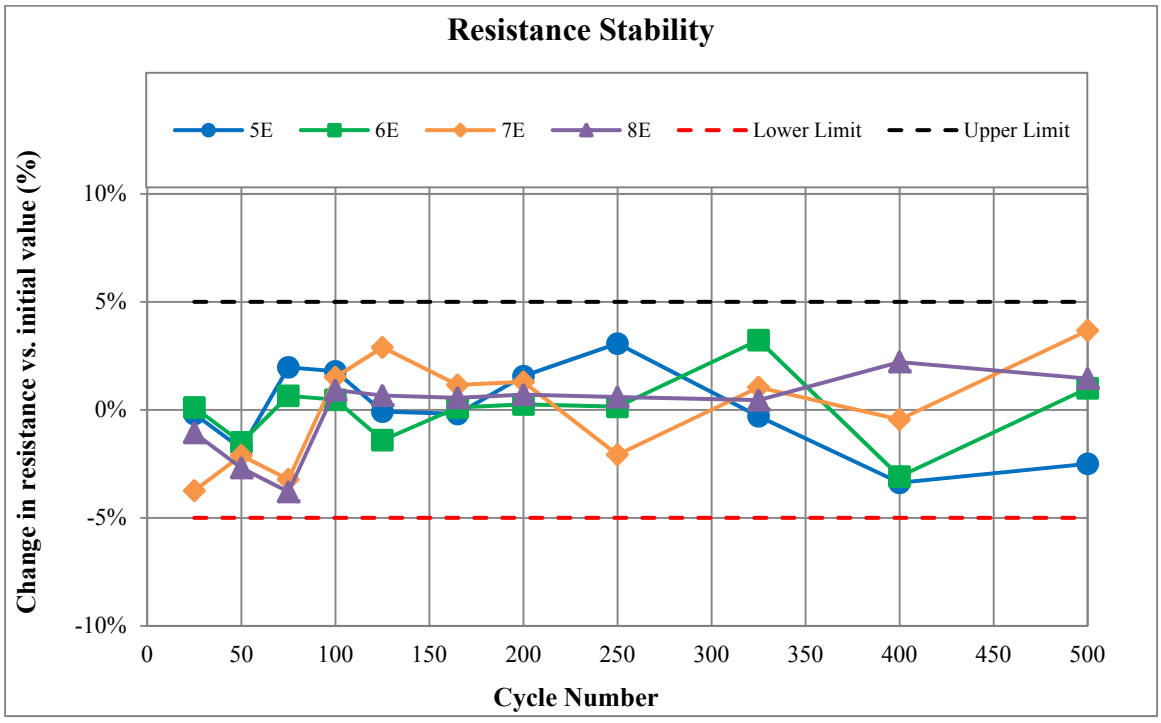

Figure 6: Uninsulated components current cycling test, resistance stability graph

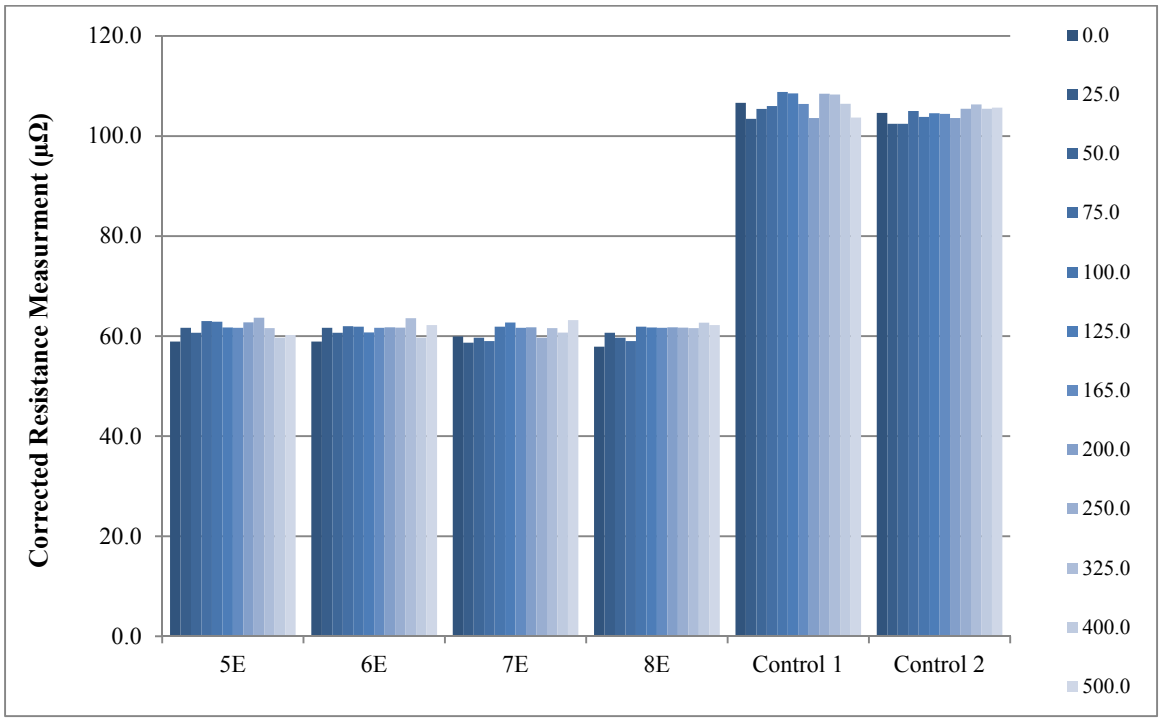

Figure 7: Uninsulated components current cycling test, resistance measurements

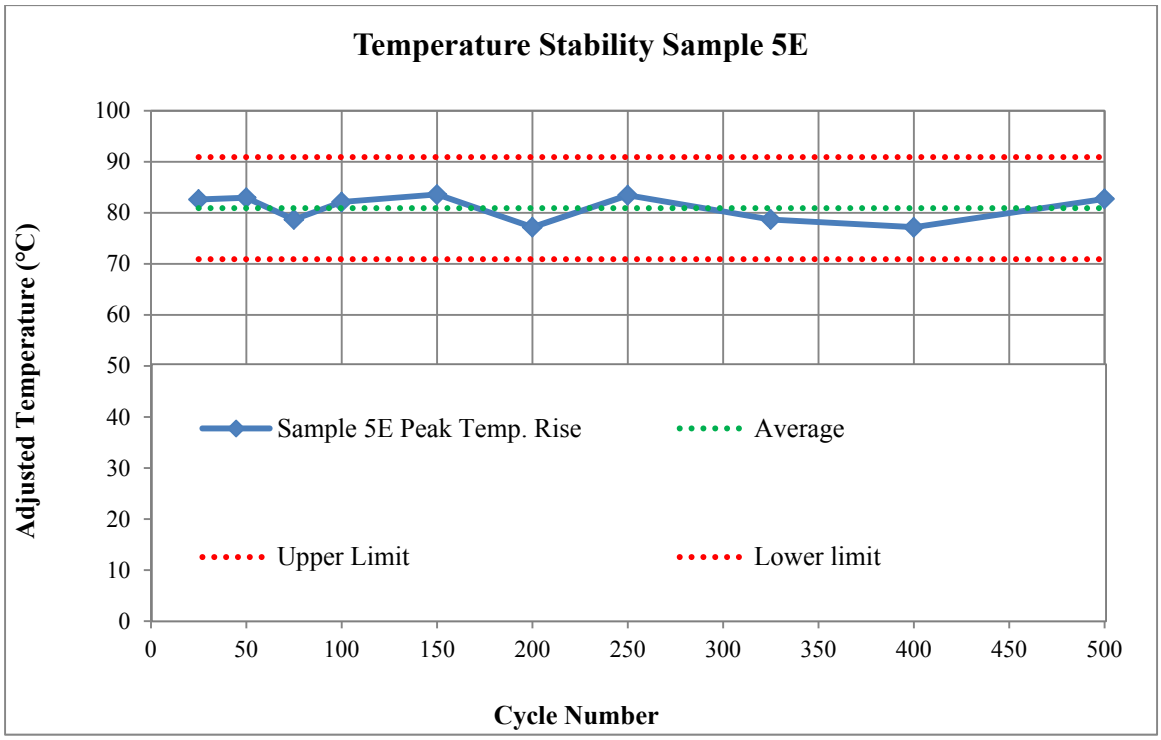

Figure 8: Uninsulated components current cycling test, temperature stability graph

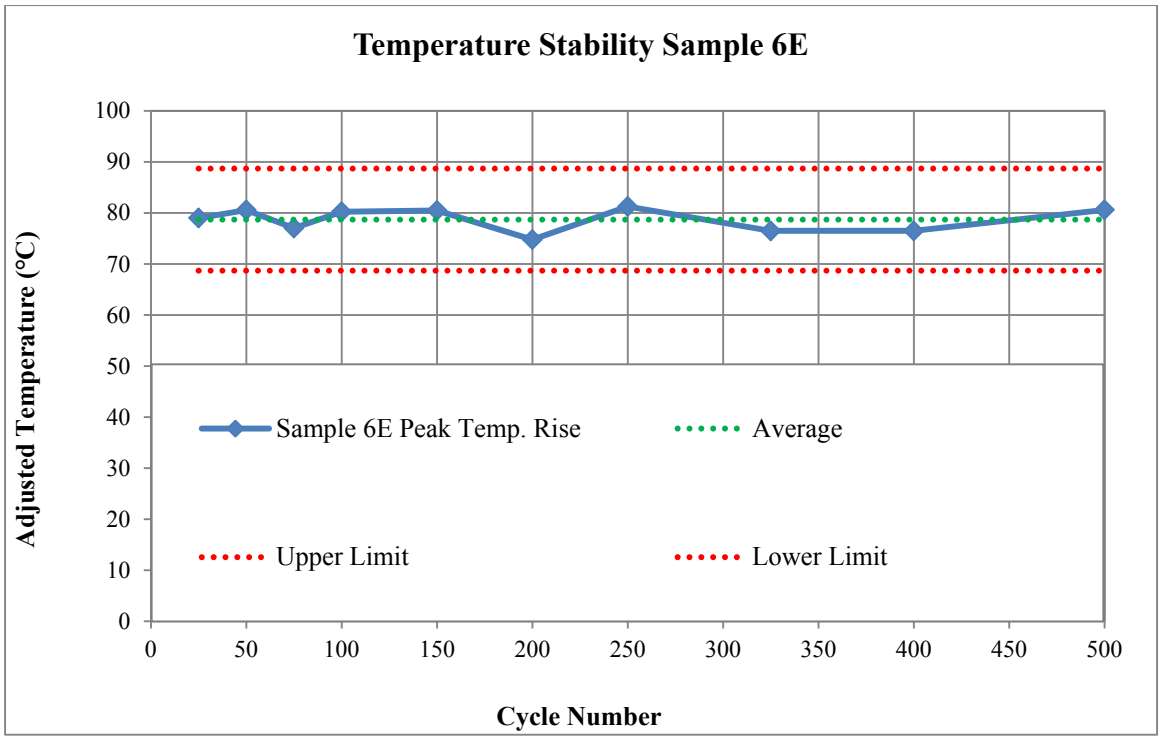

Figure 9: Uninsulated components current cycling test, temperature stability graph

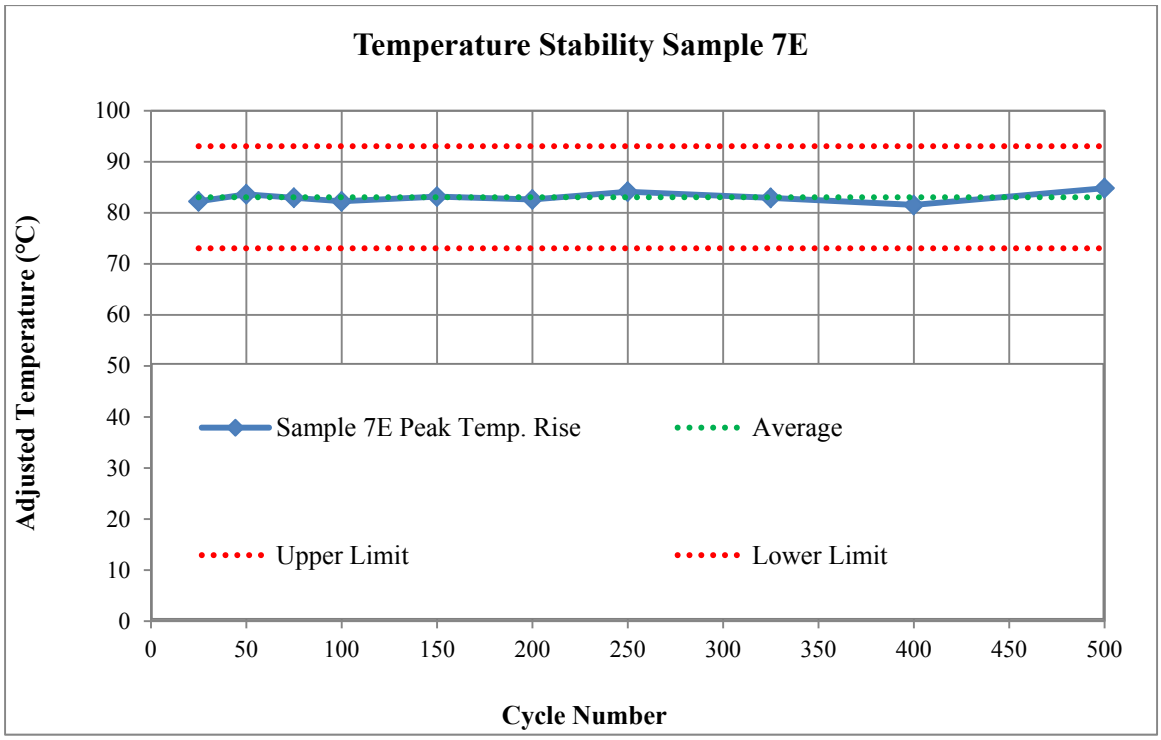

Figure 10: Uninsulated components current cycling test, temperature stability graph

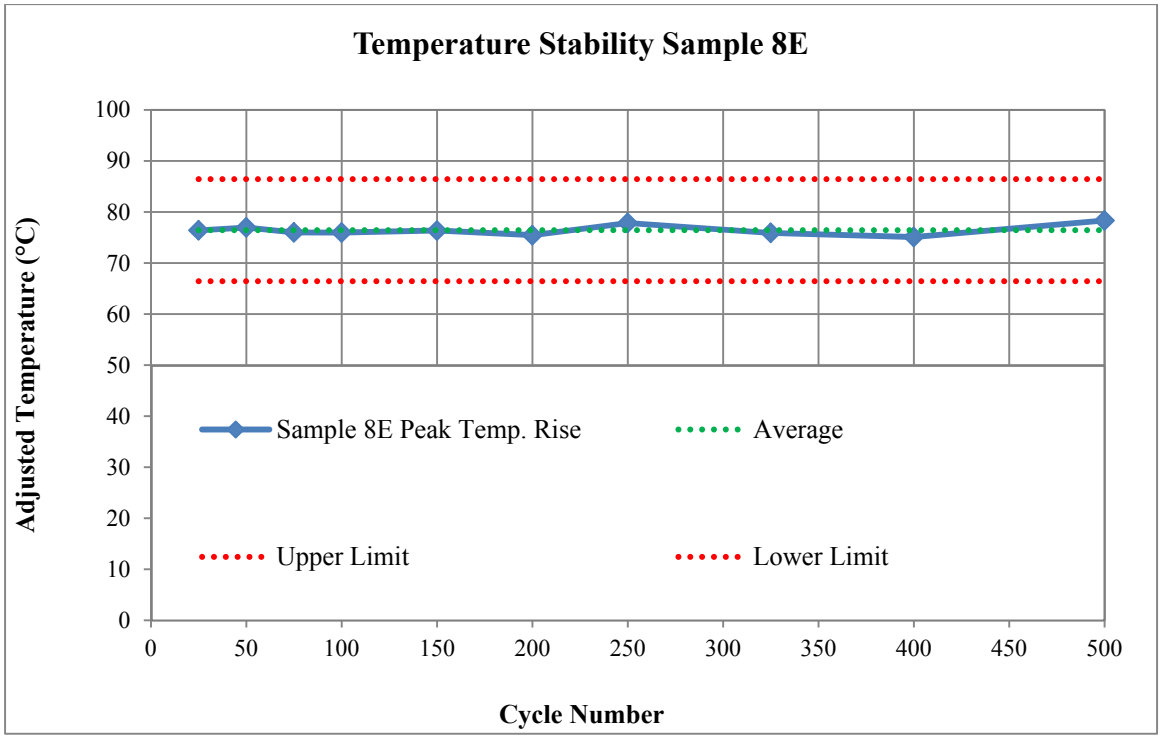

Figure 11: Uninsulated components current cycling test, temperature stability graph

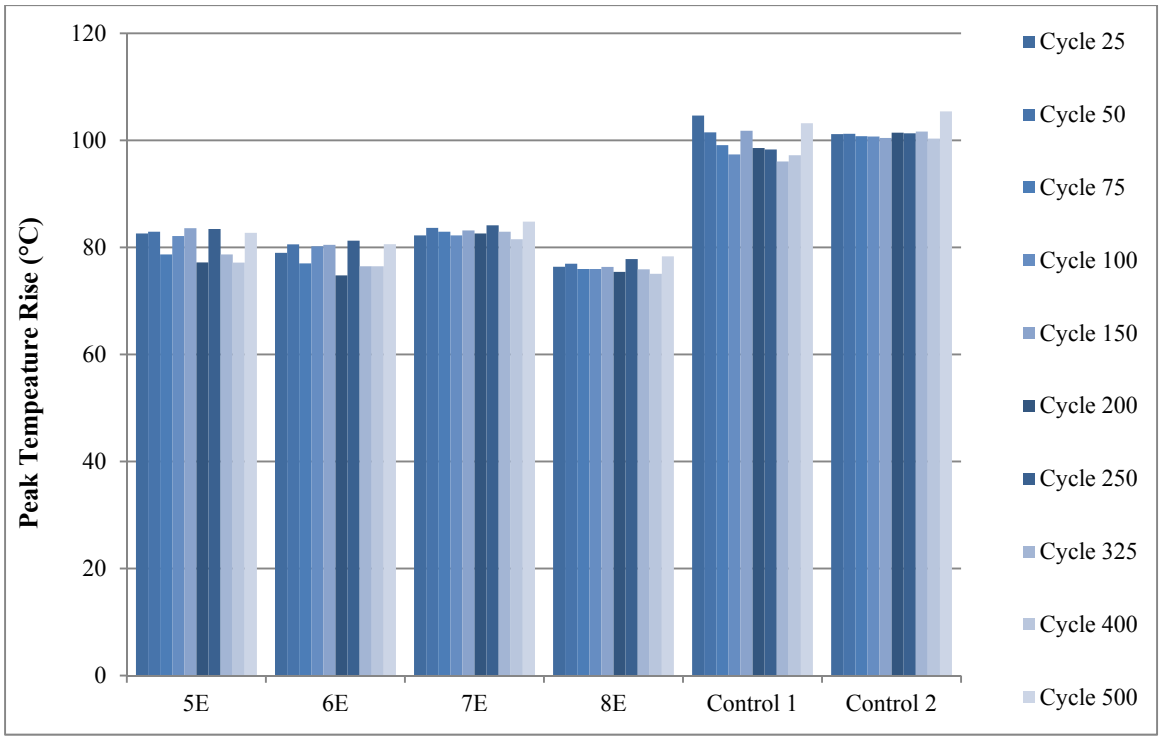

Figure 12: Uninsulated components current cycling test, peak temperature rise graph

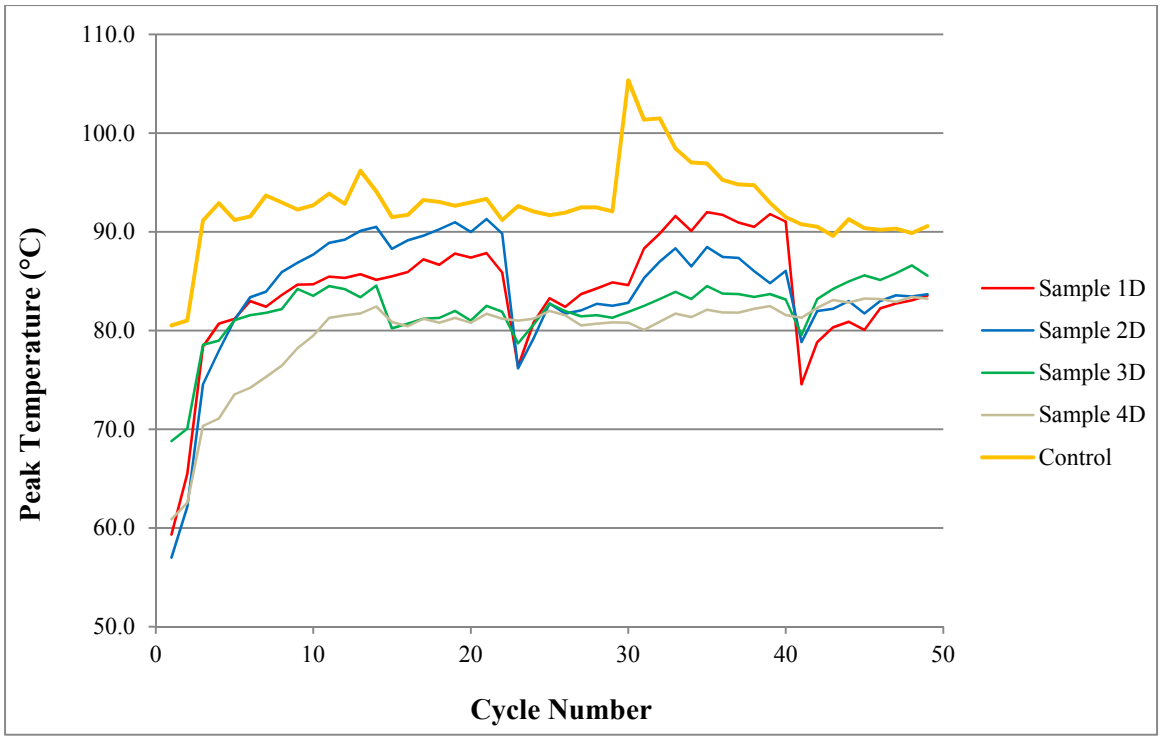

Figure 13: 600 A connectors current cycling test, peak temperature measurements

10.0 PHOTOS

Figure 14: Typical sample, test sequence A

Figure 15: Typical sample, test sequence B

Figure 16: Test setup, short time test

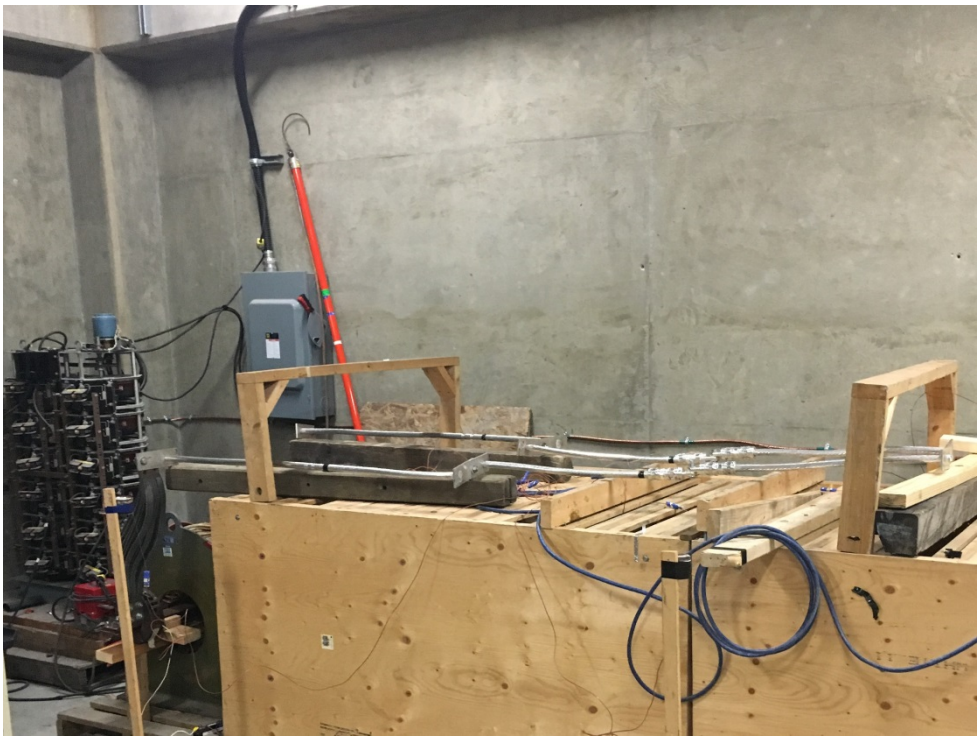

Figure 17: Test setup, uninsulated components- current cycling test

Figure 18: Test setup, 600 A connectors- current cycling test

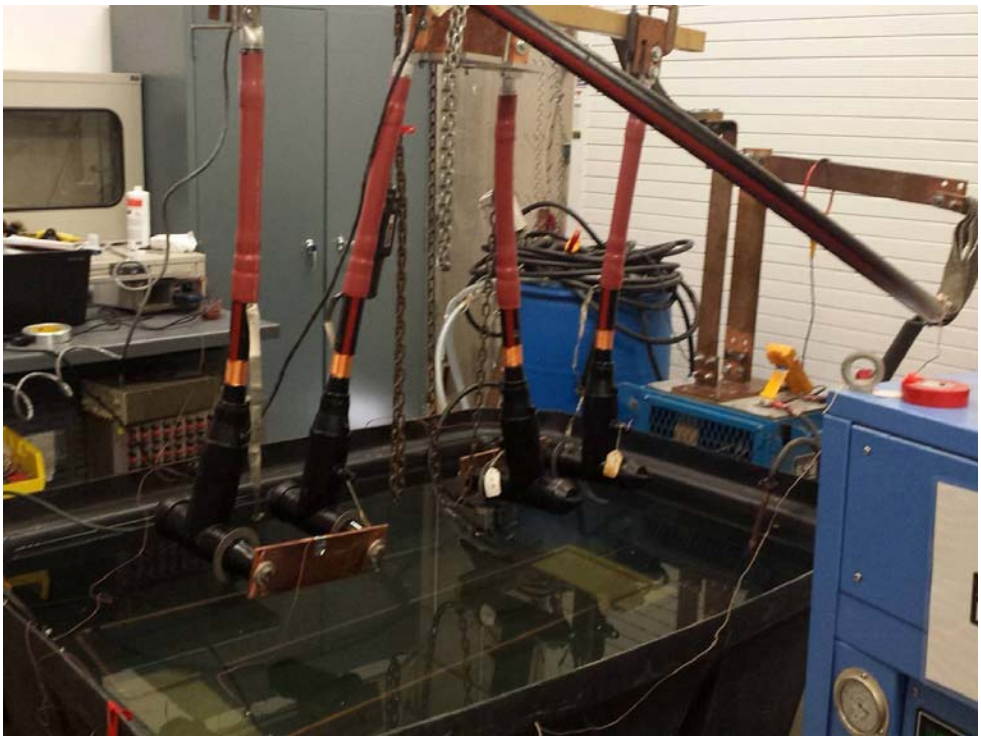

Figure 19: Accelerated aging life test setup

Figure 20: Shield test- fault current initiation test setup

POWERTECH LABS INC.

TEST REPORT
TEST POINT CAP TEST ON
CABLEMATE TDD1 DEADBREAK
600A, 15kV/25kV CONNECTORS

Prepared for
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PROJECT No. PL-01263

December 2016

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Dec 20, 2016

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1.0 TEST LOCATION AND DATE

The tests were performed at the Powertech Labs in Surrey, British Columbia during the period of August 14, 2016 and August 16, 2016.

2.0 TEST OBJECT DATA

The tests were carried out on the following item:

- Manufacturer: Taimold Electrical Ltd.
- Supplier: Ardry Trading Company
- Model #: CableMate TDD1 600 Amp Deadbreak 15kV/25kV Connectors
- Number of samples: 12
- Rated L-L Voltage: 25 kV
- BIL: 140 kV
- Rated Current: 600 A

3.0 TEST PROCEDURE

The test was conducted in accordance with IEEE 386-2006 Clause 7.16, “Test Point Cap Test”. Test samples were first subjected to a tensile force applied to the test point cap parallel with the test point axis to determine the force required to remove the cap. Following the operating-force test sample caps were permanently attached glued in place and subjected to tensile force of 100 lbf for 1 minute.

The tests were conducted at -20 ºC, 25 ºC and 65 ºC. Each set of four elbows was tested at one temperature. Samples were conditioned at each temperature for 180 minutes prior to the test.

4.0 TEST RESULTS

All test samples passed the removal force test at all three temperatures and withstand force test at all three temperatures. See attached Table 1 for removal force measurements.

5.0 TABLES

Table 1: Test force measurements, pass/fail criteria and results

Testing at -65° C			
Sample ID	**Pullout Force (lbf)**	**Pass if 8 <F< 49 lbf**	**Sustained Load test at 100 lbf for 1min**
HTP-1	16.1	Pass	Pass
HTP-2	14.1	Pass	Pass
HTP-3	20.0	Pass	Pass
HTP-4	12.3	Pass	Pass
Testing at 25° C			
Sample ID	**Pullout Force (lbf)**	**Pass if 8 <F< 49 lbf**	**Sustained Load test at 100 lbf for 1min**
1306-E3	17.4	Pass	Pass
1306-1A	13.7	Pass	Pass
1306-32	14.3	Pass	Pass
1306-6A	15.2	Pass	Pass
Testing at -20° C			
Sample ID	**Pullout Force (lbf)**	**Pass if 8 <F< 49 lbf**	**Sustained Load test at 100 lbf for 1min**
1306-7B	42.7	Pass	Pass
1306-8B	45.5	Pass	Pass
1306-6B	39.9	Pass	Pass
1306-E1	35.6	Pass	Pass