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Final Engineering Report

Northern Electric Power Co.

MLRSD Testing

Report No.:R8271A-2
Date: 31 May 2022

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Task and objective:
Assessment of the NEP PVG-2-L MLRSD to a powered thermal cycling test and a temperature verification of the RSD thermal shutdown function.

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1	April 27, 2022	Final	Kevin Ly	Hazem Ajlani	Todd Karin
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1 Executive Summary

Northern Electric Power Co. (NEP) retained PVEL, LLC (“PVEL”) to perform third-party independent performance and reliability qualification testing. This Final Engineering Report evaluates the NEP PVG-2-L module-level rapid shutdown device (MLRSD).

5 RSD devices were subjected to the powered thermal cycling test with 2 solar array simulators pushing PV power into each of the RSD. Throughout the 200 thermal cycles, the DuT remained operational throughout the test with no mis-operation nor derate.

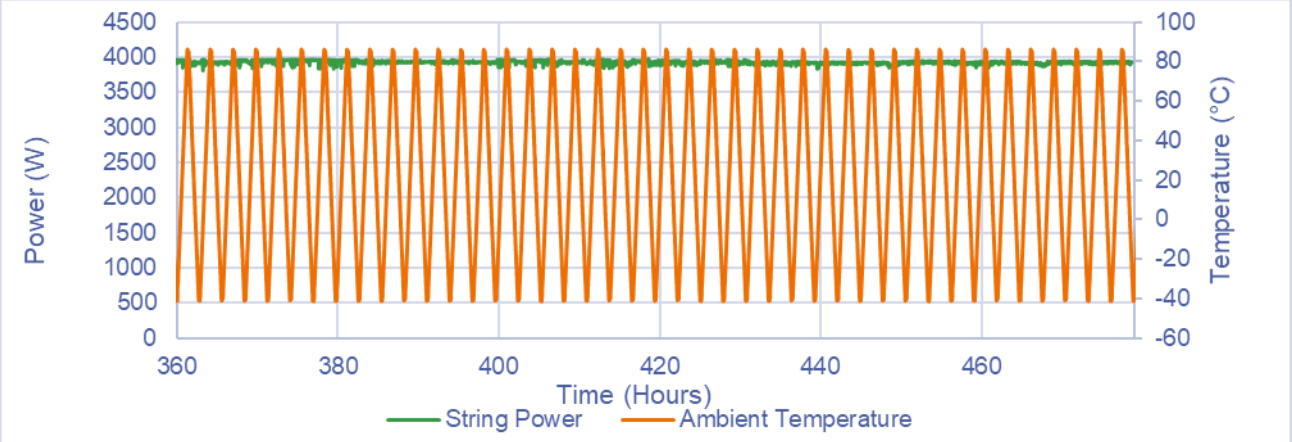

Figure 1-1: Last 5 Days of TC200

The same 5 RSD devices were then subjected to a thermal shutdown validation by ramping up the temperature from its maximum operating temperature until the RSDs automatically shutdown. The first RSD began shutting down at 112.5°C and the last RSD shutdown at 117.5°C. Once the ambient temperature fell below the maximum operating temperature, the RSD’s turned back on and the system continued to output power.

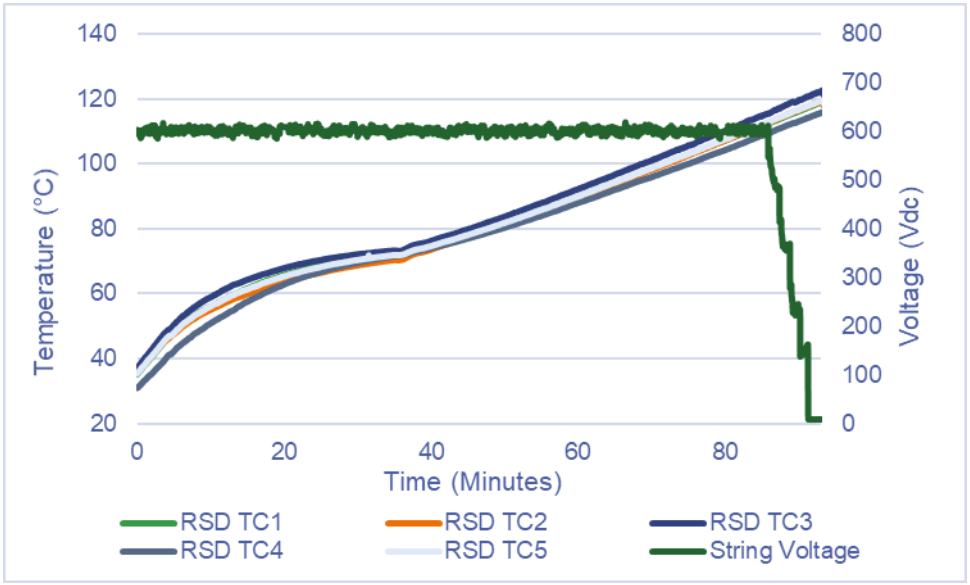

Figure 1-2: Thermal Shutdown Results

An RSD was subjected to a localized flame in order to observe the RSD's response to a flame. Throughout the test, the RSD remained operational even while the plastic enclosure of the RSD was melting.

Upon removal the of the flame source, the plastic enclosure quickly stopped burning.

Figure 1-3: Flame / Burn Test in Progress

Figure 1-4: Post Flame / Burn Test

2 Test Plan Overview

This report outlines the TC200 reliability test and thermal shutdown validation test performed on the NEP PVG-2-L MLRSD. The testing sequence aims to validate the MLRSD's performance over the reliability and validation tests to better understand operational advantages, while providing design feedback and supporting datasets on design and performance deficiencies.

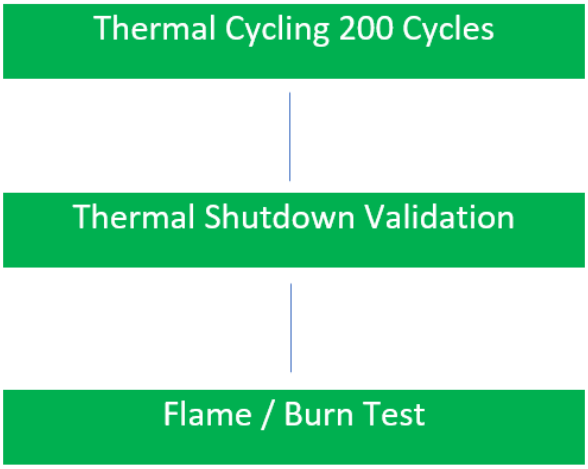

Figure 2-1: Test plan process diagram

This evaluation focuses on a series of indoor (laboratory) tests to monitor the RSDs' capability to remain operational throughout the thermal cycling accelerated age testing profile as well as to validate the RSDs' ability to shut down upon an over temperature event. An explanation of each test is provided along with a description of the setup, equipment used to evaluate the results, and a short analysis of the inverter's performance.

2.1 Test Population

The NEP PVG-2-L PV device, presented in Figure 2-2 and Figure 2-3, is the module-level rapid shutdown device (RSD).

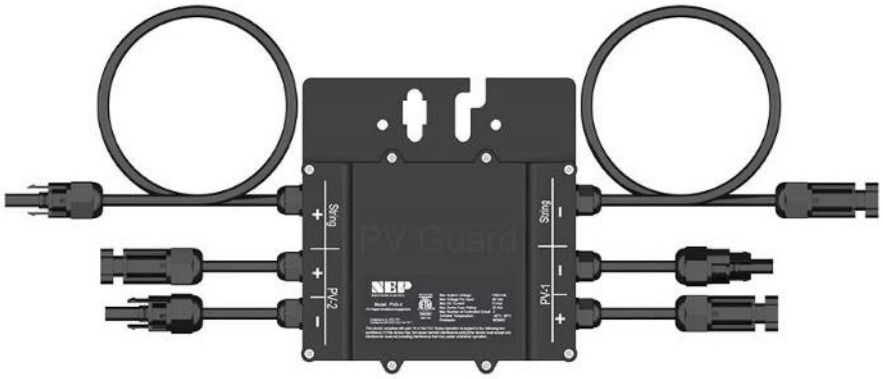

Figure 2-2: NEP PV Guard RSD

Figure 2-3: NEP PV Guard RSD

Table 2-1 details the testing population.

Table 2-1 Test Population Summary

Test DuT	Serial Number	Model Number
1	32110-110552d0-U	PVG-2-L
2	32110-11056AE0-U	PVG-2-L
3	32110-11055830-U	PVG-2-L
4	32110-11056E80-U	PVG-2-L
5	32110-11056900-U	PVG-2-L

2.2 Powered Thermal Cycling

During the powered thermal cycling test, each RSD is powered by 2 ETS80 solar array simulators (SAS) which feeds into the CPS inverter. Power is monitored from the ETS80 and at the string output.

Figure 2-4: DuT Setup

The thermal cycling test exposed the RSDs to rapid changes in environmental temperatures known to induce thermal cyclic fatigue on specific connections and components, including solder joints and PCBs. The temperature was cycled between -40 °C and 85 °C, as detailed in Figure 2-5,a total of two-hundred (200) times.

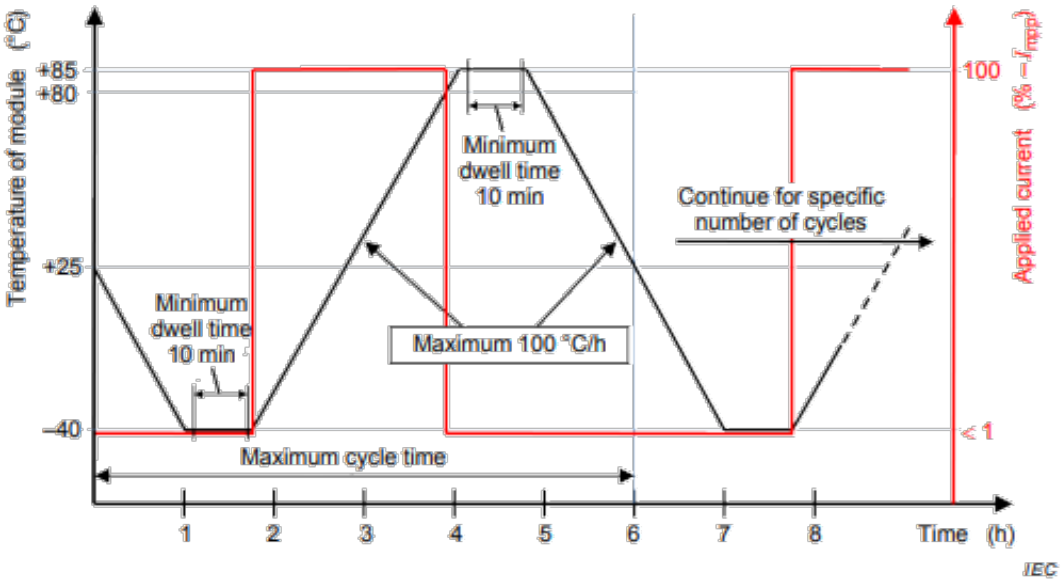

Figure 2-5: IEC 61215-2 2016 Thermal Cycling Profile

2.3 Thermal Shutdown Validation

The NEP PVG-2-L has a built in function that allows the RSD to shut down in the event of an over-temperature event. According to the datasheet below, the NEP PVG-2-L operating temperature range is between -40°C and 85°C.
Testing begins at the maximum operating temperature during normal operations and ramps up at 1°C per minute. Voltage, current, and temperature are continually measured to pinpoint the temperatures at which the RSDs' begin to open its relays and halt operations.

INPUT(DC)	Max DC Open Circuit Voltage per Input (Vdc)	90
	Max DC Current per input (Adc)	15
OUTPUT(DC)	Maximum Output Voltage (Vdc)	Voc * n (n=1/2/3/4)
SYSTEM	Maximum System Voltage (Vdc)	1500
MECHANICS	PV Cable	12AWG
	PV Connectors	Mc4 (Contact NEP for other connectors options)
	Size (not including PV cable)	5.12' x 4.73' x 1. 14' (PVG-1) 5.90' x 5.71' x 1. 00' (PVG- 2, PVG-3) 10.5' x 8.25' x 1.25' (PVG-4)
	Protection Degree	NEMA 6
	Operating Ambient Temperature	-40℃--+85℃
	Mounting Method	Rail, Frame (option)
SIGNAL	Communications	DC Power Line Compatible with SunSpec signaling
CERTIFICATION	Product Safety Compliance	UL 1741 CSA C22.2 No. 107.1 NEC 2014/2017 690.12 Canada CEC 2015 64-218

Figure 2-6: NEP PVG Datasheet

2.4 Flame / Burn Test

The flame / burn test is a quick safety test that characterizes the RSDs' response to fires. A butane torch applies high heat and flame to a localized point on the RSD to validate the RSDs' enclosure protection.

During the flame / burn test, the system is in normal operations.

3 Test Results

3.1 Powered Thermal Cycling

During the powered thermal cycling reliability test, the DuT are placed in an environmental chamber that can simulate high thermal stress environments.

Powered thermal cycling exposes the RSDs to a rapidly cycling temperature environment between -40°C and 85°C while the DuT are operating. The temperature is cycled 10 times per day over 20 days. During this reliability test, voltage and current is logged to observe the RSDs' response to temperature cycling stress.

Over the 200 thermal cycles, the RSDs continued to output power with no sign of mis-operation. Refer to Figure 3-1 through Figure 3-4 for the thermal cycling temperature and power graphs.

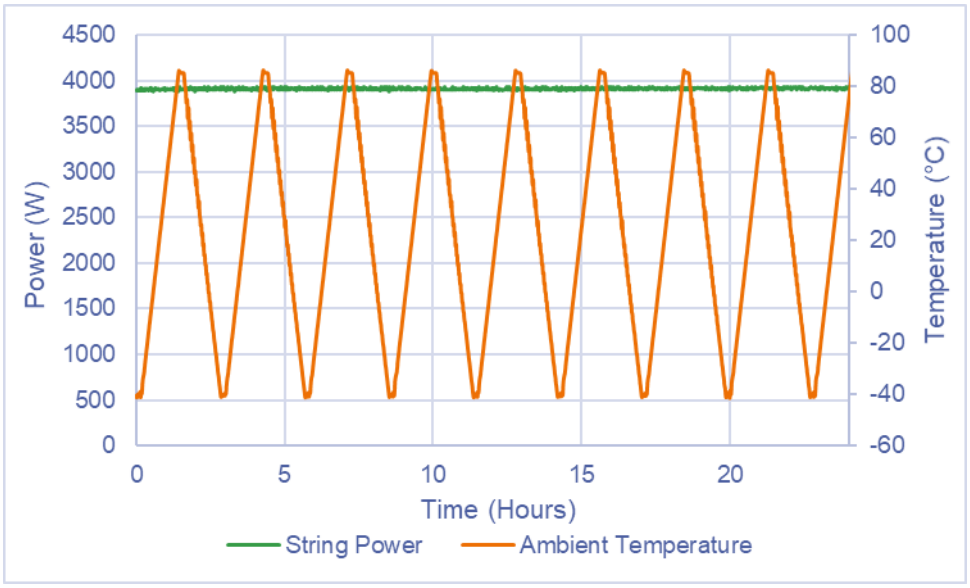

Figure 3-1: Thermal Cycling First 24 Hours

*Operational Note: During testing, 1 out of 5 RSD did not receive the full voltage and current throughout the test due to test equipment malfunction. Once the test equipment was resolved, the individual RSD returned to full operations for the remainder of the test. Data and graph represent the 4 out of 5 RSD that received the full voltage and current throughout the test. Dip in MPPT may be due to PVEL test equipment malfunction.

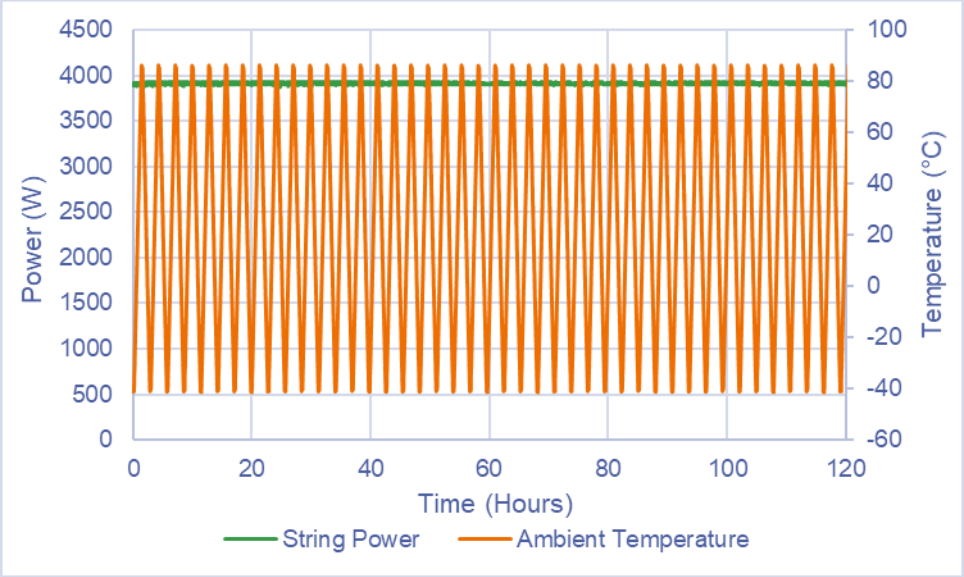

Figure 3-2: Thermal Cycling First 5 Days

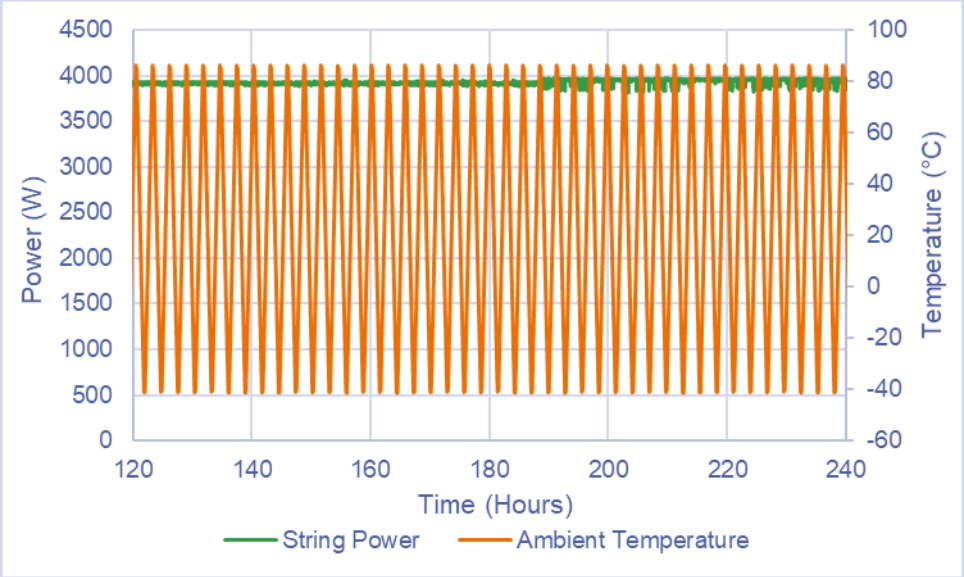

Figure 3-3: Thermal Cycling Day 5 to Day 10

*Operational Note: During testing, 1 out of 5 RSD did not receive the full voltage and current throughout the test due to test equipment malfunction. Once the test equipment was resolved, the individual RSD returned to full operations for the remainder of the test. Data and graph represent the 4 out of 5 RSD that received the full voltage and current throughout the test. Dip in MPPT may be due to PVEL test equipment malfunction.

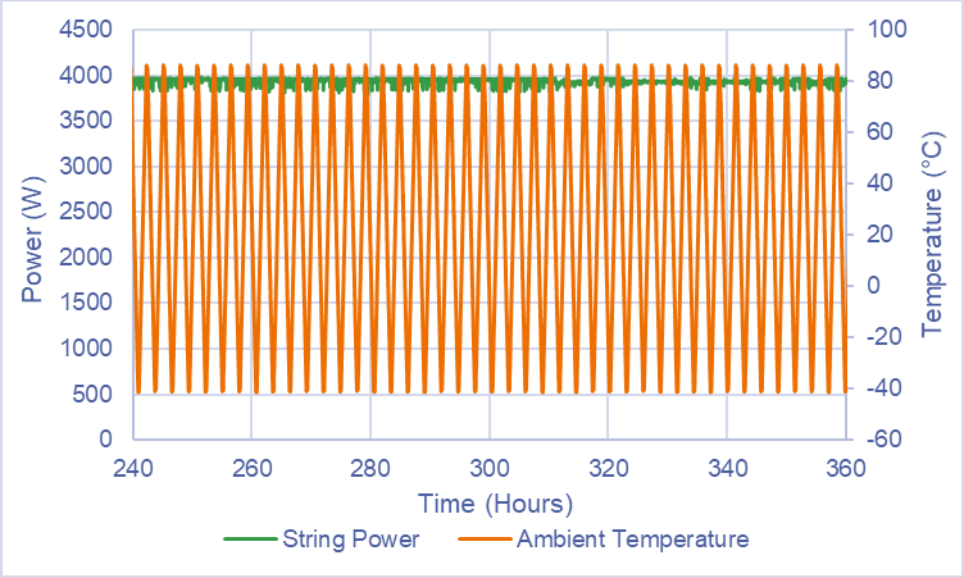

Figure 3-4: Thermal Cycling Day 10 to Day 15

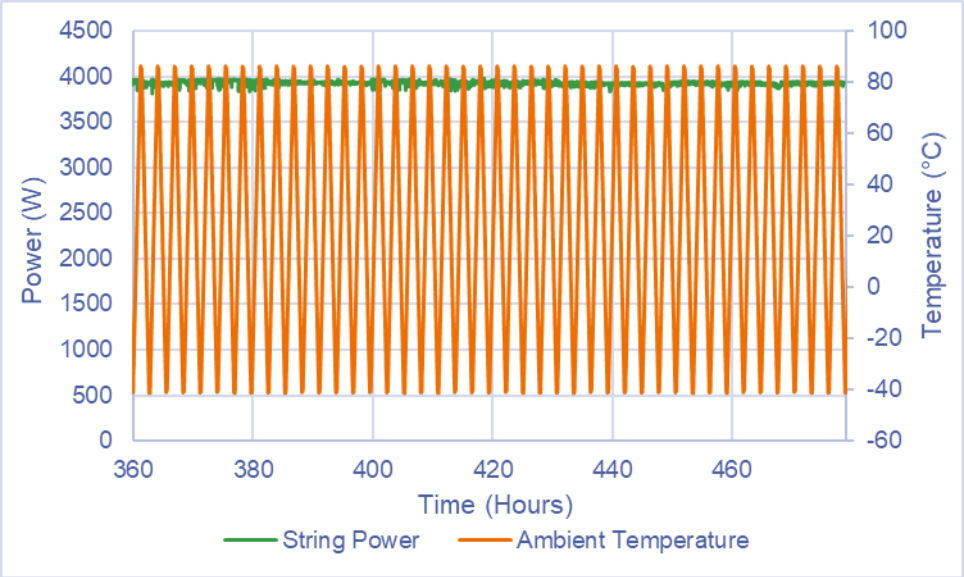

Figure 3-5: Thermal Cycling Day 15 to Day 20

*Operational Note: During testing, 1 out of 5 RSD did not receive the full voltage and current throughout the test due to test equipment malfunction. Once the test equipment was resolved, the individual RSD returned to full operations for the remainder of the test. Data and graph represent the 4 out of 5 RSD that received the full voltage and current throughout the test. Dip in MPPT may be due to PVEL test equipment malfunction.

3.2 Thermal Shutdown Validation

Thermal Shutdown Validation tests the RSDs' ability to shutdown during an over-temperature event as well as its ability to restart once the temperature returns to its operating temperature range.

Testing begins during normal operations and at the maximum operating temperature of the DuT (85°C). The ambient temperature is increased at a rate of 1°C per minute until the RSDs shutdown.

Beginning at 112.50°C, individual RSDs began shutting down. Shown in Figure 3-6, the string voltage stepped down as each RSD opened their circuits. The final RSD shutdown at 117.54°C. Thermocouples are applied to RSDs using Kapton tape.

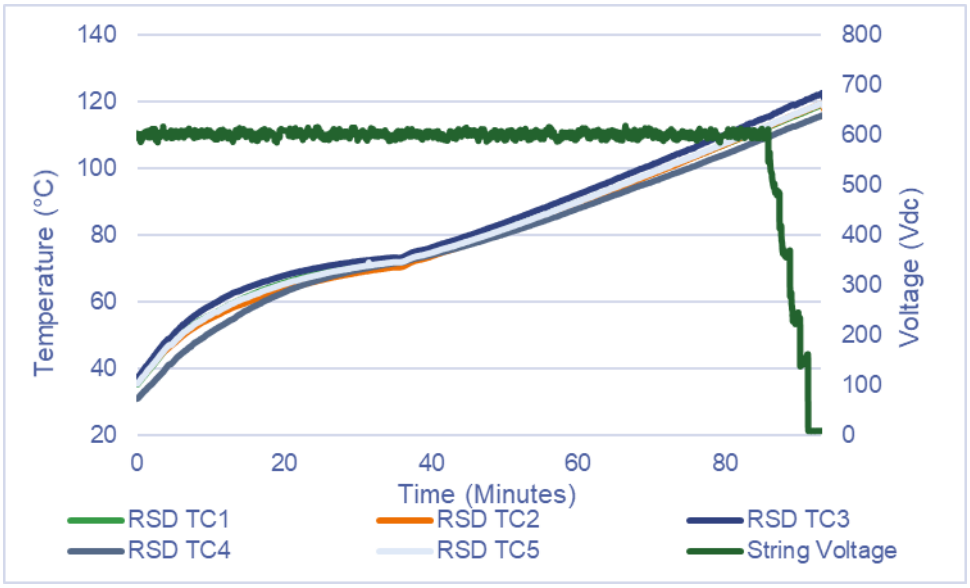

Figure 3-6: Thermal Shutdown Temperature vs Voltage

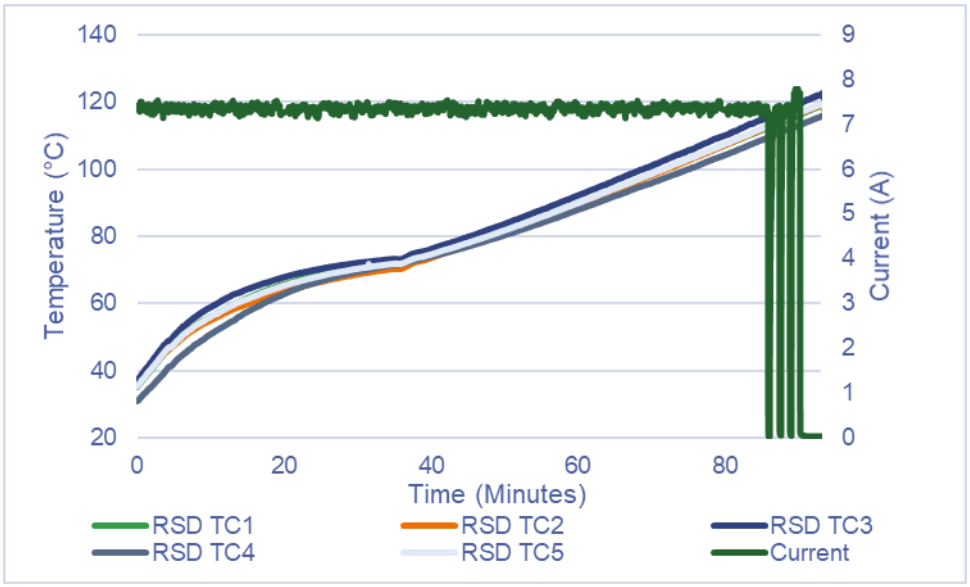

Figure 3-7: Thermal Shutdown Temperature vs Current

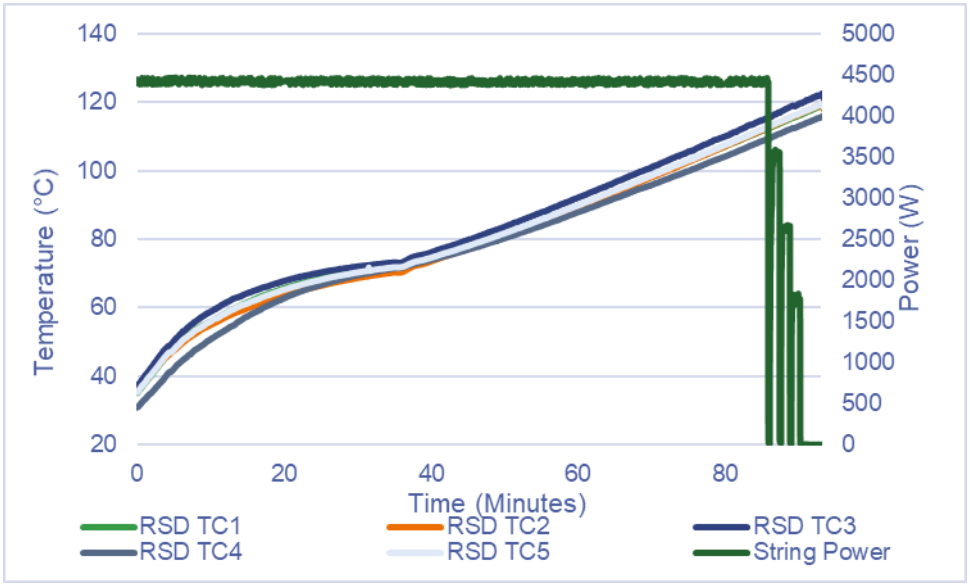

Figure 3-8: Thermal Shutdown Temperature vs Power

Once the thermal shutdown test concluded, the chamber doors were opened to allow the ambient temperature to gradually approach room temperature. As the RSDs cooled down, they returned to normal operations as the RSD temperature went below the maximum operating temperature (85°C).

The first RSDs began turning on at an average temperature of 81.99°C and the final RSD turned on at an average temperature of 75.44°C.

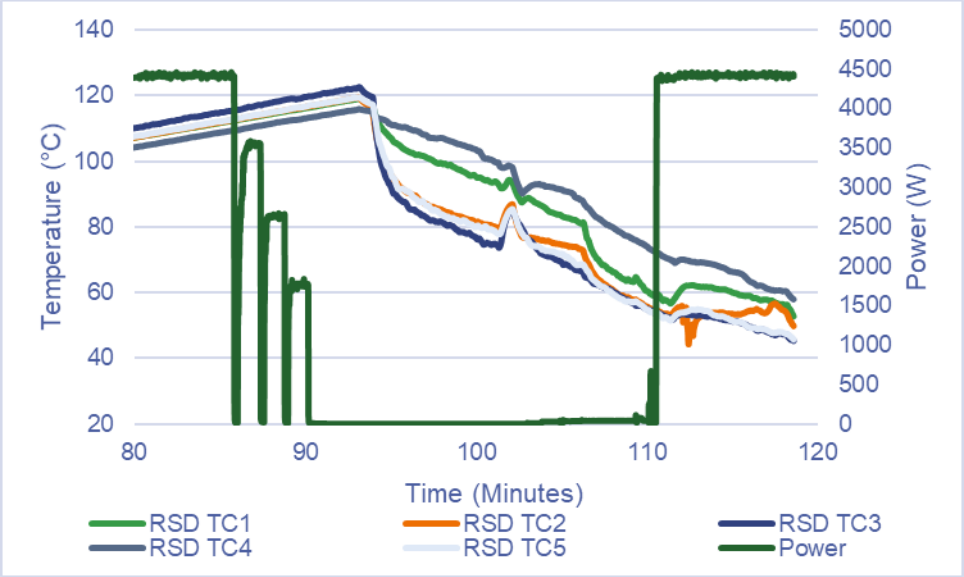

Figure 3-9: Restart Operations Once Temperature Reaches Operating Range

3.3 Flame / Burn Test

The flame / burn test is a quick safety test that characterizes the RSDs' respond to fires. A butane torch applies high heat and flame to a localized point on the RSD to validate the RSDs' enclosure protection.

Throughout the test, the unit continued to operate while the plastic RSD enclosure was melting.

*Operational Note: This Flame / Burn Test is a quick test which is not equivalent to a field fire

Figure 3-10: Flame / Burn Test in Progress

Upon removal of the flame, the unit did not continue to burn.

Figure 3-11: RSD Enclosure Once Flame Source was Removed

Appendix

NEP PVG-2-L Datasheet

INPUT(DC)	Max DC Open Circuit Voltage per Input (Vdc)	90
	Max DC Current per input (Adc)	15
OUTPUT(DC)	Maximum Output Voltage (Vdc)	Voc * n (n=1/2/3/4)
SYSTEM	Maximum System Voltage (Vdc)	1500
MECHANICS	PV Cable	12AWG
	PV Connectors	Mc4 (Contact NEP for other connectors options)
	Size (not including PV cable)	5.12' x 4.73' x 1. 14' (PVG-1) 5.90' x 5.71' x 1. 00' (PVG- 2, PVG-3) 10.5' x 8.25' x 1.25' (PVG-4)
	Protection Degree	NEMA 6
	Operating Ambient Temperature	-40°C--+85°C
	Mounting Method	Rail, Frame (option)
SIGNAL	Communications	DC Power Line Compatible with SunSpec signaling
CERTIFICATION	Product Safety Compliance	UL 1741 CSA C22.2 No. 107.1 NEC 2014/2017 690.12 Canada CEC 2015 64-218

CPS Inverter Datasheet

Model Name	CPS SCA50KTL-DO/US-480	CPS SCA60KTL-DO/US-480
DC Input		
Max. PV Power	90kW (33kW per MPPT)	
Max. DC Input Voltage	1000Vdc	
Operating DC Input Voltage Range	200-950Vdc	
Start-up DC Input Voltage / Power	330V / 80W	
Number of MPP Trackers	3	
MPPT Voltage Range @ PF>0.99	480-850Vdc	540-850Vdc
Max. PV Short-Circuit Current (Isc x 1.25)	204A (68A per MPPT)	
Number of DC Inputs	15 inputs, 5 per MPPT	
DC Disconnection Type	Load-rated DC switch	
DC Surge Protection	Type II MOV, 2800V_C, 20kA I_{TM} (8/20..S)	
AC Output		
Rated AC Output Power @ PF>0.99 to ±0.91[1]	50kW	60kW
Max. AC Apparent Power (Selectable)	50/55kVA	60/66kVA
Rated Output Voltage	480Vac	
Output Voltage Range[2]	422 - 528Vac	
Grid Connection Type	3Φ / PE / N (Neutral optional)	
Max. AC Output Current @480Vac	60.2/66.2A	72.2/79.4A
Rated Output Frequency	60Hz	
Output Frequency Range[2]	57 - 63Hz	
Power Factor	>0.99 (±0.8 adjustable)	
Current THD @ Rated Load	<3%	
Max. Fault Current Contribution (1 Cycle RMS)	64.1A (1.06/0.88 PU)	
Max. OCPD Rating	110A	125A
AC Disconnection Type	Load-break rated AC switch	
AC Surge Protection	Type II MOV, 1240V_C, 15kA I_{TM} (8/20..S)	
System and Performance		
Topology	Transformerless	
Max. Efficiency	98.8%	
CEC Efficiency	98.5%	
Stand-by / Night Consumption	<1W	
Environment		
Enclosure Protection Degree	NEMA Type 4X	
Cooling Method	Variable speed cooling fans	
Operating Temperature Range[3]	-22°F to +140°F / - 30°C to +60°C	
Non-Operating Temperature Range[4]	No low temp minimum to +158°F / +70°C maximum	
Operating Humidity	0 to 100%	
Operating Altitude	13,123.4ft / 4000m (derating from 9842.5ft / 3000m)	
Audible Noise	<60dBA @ 1m and 25°C	
Display and Communication		
User Interface and Display	LCD+LED	
Inverter Monitoring	SunSpec, Modbus RS485	
Site Level Monitoring	CPS FlexOM Gateway (1 per 32 inverters)	
Modbus Data Mapping	CPS	
Remote Diagnostics / FW Upgrade Functions	Standard / (with FlexOM Gateway)	
Mechanical		
Dimensions (HxWxD)	39.4 x 23.6 x 10.24in. (1000 x 600 x 260mm)	
Weight	Inverter: 123.5lbs/56kg; Wire-box: 33lbs/15kg	
Mounting / Installation Angle[5]	15 to 90 degrees from horizontal (vertical or angled)	
AC Termination	M8 Stud Type Terminal Block (Wire range: #6 - 3/0AWG CU/AL , Lugs not supplied)	
DC Termination[6]	Screw Clamp, Neg. Busbar (RSD version[8]) Wire range: #14 - #6AWG CU	
Fused String Inputs (5 per MPPT)[7]	RSD[8] and Standard Wire-box: 20A fuses provided (Fuse values up to 30A acceptable)	
Safety		
Certifications and Standards	UL1741SA-2016, UL1699B, CSA-C22.2 NO.107.1-01, IEEE1547a-2014; FCC PART15	
Selectable Grid Standard	IEEE 1547a-2014, CA Rule 21, ISO-NE	
Smart-Grid Features	Volt-RideThru, Freq-RideThru, Ramp-Rate, Specified-PF, Volt-VAr, Freq-Watt, Volt-Watt	
Warranty		
Standard	10 years	
Extended Terms	15 and 20 years	

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