



PV Connector Reliability: Initial Results from Field inspections Across the US

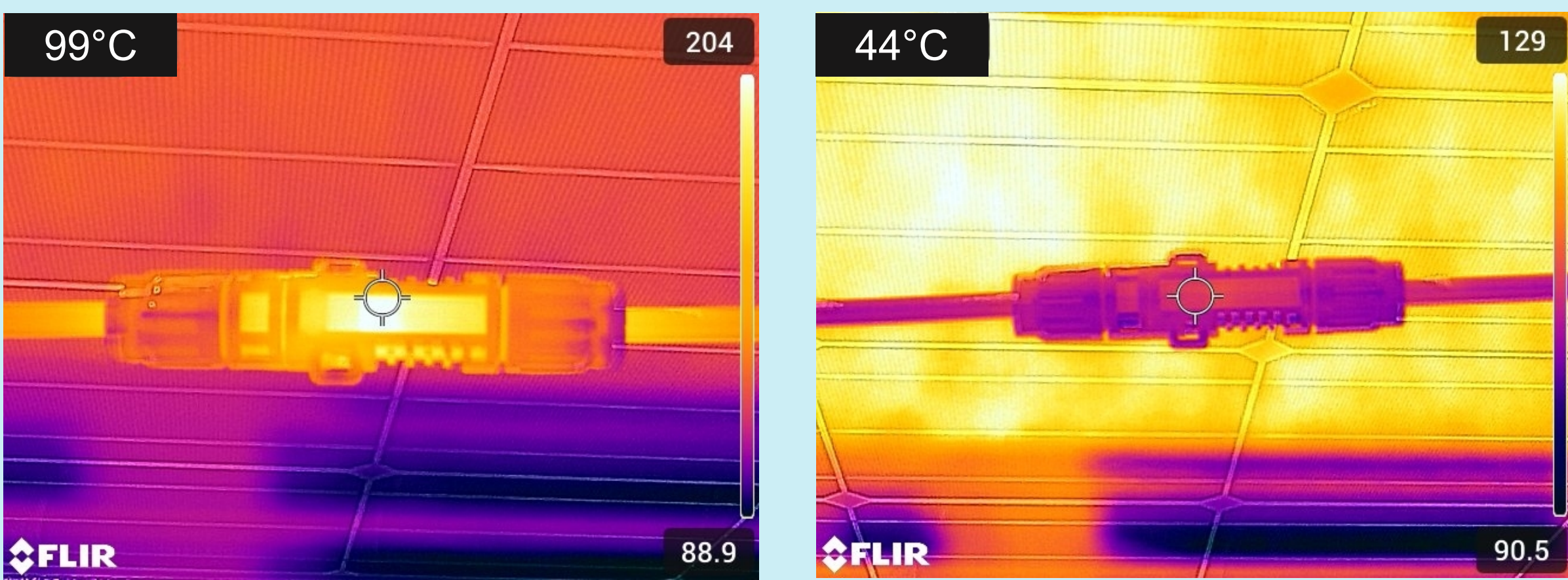
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As the PV industry looks toward 50-year modules, reliability research is often focused on cell integrity and packaging materials. However, recent reports from asset owners and O&M providers suggest that connector failures are on the rise. Connectors must carry the high current output of the system with low resistive losses while providing high voltage insulation. Any degradation in performance has serious consequences. In the best case, failure causes reduced system power output and lost revenue, while in the worst case, can cause fires and catastrophic damage to the PV array and surrounding structures.

The root causes for failures have not been well-established and multiple factors are likely involved. Use of counterfeit products, cross-mating between different makes and poor manufacturing quality are often cited. Poor installation practices during construction are also to blame. Improper assembly of connectors built in the field, connector contamination prior to final stringing and incomplete mating of connectors have been observed.

Sandia, in partnership with EPRI and NREL has launched a comprehensive study of fielded connector reliability. In this three-part study, we focus on 1) onsite inspections of utility and commercial PV sites; 2) field harvesting of failed connectors and follow-on forensics analyses to identify Connector failures observed during site inspections; 3) forensic assessments to quantify associated National Mail-in Campaign



Ambient Temp: 36°C | GPOA: 1017 W/m² | Imp: 9.2A

1. Increased Contact Resistance
 - Expected $\Delta T < 30^\circ C$ (per UL/IEC ratings)
 - "Cool connectors" imply $\Delta T = 8^\circ C$
 - Many connectors exceed $\Delta T = 30^\circ C$ Observations:
 - All ferrules could be loosened by hand
 - Heat spread laterally into PV wire



2. Seal failures at the ferrule
 - Over stripping or insulation "pullout"?
 - Incipient copper cable corrosion
 - Water ingress into housing is inevitable



3. Housing failure
 - Melting of the housing due to increased contact resistance can directly expose energized contacts and compromise the o-ring seal.



4. Catastrophic failure
 - Connector housing failure, whether from improper assembly and water ingress or plastic melting can cause catastrophic arcing to nearby metallic components



Harvesting Instructions for PV Power Plant Connectors

BACKGROUND

To better understand the failure mechanisms and root causes for connector failure, Sandia National Laboratories has launched a campaign to collect failed and degraded connectors from PV power plants and commercial rooftops across the US. Connectors will be subjected to electrical and metallurgical forensics analysis to look for evidence of corrosion, contamination, defective and degraded materials, cross-mating incompatibility, etc. In return, Sandia will share diagnostic results with participating companies.

HOW TO IDENTIFY DEGRADED/FAILED PV CONNECTORS

Problems may be first identified at the inverter level, when performance drops, or at the string and module level, when aerial infra-red (IR) images reveal hot, i.e., failed, modules. Visual inspections of connectors can reveal melting (glossy appearance or deformation), corrosion of the connector and/or cable, arc fault, internal resistance indicated by high temperature readings on an infrared camera, abrasion of the cable sheath, exposed conductors, cross threading, misalignment, damaged or loose gland seals, and loose connection of the plug and socket.

HOW TO HARVEST A PV CONNECTOR FOR FORENSICS ANALYSIS

1. Connector should be removed with sufficient cable length attached to enable electrical analysis. We recommend a cable length on both positive and negative sides of 10" in length.
2. An identification number (1,2, etc.) should be taped directly to the cable, with details provided on the accompanying data sheet.
 - Date of Collection
 - Site Name/PV Plant Identifier
 - Location on site (String/Module #)
3. Send harvested connectors to:

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At least 10" of cable should remain at both ends; the connector itself should be left intact and labeled.

Figure 1: Example of a correctly harvested connector, with adequate cable length and proper labeling.

Figure 2: Left to Right: IR image of hot connector; melted connector; external signs of corrosion on the right cable; corroded socket and pins

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- <https://energy.sandia.gov/pv-connectors>

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Safe harvesting requires proper electrical training, PPE and scheduled system outages. This is often best conducted by on-site O&M personnel. Sandia has established a collection program to facilitate the safe harvesting of connectors that are then shipped to Sandia. Harvest connectors are subjected to non-destructive and destructive forensics analysis and inclusion in an anonymous but open-source database of failure types.

The mail-in program increases the scale and diversity of failure mechanisms that are identified. It facilitates correlation of failure mechanisms with climate, weather events, installation practices and other categorical factors.

Market survey of connectors in-use/available in the US

Manufacturer	Model	Manufacturer	Model
Amphenol	H4	Stäubli	MC3
	H4 Plus		MC4
	UTX		MC4-Evo 2
Bizlink Sunbolts	S418	Sunter	PV-ZH202B
Holysun	LJ-01	Taizhou Jinxiu	LJQ-1
	PV-JK00MO		LJQ-3
Jinko	PV-JK03M	TE Connectivity	Solarlok
JMTHY	PV-JM608		Solarlok PV4
Longi	PV-LR5		Solarlok PV4-S
Minghe	MH5	Tlain (Canadian Solar)	T4
QC Solar	QC4.10	Trina	TS4
Renhe Solar	05-8	Xinhui	PV-HCB40

This non-exhaustive survey identified connectors that were either readily available from resellers or encountered in the field. The market is dominated by a few well-known brands; however, module manufacturers have many options and several have adopted private label solutions. Many connectors have a similar appearance to to one another and are physically inter-mateable, increasing the risk of failure.