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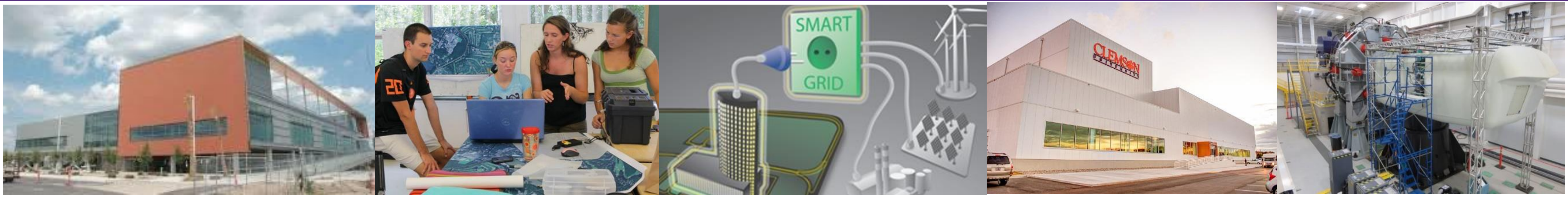

Tool for Reliability Assessment of Critical Electronics in PV (TRACE-PV)

FMEA for a PV Inverter
February 21-25, 2022

Participants: Buck Brown, Zheyu Zhang, Johan Enslin, Shuangshuang Jin, Ramtin Hadidi, Clemson University; Jin Tan, Peter Hacke, Ram Thiagarajan, Shuan Dong, NREL; Xiaonan Lu, Temple University; Miles Russell, Matt Ursino, Yaskawa Solectria Solar; Joe Hodges, Dominion Energy; Ford Brendan, The InterTech Group; Daniel Clemens, SMA Solar Technology AG

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Motivation

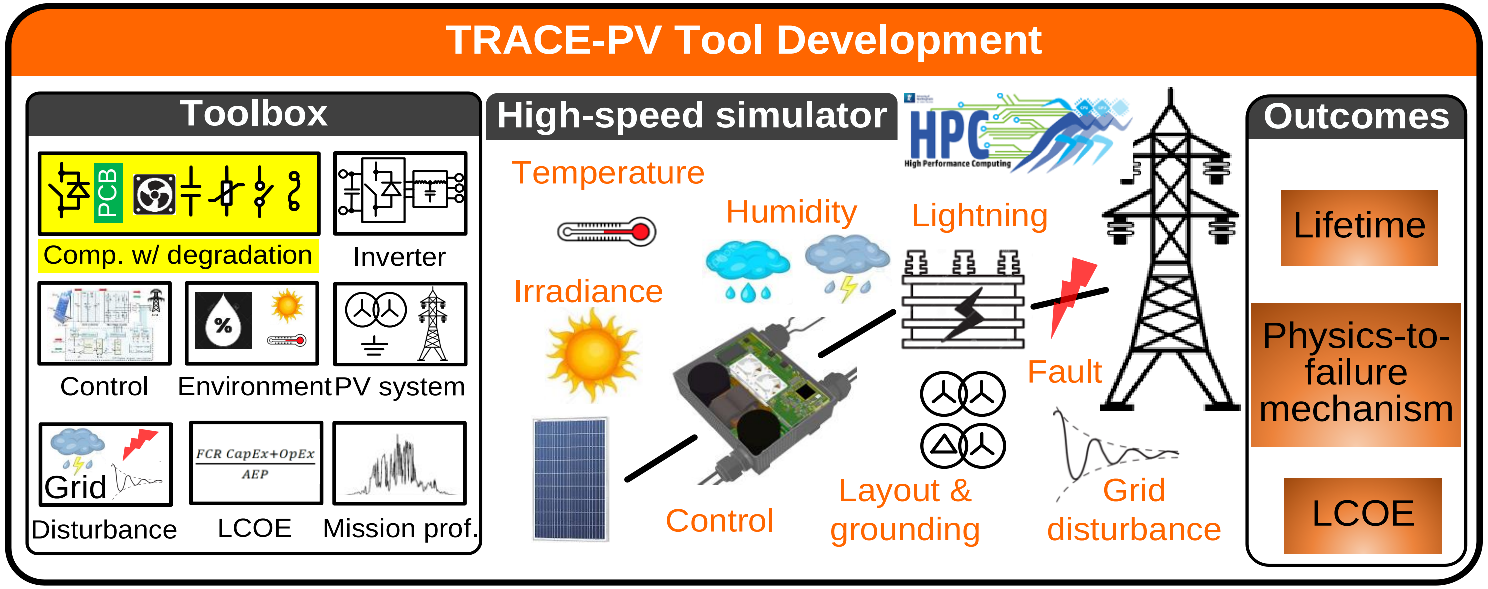
- The U.S. Department of Energy (DOE) has an estimated PV penetration into the U.S. power market to be upward of 18% by 2050 with a $1/watt price-point.
- As the price of PV modules drops, the price of inverters becomes more important [1].
- Inverters now constitute 8–12% of the total PV lifetime cost. One of the key price drivers of the inverter components is inverter reliability.
    - PV modules are offered up to 30-year warranties; in contrast, typical warranties on inverters last only 5–10 years [2].
    - It is evidenced by field data from PV power plant operators that power electronic converters contribute most to operation and maintenance (O&M) events, responsible for between 43% and 70% of the service calls [3].
- Consequently, it is critical to have a generic tool from a third-party for PV inverter reliability assessment to help 1) utilities/PV farm operators schedule maintenance in advance; and 2) inverter developers improve the next-generation design.

[1] $1/Watt Photovoltaic Systems, U.S. Department of Energy, White Paper 2010.
[2] J. Flicker "Reliability of power conversion systems in photovoltaic applications," Sandia, NW, 2015.
[3] P. Hacke, et al. "A status review of photovoltaic power conversion equipment reliability, safety, and quality assurance protocols." Renewable and Sustainable Energy Reviews 82 (2018): 1097-1112.

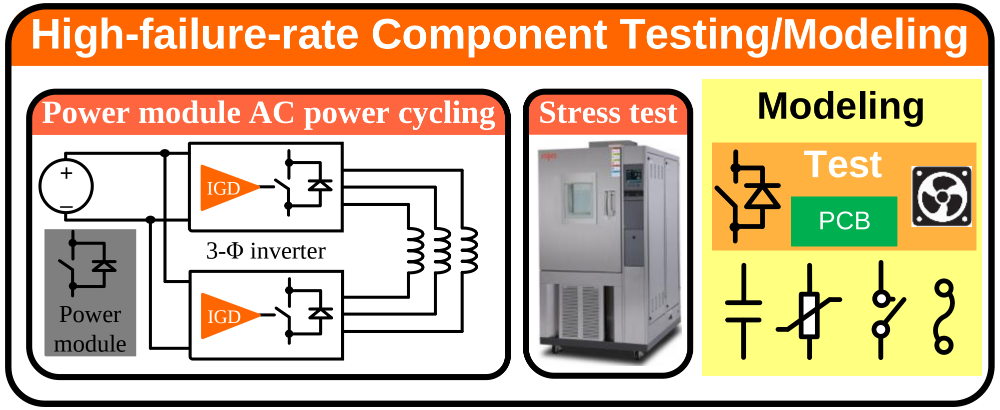
Proposed TRACE-PV Tool

- Develop and validate a general TRACE-PV tool for lifetime prediction, physics-to-failure mechanism identification, and LCOE assessment of PCE in PV system

Component reliability modeling



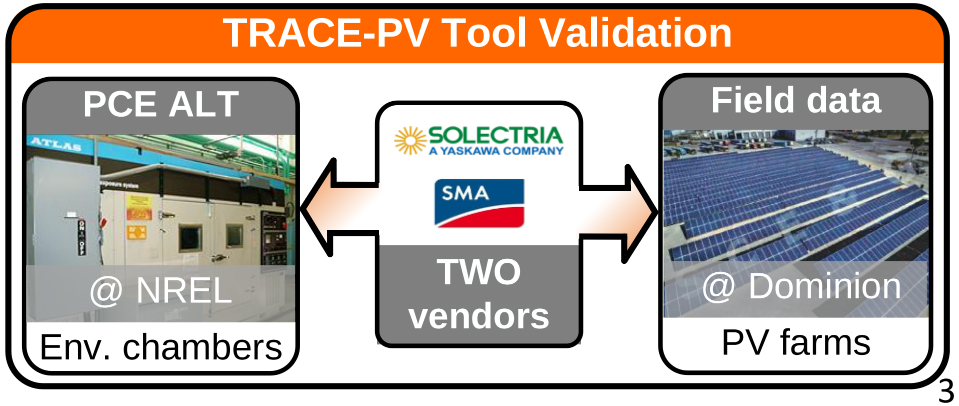
Tool validation



LCOE — Levelized cost of energy

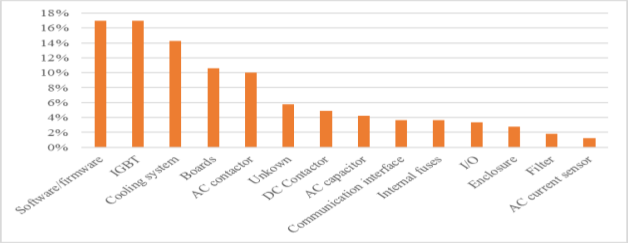
PCE — Power conversion equipment

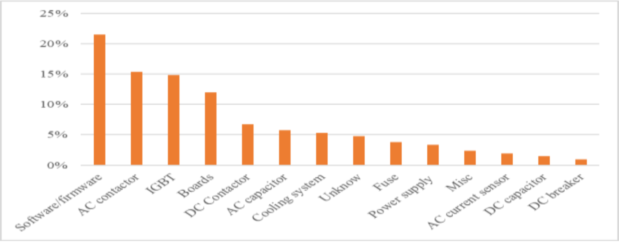
ALT — Accelerated life testing



PV Inverter FMEA – Methodology

Step 1 − Components of a PV inverter with the highest failure rates were identified based on field reliability data reports provided by PV plant operators





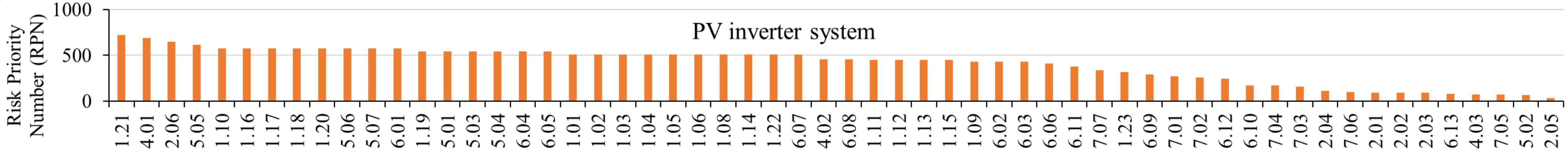
- Frequency of tickets
- Energy loss due to inverter downtime

Step 2 − An FMEA study was performed for the individual component, including failure modes, corresponding failure mechanisms, and critical stressors

Component	Type	Failure Modes	Failure Mechanisms	Critical Stressors	ID	O	S	D
Cooling System	Fan [7]	Mechanical	Cage damage	Vibration	2.01	3	4	8
			Bearing failure	Lack of lubrication	2.02	3	4	8
			Lubrication deterioration	Wear out	2.03	3	4	8
		Electrical	Cracks in fan's PCB	Excessive vibration, T, RH	2.04	2	7	8
			Wiring errors	Manufacturing/human error	2.05	1	8	5
			Environmental stress	Ingress Protection (IP), T, RH	2.06	9	9	8

PVQAT Task Group 11 led by NREL NATIONAL RENEWABLE ENERGY LABORATORY

Step 3 − Risk priority number (RPN) sorting was conducted to prioritize failure modes, mechanisms, and stressors for subsequent stress testing and reliability modeling tasks



PV Inverter FMEA Survey

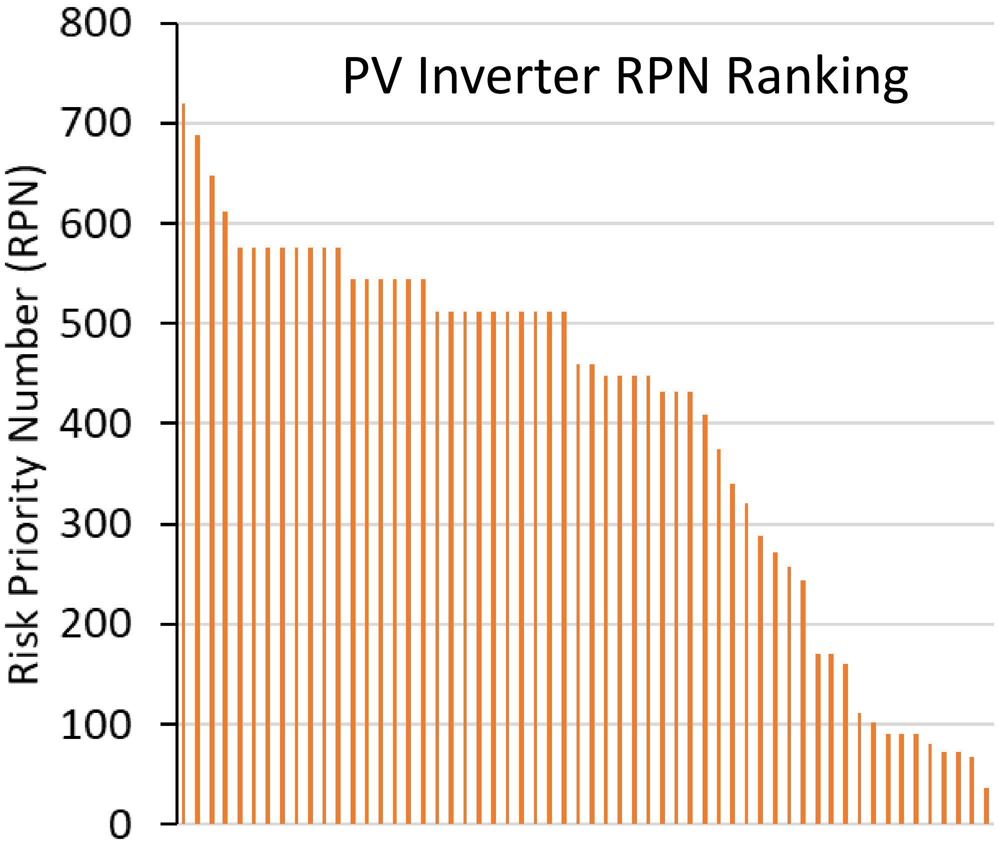
- Based on three reports with field reliability data provided by PV plant operators, seven components with high-failure-rate identified

#	Report 1 (Tickets)	Report 1 (Energy loss)	Report 2 (Tickets)	Report 2 (Energy loss)	Report 3 (Tickets)
1	Control software	PCB	Control software	Control software	Control software
2	PCB	Control software	IGBT	Contactor	PCB
3	Relay	Relay	Cooling	IGBT	Power supply
4	Fans	Fuse	PCB	PCB	Surge protection
5	IGBT	Capacitor	Contactor	Capacitor	Contactor

Components to be identified
Capacitor (liquid electrolytic, film, and ceramic)
Cooling system (with fan emphasized)
Fuse
Metal oxide varistor (MOV)
Printed circuit board (PCB)
Power module
Relay & contactor

[1] Golnas A, System PV. Reliability: an Operator's Perspective. IEEE J Photovolt . 2013;3(1):416–21.
[2] Lokanath S, Williams P. Power Plant and Central Inverter Failure Analysis, IEC Technical Committee 82 Working Group 3,6 and Joint Working Group 1 Meetings; Tempe, AZ; May 22-27, 2016.
[3] Hibberd B. PV Reliability & Performance, A Project Developers Experience, In: Proceedings of the NREL Photovoltaic Module Reliability Workshop 2011, NREL/ TP-5200–60170; Feb 16–17, 2011.

Risk Priority Number (RPN) Ranking



> 50 failure modes and mechanisms
(details summarized in an FMEA report)

- FMEA formed through collective opinions of team members
- RPN might change as team gains new insight

#	Comp.	Failure Modes	Failure Mechanisms	Critical Stressors
1	Ceramic Cap.	Open/ Short Circuit	Cracking as a result of PCB flexing, CTE mismatch, excess current, etc.	Stress on the PCB, I_C, vibration/ shock
2	MOV	Short Circuit	Repeated exposure to current surges	Surge current
3	Cooling Fan	Electronic part failed	Environmental stress	Temp., RH
4	PCB	Short Circuit	Conductive filament formation	RH, I_C
5	Electrolytic Cap.	Open Circuit	Corrosion of the tab due to presence of chloride	Temp., RH
6	Film Cap.	Short Circuit	Conductor sizing, dielectric film thickness – design related issues	V_C, I_C, T_A
7	Power Module	R_{ds} on Drift, R_{th} increase	Die-attach degradation due to thermo-mechanical fatigue	Junction Temp.

Acknowledgement

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