Impacts of PV Module Connector Failures on Cost and Performance of Utility Scale Photovoltaic Systems

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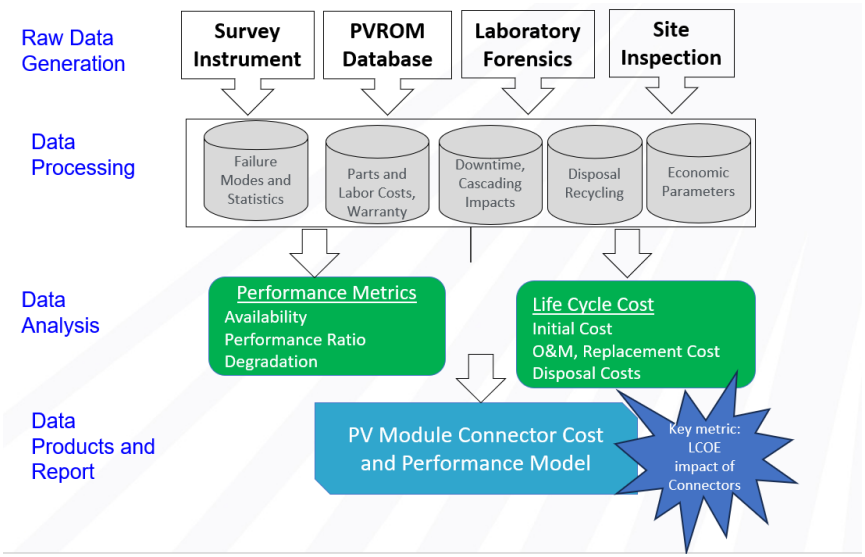
- ***Connectors have historically been viewed as essential—but relatively uninteresting—components of a PV system, with a functional role that has been overshadowed by the industry's focus on module efficiency and lower manufacturing and installation costs.***
- ***Defective and degraded connectors affect system performance in profound ways, from power losses to increased O&M needs, to catastrophic failure and fire. In addition, degrading and failed connectors raise the specter of higher insurance rates, levelized cost-of-energy (LCOE) increases, and decreased confidence in the reliability of solar-generated power.***
- ***To advance the science of connector reliability, the US Department of Energy has funded a collaboration of Sandia National Laboratories, National Renewable Energy Laboratories, Electric Power Research Institute with activities described on the project website: https://energy.sandia.gov/programs/renewable-energy/photovoltaic-solar-energy/projects/pv-connectors/.***
- ***Overall, the objective of this project is to help drive the industry toward higher-quality connectors and improved installation practices, thus increasing the performance, reliability, safety and availability of the US solar infrastructure.***
- ***Techno-economic analysis (TEA) data is collected in parallel with field data and industry interviews to quantify the impact of connector failure on PV lifecycle economic metrics, including energy yield, O&M expenses and levelized-cost-of-energy (LCOE). This work will include the modeling and analysis of power losses, O&M expenses and other soft costs related to failed connectors and will measure the impact of connector degradation and failure on a plant's LCOE.***

Methodology:



Word Occurrence in 522 O&M Work Orders (PVROM)

ENVIRONMENT	
Water	18
Snow	9
Moisture	3
Lightning	3
Wind	1
Hurricane	1
Hail	1

CAUSE OF DAMAGE	
Recall	70
Install Error	24
Broken Modules	19
Mowing	10
Corrosion	10
Vegetation	9
Animal	4
Dirt	4

CONDITION	
Ground Fault	136
Burn	90
Melt	56
Loose/Pulled	49
Arc Fault	40
Damage	40
Fire	32
Crimp	4

DETECTION OF FAILURE	
Inspect	86
Thermal/Infrared	74
UAS/UAV/Drone	52
Aerial	25

Failed Connector (photo by Bruce King, Sandia National Laboratories)

Results:

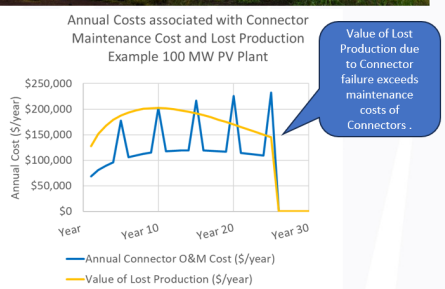
- ***In the example of this 100 MW Utility-Scale PV system, the annual maintenance cost varies from year to year . There is an upward escalation of corrective maintenance costs caused by: 1) inflation increasing the cost of O&M; and 2) Weibull distributions showing increasing failure in later years. Every five years the cost of cleaning and inspection is visible.***
- ***The "annualized" value (life cycle cost/year) is $72k/year associated with connectors. Dividing by plant size gives $0.72/kW/year additional O&M costs for connectors.***
- ***A reserve account of $187k would be arranged to quickly repair larger-than-average correctional maintenance costs (such as storm damage).***
- ***Over the 25-year analysis period connectors represent almost $1.5M in life cycle cost.***

System Name	100 MW Utility-Scale PV

Results	
Annualized O&M Costs ($/year)	$1,774,563
Annualized Unit O&M Costs ($/kW/year)	$17.75
Maximum Reserve Account	$5,299,351
Net Present Value O&M Costs (project life)	$27,923,565
Net Present Value (project life) per Wp	$0.279
NPV Annual O&M Cost per kWh	$0.016

	Lifetime NPV by Component Type		
Component	Avg. Cost/Yr	NPV (Life)	% of Total
AC wiring	$9,859	$155,132	1%
Insurance	$447,500	$7,041,618	25%
Asset Management	$610,731	$9,610,140	34%
Cleaning/Veg	$253,380	$3,987,052	14%
DC wiring	$18,417	$289,805	1%
Connector	$103,507	$1,628,726	6%
Documents	$22,952	$361,155	1%
Electrical	$6,719	$105,722	0%
Inverter	$84,302	$1,326,529	5%
Mechanical	$92,986	$1,463,177	5%
Meter	$16	$248	0%
Monitoring	$61	$957	0%
PV Array	$118,116	$1,858,609	7%
PV module	$5,570	$87,641	0%
Roof	$0	$0	0%
Tracker	$0	$0	0%
Transformer	$448	$7,053	0%
(blank)	$0	$0	0%
Total	$1,774,563	$27,923,565	100%

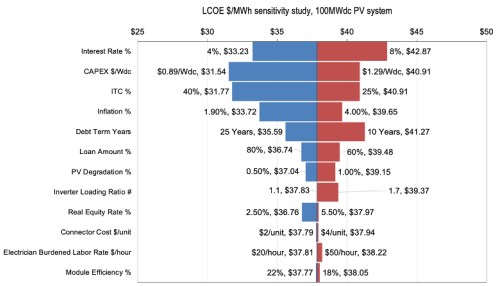
Connectors about 6% of O&M cost.



Value of Lost Production due to Connector failure exceeds maintenance costs of Connectors .

- ***In addition to the maintenance costs of connector, they contribute to downtime and lost production (kWh not generated due to connector failure).***
- ***In dividing by reduced production, the per-kWh-delivered of $0.00088/kWh includes the cost of maintenance and also the lost production of connector maintenance and underperformance and represents about 7% of the maintenance cost per kWh.***

	Cost with Connectors	Cost without Connectors	Impact due to Connectors
Annualized O&M Costs ($/year)	$ 1,361,350	$ 1,289,417	$ 71,933
Annualized Unit O&M Costs ($/kW/year)	$ 13.61	$ 12.89	$ 0.72
Maximum Reserve Account	$ 5,216,127	$ 5,028,907	$ 187,220
Net Present Value O&M Costs (project life)	$ 28,274,335	$ 26,780,331	$ 1,494,004
Net Present Value (project life) per Wp	$ 0.28274	$ 0.26780	$ 0.01494
NPV Annual O&M Cost per kWh	$ 0.01259	$ 0.01172	$ 0.00088



Future Work:

- ***Collect More Failure Data***
- ***Address Liability Risk***
- ***Expand TEA analysis to include other PV system components***
  - ***Other types of connectors (IDC)***
  - ***Rapid Shutdown Devices***
  - ***Eventually all components***

References:

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