Solar Under Storm III

Updated best practices for resilient ground-mount PV systems with hurricane exposure

Report / June 2025

Failed solar installation on Carriacou, Grenada, in July 2025. Photo courtesy Christopher Burgess, RMI.

> “Robust solar abundancy coupled with annual hurricane vulnerability is a reality the USVI must grapple with in order to holistically relieve the energy burdens inherent to our historically fossil fuel dependent power system. As we lean further into solar becoming the backbone of our centralized and decentralized energy systems, it’s imperative that Category 5 resilient installation standards are upheld. Building solar systems to withstand the inevitable hurricane, ensures the ‘blue sky’ operational benefits of solar continue to support our community especially after the darkest of days.”
>
> **— Kyle Fleming, Director of the US Virgin Islands Energy Office**

Authors and Acknowledgments

Authors

Christopher Burgess
Chris Needham, Azimuth Advisory Services
Fidel Neverson
Frank Oudheusden, Azimuth Advisory Services

Authors listed alphabetically. All authors from RMI unless otherwise noted.

Contributors

Micheal Vance, Asante Energy
Colleen O'Brien, Underwriters Laboratories (UL)
Andrew Richards, Lightwork Power Caribbean
Kyle Fleming, Virgin Islands Energy Office

Contacts

Christopher Burgess, cburgess@rmi.org

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Cover photo of failed solar installation on Union Island, Saint Vincent and the Grenadines, July 2025, courtesy Frank Oudheusden, Azimuth Advisory Services.

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About RMI

Rocky Mountain Institute (RMI) is an independent, nonpartisan nonprofit founded in 1982 that transforms global energy systems through market-driven solutions to secure a prosperous, resilient, clean energy future for all. In collaboration with businesses, policymakers, funders, communities, and other partners, RMI drives investment to scale clean energy solutions, reduce energy waste, and boost access to affordable clean energy in ways that enhance security, strengthen the economy, and improve people's livelihoods. RMI is active in over 60 countries.

CARILEC

Caribbean Electric Utility Services Corporation (CARILEC) is an association of electric services, dealers, manufactures and other stakeholders operating in the electricity industry in the Caribbean region, Central and South America, and globally. The CARILEC Secretariat endeavors to improve communication among its members, providing technical information, training, capacity building, conference, and other services. The Secretariat plays a leading role in electric utility advocacy, growth, and sustainability in the Caribbean region and Central and South America.

Global Solar Council

The Global Solar Council is the voice of the world's solar PV industry representing corporate members across the value chain as well as national, regional and international associations to accelerate solar deployment globally. To fulfill our mission and vision, the GSC advocates for transformative policies, creates platforms for best practices and knowledge exchange, builds capacity and skills, and fosters network building and collaboration that can unlock the benefits of solar PV around the world. Powering GSC's efforts are workstreams on critical challenges and topics that are essential to accelerate the sustainable and cost-effective deployment of solar in countries worldwide.

Azimuth Advisory Services

Azimuth Advisory Services (AAS) is an engineering partnership between Frank Oudheusden and Christopher Needham. With 39 years of combined experience in the solar industry, they've been consulting together since 2016 on projects ranging from commercial to large-scale utility plants. AAS provides venture capital firms, private equity investors, developers, insurers, and racking manufacturers with specialized services including technical due diligence, failure analysis, structural resiliency, and remediation planning. The team has also pioneered a number of technological innovations aimed at improving the reliability and resiliency of solar assets, particularly in high-risk environments across North America and the Caribbean.

Asante Energy

Asante Energy is a specialized energy consultancy and project delivery firm focused on renewable energy, microgrids, and sustainable infrastructure in emerging markets. We support clients across the full project lifecycle—from feasibility and design to procurement, construction oversight, and commissioning. With a deep understanding of island and remote-area challenges, Asante Energy delivers technically sound, context-sensitive solutions that align with climate resilience and long-term sustainability goals. Our team brings hands-on experience, strategic insight, and a commitment to quality, helping public and private stakeholders accelerate their clean energy transition.

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A global leader in applied safety science, UL Solutions transforms safety, security and sustainability challenges into opportunities for customers in more than 110 countries. We deliver testing, inspection and certification services, plus software and advisory offerings that support our customers' product innovation and business growth. UL certification Marks serve as a recognized symbol of trust in our customers' products and reflect an unwavering commitment to advancing our safety mission. We help our customers innovate, launch new products and services, navigate global markets and complex supply chains, and grow sustainably and responsibly. From the adoption of electrification to the enablement of 5G and new mobility, we look toward new frontiers. Our science is your advantage.

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Foreword

Sonia Dunlop | *CEO* | Global Solar Council

Solar energy lies at the heart of a just and sustainable future. Today, it is a mainstream power source in many countries, driving down carbon emissions, expanding energy access, strengthening energy security, and creating millions of jobs and economic opportunities. With approximately 2.2 terawatts of solar capacity now installed worldwide and nearly a billion dollars invested in solar projects every single day, the momentum behind solar power is reshaping the global energy landscape.

This growth is nothing short of extraordinary. Since 2004, solar has been the fastest-growing energy source globally, with an average annual growth rate of 25%. It took the industry nearly seven decades — from 1954 to 2022 — to reach 1 terawatt of installed capacity. Remarkably, it took only two more years to add the second terawatt.

In many countries, solar is now among the most affordable sources of electricity, a trend that shows no sign of slowing. Its flexibility — ranging from off-grid rooftop systems to utility-scale installations — makes it a powerful tool for enabling decentralized, locally driven solutions. As climate change and geopolitical tensions put increasing pressure on traditional energy systems, solar offers a resilient, clean alternative. But to truly deliver on its promise, the solar industry itself must be resilient to the very climate threats it helps to mitigate. As extreme weather events intensify, particularly in hurricane-prone regions, the risk to solar infrastructure increases. Hundreds of gigawatts of solar installations are now in the path of tropical cyclones each year — an escalating vulnerability as the market expands.

That's why the *Solar Under Storm* series is so vital. RMI's work provides much-needed technical guidance to improve the durability of solar systems in the face of Category 5 hurricanes. These reports offer practical, field-tested strategies for manufacturing, design, installation, and operations that are essential for protecting investments, ensuring safety, and sustaining energy access during and after major storms.

For solar, in all its shapes and sizes, to provide energy resilience to communities, we ourselves have to be resilient to natural disasters, extreme weather events, and other exogenous shocks. Solar is not just about mitigation, but also adaptation and resilience. All over the world, people are turning to off-grid enabled solar and storage in preparation for hurricanes, to back up unreliable grids, or to be able to ride through conflict situations. If we implement these recommendations, we can provide those people with even greater certainty of energy access.

By embracing these best practices and embedding resilience into the foundation of every solar deployment, we can safeguard the future of solar energy, and with it, the communities and economies that depend on it.

Sonia Dunlop

Sonia Dunlop
CEO, Global Solar Council

Executive Summary

Poorly secured solar panels became flying debris within a ground mount solar installation on Carriacou, Grenada during Hurricane Beryl, July 2025. Photo courtesy of Skylar Bee, RMI

Executive Summary

Eight years have passed since the deadly 2017 hurricane season, still one of the most destructive in recorded history.[1] Hurricanes Harvey, Irma, and Maria brought unprecedented destruction to the Caribbean. The devastation also illuminated for a growing solar industry what could quickly go wrong as well as what could remarkably survive by implementing certain solar design and installation best practices. As we researched and reported after the hurricane season of 2017, a number of solar PV systems in the Caribbean survived, despite record sustained wind speeds of over 180 miles per hour. Some solar installations in the British Virgin Islands, Turks and Caicos, Puerto Rico, and St. Eustatius faced historic wind conditions yet continued producing power the following day. In contrast, other PV systems in Puerto Rico, the US Virgin Islands, and Barbuda suffered major damage or complete failure.

Since the last *Solar under Storm* report, the Atlantic, Pacific, and Indian Oceans have endured a barrage of tropical cyclone impacts. The 2020 North Atlantic season was the most active on historical record with 30 named storms, 11 of which made landfall in the continental United States.[1] This past summer, in July 2024, the earliest category 5 hurricane to ever form in the North Atlantic,[2] Hurricane Beryl, destroyed homes and infrastructure across Grenada and Saint Vincent and the Grenadines.

Our team investigated three ground-mount solar installations in the path of the deadly hurricane. This update to our first *Solar under Storm* report takes the learnings from those installations and provides a comprehensive update to Solar under Storm specifications, best practices, checklists, industry codes, and recommended references based on evolution of the solar industry, advancements in technology, and additional seasons of experience and field investigation.

Hurricane Beryl over the eastern Caribbean, July 2024

Since the first publication of this series of reports, electricity generated by PV has been growing exponentially. The technology is modular and scalable, supplementing energy needs in homes, businesses, industries, government facilities, and utilities worldwide. Gigawatts of solar are now installed across rooftops, parking canopies, and large tracts of land in vulnerable tropical and coastal areas. Solar PV is the most rapidly growing source of power in the world and for all Caribbean islands.[3] In fact, 90% of Caribbean electric utilities now own or dispatch solar PV as part of their generation mix.

Generating energy with solar PV is a cost-effective and reliable solution for power generation. Incorporation of the best available engineering, design, delivery, and operational practices can increase reliability and survival rates from extreme wind loading.

There are several islands in the Caribbean that operate above 90% solar generation, firming the resource with lithium-ion batteries and cycling diesel generators for less than 10% of the year. As islands and other vulnerable coastal jurisdictions grow more dependent on solar for local electricity generation, securing these generation assets becomes more critical.

Given the variability in wind speed, wind direction, wind duration, topography, design, and construction, along with limited global datasets, we cannot give an overarching statistical conclusion to explain survivorship versus failure. Instead, this guide combines recent field observations along with expert analysis and the benefit of previous hurricane season investigations to deliver an updated set of actionable recommendations for increasing resiliency among retrofit and new construction solar PV installations.

This report is organized into four sections:

1. Introduction
2. Root cause identification methodology and findings
3. Failure mode and effects analysis (FMEA)
4. Summary of recommendations

Sections 1 and 4 are intended for a general audience of governments, utilities, regulators, developers, and PV system installers who are interested in improving PV system survivability to intense wind-loading events. Sections 2 and 3 are intended for engineering professionals responsible for PV system design, PV system specifications, and/or PV system construction oversight and approval.

Summary of Findings

We had the unique opportunity to observe three ground-mount systems in the Grenadines in the wake of Hurricane Beryl. There was a stark contrast between the use of Solar under Storm best practices on one project and the absence of those mitigative actions on two other projects in the same geographic area under identical storm conditions.

An expert structural engineering team uncovered several root causes of system failure through observation and discovered one critical module failure that was a “lurking failure mode” but not observed or reported on in our previous editions.

Similarities of failed systems in the wake of Hurricanes Irma and Maria and further validated by investigations in the Grenadines after Hurricane Beryl include:

1. Top down or T clamp failure of modules
2. Undersized rack or rack not designed for wind load
3. Lack of lateral racking support (rack not properly designed for wind loading from the side)
4. Undersized bolts
5. Under-torqued bolts
6. Lack of vibration-resistant connections
7. PV module design pressure too low for environment
8. PV module frame experience low-cycle fatigue failure
9. Use of self-tapping screws instead of through bolting

Some common ground-mount PV attributes of surviving systems in the wake of Hurricanes Irma and Maria further validated by the investigations in the Grenadines after Hurricane Beryl include:

1. Dual post piers
2. Through bolting of solar modules (no top down or T clamps)
3. Lateral racking supports
4. Structural calculations on record
5. Owner's engineer of record with QA/QC program
6. Vibration-resistant module bolted connections such as Nylocs.

Chub Cay Bahamas 4 MW ground-mount solar installation that provides over 90% of the island's electricity.
Photo courtesy Michael Vance, Asante Energy

Recommendations

This report provides an updated list of recommendations for building more resilient solar PV power plants. The recommendations are organized into two categories: 1) specifications and 2) collaboration.

1. Specifications:

- Specify high-load (4,000 Pa uplift) PV modules, based on structural calculations (not module datasheets); these are currently available from a number of Tier-1 module manufacturers.
- Require structural engineering in accordance with ASCE 7 and site conditions, with engineer sealed calculations for wind forces, reactions, and attachment design (ground-mount foundation). Check that the K_{zt} assumed for the project includes both topography within the project boundary and outside in accordance with ASCE code (see *Appendix D*).
- Confirm with racking manufacturers that actual site conditions (topography) comply with their base condition assumptions from wind-tunnel testing.
- Specify bolt QA/QC process: there were several instances of inadequate torquing of bolts in the investigation — a workmanship and oversight issue.
- Specify bolt hardware locking solution.
- Specify through bolting of modules as opposed to top-down or T clamps, or if top clamping is required, use clamps that hold modules individually or independently, no shared clips.
    - When through bolting modules, use a specialized washer as opposed to standard round washers to spread the low-cycle fatigue away from concentrated areas of the module frame. RMI will be requiring a specialty washer such as the StormPlate™ on future Caribbean and Pacific solar projects. Refer to *Appendix C*.
- Require structural engineer review of lateral loads due to racking and electrical hardware. Often lateral loads are missed, and recent failures have proven them to be a critical source of weakness (e.g., combiner boxes attached to end solar array posts caused increased loading and led to failure).
- Do not recommend trackers for projects in Category 3 or higher wind zones.
- Specify all hardware based on 25 years of corrosion.
- Do not recommend any self-tapping screws.

2. Collaboration:

Collaboration recommendations identify opportunities for increased resiliency, which require multiparty consideration and action but do not represent current industry standard actions.

- Collaborate with module suppliers to implement static and dynamic load tests representative of 180 mph wind speeds — exceeding current Category 5 hurricane standards.
- Collaborate with racking suppliers to perform full-scale and connection tests representative of 180 mph wind loads.
- Collaborate with suppliers to document manufacturer quality, material origin, and certifications through a third-party audit aligned with engineering assumptions (see box below).

Perhaps the most opportune recommendation is for an international community of solar PV power plant stakeholders who have extreme wind exposure to regularly share lessons learned from new designs and extreme wind events. To that end, we formed a PV Resiliency working group on the online Caribbean Renewable Energy Community (CAREC), which is hosted by CARILEC, to connect, innovate, and collaborate. Join the working group at **http://community.carilec.org/**.

> **Clean Energy Associates has conducted more than 70,000 quality inspections in over 300 PV module factories since 2016. Data from the past few years highlights concerning quality trends in PV module manufacturing, which could lead to performance and safety risks in the field.**
>
> — *Ensuring PV Manufacturing Quality,* Clean Energy Associates, October 16, 2024

Introduction

Destroyed houses, Hurricane Irma, St. John, United States Virgin Islands in 2017.

Introduction

Solar energy has quickly become the fastest growing energy generation source in the world, with more than 500 gigawatts (GW) installed in 2024 alone.[4] Solar coupled with battery storage has demonstrated an increased technical and economic ability to support global energy transitions. Several major islands have tripled their solar installations since our last *Solar under Storm* publication, including Barbados which is now on a pathway to reach 30% solar by 2030;[5] Hawaii, which is now at over 1400 MW with 43% of utility customers hosting rooftop solar;[6] and the Philippines, which has installed nearly 3 GW of solar as of the end of 2024.[7] With that much solar exposed annually to tropical cyclones, coupled with significant reliance for electricity generation, it is vital to ensure its resilience. *Solar under Storm I* (2018), provided a set of best practices that were observed and documented to improve the resilience of ground-mount solar systems and help them survive tropical cyclone events.

Given any North Atlantic hurricane, Pacific typhoon, or Indian Ocean cyclone's variability in wind speed, wind direction, or duration along with limited data from each solar project, one overarching conclusion cannot be made to explain the diversity of outcomes. However, the best practices identified in *Solar under Storm I* have stood the test of time and several seasons of cyclone exposure. The purpose of this report is to combine recent field observations from Hurricane Beryl along with expert analysis and new industry standards to provide updated recommendations aimed at increasing the resiliency of retrofit and new construction solar PV installations. More specifically, this report provides guidance applicable specifically to ground-mount and canopy PV power plants with a fixed tilt or a dual tilt (E–W) configuration. Rooftop systems experience unique aerodynamic phenomena that are not within the scope of this report but were addressed comprehensively in *Solar under Storm II* and may be addressed in future versions in response to interest.

The island of Carriacou suffered through Category 5 winds from Hurricane Beryl in July 2024, but this solar array survived. Photo courtesy Christopher Burgess, RMI

Approach

Our approach to increasing the ability of PV systems to withstand hurricane winds utilizes design-for-reliability principles and methods.

Guiding principles of this work include:

1. Collaborate across organizations and expertise.
2. Address observed failure modes and lurking failure modes (ones that did not occur only because something else failed first).
3. Plan for advancement of hardware, reliability statistics, and expert knowledge.
4. Provide performance-based recommendations where possible to allow for innovative solutions.
5. Limit recommendations to only those that provide a risk-adjusted economic benefit.

To realize these guiding principles, we conducted a five-step process:

1. Conduct failure analysis of three ground-mount solar project sites impacted by the 2024 hurricane season (*Appendix B* provides the field report from each site).
2. Engage experts responsible for managing or analyzing historical failures of solar projects.
3. Identify and prioritize root causes through collaborative completion of a “fishbone” tool.
4. Update the failure mode effects analysis (FMEA) for the prioritized root causes.
5. Synthesize recommendations from the FMEA for communication and consideration.

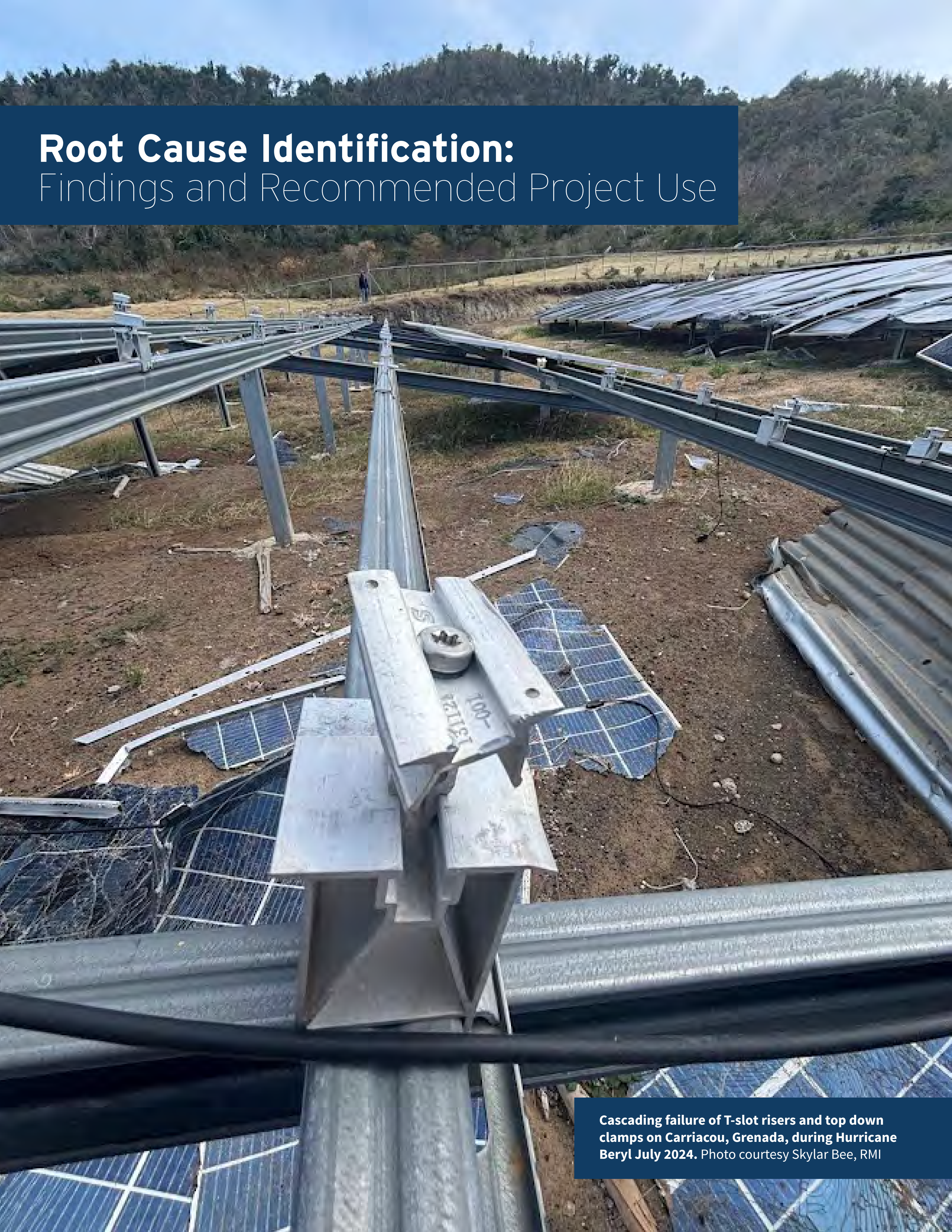
The key output of this report is an updated list of recommendations for building more resilient solar PV power plants. The recommendations are organized into two categories: 1) specifications and 2) collaboration. To the extent possible, the specifications are performance-based to allow for individual project teams to provide the most cost-effective and resilient solution.

Organization

This document is organized to present readers with each of the major analysis steps in order of completion. Section 2 presents the root cause identification methodology and findings, along with recommendations for using the findings and the method. Section 3 utilizes the root causes identified in an FMEA. The output of this analysis includes mitigation actions that are evaluated by cost and impact. Section 4 synthesizes mitigation actions identified in the FMEA into a list of recommendations for ease of communication and consideration by the reader.

Root Cause Identification:

Findings and Recommended Project Use



Cascading failure of T-slot risers and top down clamps on Carriacou, Grenada, during Hurricane Beryl July 2024. Photo courtesy Skylar Bee, RMI

Root Cause Identification: Findings And Recommended Project Use

The recent hurricane season, combined with the exponential increase of solar power plants in the region, has provided an exceptional body of evidence for updating resiliency guidelines for future Caribbean projects. However, the development of hurricane resiliency guidelines based on observed failure modes alone has limitations.

Resiliency measures are akin to strengthening links in a chain. The goal is that by strengthening the weakest links, the entire chain has the capacity to perform the task at hand. However, this doesn't mean that another link doesn't break before the job is complete. Therefore, the observed failure modes and the recommended actions may improve the regional design of PV systems, and evidence has shown that recommendations from *Solar Under Storm I* and *Solar Under Storm II* have done exactly that. But the due diligence continues as the industry evolves, storms strengthen, and the newest link in the chain unveils itself.

The island of Mayreau, part of Saint Vincent and the Grenadines, hosts a 100 kilowatt solar and battery microgrid that supports half of the island's electricity needs. The 100 kW solar ground-mount system was built to 180 mph wind standards using Solar under Storm best practices. The arrays all survived remarkably well during Hurricane Beryl — every foundation post, purlin, and bolt connection held in place. However, roughly 70% of modules failed at the frame mounting holes. Photo courtesy Frank Oudheusden, AAS

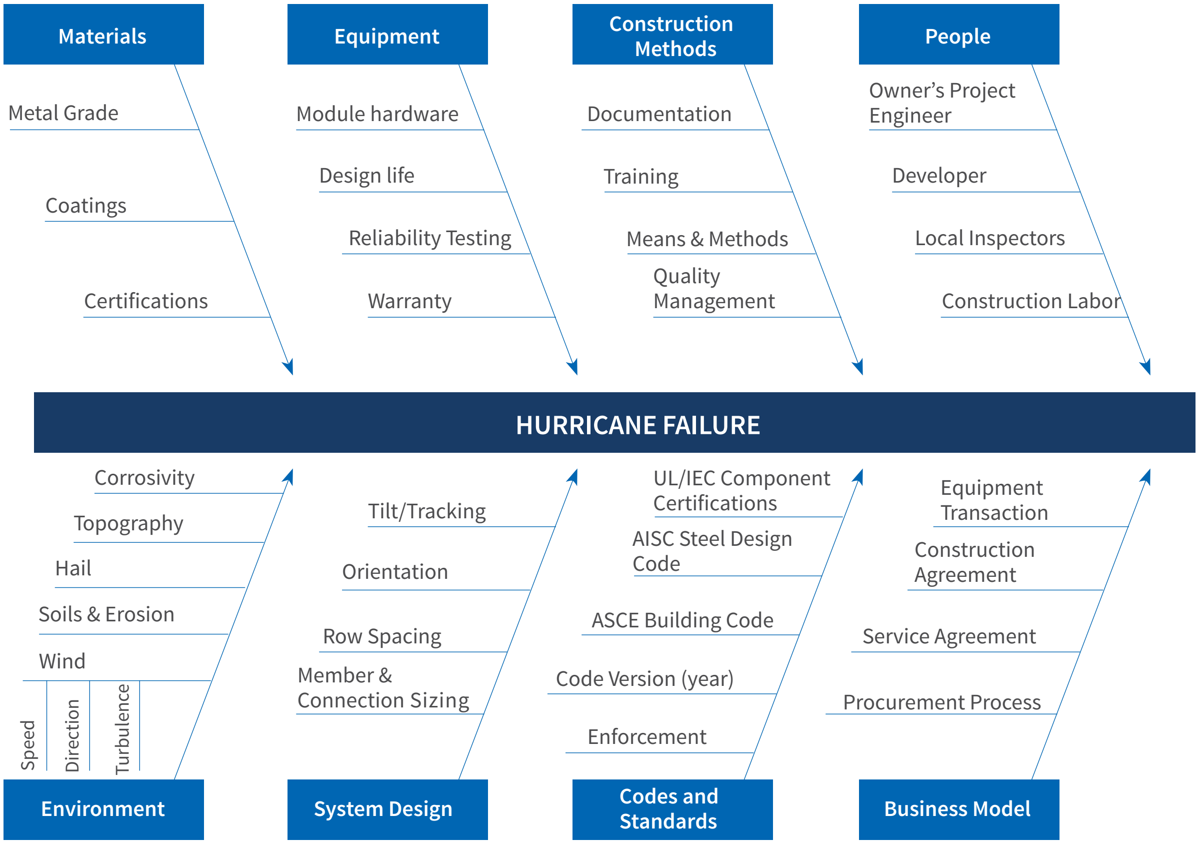
In the event that future systems only address the observed failure modes, forces may trigger additional failure modes, such as low-cycle module frame fatigue, as we witnessed firsthand on Mayreau (see *Appendix C*).

To address both observed and potential failure modes, we take a classical reliability engineering approach to design for reliability. Exhibit 1 illustrates a common reliability tool for systematic cause and effect identification called a fishbone diagram. The diagram shows the supply chain responsible for design, manufacturing, procurement, delivery, installation, and operations of a solar power plant, along with the operational use case.

The current fishbone draft is limited by the data set, authors' expertise, and current technology; consequently, this analysis should be updated to incorporate new data, expertise, and technology as they become available.

Exhibit 1

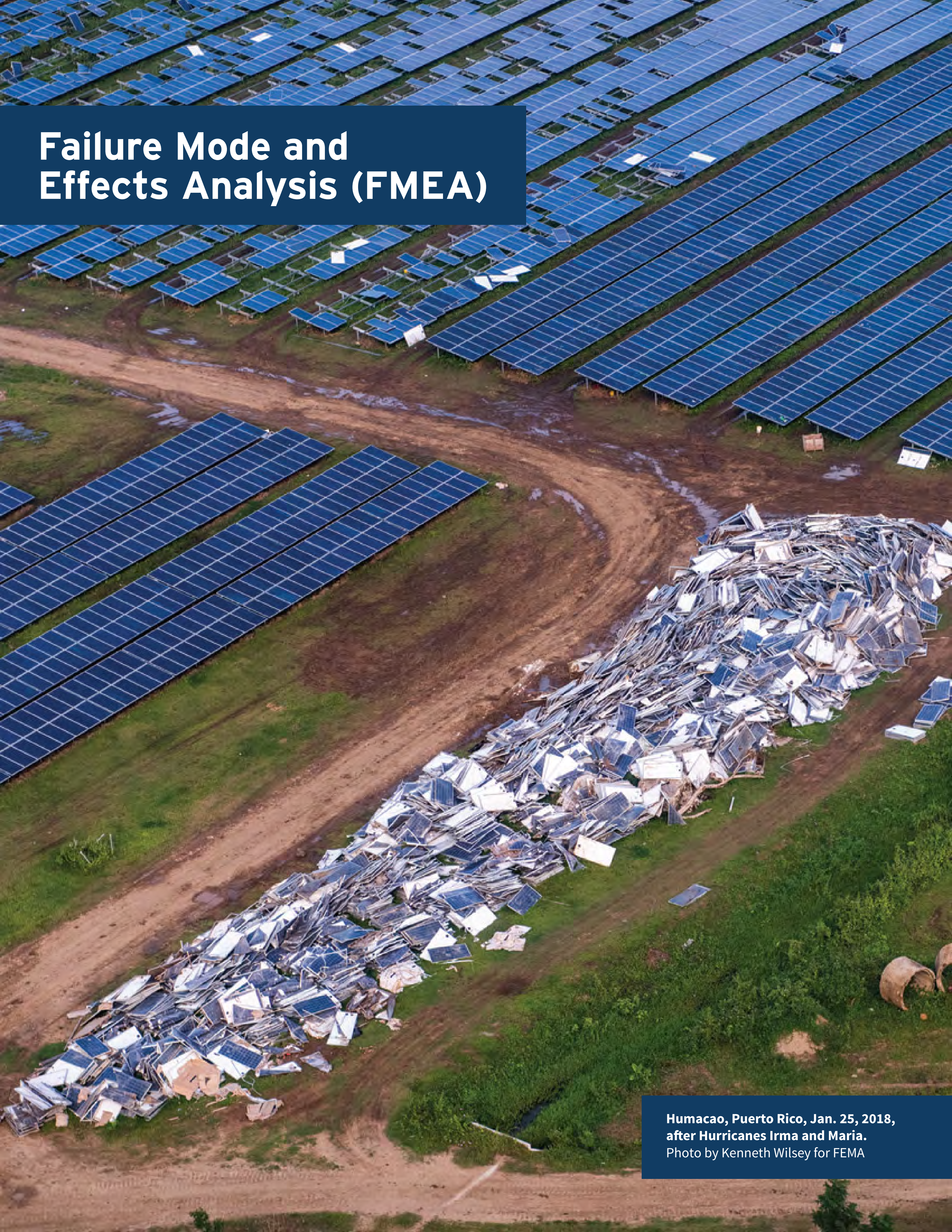
Fishbone diagram for root cause analysis identification



RMI Graphic.

Future solar power plant project teams are invited to utilize Exhibit 1 as a facilitation tool to explore project-specific opportunities to eliminate causes of failure in response to extreme wind or other hazards. During a project delivery process, the project team may explore the categories provided along with additional factors to identify causes of failure and potential mitigations. Project teams that complete the root cause analysis are invited to annotate Exhibit 1 and share their findings.

Failure Mode and Effects Analysis (FMEA)



Humacao, Puerto Rico, Jan. 25, 2018, after Hurricanes Irma and Maria. Photo by Kenneth Wilsey for FEMA

Failure Mode and Effects Analysis (FMEA)

Improving the ability of PV systems to withstand hurricane winds requires identification of failure modes and a cost-effective mitigation action plan. The industry does not benefit from mitigation actions that undermine the economics of solar projects on a levelized cost of energy (LCOE) basis.[8] The FMEA framework identifies economically practical mitigation actions that are commercially available. Moreover, actions are provided that have a net positive impact on cost when considering the cost and benefit in a risk-adjusted financial analysis.

The synthesis of the FMEA presented below is designed to organize and showcase the current mitigation actions and associated limitations of the most relevant failure modes and also to provide a cost-effective mitigation action plan. The table is organized by subsystems and assemblies.

Exhibit 2 **Failure mode and effects tables**

Table 1 **PV module frame and laminate**

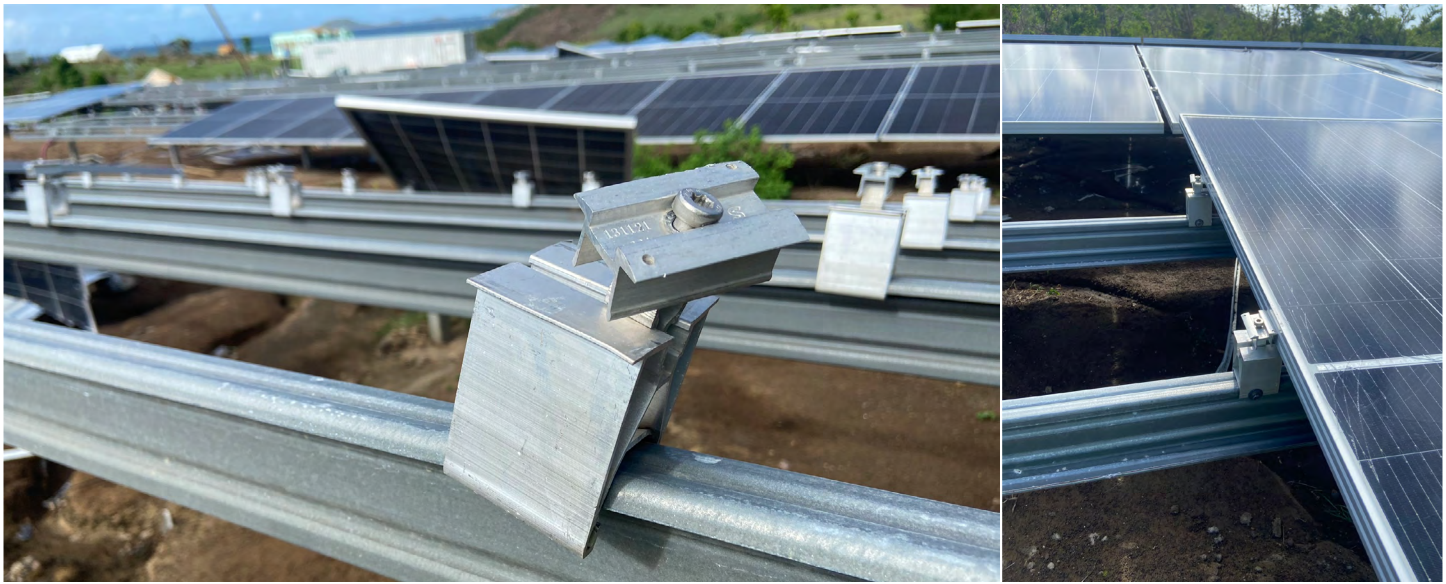
#	Failure Mode(s)	Current Mitigation	Limitations	Potential Mitigation Action	Cost/Impact
1a	Laminate tear-out (module glass dislodged from frame)	UL 61730/ IEC 61215 static load (global PV module testing standard)	Local pressure may exceed module rated pressure	Review racking system/full structural system wind tunnel test report for module-level wind pressure and compare against module front and back rated pressure. Refer to example in *Appendix A*. Racking suppliers furnish these wind tunnel test reports upon request. Results of the test will determine the proper rating for modules (which will differ across the design of the array).	Low/Medium

Table 1 PV module frame and laminate, continued

#	Failure Mode(s)	Current Mitigation	Limitations	Potential Mitigation Action	Cost/Impact
1b	Frame bolt hole failure	Engineering connection calculations	Module back side (uplift force) rating may not be adequate for local loads	Specify engineer calculations for module connection hardware, including frame where used. Note that module pressures on single connections (¼ module area) can be 50% higher than on full modules. Collaborate with module manufacturers to improve supply chain. Engineer of record for the project should request and approve engineering connection calculations.	Low/High
1c	Frame buckling failure	UL 61730/ IEC 61215 static load (global PV module testing standard)	Local pressure may exceed module-rated pressure	Review racking system/full structural system wind tunnel test report for module-level wind pressures and compare against module front- and back-rated pressure. Refer to example in *Appendix A*. Racking suppliers furnish these wind tunnel test reports upon request. Results of the test will determine the proper rating for modules (which will differ across the design of the array).	Low/High
1d	Module frame fatigue failure	IEC 61215-2 Dynamic Module Loading Test Additional safety factor selection for module frames.	Cyclical (dynamic) loading often causes failures below 50% of the static load rating.	Ensure that module data sheets specify additional safety factors on module design ratings (test loading = 1.5 * design loading). Design module connections that distribute loading into the frame in a manner that minimizes stress concentration. Examples include backing plates on aluminum module frames for bolted connections, using more than (4) bolts per module, and use of individual top clamps (no shared clips) or other proprietary methods or rapid-install panel mounting. See Appendix C.	Low/High
1e	Laminate impact damage	UL 61730 hail impact tests and ASCE wind-prone debris. Some severe hail-damaged modules are available	Hurricane debris can be large compared to hail	Specify that site prep and clean-up shall include removal or securement of all foreign objects (debris).	Low/High

Photo courtesy Chris Needham, AAS

Table 2 PV module connection hardware



#	Failure Mode(s)	Current Mitigation	Limitations	Potential Mitigation Action	Cost/Impact
2a	Bolt self-loosening	Partial torque check and proper documentation of the torque checks	Self-loosening common due to washer-clamping surface translation during vibration	Specify bolt locking solution appropriate for the environment and workforce. (Nyloc nuts have demonstrated resistance to self-loosening even when not torqued properly.)	Low/High
2b	Connection hardware failure (fracture, rupture, tear out, shear)	SE hand calculations are typical	Hand calculations not always updated with site-specific wind load and topography	Specify SE site-specific review of module attachment hardware per AISC or equivalent. Engineer of Record should fully understand wind-tunnel testing and application to the racking and not simply rely on racking vendor to supply these checks.	Low/High
2c	Cascading failure of top down clamps	Module top down clamps clamps designed for symmetric boundary conditions	Module top down clamps clamps rotate with loss of one module and allow liberation of second module	Specify module frames to be through bolted in accordance with manufacturing specification for the design wind speed. If necessary, use top clamps that do not allow cascading failure. Aluminum t-slot rails should be avoided.	Low/High

Photos courtesy Christopher Burgess, RMI

Table 3 **Structural racking member**

#	Failure Mode(s)	Current Mitigation	Limitations	Potential Mitigation Action	Cost/Impact
3a	Member global failure (plastic deflection, buckling, torsion)	Steel code (AISC or equivalent) check with software package (RISA 3D or equiv.) and updated according to site-specific ASCE 7 loads	ASCE 7 prioritizes normal loads due to buildings focus. Lateral loads on electrical balance of system (eBoS) commonly omitted	1. Utilize owner's project engineer to review calculation package. 2. Specify racking design for the wind speed recommended by ASCE 7-16. 3. Specify SE review of lateral loads due to racking and eBoS hardware. 4. Specify racking with documentation of full-scale load test (sandbag). 5. Specify any tracker included in the project shall be designed for worst case wind exposure, no stow position for extreme wind allowed.	1. Low/ Medium 2. Med/High 3. Low/High 4. Low/ Medium 5. Medium (Tracking only)
3b	Topographic load increase	Topographical impact is considered for both velocity pressure and pressure coefficients.	ASCE7 Chapter 26 Wind tunnel testing often does not include adequate topographical consideration.	Ensure topographic load scalars (Kzt) are included in wind design. Ensure topographic effects are considered in wind tunnel testing, if applicable.	Low/High
3c	Dynamic excitation	Building code requires dynamic load amplification for structures with resonant frequency <1 Hz>	PV arrays with inter-row spacing experience modified airflow more conducive to dynamic excitation	SE project engineer should check dynamic loading if resonant frequency is <5 Hz (Cain and Banks, 2015). If deviating from the recommended dual-post fixed-tilt structure recommended in this report, any wind tunnel testing should be peer reviewed as required in ASCE 7 to verify compliance with industry best practices. Aeroelastic and dynamic effects should be included in design.	Low-High

Left photo courtesy Frank Oudheusden, AAS; Right photo courtesy NREL

Table 4 **Structural racking connections**

#	Failure Mode(s)	Current Mitigation	Limitations	Potential Mitigation Action	Cost/Impact
4a	Bearing bolt shear	AISC check with hand calculations typical	Hand calculations not always updated with site-specific wind loads	Specify structural engineer to complete site-specific connection review	Low/High
4b	Bolt self-loosening	Partial torque check and documentation typical	Self-loosening common due to washer-clamping surface translation during vibration	Specify bolt-locking solution appropriate for the environment and workforce.[6]	Low/High
4c	Self-tapping screw corrosion and shear failure	Steel code	Sizing does not always account for highly corrosive environment	Recommend no self-tapping screws be used in new project design. For retrofit applications, carefully monitor installation practices to ensure proper function as these screws often underperform due to installation error.	Low/High

Left photo courtesy NREL; Middle photo courtesy Frank Oudheusden, AAS; Right photo courtesy Christopher Burgess, RMI

Table 5 **Racking foundations**

#	Failure Mode(s)	Current Mitigation	Limitations	Potential Mitigation Action	Cost/Impact
5a	Foundation structural failure	ASCE 20	Requires site-specific geotechnical data	Specify complete suite of geotechnical test for foundation design. Where feasible, a corrosion analysis should be conducted based on site-specific geotechnical data.	Medium/ Medium
5b	Overturning foundation posts	Structural design preferences	Developers want to minimize foundations per site	Specify structures with dual foundation designs over single foundation designs as they better support from an overturning moment failure. Specify low tilt angles to reduce peak module pressures and overturning moments.	Medium/High
5c	Erosion	Very few	Requires water drainage control plan	On steep-slope, loose-soil projects, develop water drainage plan and install drainage methods during site construction to control water flow. Take into account topography from surrounding land that isn't site specific.	Medium/ Medium
5d	Corrosion	American Galvanizers Association Guidance	More galvanization requires more cost	For foundations: Specify testing of soil corrosion (pH, chloride, and moisture) at multiple locations and utilize for foundation design according to ASTMA123. Be familiar with causes of accelerated corrosion like pollution, humidity, and salt water proximity and review the local (300 m radius) area for caustic-causing input to the plant.	Medium/ Medium

Left photo courtesy AquaSoli; Right photo courtesy Skylar Bee, RMI

Table 6 **Electrical balance of systems**

#	Failure Mode(s)	Current Mitigation	Limitations	Potential Mitigation Action	Cost/Impact
6a	Wire pull out or terminal damage	UL specification for each electrical component (e.g., UL 1703 PV modules)	Terminal torque values unchecked in field	Specify QA/QC procedure and documentation for terminal torques.	Low/Low
6b	Wire sheath chafing (ground fault)	NEC or IEC conductor management and support specifications	Wires sag and subject to gyration based on field installation	Specify wire management practices, including support schedule and sag tolerance. Specify stainless-steel or heavily galvanized wire clips or PVC coated stainless-steel cable clamps instead of plastic zip ties.	Low/Low
6c	Wire management fracture	NEC or IEC	Direct and reflected UV exposure increases risk of embitterment and fracture	Specify UV-resistant and corrosion-resistant wire management solution. Require plan set to incorporate wire management technique for review against NEC or IEC. Specification of conduit in lieu of open-air wire management may be appropriate in some locations.	Low/Low
6d	Rain intrusion into combiner boxes or inverters	NEC - NEMA specification	Hurricane wind blowing sideways can penetrate NEMA 3	Specify NEMA 4X to 6P enclosures based on engineering review. IEC equivalent is IP56 to IP67.	Medium/High

Photos courtesy Christopher Burgess, RMI

Conclusion

RMI technical manager, Fidel Neverson, and RMI manager, Sidney Jules, investigating failed solar project on Carriacou, Grenada, March 2025. Photo courtesy Skylar Bee, RMI

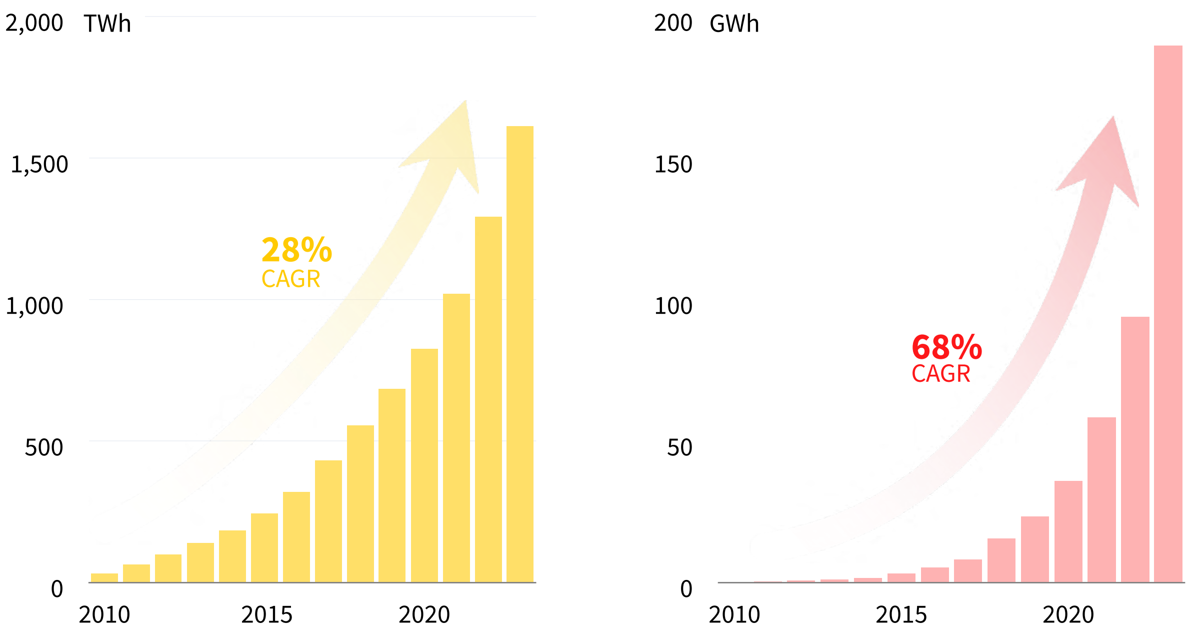
Conclusion

Generating energy with solar PV is a cost-effective and reliable solution for power generation worldwide. That is why it has been the fastest growing source of electrical generation over the past decade. Coupled with battery storage, solar PV is a firm and dispatchable resource that now accounts for over 1,500 terawatts of global generation annually.[9]

Exhibit 3

Leading to Exponential Growth in Renewables

Global solar generation has been doubling every 2–3 years, and battery storage capacity has been doubling every year:



Solar generation

Battery storage

RMI Graphic. Source: IEA, BNEF; Note: CAGR is the compound annual growth rate between 2013 and 2023.

Three of the top global leaders in solar PV installations, China,[10] the United States,[11] and India,[12] experience tropical cyclones. Those three countries alone account for over 1.2 terawatts of installed solar projects. Of course, island nations are experiencing substantial solar uptake as well and they are even more vulnerable to power system disruptions from tropical cyclone events. Incorporation of the best available engineering, design, delivery, and operational practices can increase reliability and survival rates from extreme wind loading. Additionally, more diligence is necessary when selecting solar modules for cyclone-prone areas, due to the industry's shift towards larger format modules that offer higher energy yields but possess reduced mechanical strength.[13]

This report is limited in its ability to be all-knowing of all failure modes and all corrective actions and cannot guarantee the efficacy of any recommended action. However, over the past seven years, these best practices have been tested by extreme wind events, many of them directly validated and now updated for 2025:

Specifications include:

- Specify high-load (4,000 Pa uplift) PV modules, based on structural calculations (not module datasheets); these are currently available from a number of Tier-1 module manufacturers.
- Require structural engineering in accordance with ASCE 7 and site conditions, with engineer sealed calculations for wind forces, reactions, and attachment design (ground-mount foundation). Check that the K_{zt} assumed for the project includes both topography within the project boundary and outside in accordance with ASCE code (see *Appendix D*).
- Confirm with racking manufacturers that actual site conditions (topography) comply with their base condition assumptions from wind-tunnel testing.
- Specify bolt QA/QC process: there were several instances of inadequate torquing of bolts in the investigation — a workmanship and oversight issue.
- Specify bolt hardware locking solution.
- Specify through bolting of modules as opposed to top-down or T clamps, or if top clamping is required, use clamps that hold modules individually or independently, no shared clips.
    - When through bolting modules, use a specialized washer as opposed to standard round washers to spread the low-cycle fatigue away from concentrated areas of the module frame. RMI will be requiring a specialty washer such as the StormPlate™ on future Caribbean and Pacific solar projects. Refer to *Appendix C*.
- Require structural engineer review of lateral loads due to racking and electrical hardware. Often lateral loads are missed, and recent failures have proven them to be a critical source of weakness (e.g., combiner boxes attached to end solar array posts caused increased loading and led to failure).
- Do not recommend trackers for projects in Category 3 or higher wind zones.
- Specify all hardware based on 25 years of corrosion.
- Do not recommend any self-tapping screws.
- Specify dual-post fixed-tilt ground mounts, which significantly reduce foundation failure risk.

Likely the most effective strategies for improving system survival rates are communicating clear market signals to suppliers and upstream equipment providers and coordinating closely among practitioners. This includes:

- Collaborate with module suppliers to implement static and dynamic load tests representative of 180 mph wind speeds — exceeding current Category 5 hurricane standards.
- Collaborate with racking suppliers to perform full-scale and connection tests representative of 180 mph wind loads.
- Collaborate with suppliers to document manufacturer quality, material origin, and certifications through a third-party audit aligned with engineering assumptions (see box below).

Perhaps the most opportune recommendation is for a regional and even international community of solar PV power plant stakeholders who have extreme wind exposure to regularly share lessons learned from new designs and extreme wind events. To that end, we formed a PV Resiliency working group on the online Caribbean Renewable Energy Community (CAREC), which is hosted by CARILEC, to connect, innovate, and collaborate. Join the working group at **http://community.carilec.org/**.

> **Clean Energy Associates has conducted more than 70,000 quality inspections in over 300 PV module factories since 2016. Data from the past few years highlights concerning quality trends in PV module manufacturing, which could lead to performance and safety risks in the field.**
>
> — ***Ensuring PV Manufacturing Quality,*** Clean Energy Associates, October 16, 2024

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Failed Solar Farm Carriacou, Grenada.
Photo courtesy Jordan Hayles , RMI

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Fidel Neverson, RMI, investigating failed T-slot risers and top-down clamps on Carriacou, Grenada. Photo courtesy Skylar Bee, RMI

Appendices

Construction of the first ground-mount solar project on Anegada British Virgin Islands where it will supply the majority of generation for the utility. Photo courtesy Christopher Burgess, RMI

APPENDIX A

Solar PV Power Plant Wind Pressure Checklist for Project Owners

The determination of a design wind pressure is a complex science conducted by expert scientists and engineers. Solar PV power plant owners may generally confirm that wind pressures have been appropriately determined through familiarization with the process.

General process for solar PV power plant wind pressure determination:

1. **Conduct wind tunnel study on a scaled system model in a boundary-layer wind tunnel.** Project stakeholders may review the wind tunnel test report to confirm the scale model represents the project's proposed system layout. Deviations in row length, spacing, tilt, height, and leading-edge height should be limited to the range identified in the wind tunnel report.

2. **Analyze pressure measurements to determine pressure coefficients for the module or structural member of interest.** The wind tunnel test report should contain a table of pressure coefficients for each structural member of interest corresponding to the tributary area of said member or component. A project stakeholder should be able to identify that an appropriately selected table of pressure coefficients was used for each member or component. For components that do not have a dedicated table, rounding down should provide a near approximation as long as the aspect ratio and location are also similar. If an appropriate table does not exist, the wind tunnel can most likely reprocess existing data with minimal time and resources.

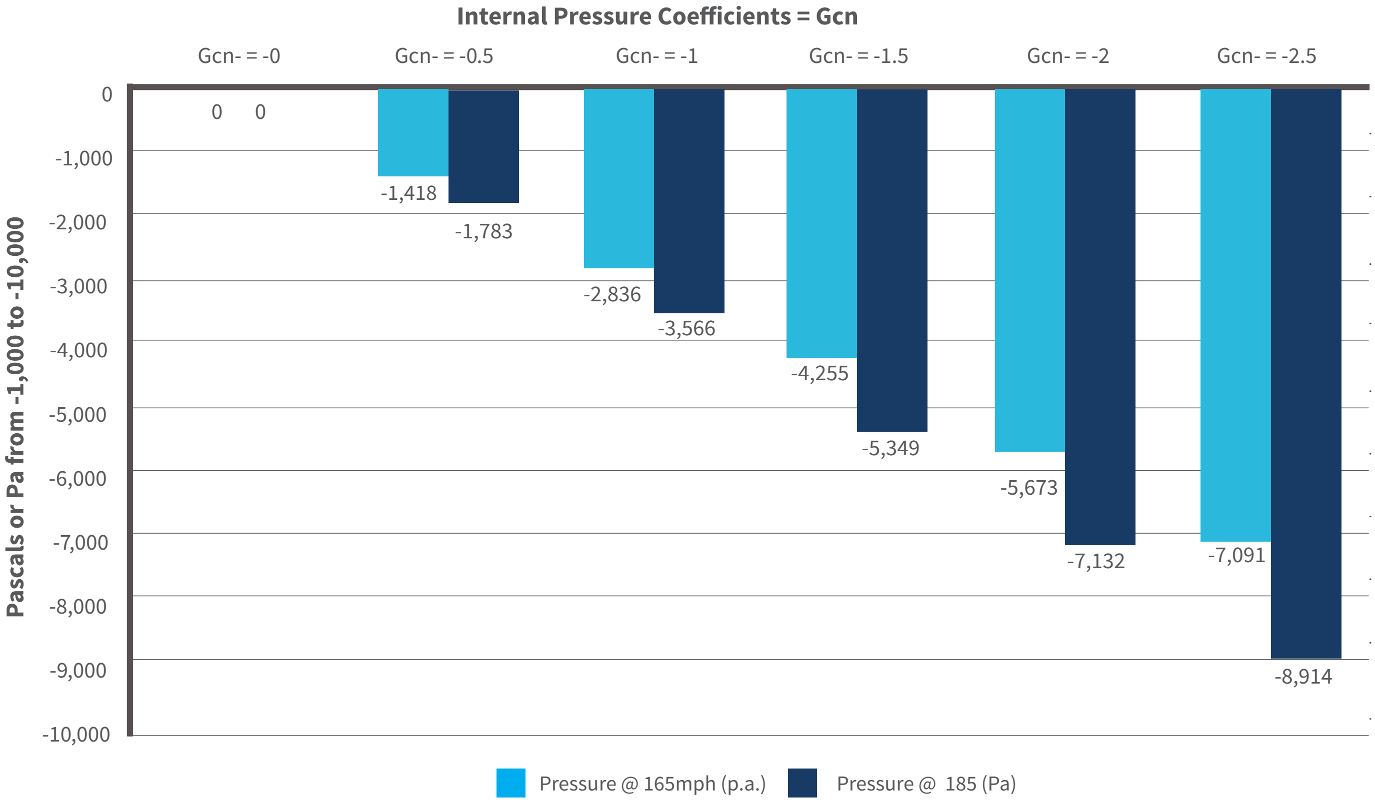
3. **Determine the wind dynamic pressure by accounting for the design wind speed, local topography, system height, directionality, and risk category.** Project stakeholders should be able to review a site-specific determination of wind dynamic pressure. The calculation should comply with the governing code and version (e.g., ASCE 7-16, ASCE 7-22) and incorporate the regional design wind speed, system height, topography, and importance. Projects with any topographic features should ensure appropriate treatment of said features.

4. **Combine the pressure coefficients and dynamic pressure to calculate a wind pressure.** Project stakeholders should be able to review structural calculation to determine a design wind pressure for each component or member of interest. Exhibit A1 illustrates a set of wind pressures for design wind speeds of 165 and 185 mph for pressure coefficients from 0 to 2.5. In this example, a pressure coefficient of 0.5 corresponds to design pressures less than 2,000 Pa (Pascals, 49 Pa = 1 PSF). In contrast, a pressure coefficient of 2.5 corresponds to design pressures in excess of 7,000 Pa. Given the potential variability, one can not assume that a high load rating module is either necessary or adequate.

5. **Review component and member specifications.** Project stakeholders should be able to review product specifications or engineering sets for all structural components, members, and connectors, including PV modules. Exhibit A2 illustrates the specification from a module that has one of the highest structural capacities known to the authors. Key information in this specification includes the range of allowable support conditions (AI) along with the specific and unique uplift load.

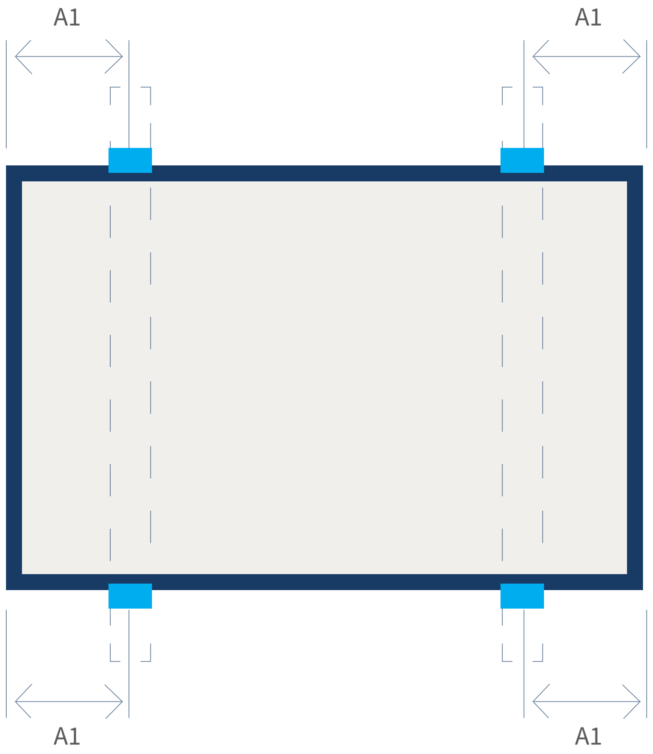
> **“The selection of Risk Category is ultimately the responsibility of the Engineer of Record (EOR) and should be based on the specific function of the PV system within the broader energy or infrastructure context. While most ground-mounted PV systems fall under Risk Category II, there are cases—such as systems located on remote islands or in isolated grids—where the solar array contributes a significant portion of the total electrical supply. In such scenarios, particularly when the system supports critical facilities or enables rapid post-disaster recovery, classification as Risk Category III or IV may be appropriate.”**

Exhibit A1 **Sample extreme wind uplift pressure on module surface**



RMI Graphic.

Exhibit A2 **PV module mounting specification**



Use four through bolts on the long side. Use bolt stack with Stormplate™ and nyloc nut (no round washers). Mounting rails run perpendicular to the long side frame.

A1 range= (300–330)mm

Maximum Load:
Uplift load < 4,000 Pa
Downforce load < 8,100 Pa

RMI Graphic.

APPENDIX B

Hurricane Beryl Field Reports

Carriacou — Inspection Date: July 29, 2024

Modules Remaining Visibly Undamaged: 35%

Failed Solar installation. Carriacou, Grenada. July 2024. Photo courtesy Chris Needham, AAS

Positive Design Elements: "What went right"

1. 3 rail support of modules / 6 attachment points.
2. Dual-post foundation design prevented any primary failures due to the superstructure. No tables overturned.
3. Use of a dual-tilt system (E-W) in an attempt to lower wind pressures on panels and system.

Observed Failure Modes: "What went wrong"

1. Shared top-down clips. Portions of the array exist with shared clips remaining, but complete loss of major portions of the project.
    - Responsible for >50% of system damage.
    - Most damage to panels still in place was observed to be from other liberated panels.

Failure #1: Shared top-down clips
Photo courtesy Frank Oudheusden, AAS

2. Use of a dual-tilt system (E-W) on a sloped terrain caused acceleration of wind onto the backside of leeward panel tilt. A significant portion of panel liberation was on these panels, which were otherwise relatively protected from debris. This is similar to the failure mode outlined in *Solar Under Storm II* where recommendations for not placing panels over roof ridgelines prevents module liberation.*
    - Responsible for ~30% of system damage.

Modules Overhanging the Roof Edge. Image courtesy of Marc Lopata, Solar Island Energy

East-west fixed tilt on sloped terrain failure #2.
Photo courtesy Chris Needham, AAS

3. Use of self-tapping screws. These were observed to allow rotation of components, contributing to loss of shared clamps and modules.

4. Aluminum t-slot connections provide easier tear-out, cyclical loading, and installation error practices and should be avoided.

RMI technical manager Fidel Neverson examining observed failure #4.
Photo courtesy Skylar Bee, RMI

5. Topographical features surrounding the site suggest a Kzt of >1 should have been assumed.** Depending on wind direction, this may be a contributing factor and must be considered and checked in the structural calculations.

6. Large-format panels (1.3 meters wide) showed permanent sagging over the panel surface, contributing to loss of modules when combined with the flexible overall panel retention design. These sized modules often do not have sufficient pressure rating for the site design wind pressures.

7. Combiner boxes showed significant movement under wind loading. Their structural capacity and foundation design did not take their dedicated wind pressure into account.

Failure #7: Combiner boxes affected by wind pressure. Photo courtesy Christopher Burgess, RMI

8. Lack of erosion mitigation caused severe erosion in certain parts of the array. This may have compromised the racking foundations in many locations.

---

* See page 29 in ***Solar Under Storm Part II: Select Best Practices for Resilient Roof-Mount PV Systems with Hurricane Exposure*** for more information.

** Kzt is the Topographic Factor in the wind load equation defined in ASCE 7. See *Appendix D* for more details.

Union — Inspection Date: July 30, 2024

Modules Remaining Visibly Undamaged: 40%

Significant module and racking failure at the apex of the slope (failure #4), Union Island.
Photo courtesy Frank Oudheusden, AAS

Positive Design Elements: "What went right"

1. Visible torque marks on all fasteners
2. Good foundation bracing in the east-west direction.
3. Selection of smaller PV panels with taller frame profile meant no primary failures were attributed to panel structural failures (laminate tear-out, frame buckling, bolt hole tear-out, or cyclical loading)
4. Erosion control was implemented on site, and the site did not show significant erosion post-event. This protects the foundation's structural integrity.
5. No tek-screws or aluminum t-slots were utilized.

Observed failure modes: "What went wrong"

1. Shared top-down clips. Portions of the array exist with shared clips remaining, but there was a complete loss of groups of modules.
   - Responsible for approximately 30% of system damage.

Failure #1: Shared top-down clip, Union Island, July 2024.
Photo courtesy Frank Oudheusden, AAS

2. Lack of vibration-resistant hardware allowed bolts to vibrate free.
    - Responsible for 20% of system damage.

3. Use of a single-post foundation caused two failure modes: overstress of top chords and rotation of the array (see photo below). Both issues would be addressed through the use of a dual-post foundation.

Failed solar array racking on Union Island, July 2024. Photo courtesy Frank Oudheusden, AAS

4. Topographical features surrounding the site suggest a K_{zt} of >1 should have been assumed. Depending on wind direction, this may be a contributing factor and needs to be considered and checked in the structural calculations (see *Appendix D*). There was an obvious loss of more modules toward the apex of the slope.

5. Inverter pad walls and combiner boxes wind pressure considerations were understated and exhibited wind-related movement or failure.

Inverter housing turn over on Union Island, St Vincent in the Grenadines. Photo courtesy Frank Oudheusden, AAS

Mayreau — Inspection Date: July 30, 2024

Modules Remaining Visibly Undamaged: 31%

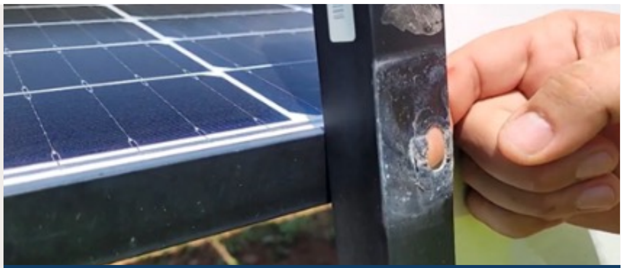
Mayreau solar farm after Hurricane Beryl. Photo courtesy Fidel Neverson, RMI

Positive Design Elements: “What went right”

1. Through-bolted module mounting with vibration resistant hardware. No failures were attributed to hardware loosening on the site.
2. Dual-post foundation design resulted in zero primary failures due to the superstructure. The racking for this project can be fully reused during repowering.
3. Low-tilt design helped reduce panel pressures and increase power density on site.
4. Electrical balance of system was in good shape. No wire sheath chafing, exposures, terminal damage, or pull outs besides where modules were missing.

Observed failure modes: “What went wrong”

1. The panels experienced low-cycle fatigue failure of the module frame (see *Appendix C*). This is effectively the final link in the chain of structural failures before the glass itself fails.
    - Responsible for 95% of system damage.
    - Panels used shorter, thinner aluminum alloy frame sections typical of most modern panels.



Low-cycle solar frame hole fatigue, Mayreau, July 2024. Photo courtesy Chris Needham, AAS

Solar module frame hole tear out, Mayreau, July 2024. Photo courtesy Chris Needham, AAS

2. High site topography affected the PV panel pressures. This increased the fatigue failure effect and is a topic currently evolving within the industry. Use of a conservative topographical factor is recommended for high slope sites (see Appendix D).

3. Corrosion of the supporting structure is underway, which is common for Caribbean projects, but was not a contributing factor in any failure modes. Specifying high protective layer thicknesses and/or materials for higher corrosion zones is recommended. The dual-post foundation design provides some higher capacity to account for loss of material strength over the life of the project but only buys a few extra years in practice.

APPENDIX C

Low-Cycle Fatigue of PV Panel Frames

Chris Needham taking inventory of failed solar modules on Mayreau, July 2024. Photo courtesy Frank Oudheusden, AAS

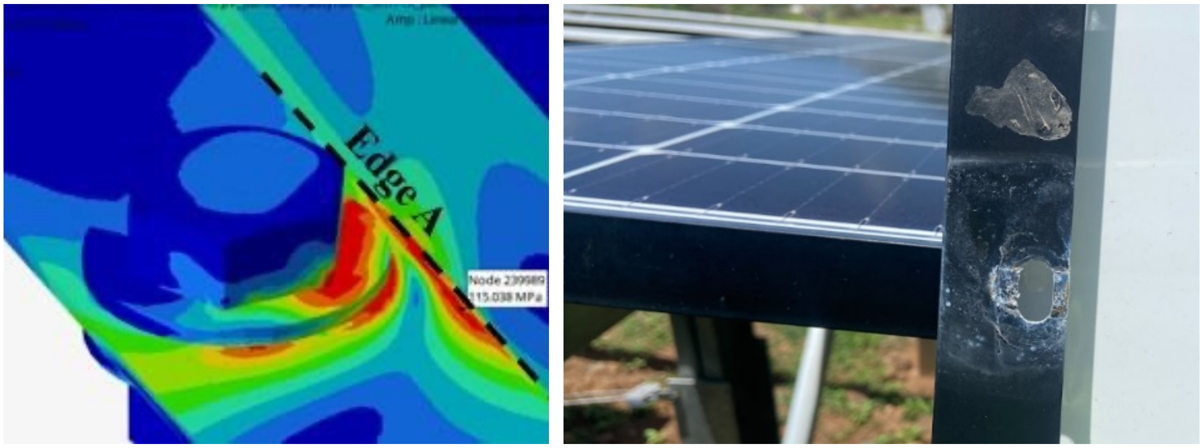
PV panel frames have evolved to be shorter and thinner over the past 10 years, even as modules have grown in area as much as 50%. Of particular importance, the bottom flange of PV frames has been reduced from 2 mm to as low as 1.1 mm, with 1.5 mm being a typical thickness for large-frame modules today. This means that the frames have more stress concentration than ever before.

The aluminum that PV frames are made from has no effective endurance limit, meaning it will always have an amount of loading cycles where it will fail for a given peak stress. With the taller, thicker frames of the past, the peak stress was lower for a given load, so the number of cycles to failure was high enough to not occur in practice for almost all projects. Unfortunately, this is no longer the case.

Shorter frames, thinner bottom flanges, larger panel areas, and higher winds have all brought peak panel stresses to the point where low-cycle fatigue can be a governing factor. Indeed, this is the primary and arguably only failure mode observed for the Mayreau project which experienced sustained Category 4 wind and Category 5 gusts.

Solar module frame hole tear out. Photo courtesy Chris Needham, AAS

On this project, the use of a typical bolt stack (bolt, round washers, nyloc nut) meant that stress from the round washer was concentrated directly on a relatively small area of the panel frame where the bottom flange transitions to the vertical box section. This has been evaluated and confirmed with a non-linear finite element analysis (FEA) model to produce initial cracks that propagate into failures in the exact manner witnessed on Mayreau.[i] The photo below shows a comparison of the predicted frame stress with an otherwise undamaged panel found still on the rack at Mayreau. This failure mode primarily exists for backside (wind) panel loading.



Comparison of FEA and Mayreau panel showing low-cycle fatigue failure of frame. Photo courtesy Chris Needham, AAS

Industry test standards exist to evaluate cyclical (dynamic) loading. The current standard is IEC 62782, which subjects a panel to 1,000 Pa for 1,000 cycles. However, this is a simplified test and real-world loading is complex and dependent on many factors. For example, in some instances, panels may experience 1,000 cycles over as little as 8 minutes of sustained wind. In addition, 1,000 Pa is relatively low loading for the Caribbean region. Still, many panels today are struggling to pass this test when mounted with a typical bolt stack.

Several options exist to greatly reduce the risk of low-cycle fatigue failure of PV panel frames. Some of the more common options available today include:

1. Use of *individual* top-clamps (four per module), which spread the backside wind loading over a wider portion of the top of the aluminum frames. This option is not readily employed in the industry today and has not been evaluated for fatigue failures.

2. Through-bolt mounting panels with more than (4) fasteners to reduce the peak loading of any individual fastener. It should be noted that this may still leave the panel susceptible to low-cycle fatigue and should be carefully evaluated.

3. Slide-in rails and other proprietary methods or rapid-install panel mounting that support the PV frames more fully against both front and backside loading.

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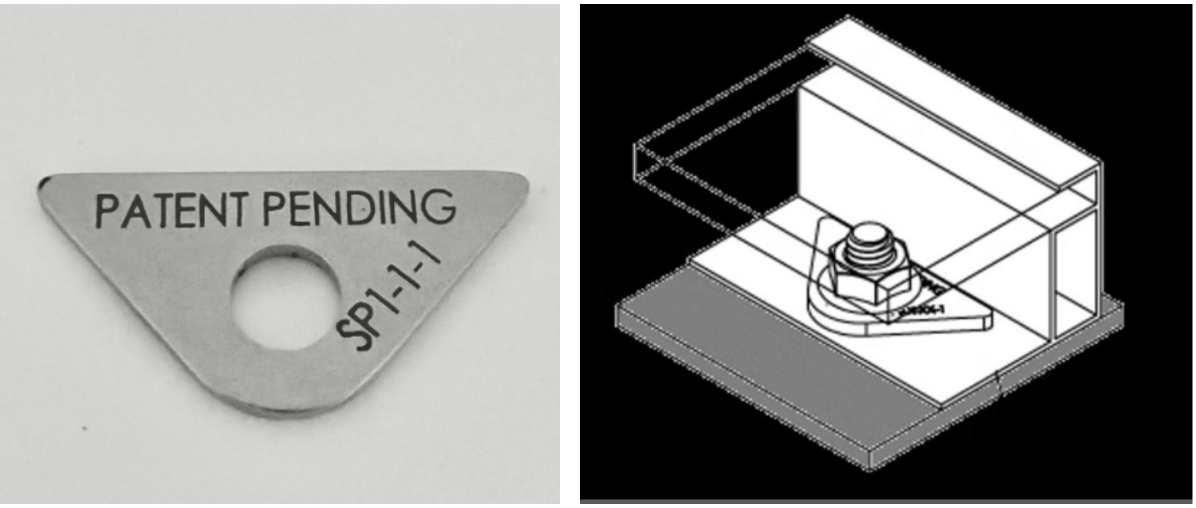
[i] An FEA is a computer-generated simulation of mechanical components under stress and load.

SunPower Helix mounting on Ragged Island Bahamas installed after Hurricane Irma, 2019. Photo courtesy David Kaul, Salt Energy

The SunPower® Helix™ mounting system is a proprietary rapid install system that has been utilized to meet 180 mph wind resilience requirements in the Caribbean.

4. Use of specialty backing plates that spread load over the panel frame better than a standard round washer. Models show an increase in cyclical loading failure cycles of ~450x that of a standard round washer and 33% higher uplift pressure capacity in the frame.



StormPlate™ SP1 by Resilient Solarworks (www.resilientsolarworks.com)

In the Mayreau case study, after Hurricane Beryl, it was evident that the module frames had suffered low-cycle fatigue and failed across the ground-mount array. Furthermore, the same module brand and series failed on roof mount projects in the exact same manner on the main island of Saint Vincent.

Several of the modules on Saint Vincent dislodged partially and several dislodged completely from the racking on two separate roof mount projects. This was due to low-cycle frame hole fatigue, given that the maximum wind speeds experienced on Saint Vincent were Category 1 and lower, well below the warranted design uplift/backsheet pressure rating (- 2667 p.a.).

In order to restore renewable power on Mayreau, RMI secured grant funds to replace the remaining modules. The new modules come with product certificates IEC 61215, 61730, FSEC (US Florida) UL 61730, IEC 61701, 62716, 62782, and 63126 with a design warranty up to 4,000 p.a. with a four through bolt install.

Failed module frame on St Vincent under low-cycle conditions. Photo courtesy Fidel Neverson, RMI

In addition to full module replacement, RMI will also secure each connection with a stainless-steel fastener stackup consisting of a M8 bolt, nylock nut, and a StormPlate^{TM}, a specialty backing plate that will replace the standard round washer in the bolt stack. StormPlate^{TM} improves cyclical fatigue resistance over 450 times that of a conventional flat washer. This extra mitigation measure is low in hardware cost, labor neutral, and a recommended best practice for solar projects in tropical cyclone regions.

APPENDIX D

Topographic Considerations for Ground-Mount Solar PV Design

What is K_{zt}?

K_{zt} is the topographic factor in the wind load equation defined in ASCE 7 (e.g., ASCE 7-16 or 7-22). It is a mathematical approximation of the terrain of the site and the surrounding area. It accounts for wind speed-up effects due to local topography, such as hills, ridges, and escarpments.

K_{zt} is covered in Chapter 26 (Wind Loads – General) of the ASCE 7 standard, with guidance on how to calculate it in section 26.8.

Why does K_{zt} matter for Island nations and coastal areas? Island sites often feature:

- Steep terrain near coastlines
- Elevated locations for solar arrays
- Exposure to extreme cyclonic wind events

Neglecting K_{zt} can lead to underestimating design wind pressures, especially for ridgetop or hillside arrays. For hurricane-prone islands, this factor can significantly alter the forces on solar racking and modules, as can be seen above on Union Island.

If K_{zt} is not properly applied, the resulting underestimation of wind pressures can lead to structural failures of racking or modules, damage during moderate-to-severe wind events, and ultimately financial losses and insurance claim disputes.

Actionable steps designers for the region can take to ensure K_{zt} is appropriate for the site design:

1. Determine if your project site qualifies as having topographic effects (slope with significant elevation changes).
2. Consult ASCE 7-16 Section 26.8 to identify if K_{zt} must be applied.
3. Use K_{zt} = 1.0 only if your site is flat or sheltered, this is the default for no wind speed-up.
4. For solar arrays at or near hilltops or escarpments, do a K_{zt} evaluation using site-specific terrain features.
5. Engage a structural engineer to determine Kzt; improper assumptions could cause catastrophic under-design.

Union Island K_{zt} speed-up evidence. Photo courtesy Frank Oudheusden, AAS

Endnotes

CBS News "60 Minutes" interviewing Bahamas Power & Light officials December 2019 regarding solar power resilience on Ragged Island, Bahamas. Photo courtesy Christopher Burgess, RMI

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All images used are from iStock.com unless otherwise noted.

RMI Innovation Center
22830 Two Rivers Road
Basalt, CO 81621

www.rmi.org