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Microgrid Hardening Design Toolkit: Puerto Rico Use Case

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Introduction

This document provides a comprehensive example of the microgrid hardening framework and the Sandia-developed Microgrid Hardening Design Toolkit v0.27[1] using a census tract in a coastal area of southern Puerto Rico as a case study. The census tract (72123953100) is located in the municipality of Salinas. Currently, the La Margarita neighborhood within this census tract is part of the Department of Energy's Cohort 5 of the Energy Technology Innovation and Partnership Program (ETIPP)[2]. The neighborhood's local energy cooperative, Abeyno Coop[3], has been operating several residential solar photovoltaic (PV) and battery energy storage system (BESS) installations (with around 30 rooftop solar systems as of 2026). As part of the ETIPP project, Abeyno Coop is planning to integrate a larger microgrid into the existing distribution feeder in the area, including solar PV and BESS to supply energy for homes and critical loads such as the medical facilities and the community center that provides emergency shelter and backup power during outages.

Figure 1 shows the location of the case study census tract within Puerto Rico.

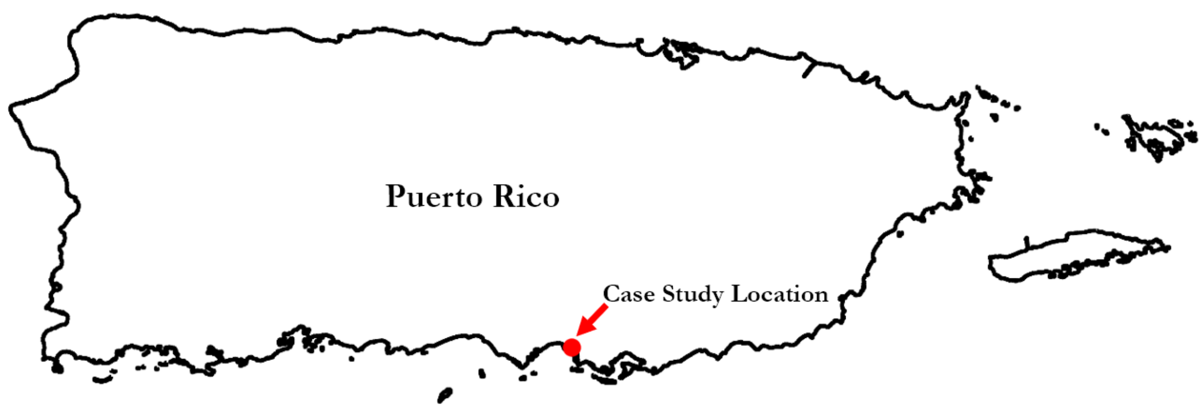

Figure 1. Map highlighting the selected location (census tract 72123953100).

From an early-stage design perspective in this case study, the Microgrid Hardening Design Toolkit can be helpful for providing context and a starting point for design considerations relevant to anticipated natural disasters.

Microgrid Hardening Design Toolkit Inputs

The Microgrid Hardening Design Toolkit has a community filter option that allows a user to select the census tract of interest. For this example, the "State" field was set to "Puerto Rico," the "County" field was set to

[1] G. Ponce, J. Choi, and J. Flicker, Microgrid Hardening Design Toolkit. (2026). Sandia National Laboratories. [Online]. Available: https://www.sandia.gov/microgrid-harshness-tool/

[2] J. Daughterty, "38 Coastal, Remote, and Island Communities to Pursue Energy Reliability via Energy Technology Innovation Partnership Project," National Laboratory of the Rockies. Accessed: Apr. 28, 2026. [Online]. Available: https://www.nlr.gov/news/detail/program/2025/38-coastal-remote-and-island-communities-to-pursue-energy-reliability-via-energy-technology-innovation-partnership-project

[3] "Cooperativa de Energía La Margarita Abeyno Coop." Accessed: Apr. 28, 2025. [Online]. Available: https://abeynocoop.coop/

"Salinas," the "ZIP" field was set to "00751," and the "Census Tract" field was set to "72123953100." The Microgrid Hardening Design Toolkit v0.27 was used for the results shown in this case study.

Figure 2. Filters used in the Microgrid Hardening Design Toolkit to select the case study census tract.

Results

The toolkit provides several results and insights for the census tract of interest. First, the tool provides its own visualization of the map of the United States and Puerto Rico. A zoomed-in screenshot of the census tract of interest indicated on the map of Puerto Rico is shown in Figure 3 below. When multiple case study census tracts are selected, they can be visualized simultaneously as well.

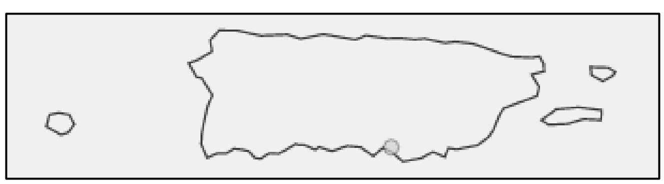

Figure 3. Map of Puerto Rico with selected census tract provided by the Microgrid Hardening Design Toolkit.

The tool provides a spider chart (Figure 4) to visually indicate the highest risk hazards for the census tract of interest. Coastal flooding appears to be the highest risk hazard, with hurricane, tsunami, and earthquake risk also quite high, and lightning and landslide hazards appear to also carry moderate risks. As described in the documentation for the toolkit, the composite risk is comprised of the individual hazard risks, which each account for the hazard frequency or likelihood, as well as the severity and impact of the hazard (measured in economic metrics from the Federal Emergency Management Agency's National Risk Index[4] for version 0.26 of the toolkit).

[4] "National Risk Index Data Technical Documentation," Federal Emergency Management Agency, Dec. 2025. Accessed: Mar. 19, 2026. [Online]. Available: https://www.fema.gov/sites/default/files/documents/fema_national-risk-index_technical-documentation.pdf

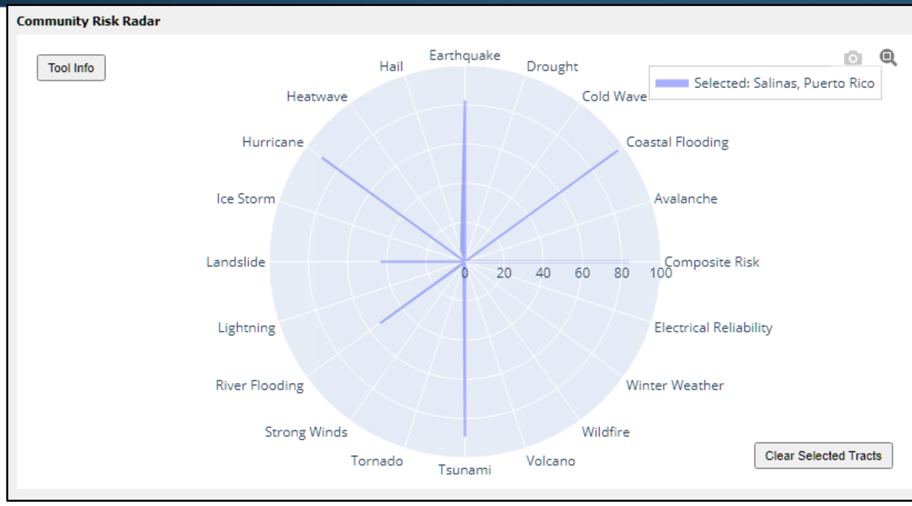

Figure 4. Spider chart showing hazards of interest for the La Margarita community in the Microgrid Hardening Design Toolkit.

The toolkit also contains a Hazards and Mitigation Table. The first tab of this table shows general Community Data, which includes a summary of the selected community's identifying information, county reliability indices, high-risk community risk hazards, and high-risk community risk twins. A screenshot of what the tool shows in the first tab for community information for the selected case study community is shown in Figure 5.

Hazard and Mitigations Table — Salinas, Puerto Rico (Tract 72123953100)

Community Data	Coastal Flooding	Hurricane

Community Data
Census Tract: 72123953100
County: Salinas
State: Puerto Rico
ZIP(s): 00751

County Reliability Index
SAIDI:
SAIFI:
CAIDI:

High Risk Community Risk Hazards (Normalized Risk Index)
1: Coastal Flooding (96.6)
2: Hurricane (90.3)

High risk community risk twins
1: 06081984300, San Mateo, CA (corr 0.98, ~5837 km)
2: 06079010602, San Luis Obispo, CA (corr 0.98, ~5676 km)
3: 06059062900, Orange, CA (corr 0.98, ~5392 km)

Figure 5. Community data and hazard and mitigations table for selected census tract in the Microgrid Hardening Design Toolkit.

The County Reliability Indices for electrical reliability that are available in the tool include System Average Interruption Duration Index (SAIDI), System Average Interruption Frequency Index (SAIFI), and Customer Average Interruption Duration Index (CAIDI), and represent 2022 values. The tool contains reliability indices at the county-level, and the municipality-level SAIDI[5] and SAIFI[6] data in Puerto Rico was taken from the local utility dashboard and CAIDI was calculated from the previous two metrics. However, the dashboard does not include

[5] LUMA, "SAIDI_data." Accessed: May 06, 2026. [Online]. Available: https://dashboard.energia.pr.gov/Transmission_Distribution
[6] LUMA, "SAIFI_data." Accessed: May 06, 2026. [Online]. Available: https://dashboard.energia.pr.gov/Transmission_Distribution

every municipality in Puerto Rico, so census tracts in certain municipalities, including this case study census tract, do not have electrical reliability indices documented in this tool.

The high-risk community hazards or natural disasters, align with the results from the spider chart shown in Figure 4. Hazards with a normalized risk index above 90, described in the Microgrid Hardening Design Toolkit User Guide[7] and its associated informational report[8], are included in this list.

In addition, the Microgrid Hardening Design Toolkit v0.27 also provides a list of other census tracts throughout the United States and U.S. territories that have the closest risk correlation to the census tract of interest (under "High risk community risk twins" in Figure 5. As shown, all the census tracts shown are in coastal areas (all are in California), so it is expected that the hazards they experience are comparable. The risk twins may be helpful for researching solutions implemented by microgrid owner-operators in places experiencing or expecting similar hazards. The tool provides a map that matches these risk twins, shown in Figure 6 with the selected community census tract represented with a circular point in Puerto Rico (near the bottom right of the figure) and the risk twin census tracts indicated with square points along the coast of California (at the left of the figure).

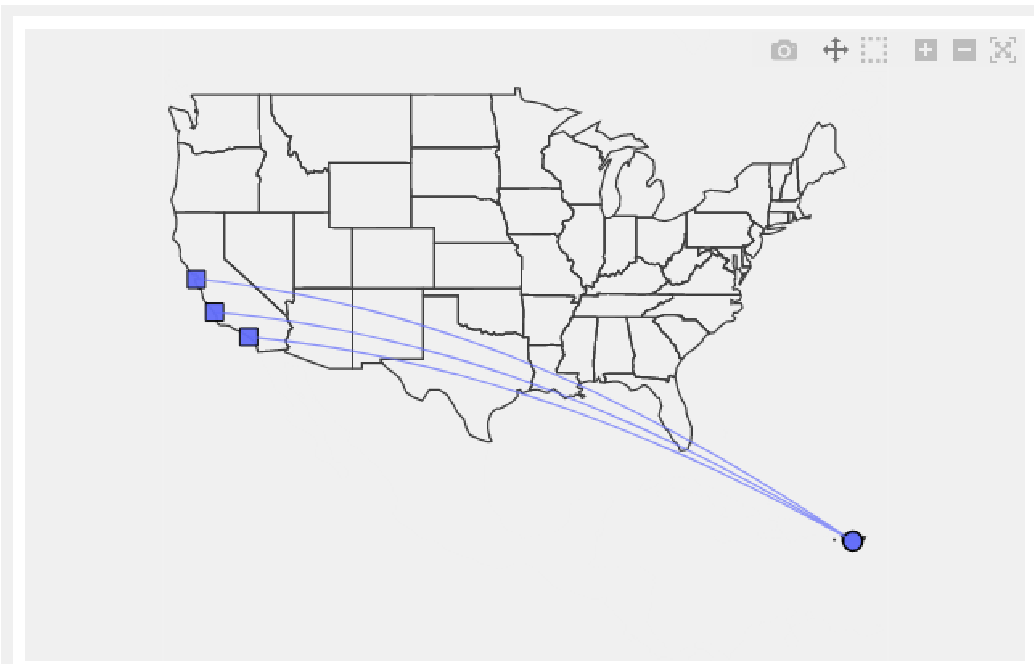

Figure 6. Map of community risk twins in the Microgrid Hardening Design Toolkit.

In the other tabs shown in the window in Figure 5, the tool provides a list of strategies for microgrid hardening and risk mitigation by microgrid component or subsystem type, for the highest risk hazards listed under "High Risk Community Risk Hazards". An image from the tool for one example hazard is provided in Figure 7, but total results for coastal flooding and hurricane hazards were copied from the tool and provided in Table 1 and Table 2, respectively, for readability.

[7] J. Choi, M. S. Louie, R. Darbali-Zamora, and J. D. Flicker, "Microgrid Hardening Design Toolkit User Guide," Sandia National Laboratories, 2026.

[8] R. Darbali-Zamora, M. S. Louie, J. Choi, G. Ponce, and J. D. Flicker, "Characterization of Harsh Environments, At-Risk Microgrid Components, and Hardening Technologies (Report Version 0.1)," Sandia National Laboratories, SAND2026-19208, Mar. 2026. Accessed: Apr. 28, 2026. [Online]. Available: https://doi.org/10.2172/3028594

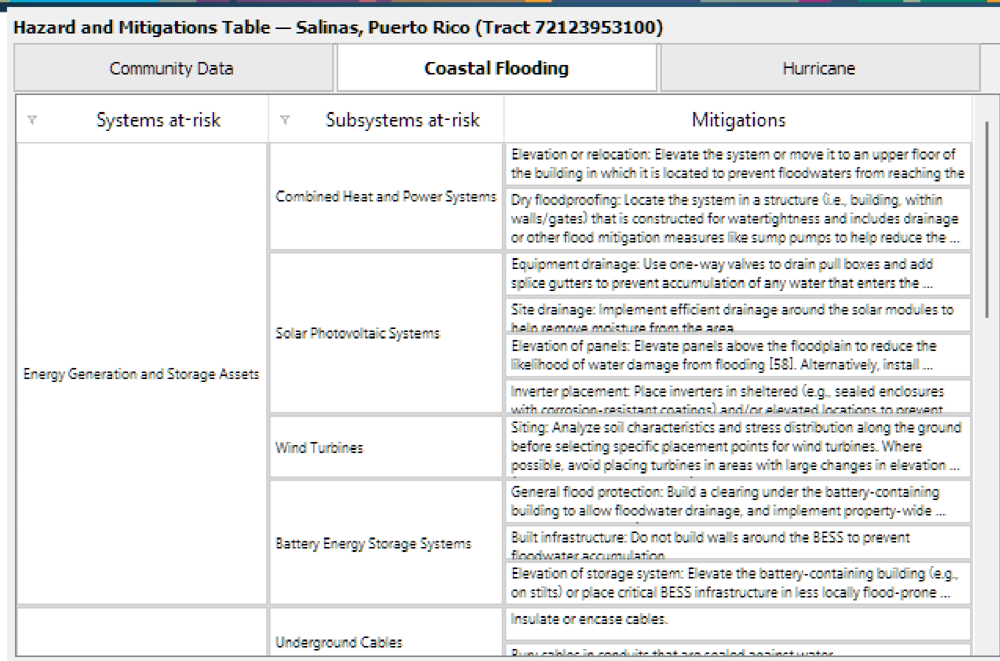

Figure 7. Hazard and mitigation table for coastal flooding natural hazard for selected census tract in the Microgrid Hardening Design Toolkit.

Table 1. Mitigations for coastal flooding hazard in case study census tract 72123953100 in Salinas, Puerto Rico.

At-Risk System	At-Risk Subsystem	Mitigations
Energy Generation and Storage Assets	Combined Heat and Power Systems	Elevation or relocation: Elevate the system or move it to an upper floor of the building in which it is located to prevent floodwaters from reaching the major electrical components.
		Dry floodproofing: Locate the system in a structure (i.e., building, within walls, gates) that is constructed for watertightness and includes drainage or other flood mitigation measures like sump pumps to help reduce the risk of water damage to CHP systems from flooding.
	Solar Photovoltaic Systems	Equipment drainage: Use one-way valves to drain pull boxes and add splice gutters to prevent accumulation of any water that enters the electronics containers
		Site drainage: Implement efficient drainage around the solar modules to help remove moisture from the area
		Elevation of panels: Elevate panels above the floodplain to reduce the likelihood of water damage from flooding. Alternatively, install floating solar systems as a potential solution in flood-prone areas.
		Inverter placement: Place inverters in sheltered (e.g., sealed enclosures with corrosion-resistant coatings)
	Wind Turbines	Siting: Analyze soil characteristics and stress distribution along the ground before selecting specific placement options for wind turbines. Where possible, avoid placing turbines in areas with large changes in elevation (more susceptible to flooding) or with inadequate ground/soil drainage and infiltration.
	Battery Energy Storage Systems	General flood protection: Build a clearing under the battery-containing building to allow floodwater drainage and implement property-wide flood management (e.g., shingle drainage, swales, permeable paving, retention ponds).
		Elevation of storage system: Elevate the battery-containing building (e.g., on stilts) or place critical BESS infrastructure in less locally flood-prone locations to prevent water ingress.
Power Delivery	Underground Cables	Insulate or encase cables.
		Bury cables in conduits that are sealed against water.
	Overhead Power Lines	Implement a flood mitigation strategy that considers maintaining road access to critical infrastructure to facilitate recovery.
		Construct power lines with minimum ground clearance based on locally anticipated flood conditions.
	Transformers	Use waterproof seals and gaskets.
		Elevate the system.
		Install flood barriers.
		Anchor the system securely.
		Use watertight enclosures.
	Switchgear	Elevate the system.
		Dry floodproof the system using a watertight, flood-resistant enclosure.
		Use marine-grade materials.
	Capacitors	Elevate the system
		Dry floodproof the system using a watertight, flood-resistant enclosure.
		Use marine-grade materials or coatings.
	Breakers	Elevate the system.

		Dry floodproof the system using a watertight, flood-resistant enclosure.
		Use circuit breakers with electronic trip units to protect against cascading failures.
		Use marine-grade and corrosion-resistant materials (e.g., protective polymer coatings).
	Disconnects	Elevate the system.
		Dry floodproof the system using a watertight, flood-resistant enclosure.
		Use stainless steel or coated materials.
		Use floating disconnects.
Sensing, Controls, and Communication	Sensors	Use waterproof sensors and sealed connectors.
	Control System	Use waterproof, sealed enclosures.
	Communications	Waterproof equipment and enclosures, elevate communication equipment, and add redundancy in communication paths.

Table 2. Mitigations for hurricane hazard in case study census tract 72123953100 in Salinas, Puerto Rico.

At-Risk System	At-Risk Subsystem	Mitigations
Energy Generation and Storage Assets	Combined Heat and Power Systems	Elevation or relocation: Elevate the system or move it to an upper floor of the building in which it is located to prevent floodwaters from reaching the major electrical components.
		Dry floodproofing: Locate the system in a structure (i.e., building within walls/gates) that is constructed for watertightness and includes drainage or other flood mitigation measures like sump pumps to help reduce the risk of water damage to CHP systems from flooding.
		Structural protection: Locate the system within a shelter structure to prevent hurricane impacts.
		Emergency shutdown protocols: Ensure that the system has protocols and possibly automation in place to power down equipment if water enters the system to preserve the mechanical equipment.
	Solar Photovoltaic Systems	Equipment drainage: Use one-way valves to drain pull boxes and add splice gutters to prevent accumulation of any water that enters the electronics containers.
		Site drainage: Implement efficient drainage around the solar modules to help remove moisture from the area.
		Elevation of panels: Elevate panels above the floodplain to reduce the likelihood of water damage from flooding. Alternatively, install floating solar systems as a potential solution in flood-prone areas.
		Inverter placement: Place inverters in sheltered (e.g., sealed enclosures with corrosion-resistant coatings) and/or elevated locations to prevent water ingress.
		Material design: Use monocrystalline rather than amorphous PV systems to protect the system against the combination of high relative humidity and temperature.
	Wind Turbines	Siting: Analyze soil characteristics and stress distribution along the ground before selecting specific placement points for wind turbines. Where possible, avoid placing turbines in areas with large changes in elevation (more susceptible to flooding) or with inadequate ground/soil drainage and infiltration.
		High wind speed design: Increase the safety factor or other engineering design parameters above regulatory requirements to design for non-routine high-risk events such as hurricanes.
		Yaw controls: Install an additional power source (e.g., batteries) to keep yaw controls available during hurricane events.
	Battery Energy Storage Systems	General flood protection: Build a clearing under the battery-containing building to allow floodwater drainage, and implement property-wide flood management (e.g., shingle drainage, swales, permeable paving, retention ponds).
		Built infrastructure: Do not build walls around the BESS to prevent floodwater accumulation.
		Elevation of storage system: Elevate the battery-containing building (e.g., on stilts) or place critical BESS infrastructure in less locally flood-prone locations to prevent water ingress.
		Battery tab protection: Use battery tab protection to prevent battery degradation.
Power Delivery	Underground Cables	Insulate or encase cables.
		Bury cables in conduits that are sealed against water.
		Use protective, waterproof conduits for buried cables to prevent water damage.
	Overhead Power Lines	Implement a flood mitigation strategy that considers maintaining road access to critical infrastructure to facilitate recovery.
		Construct power lines with minimum ground clearance based on locally anticipated flood conditions.
		Reinforce power line poles with guy wires.
		Use metal (e.g., steel, ductile iron) power line poles.
		Replace old poles with new ones to prevent damage to weak poles during high wind conditions.
		Add redundant power lines with open switches.
		Create protocols for pre- and post-storm line inspections to address wire damage and fire hazards as soon as possible.
		Ensure adequate vegetation maintenance around power lines.
		When building new overhead lines and selecting pole locations, place poles in easy-to-access areas for maintenance and repair (e.g., avoid highly vegetated locations).
		Use underground lines.
	Transformers	Use weatherproof seals and gaskets.
		Elevate the system.
		Install flood barriers.
		Anchor the system securely.
		Use watertight enclosures.

		Use moisture absorbers such as silica gel.
		Implement remote sensors and alarms for temperature, oil level, and pressure.
		Anchor equipment to stable foundations.
		Install equipment in storm-rated housing.
	Switchgear	Elevate the system.
		Dry floodproof the system using a watertight, flood-resistant enclosure.
		Use marine-grade materials.
		Use storm-rated equipment.
		Anchor equipment to stable foundations.
		Install equipment in storm-rated housing.
		Implement environmental controls (temperature and humidity).
	Capacitors	Elevate the system.
		Dry floodproof the system using a watertight, flood-resistant enclosure.
		Use marine-grade and corrosion-resistant materials (e.g., protective polymer coatings).
		Use storm-rated equipment.
		Anchor equipment to stable foundations.
		Install equipment in storm-rated housing.
	Breakers	Elevate the system.
		Dry floodproof the system using a watertight, flood-resistant enclosure.
		Use circuit breakers with electronic trip units to protect against cascading failures.
		Use marine-grade and corrosion-resistant materials (e.g., protective polymer coatings).
		Use storm-rated equipment.
		Anchor equipment to stable foundations.
		Install equipment in storm-rated housing.
	Disconnects	Elevate the system
		Dry floodproof the system using a watertight, flood-resistant enclosure, or use storm-rated covers.
		Use stainless steel or coated materials.
		Use floating disconnects.
		Use storm-rated equipment.
		Anchor equipment to stable foundations.
		Install equipment in storm-rated housing.
Sensing, Controls, and Communication	Sensors	Use waterproof sensors and sealed connectors
		Use storm-resistant, hardened housings.
	Control System	Use waterproof, sealed enclosures
		Use hardened, stormproof buildings.
	Communications	Waterproof equipment and enclosures, elevate communication equipment, and add redundancy in communication paths.
		Use wind-resistant towers and flood-protection enclosures.

Implications of Results for Case Study Census Tract

This case study of a census tract in Salinas, Puerto Rico, shows an example of how the Microgrid Hardening Design Toolkit can be used to inform early-stage decision-making and design for microgrid development. Providing context about which natural hazards are highest risk for a location can be useful for selecting hardening methods since other factors such as cost, timeline, and technical feasibility make prioritization of risk mitigation strategies necessary. For the case study census tract, it would make sense to look more into risk mitigation strategies to protect the system from coastal flooding and hurricanes in particular. Depending on the goals of the community or other decision-makers, as well as the resources available in this case, it may also help to look at the other moderately high risk hazards indicated in Figure 4. The hazard mitigation tables may be filtered by the types of equipment that will be incorporated in the microgrid; as discussed, these subsystems will likely include solar PV generation and BESS storage, with power delivery and sensing, controls, and communication equipment listed in the tables. While the mitigations provided in the table are generic and do not provide specific information about design configurations, available products, expected cost, or other aspects, they can provide a starting point for mitigation strategies to look further into depending on the site-specific context and needs.