Renewables and Natural Disasters

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1. Introduction

For any electric generation source. It is reasonable to ask how resilient it will be in the face of expected natural disasters. The answers for these questions are complicated by the impact of these disasters becoming worse over time. This has recently been the case due to climate change creating more and much worse weather-related disasters.

The most recent disasters worsened by climate change in the U.S. include wildfires (in the west), hurricanes (mainly on the Gulf and East Coasts) and non-coastal flooding (widespread). Specifically, in September the following two major hurricanes out of the Caribbean hit the US:

Hurricane Fiona

September 14, 2022 - Tropical Storm Fiona forms in the Atlantic, 625 miles east of the Leeward Islands.

September 18, 2022 - Fiona makes landfall in Puerto Rico as a Category 1 hurricane. The hurricane causes catastrophic flooding and at least three people are killed.

September 19, 2022 - Fiona makes landfall in the Dominican Republic. At least two people die due to the storm.

September 20, 2022 - Strengthens to a Category 3 hurricane.

September 24, 2022 - Fiona morphs into a post-tropical cyclone and makes landfall in Canada's Nova Scotia. At least one person dies due to the storm.

Hurricane Ian

September 23, 2022 - Tropical Storm Ian forms over the central Caribbean.

September 27, 2022 - Hurricane Ian makes landfall in Cuba as a Category 3 storm, leaving at least two people dead and the entire island without power.

September 28, 2022 - Hurricane Ian makes landfall along the southwestern coast of Florida a as a Category 4 storm. At least 126 people are killed in central Florida.

September 30, 2022 - Hurricane Ian makes landfall near Georgetown, South Carolina, as a Category 1 storm. Five people are killed in North Carolina.

This post will cover two subjects. The first and primary subject is hardening photovoltaic (PV) projects to withstand storms. The second subject is a case study for a small community's recovery efforts after extensive river flooding.

2. Storm-Hardening PV

Distributed power (of any kind) can be built such that it will be more resilient in the face of storms than centralized generation and the transmission lines needed to carry power to consumers. Obviously, in coastal areas prone to hurricanes, any electric infrastructure faced with sustained hurricane winds or (especially) storm surge will be taken out whether this is distributed or centralized facilities. Also, PV is particularly susceptible to severe damage by wind-driven projectiles, damage to supporting structures (racking), and module dislocation by hurricane-force wind. However there are methods to limit this damage if these arrays are designed to survive reasonably anticipated wind, heavy rain, small hail and other small projectiles. The recommendations and references in this section will discuss these methods.

2.1. Site Survey

Severe weather events strong enough to cause damage to a solar PV system occur in nearly every region of the country. The Federal Emergency Management Agency (FEMA) produces a National Risk Index (NRI) which details 18 weather and environmental parameters at a county level. Use the NRI tool to look up weather risks at your site. If the results show at least "relatively high" rating for a weather event, then the technical specifications shown below should be added to solicitation and contract documents.[1]

The National Risk Index is a dataset and online tool to help illustrate the United States communities most at risk for 18 natural hazards. It was designed and built by FEMA in close collaboration with various stakeholders and partners in academia; local, state and federal government; and private industry.

Natural hazards are defined as environmental phenomena that have the potential to impact societies and the human environment. These should not be confused with other types of hazards, such as manmade hazards. For example, a flood resulting from changes in river flows is a natural hazard, whereas flooding due to a dam failure is considered a manmade hazard, and therefore excluded from the National Risk Index.

In the National Risk Index, natural hazards are represented in terms of Expected Annual Loss, which incorporate data for exposure, annualized frequency, and historic loss ratio.

The 18 natural hazards included in the National Risk Index are:

Avalanche	*Coastal Flooding*	*Cold Wave*
Drought	*Earthquake*	*Hail*
Heat Wave	*Hurricane*	*Ice Storm*
Landslide	*Lightning*	*Riverine Flooding*
Strong Wind	*Tornado*	*Tsunami*
Volcanic Activity	*Wildfire*	*Winter Weather*

Natural hazards can also cause secondary natural hazard events that create additional hazards. For example, Volcanic Activity can create other hazards, such as ash and lava spread. The National Risk Index only considers main natural hazard events and not their results or after-effects.

Author's comment: The link below is to the NRI tool mentioned above. This will bring up a US Map, and as I zoomed down I could see individual counties.

https://hazards.fema.gov/nri/map

[1] Energy.gov, Federal Energy Management Program, "Severe Weather Resilience in Solar Photovoltaic System Design," https://www.energy.gov/eere/femp/severe-weather-resilience-solar-photovoltaic-system-design

I produced a quick report for my county (Alameda County, California). The report quantified the risks for each of the natural hazards that were applicable to my county. The highest risk hazards were drought, earthquake and wildfire. The risk index for each of these was over 20, and earthquake was over 40. There are other metrics for risk on the report tool.

By clicking on "Learn More" in the header, you will be taken to resources that will help you understand the risk index and tool better.

However, I don't want to get to far afield per the different hazards. We are focusing on storm damage from precipitation (rain or hail) and wind. There are many resources on National Risk Index site for all types of hazards from all sorts of disasters, but we will drill down into the information on storms.

2.2. PV Project Components

2.2.1. Racking

Racking is the framework on which the PV Modules, cabling and other small components are mounted. There are two typed of racking, fixed and tracking (the latter are frequently called "trackers" instead of "racking"). Either type is used for ground-mounted projects, and to a lesser extent, arrays mounted on large buildings. These projects may be either commercial- or utility-scale.

When exposed to wind, all objects vibrate, and depending on several characteristics of the array structures, arrays may experience violent resonance or severe frame member deflection, which could lead to catastrophic losses. Ensure that the racking design is engineered to withstand highly turbulent wind forces. [1]

For PV projects using trackers there are basically two strategies for high-wind events. Some trackers' stow-configuration is tilted at a steep angle with the light-receiving (front) surface facing the wind. The stow-configuration for the other design is zero-degrees (parallel to the ground). The wind stow speed is typically around 12 m/s or 25 mph, however, this is both a function of tracker design and the PV module format. Large-format PV modules typically require lower stowing wind-speeds.

In general, fixed tilt racking (no tracking) can withstand higher wind-speeds than trackers. I have seen some claim that these can withstand up to 140 mph, and perhaps higher wind-speeds.[2]

Also at these speeds projectiles come into play. Ground-mounted arrays are much more likely to be damaged by wind-driven projectiles than arrays on substantially elevated structures (like on top of multi-story buildings).

2.2.2. Modules

Wind pressure can put substantial loads on the front and back of modules and lead to micro-cracking of the solar cells and even fracture of the module glass.[1]

[2] Matt Kundo, Chariot Energy, "Can Solar Panels Withstand a Hurricane?" Aug 9, 2022, https://chariotenergy.com/blog/can-solar-panels-withstand-hurricanes/

Recommended Actions for Front and Back Pressure Ratings:

For modules placed in service at a site where the FEMA NRI tool shows relatively high risk of a strong wind event, specify modules with front and back pressure ratings. PV modules should be tested per ASTM E1830-15 prescribed test parameters for loading (snow and wind) of solar modules (front and back). This test also covers several other stress factors relevant to high winds such as the "twist test."

Minimum Front and Back Pressure Ratings for Loading Strength of Modules

MODULE SIDE	*PASCALS*	*POUNDS PER SQUARE FOOT*
Front Load (Push) Rating	*5,400*	*113*
Back Load (Pull) Rating	*3,600*	*75*

2.2.3. Wire Management

Poorly secured or routed wire or cable can be damaged from weather events and cause electrical faults. Plastic cable ties (regardless of rating or material composition) can fail from exposure to heat, ultraviolet light, and moisture. There is general concern that even exterior-grade cable ties rated to be ultraviolet-resistant are inadequate for longevity in field use. If plastic ties fail, wind can cause the loose wire to rub against sharp edges or abrasive objects, resulting in electrical faults.

Author's comment: The ideal hardware for securing cables are cushioned cable clamps like as seen on the figure to the right. These have a steel or stainless steel structural clamp with high-durability rubber cushion (like a fluoroelastomer).

2.2.4. Electrical Cabinets

Most electrical switchgear is shipped with default cabinet options which are not suitable for areas with marine misting, high winds, or wind-driven rains. The default cabinets can collapse when exposed to heavy wind, driven rain can bypass door gaskets, and a standard door latch can blow open in high wind.

For sites where the FEMA NRI tool indicated "relatively high" risk of a strong wind event, electrical enclosures should have a minimum rating of NEMA 3, and if exposed to marine environments or wind-driven wind, should utilize NEMA 3RX. Sites in hurricane prone areas shall utilize NEMA 4X-rated enclosures. Screw-clamps should secure the perimeter of the door. The door should <u>not</u> use a single-point or three-point door handle/latch.

2.3. Areas Prone to Hail

According to test lab engineers, most modules currently pass the IEC 61215 hail test standard, yet field experience has demonstrated that hail exceeding this standard can occur frequently in areas where FEMA indicates at least a "relatively high" risk of a hail event.

For sites at risk of moderate to severe hail, contractor shall select a module that meets either the FM Global "Very Severe Hail Rating" (FM 4478), or Renewable Energy Test Center Hail Durability Test, or the Photovoltaic Evolution Labs hail test standards.

Tracker manufacturers have developed controls strategies that drive rows of modules into a stow-position if a hailstorm is predicted. This stow position for hail is typically the maximum vertical tilt the tracker system allows, which should decrease the angle of impact of most hail balls. Some manufacturers have lab-tested these stow strategies using hail cannons and have demonstrated good results. Consider requiring the use of tracker technologies if the FEMA NRI resource indicates that hail is rated as a "relatively high" risk or greater for your site even though this may add cost.

2.4. Areas Prone to Flooding

Weather events that produce standing water and/or wind can flood underground pull boxes and conduit. Water can then flow into electrical cabinets that house inverters, switchgear, controls, meters, and transformers. Array fields that are either uphill from or at about the same elevation as supporting electrical equipment are at risk of unintentional flooding through pull boxes and conduit.

Require project engineers to place electrical equipment at higher elevations than the array field and route conduit to prevent flooding. Cabinets shall be NEMA 4X and equipped with purpose-built one-way drain plugs to allow water to evacuate.

3. Flooding Case Study

During the spring break up[3] in May of 2013, flood waters carrying massive ice chunks from the Yukon River inundated nearly 90% of the homes, businesses, and government facilities in the small town of Galena, Alaska. An ice jam downriver caused floodwaters to rise and back up overbank in Galena. House-sized chunks of ice mowed down the native birch trees and ripped homes off of pilings. Most areas received between seven and nine feet of water. The event forced nearly all of the 472 residents to evacuate by air to Fairbanks and Anchorage as waters quickly rose and local roads became impassable.[4]

Galena has experienced several major flooding events, with the Old Town neighborhood receiving the worst of the damage due to its location between the Yukon River and the levee constructed to protect the air strip. Community members have long recognized the town's vulnerability and were adamant in their desire to incorporate resiliency into all re-building and recovery efforts. For instance, after a major flood in 1971, the community rebuilt critical facilities, city offices, the health clinic, and many homes at a less vulnerable site 1.5 miles further from the river, locally called New Town.

The sustainability and growth of Galena depends on addressing critical energy challenges which include the need to find alternative, lower-cost sources of fuel. When the U.S. Air Force left Galena, it also left the air base to the community, along with approximately 1.5 million gallons of fuel for power generation. However, that supply has been dwindling and aging. Fuel is resupplied by barging diesel fuel up the Yukon River in the summer, resulting in energy costs of 67 cents/kilowatt hour (kWh) for the residents of Galena.

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[3] The period of time in spring when the ice on the river physically breaks and the surface becomes free flowing again. Seasonal snow melt adds to the Yukon River's water level, and shifting pieces of ice pile up to create ice jams that break unpredictably

[4] FEMA, Case Study, "Galena, Alaska Flood Recovery," May 2019, https://www.fema.gov/sites/default/files/2020-09/galena-energy-generation_case-study_teaching-notes.pdf

Author's comment: Galena Forward Operating Air Force Base, Alaska, was established as an airfield during World War II and served as a forward operating base for the Pacific Air Force's 611th Air Support Group headquartered at Elmendorf Air Force Base, Alaska. Due to its strategic location in interior Alaska, Galena's mission was to intercept incoming Soviet aircraft during the Cold War.

Galena Forward Operating Base was recommended for closure by the Defense Base Realignment and Closure Commission in 2005. The base was officially closed September 30, 2008.

This situation forced a discussion about expensive fossil fuel reliance and a transition to a local, renewable energy source. Galena residents emphasized this desire for a long-term, sustainable energy solution for the community in recovery coordination meetings with local and state leadership. Galena residents identified "Improving energy generation and efficiency" as one of their top five priority goals for the flood recovery process.

Public support for increased energy efficiency was one of the main driving forces for leaders to study the possibility of replacing damaged energy systems with a community biomass power plant project, which was already in the planning stages prior to the flood. Community leaders set to work identifying partners that could help with determining the feasibility of building a biomass power plant, as well as other energy system improvements.

Galena is geographically isolated from larger towns, cities, and traditional power grid systems due to its location in remote Alaska. Therefore, the Galena community and its critical infrastructure (such as medical facilities and community centers) are vulnerable to power outages. Fuel deliveries must be transported via boat in the summer or plane in the winter. Fluctuations in global fuel prices can significantly increase the already expensive delivery costs.

Snow and freezing temperatures typically begin in late September, so the recovery timeline needed to be expedited to get critical facilities back up before the fall. Galena residents, volunteers and contractors worked hard throughout the summer to repair and rebuild as many homes and facilities as quickly as possible. Destroyed homes and critical infrastructure – including septic and sewer systems – were the highest priority to complete before the Yukon froze.

The expedited rebuilding process involved significant logistical challenges. With no road or rail system connecting Galena to other communities in Alaska, people and goods – including emergency supplies and building materials – must be brought in via barge or plane. Timelines were highly dependent on weather conditions, supply availability, and higher prices, which impacted the timely arrival of critical personnel and materials recovery projects were depending on.

Galena also has two governing bodies – the Louden Tribal Council and the City Council. The population is a mix of Alaskan Native and non-native residents. In many communities throughout Alaska, tribal communities retain traditional claims to land and resources. In Galena, this traditional system of resource management posed a challenge to the biomass project because land titles for accessible forested areas were held by a disparate group of tribal members. Biomass power plants require a readily available supply of fuel from material that comes from plants and animals, such as wood, agricultural waste, garbage, or animal manure. A non-profit organization, Sustainable

Energy for Galena Alaska (SEGA), was established specifically to negotiate access to tribal lands to harvest timber for the biomass energy plant.

As part of the long-term recovery mission, FEMA requested technical assistance from the National Renewable Energy Laboratory (NREL) to conduct energy audits and identify opportunities to improve the energy systems in Galena. NREL participated in an Energy Summit, held in October of 2013, with other key partners to discuss the community's priorities for its energy systems and learn about ways to leverage the recovery process to achieve its energy goals. The opportunities identified at the summit included upgrades to the heat distribution system, evaluation of electric distribution system to better quantify use and reduce losses, improve the powerhouse (power plant and control station), and various energy efficiency measures.

Some of the proposed transmission / distribution upgrades included implementing smart meters, identifying and reducing losses from unmetered loads and idle and over-sized transformers, voltage conversion of overhead lines between New Town and the Base (or removal of transformers), and quantifying and reporting service station losses.

Recommendations for energy efficiency upgrades included expanding energy audits to the remaining large public and commercial buildings, implementing recommended measures from existing and new audits, replacement of remaining streetlights, and expanding and improving the city's water and sewer pipe network. Finally, recommendations for powerhouse and heating system improvements included incorporating a biomass boiler system into the Galena Base Steam Plant, powerhouse operator training, new diesel generators to replace the old, inefficient generators damaged during the flood, new switch gear, new heat recovery equipment, and a behavior change campaign.

Following the summit, the community developed a plan for energy projects, including a biomass plant – an idea that had been discussed prior to the flood. Biomass is any organic matter used as a combustion fuel to generate electricity. In Galena's case, the proposal was for a wood-fueled central boiler, which would power the central steam plant within the levee, an area that had been undamaged by the flood. Steam heat produced by the system would be transmitted through the existing utility corridor (known as the utilidor) system to key facilities on the Air Force Base land, which today holds the Galena Interior Learning Academy (GILA).

The Energy Summit provided a laundry list of energy priorities, tasks, and opportunities. A general axiom of energy development, especially when addressing existing infrastructure, is to begin with efficiency improvements, since they typically incur the least cost with the best payback. Targeting efficiency first improves other capital projects, such as installing biomass plants and solar photovoltaics (PV). NREL conducted energy audits to identify potential energy efficiency measures that could be implemented throughout the rebuilding process, with a focus on the Galena power plant and power generation options. The NREL findings contributed significantly to the community's plans for the biomass-fueled power generation system.

The City of Galena has been pursuing energy and water conservation projects for several years to reduce cost and increase resilience to future natural disasters. Numerous feasibility studies have been conducted on behalf of the City. In order to fill the gaps on the audits that had already been conducted, a team led by NREL (and *attended by an Alaska Energy Authority (AEA) representative with local and state knowledge) conducted assessments with City of Galena and tribal personnel.*

The NREL team conducted an ASHRAE Level II energy audit, site survey, and initial analysis with spot measurements and short-term monitoring for lighting, temperature, humidity, boiler combustion efficiency, electrical power, and available solar resources. Additionally, the team reviewed historical energy data and previous audits to determine where opportunities exist. The team audited nine separate buildings.

The community and FEMA successfully collaborated to convert this challenge into an opportunity and found a path forward to both comply with federal requirements and create a legacy that reduces Galena's ongoing energy needs.

The audits identified opportunities in the areas of HVAC, lighting and plug loads, water use, building envelopes, and renewable energy.

Additionally, the NREL audit team created a table showing potential costs and savings associated with the recommended measures. The audit results included anticipated simple paybacks for decision- making. It is estimated that if all 41 measures the team identified were implemented, the total installation cost would be just over $620,000 and the annual savings would be over $165,000, taking just under four years to payback the investment.

The biomass plant is now operational, and many of the buildings on the old Air Force Base land are now heated by biomass, as planned. This project has increased the resiliency, sustainability, and energy conservation of the Galena community for many years to come.

Author's final comment: The one thing that was unclear to me was the configuration of Galena's electric generation. The above text did say that they replaced their old diesel generators with more efficient units. It also mentioned "…*plans for the biomass-fueled power generation system."* I would guess that the most efficient method given their location and the year this project was implemented might be to use their biomass boiler (or add a higher pressure / superheat boiler) to drive a steam turbine / generator. Then use steam turbine / generator for their base load, and only use the diesels for peak-demand and emergency generation.