DISTRIBUTED ENERGY RESOURCES DISASTER MATRIX

How Do Natural Disasters Impact DER Performance?

Widespread electrical outages are becoming more prevalent in the United States, typically caused by weather-related events. As shown in **Figure 1** on the following page, in 2017 alone, communities across the country were impacted by 16 separate billion-dollar weather-related disaster events, leading to a growing need to protect against the risks of these disruptions.[1]

To address the increased risk of electricity system outages, communities and businesses are increasingly exploring options to invest in distributed energy resources (DERs) that can be strategically deployed to continue operations or restore power quickly in critical areas. Examples of different types of DERs include solar photovoltaic (PV), wind, combined heat and power (CHP), energy storage, demand response, electric vehicles, microgrids, and energy efficiency.[2]

This issue brief explores how different DERs are impacted by various types of natural disasters to assist stakeholders in evaluating the technology options best able to meet their resilience priorities. Each DER technology brings different capabilities and performance characteristics, as shown in **Table 1**. The combination of a controllable source of generation, such as CHP, and energy storage, along with the integration of other variable DERs, is most likely to deliver an optimal source of resilient power.

Ranking Criteria

Four basic criteria were used to estimate the vulnerability of a resource during each type of disaster event. They include the likelihood of experiencing:

1. *a fuel supply interruption,*
2. *damage to equipment,*
3. *performance limitations, or*
4. *a planned or forced shutdown*

○ *indicates the resource is unlikely to experience any impacts*

◒ *indicates the resource is likely to experience one, two, or three impacts*

● *indicates the resource is likely to experience all four impacts*

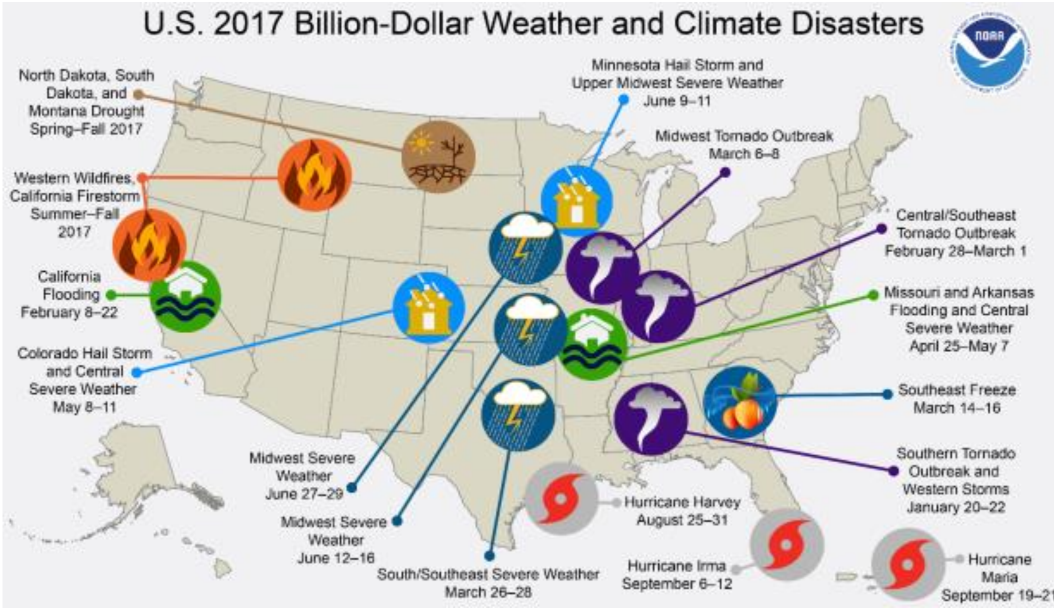
Table 1. Matrix of DER Vulnerability to Weather Events

Natural Disaster or Storm Events	*Flooding*	*High Winds*	*Earthquakes*	*Wildfires*	*Snow/Ice*	*Extreme Temperature*
Battery Storage	◒	○	◒	●	○	◒
Biomass/Biogas CHP	◒	◒	◒	●	○	○
Distributed Solar	○	◒	◒	●	◒	◒
Distributed Wind	○	◒	◒	◒	◒	◒
Natural Gas CHP	○	○	◒	◒	○	○
Standby Generators	◒	○	◒	●	◒	○

[1] National Oceanic and Atmospheric Administration, Climate. January 8, 2018. "2017 U.S. billion-dollar weather and climate disasters: a historic year in context." Available at https://www.climate.gov/news-features/blogs/beyond-data/2017-us-billion-dollar-weather-and-climate-disasters-historic-year

[2] The National Association of Regulatory Utility Commissioners (NARUC). *Distributed Energy Resources and Rate Design and Compensation.* Available at https://pubs.naruc.org/pub/19FDF48B-AA57-5160-DBA1-BE2E9C2F7EA0

Figure 1. Map of U.S. 2017 Billion-Dollar Weather and Climate Disasters



Source: NOAA

Examining the Performance of DERs in Weather Events

DERs are small energy generation and storage technologies that are sited close to customers and can provide all or some of their power needs. They can also be used by the electric system to either reduce demand, such as with energy efficiency, or support the needs of the distribution grid. To provide an understanding of how DERs are impacted by weather events, their vulnerability to six types of weather events is documented in **Table 1**.

A set of criteria used to rank the resources was established based on interviews with industry experts on each DER technology. The examination shows that all DERs are susceptible to some vulnerabilities, depending on the type of natural disaster. The matrix provides a broad comparison of typical resource performance during different events, but does not reflect all situations. DER capabilities are evolving and vulnerabilities could lessen as a result of specific resilient-design strategies, integration of multiple DERs, or future technological improvements. Looking forward, many of these resources will likely be components of microgrids, which will include a combination of communications ability and energy storage coupled with generation technologies.

The following sections summarize overall observations about each DER technology's performance, followed by **Table 2**, which highlights design strategies that could lower potential risks from disaster events discussed.

Battery Storage

Battery storage commercialization is relatively new, and therefore many considerations related to resilient operations and performance during disaster events have not been widely demonstrated. Standard enclosure designs generally protect batteries from extreme conditions. For example, two 10 MW battery systems in the Dominican Republic helped the grid operator maintain operations during high winds and heavy rain from Hurricane's Irma and Maria, when nearly half of the island's power plants stopped working. The Andres array (pictured in **Figure 2**) is a 30-minute duration storage system housed in a building enclosure in Santo Domingo that helped stabilize volatile fluctuations in grid frequency during the storm.[3]

[3] Fluence. October 18, 2017. "The Importance of Grid Resilience During Severe Storm Conditions." Available at http://blog.fluenceenergy.com/the-importance-of-grid-resilience-during-severe-storm-conditions

Figure 2. The Andres energy storage system in Dominican Republic

Source: BusinessGreen

If systems or enclosures are compromised by water or other structural damage, individual batteries, inverters, and other electrical equipment could require significant repair, which can lead to weeks or months of downtime and high costs. Performance may be limited or battery systems forced to shut down if the generation source that supplies the battery system, either the grid or another DER, is interrupted.

Biogas/Biomass CHP

Certain critical facilities like wastewater treatment plants and landfills produce feedstocks that can fuel CHP systems and provide power for daily operations. Flooding, high winds, and earthquakes can threaten to disrupt fuel supply and cause equipment failures that may force plants to shut down. During Hurricane Sandy, the majority of wastewater treatment facilities in New Jersey were forced offline. However, a small number remained up and running, including the Bergen County Utilities Wastewater Treatment Plant in Little Ferry. This facility, which can be seen in **Figure 3**, continued treating water with its biogas-fueled CHP system.[4,5]

Figure 3. Bergen County Utilities Wastewater Treatment Plant

Source: Bergen County Utilities Authority

Facilities can be designed to ensure CHP systems remain unaffected by extreme conditions and most facilities safely store enough fuel feedstock onsite to enable continued operations for extended periods. Still, events such as wildfires could pose a significant threat or create long-term fuel supply challenges to facilities relying on woody biomass or forest resources. Interestingly, some disaster events such as hurricanes and tornados can create tons of biomass debris that can be used as a feedstock for power generation, depending on the condition of the debris.[6]

Distributed Solar

Today, most solar PV systems that are grid connected do not have the ability to work in an islanded mode (disconnected from the grid) and systems are powered down during a grid outage. In order to deliver power during grid outages, which can lessen the need for other emergency fuel supplies, solar PV can be designed to operate independently of the grid (islanded) and in combination with storage or another DER.[7] PV panels are somewhat vulnerable during weather events due to their lack of physical protection, and energy production is limited if panels are covered

[4] U.S. Department of Energy (DOE), Office of Energy Efficiency and Renewable Energy. *CHP: Enabling Resilient Energy Infrastructure for Critical Facilities.* Available at https://www.energy.gov/eere/amo/downloads/chp-enabling-resilient-energy-infrastructure-critical-facilities-report-march

[5] Bergen County Utilities Authority. *Combined Heat and Power Cogeneration Facilities.* Available at http://www.bcua.org/vertical/sites/%7BF76805AC-71CD-427F-AD9B-9E08876F224A%7D/uploads/2011_CHP_Congen_Brochure.pdf

[6] Rocky Mountain Institute. November 1, 2012. "Hurricane Disasters and Debris: Don't Let Renewable Fuel Go to Waste." Available at https://www.rmi.org/news/blog_hurricane_disasters_debris_dont_let_renewable_fuel_go_to_waste/

[7] For more information on how solar PV can support disaster resiliency, see: https://www.nrel.gov/docs/fy15osti/62631.pdf

by snow or if sunlight is obscured by clouds or smoke caused by wildfires.

Severe storms and other disasters have led to the destruction of portions of panels or entire systems, while others have remained intact. A 500 kW ground-mounted PV system at the Humacao wastewater treatment plant in Puerto Rico, was severely damaged after Hurricane Maria.[8] However, many systems are designed to withstand specific conditions, such as wind speeds, seismic events, or snow cover. For example, a flexible racking device allowed a 645 kW rooftop solar array on San Juan's VA Hospital in Puerto Rico to operate at full capacity after Hurricane Maria, even though it was exposed to 180 mph winds.

Distributed Wind

Distributed wind can provide basic power needs during disasters by configuring the system to allow for islanding and incorporating the right combination of supporting technologies. Most wind turbines have a rated speed at which they produce maximum power (~31 mph) and a "cut-out" speed at which they are designed to shut down (~55 mph) to prevent generator damage. If the installation is not part of a microgrid or combined with another generation or storage technology, a generator may be required to restart the system. The turbines at the Jersey Atlantic Wind Farm, located at the ACUA Wastewater Treatment Facility (**Figure 4**), withstood Hurricane Sandy's 65 mph winds and higher gusts, and produced power shortly after the storm. The turbines were programmed to shut down and the blades were pitched neutral to minimize impacts.[9]

Figure 4. ACUA Wastewater Treatment Facility

Source: Windpower Monthly

Snow and ice, and extreme cold can also impact wind production. Electrical equipment may fail in cold temperatures, leading to limited performance or long-term damage, and the accumulation of snow or ice on the blades or around the nacelle can decrease system output and affect access to critical system components for maintenance. Ice protection and advanced monitoring systems are installed in cold climates to avoid potential downtime or the need for costly repairs.

Natural Gas CHP

Natural gas CHP is highly reliable during disaster events. Gas pipelines are predominantly underground, protected from the elements, and the system can continue to operate at high pressure with only half of the compressor stations functioning. According to the Natural Gas Council, in 2016, fewer than 100,000 natural gas customers nationally experienced disruptions, while 8.1 million Americans experienced power outages.[10]

Because of the secure gas supply and the ability to limit impacts to localized effects, most disaster events pose low risks to CHP. Following Hurricane Ike in 2008, the University of Texas Medical Branch at Galveston upgraded site protections that included building an overhead distributed steam system; elevating the CHP system, boilers and chillers; and constructing high flood walls.[11] Years

[8] National Renewable Energy Laboratory (NREL). October 24, 2017. "How Is Solar PV Performing in Hurricane-struck Locations?" Available at https://www.nrel.gov/technical-assistance/blog/posts/how-is-solar-pv-performing-in-hurricane-struck-locations.html
[9] Windpower Monthly. November 2, 2012. "The wind farm that withstood Hurricane Sandy." Available at https://www.windpowermonthly.com/article/1158013/wind-farm-withstood-hurricane-sandy
[10] The Natural Gas Council. *Natural Gas Systems: Reliable & Resilient.* Available at http://www.ngsa.org/download/analysis_studies/NGC-Reliable-Resilient-Nat-Gas-WHITE-PAPER-Final.pdf
[11] Schuett, J., Presented to IDEA Campus Energy 2016. February 11,

later, the site, pictured in **Figure 5**, was able to continue to operate its CHP system throughout Hurricane Harvey, which brought heavy rains and wind speeds of up to 100 mph.

Figure 5. University of Texas Medical Branch at Galveston

Source: Schuett 2016

While most events are not likely to affect CHP system operability, interruptions in gas service could occur during extreme temperatures for customers that do not receive firm capacity. Widespread interruptions in service are not likely during wildfires since distribution pipes are buried at least three feet below ground, although large earthquakes pose a more serious threat to underground infrastructure.

Standby Generators

Standby generator systems are the most common type of distributed resource installed to provide back-up power during an outage, typically using diesel fuel stored onsite. Since standby generators do not supply daily operations, facilities can experience equipment failures linked to system maintenance issues that only become apparent during times of emergency. The New York University Langone Medical Center was criticized when its backup generator failed during Hurricane Sandy and the hospital was forced to evacuate hundreds of patients to nearby healthcare facilities.[12] Fuel availability, stemming from limited storage space or delays caused by impassable roads, is another factor that can impact the efficacy of standby generators during outages greater than a few days.

Any damages to the individual engine components caused by mud or water entering the fuel tank would limit performance or cause a shutdown, although many critical facilities are designed to prevent this type of damage. During Hurricane Harvey, diesel generators at the Skybox data center in Houston kept power on for critical operations in the building, which also housed displaced family members of workers and provided a headquarters for U.S. Marshals until the storm water receded.[13]

Considerations for Enhancing Local Resilience with DERs

As with the electrical grid, all DERs are susceptible, to a certain degree, to disaster events, with some more vulnerable than others. By configuring distributed systems with islanding capabilities and incorporating the right set of supporting technologies, DERs can enhance local resilience and provide continuous power during emergencies. Technologies that use a controllable source of generation, such as CHP systems or batteries, are able to deliver the optimal source of resilient power. These technologies can be integrated with other variable DERs, such as wind and solar, to play a complementary role in disaster response and recovery while also reducing greenhouse gases and alleviating stress on the electric grid.

As local agencies, building owners, and policymakers work to better understand options for improving energy resilience, it is important to consider both how the technology performs (summarized in **Table 1**) and design strategies than can increase energy resilience (summarized in **Table 2**).

For More Information

DOE's Better Buildings CHP for Resiliency Accelerator provides additional resources to help evaluate feasibility of options for increasing resilience with distributed generation. Visit: **https://betterbuildingsinitiative.energy.gov/accelerators/combined-heat-and-power-resiliency**

2016. "Turning Diversity into Opportunity."

[12] New York Times. October 30, 2012. "Patients Evacuated From City Medical Center After Power Failure." Available at https://www.nytimes.com/2012/10/30/nyregion/patients-evacuated-from-nyu-langone-after-power-failure.html

[13] New York Times. September 18, 2017. "How the Internet Kept Humming During 2 Hurricanes." Available at https://www.nytimes.com/2017/09/18/us/harvey-irma-internet.html

Table 2. Design considerations and other strategies to increase resilience of DER

Natural Disaster or Storm Event / Resource	Flooding	High Winds	Earthquakes	Wildfires	Snow/Ice	Extreme Temperature
Battery Storage	● Elevate equipment above flood and storm surge levels ● Use NEMA-rated enclosures that protect against water damage ● Factor equipment repair or replacement in O&M plans	● Use NEMA-rated enclosures to minimize exposure to debris ● Design EMS or protection systems to shut down at harmful wind speeds or conditions	● Utilize shock-mount system enclosures to maintain integrity of individual system components	● Use built-in fire suppression system	● Design enclosures to withstand snow/ice loads ● Design with sealings and venting to address moisture ● Use NEMA-rated enclosures to minimize exposure to moisture	● Design protection or EMS to withstand extreme temperatures ● Design system to shut down to protect component integrity
Biogas/Biomass CHP	● Elevate equipment and biomass stockpiles above flood levels ● For biogas, coordinate with the facility supplying the fuel on potential planned shutdowns	● For digesters, use rigid covers to protect tanks ● For biomass, cover or protect onsite fuel supply stockpiles	● Maintain industry standards for facilities sited near seismic activity	● For biomass, use enclosures, fire protection, or containment strategies for fuel supply	● Design with proper freeze protection ● Protect biomass stockpiles from excess snow and ice	● Use heating jackets designed for optimal temperatures and adequate thermal management systems ● Ensure systems are designed for regional temperature ranges
Distributed Solar	● Design systems and framing for easy runoff and drainage, especially for commercial rooftop systems with flat roofs ● For ground mount, avoid siting in flood zones	● Use secure, flush-mounted systems for rooftop solar ● Use flexible racking and anchoring systems ● Maintain ASCE standards for rooftop systems based on expected wind loads	● Ensure roof mount design meets ASCE building code for seismic areas	● If ground-mount, site in open areas away from flammable material (trees, shrubs, etc.)	● Manually remove snow/ice to clear panels ● Automonous mechanical cleaning (tiled removal) ● Install bifacial systems capable of absorbing irradiance on the back or front of panels	● Site systems in applicable weather conditions ● Enhance design to maximize cooling and airflow in order to ensure optimal temperature conditions for modules and electrical components (inverters)
Distributed Wind	● Design foundation for conditions in high water table ● Elevate controls and electronics above flood and storm surge levels ● Use site drainage strategy	● Include design features and braking procedures to withstand hurricane force winds (feather blades, lock rotors, change orientation, etc.)	● Design systems for ground acceleration rating based on typical seismic activity	● Extend gravel apron around base of turbine	● Install electro-thermal ice protection systems ● Use ice-resistant coating on blades	● Design uninterruptible power supply to operate within adequate temperature range ● Add on "cold weather packages"
Natural Gas CHP	● Elevate equipment above flood and storm surge levels	● Locate systems indoors or protect with containers designed to withstand high wind and debris	● Shock-mount system enclosures ● Maintain industry standards for pipelines sited near seismic activity	● Use fire protection systems for above-ground facilities associated with gas delivery networks	● No additional design consideration needed	● To ensure fuel availability, purchase "firm supply" to avoid curtailment
Standby Generators	● Elevate equipment above flood and storm surge levels ● Store enough fuel onsite to avoid delivery issues	● Locate systems indoors or protect with containers designed to withstand high wind and debris	● Purchase an earthquake-resistant model (IBC certified; subject to shake table testing)	● Avoid siting in areas prone to wildfire ● Store enough fuel onsite to avoid delivery issues	● Store enough fuel onsite to avoid delivery issues	● Check generator batteries during cold weather ● Enclose the system to protect from temperatures. ● Store "winter diesel" fuel in cold climates with additives to prevent gelling