Ensuring Resilient Operations of Solar-Plus-Storage Community Resilience Hubs

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List of Abbreviations

BESS	battery energy storage system(s)
NREL	National Renewable Energy Laboratory
OEA	operating envelope agreement
PV	photovoltaic

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Background

Resilience is "the ability to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions through adaptable and holistic planning and technical solutions" (Hotchkiss and Dane 2019). Resilience is an essential consideration for energy technologies and projects (NREL 2022a). Resilience hubs are community-serving facilities that support residents before, during, and after disruptions (such as grid outages due to storms) and can greatly enhance the ability of a community or region to withstand, respond to, and recover from disruptive events, in addition to providing an array of additional benefits (Kramer, Belding, and Coney 2023). Resilience hubs may be established in buildings that already serve the community, such as libraries, schools, or community centers. Many communities are pursuing resilience hubs as a means of mitigating the growing impacts of climate change (Musalem and Hawthorne 2023).

To reduce greenhouse gas emissions, resilience hubs may be powered by clean energy technologies, including solar photovoltaics (PV) and battery energy storage systems (BESS). This report is intended to address design and deployment considerations for such resilience hubs. Resilience hub projects of this type comprise multiple technologies with a variety of potential use cases, benefits, and costs. This multiplicity can lead to complex scenarios in which several parties form a coalition to design and/or install the many elements of a resilience hub.

Blue sky: normal, grid-connected conditions.

Black sky: conditions featuring disruptive events (such as storms) and grid outages.

To provide clarity in this complex environment and ensure that the built and installed project performs as desired, this report outlines key considerations for deploying solar PV and BESS in a resilience hub context. The report will answer the following questions:

- What is the difference between blue-sky and black-sky conditions? What is required for resilience hubs to be successfully operated under both conditions?
  - What are the different services solar PV and BESS can provide under both blue-sky and black-sky conditions?
  - How do the goals of a resilience hub inform the selection and installation of solar PV and BESS technologies?
  - What is an operating envelope agreement (OEA), and how can it be used in the resilience hub context?

This report is ownership-agnostic and does not assume that any given system component is owned by a specific entity or organization; whether the various pieces of the system are owned by the same party or different parties, it is important for resilience hub planners to clearly define the interactions of the technologies during both blue-sky and black-sky operation.

Blue-Sky Operations of Resilience Hubs

While resilience hubs warrant significant attention on their performance during disasters and outages, blue-sky conditions prevail during the vast majority of the time (over 99.9%) in the United States (Denholm 2024). As a result, the performance of a resilience hub's solar PV and BESS in blue-sky conditions is crucial for delivering the planned value of the project.

Electricity generated by solar PV is a key value proposition for many resilience hubs, routinely providing energy cost savings and greenhouse gas emissions reductions. In blue-sky conditions, solar energy can be used to supply power to the resilience hub host site's facilities and equipment, reducing demand for grid electricity (Aznar 2017). In some electric utility territories, excess solar electricity production can be sent and sold back to the grid, further improving project economics (Zinamen et al. 2017). Comprehensive guides to solar installation can be found in the references (Fekete et al. 2023), but a high-level checklist of prerequisite conditions when deploying solar PV for use in a resilience hub context includes:

- The cost savings or revenue from the solar PV aligns with the host site's economic priorities.
- The built environment supporting the solar array, especially for roof-mounted PV panels, is structurally sound and not due for replacement.
- The size and location of the solar array allows it to be successfully interconnected with the local utility's electric grid.
- The PV system is procured and installed with components that can withstand storms and continue operating during emergencies and natural disasters (NREL 2022b).

A BESS can also provide cost savings or revenue during blue-sky conditions when the electric grid is operating without issue. The blue-sky function performed by a BESS is typically determined during the project design phase so that the BESS specifications can be tailored to maximize the effectiveness of this function; common BESS use cases are described by Elgqvist (2021) and include:

- Behind-the-meter cost savings: A BESS can supply power to the resilience hub host site when electricity prices are high. The BESS is then recharged from the grid when electricity prices are low. This price arbitrage reliably results in lower electric bills for the host site.
- Front-of-the-meter grid services: A BESS can send power directly to the electric grid. This arrangement can provide value to utilities by supplying electricity for broader consumption, or by managing electricity quality through ancillary services such as voltage or frequency regulation. Many utilities offer programs to compensate BESS owners for these services.
- Demand management: Utilities may provide structured compensation to customers who can guarantee lower electricity consumption during times of peak demand on the grid (such as hot summer days). A BESS can support this demand management by providing a portion of the host site's electricity that would otherwise have to be supplied by the grid.

For both solar PV and battery technologies, it is important to consider the operational lifetime of the systems. During said lifetime, routine maintenance is key to maximizing system performance and identifying issues before the system is impacted. While operations and maintenance costs may be small relative to the cost of the system (NREL 2023), maintenance services should be performed by an experienced and skilled provider, and those services should be agreed upon before the system is installed. Once a technology reaches the end of its useful life, having a plan for decommissioning the system can ensure that its environmental impacts are minimized in alignment with the goals of the system owner. If the system owner knows how they want the technology to be handled at the time of decommissioning, those instructions can be included in the system procurement phase. The markets for technology recycling and used/second-life batteries are also active areas of research and growth, so new opportunities and structures for system decommissioning may emerge during the system's lifetime (NREL n.d.).

Black-Sky Operations of Resilience Hubs

Resilience hubs must be able to operate reliably during a grid outage. Achieving this operational certainty can be complicated by the number of technologies and owners involved in the resilience hub project, who may have separate goals. In all cases, the component technologies of the system must be able to support the desired operations. For both solar PV and battery storage, the project design should be clear regarding how and where power is delivered during both blue-sky and black-sky operations.

Because most solar arrays do not have moving parts, little changes for the solar PV system itself when transitioning to black-sky operation. It can still produce electricity; the only difference is that the solar electricity is used for resilient power (black-sky operation) instead of providing cost savings or revenue (blue-sky operation). However, for the solar power to be effectively used during an outage, the host site must be able to electrically isolate, or "island," itself in accordance with utility requirements such that utility staff working to repair the outage are not put in danger due to the resilience hub's active power (Belding, Walker, and Watson 2020). The same islanding requirements apply to battery systems' ability to provide power during an outage. To achieve this autonomy, the resilience hub project typically must include specialized electrical islanding equipment, microgrid controls, and other site-specific electric configuration costs.

Beyond the system's ability to perform, a trade-off often encountered by resilience hub planners is the degree to which solar PV and BESS should be optimized for blue-sky economic performance versus resilience performance. Technology specifications and operational parameters may vary depending on whether a system is designed to meet certain resilience benchmarks or maximize economic gains, as evinced by the following examples:

- Technology specifications example: A BESS that provides front-of-the-meter grid services must discharge power for short periods of time to serve its function of maintaining grid stability. A battery optimized for front-of-the-meter grid service provision may be at odds with a resilience goal of surviving a 10-day power outage, which would instead require the BESS to supply its power over a longer duration. Selecting for blue-sky performance would increase the revenue generated by the system but could potentially result in less robust resilience performance, and vice versa.
- Operational parameters example: A BESS used for behind-the-meter cost savings can maximize those savings by fully discharging its energy during economically favorable conditions (e.g., high electricity prices or peak demand). Maximizing revenue in this way would shorten the payback period for the BESS. However, doing so would increase the risk that a grid outage coincides with the BESS being nearly empty of charge. If an outage were to occur while the BESS has a low state of charge, the capability of the resilience hub to provide power would be diminished. Setting a minimum allowable state of charge in the design and procurement stages of deployment can provide a baseline of certainty from which resilient operations can be planned.

For a resilience hub to achieve its ideal combination of blue-sky and black-sky performance, project planners and multi-stakeholder project development teams should be clear and aligned on the system's goals and priorities. For cases in which those goals and priorities are in competition, or are sources of disagreement among project coalition members, contractual mechanisms such as OEAs can provide clarity and certainty on resilience hub design and operation.

Operating Envelope Agreements and Resilience Hub Planning

An OEA is an emerging contractual concept between the parties involved in the development of the resilience hub site and the utility that serves it. The objective of an OEA is to identify a mutually agreeable set of technical operating requirements for a PV and storage system (including hours of enforcement, called an "operating envelope"). The operating requirements limit risk to neighboring customers and the utility's electric infrastructure. In addition, an OEA can provide certainty to both the utility and resilience hub system owner (Gill et al. 2022). From the perspective of the system owner, this contractual agreement can unlock revenue while preserving the system owner's control over the paired PV and energy storage system and providing certainty required for project financing.

An OEA can be a useful formalization of responsibilities and operating conditions for resilience hub solar PV + BESS projects in which there are multiple owners of system components or ambiguous utility policies that govern the project's operation. Scenarios in which establishing an OEA for a resilience hub may be useful include (but are not limited to):

- When an entity other than the resilience hub host site owns and operates the BESS during blue-sky conditions, an OEA could contractually stipulate that a certain amount of the battery system's state of charge be maintained at all times to ensure a minimum threshold of resilient operation in an outage.
- On electrical distribution grids with constrained hosting capacity, an OEA can help solar PV + BESS projects achieve a greater allowable system size than solar PV alone. This is accomplished by setting parameters for when the PV output to the grid will be controlled by the BESS.
- If multiple parties are responsible for installing the solar PV and BESS, an OEA template could be adapted to guarantee that those systems are installed in such a way that the solar PV is able to recharge the BESS during black-sky conditions, even if the solar PV is not designed to recharge the BESS during blue-sky operation.

Key Takeaways

Based on the points covered in this report, planners of resilience hubs featuring solar PV and BESS technologies should make sure to define the following features of their project:

- Blue-sky cost savings or revenue generation: the value propositions and use cases for solar PV and BESS at the host site during blue-sky conditions
- Black-sky resilience services and performance: the goals and functions of the resilient energy system, including the identification of electrical loads to be supported during an outage
- Islanding and utility compliance: the sufficiency of the system's electrical equipment and interconnection agreement to enable power supply during a grid outage
- System operations and maintenance: ensuring that a capable and experienced entity is tasked with operations and maintenance duties, as host site staff may not have the required expertise
- System decommissioning: a plan for technology sale, reuse, or disposal when the systems have reached the end of their useful lives (NREL n.d.).

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