PV + BESS for Electric Utility Generation

By John Benson

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1. Introduction

I try to get my paper titles down to a single line. In order to do this for this paper I needed to change the original title "Photovoltaic and Battery Energy Storage Systems for Electric Utility Generation" to the above title. Also, researching this subject was really frustrating. After searching for the better part of a day, I found very little. Eventually I found a really good reference (Reference 2 at the bottom of page 2), that was also reasonably current (December 2021). This was expected as this is a complex issue.

Part of the attraction to the title pair of electric-energy assets for my home state (California) has to do with our predictable solar energy – a large majority of our days are sunny throughout the daylight hours, even in winter (a.k.a. our rainy season, snow is not allowed in the SF Bay Area where my primary residence is, except on the highest mountain peaks: Mt. Diablo: 3,849 feet, and Mt. Hamilton: 4,265 feet).

The bad news is that the daily peak-power period goes into the evening, after PV has shut down. This is why I have PV+BESS for my primary residence, and my PG&E electric bill is close to zero, year-round.

2. Utility Scale PV+BESS

The good news is for major electric utilities and/or PV+BESS Fleet Owners that these two resources don't necessarily need to be co-located. PV takes much land (or roof-top area), and a BESS-array can be put either outdoors (via NEMA 3R or NEMA 4 enclosures) or in a large building, like a warehouse. The bad news is that if the indoors option is selected, fire-prevention should be a major design-criteria.[1]

2.1. Photovoltaic

The table on the next page shows the daily production by month of a typical PV Array in San Jose, CA (a few miles from my primary residence).

The PV arrays on my rooftop were sized to provide energy that is consistent with my yearly electricity usage, per a yearly profile that I obtained from my local utility (PG&E).

My BESS sizing (10 kWh) is consistent with my mid- to late-evening part of my peak-power usage, when the PV output is falling.

If the above is extended to an electric utility that needs to provide power during its peak demand period, the requirements are a bit more complex. All major utilities have peaking power plants that are only used to cover peak demand periods. They also can have "natural-peakers" like hydroelectric power plants that can have their output dispatched (the flow through the hydroelectric turbines increased) to provide more power during the peak demand periods, and store water during low demand periods.

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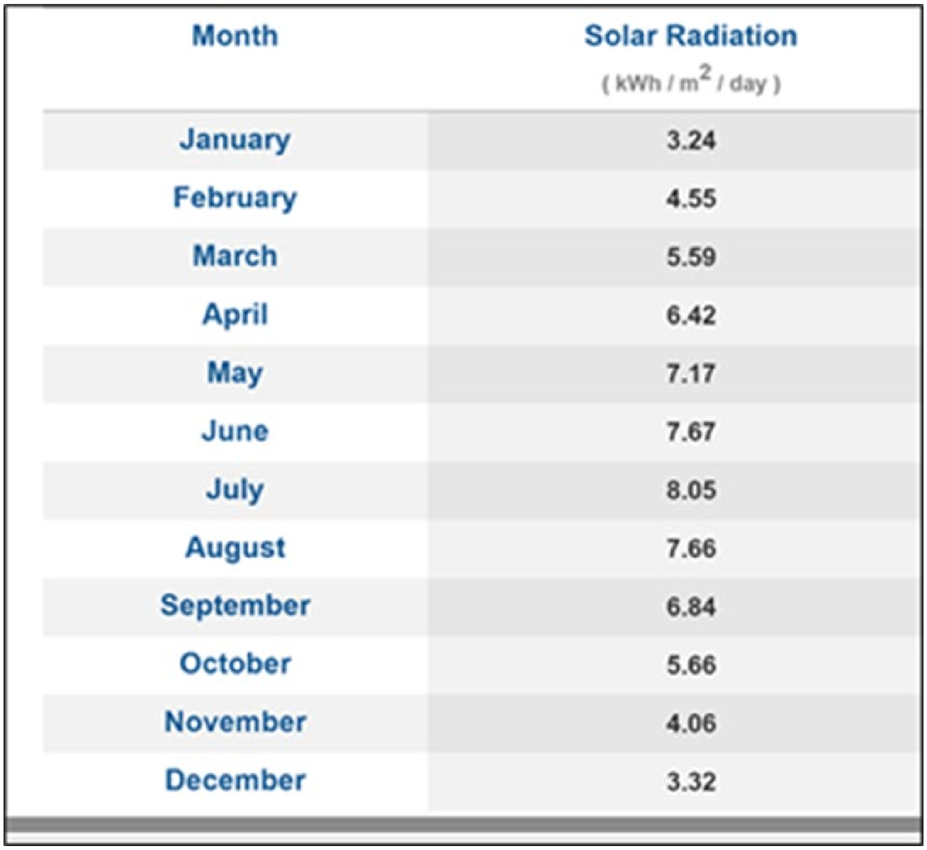
[1] See "Recent Findings from The Moss Landing Fire," https://www.energycentral.com/energy-biz/post/recent-findings-from-the-moss-landing-fire-NSqhaONwgQV0JsI



Month	Solar Radiation (kWh / m^2 / day)
January	3.24
February	4.55
March	5.59
April	6.42
May	7.17
June	7.67
July	8.05
August	7.66
September	6.84
October	5.66
November	4.06
December	3.32

Assuming a PV+BESS system is used to cover a utility's peak demand period, the PV needs to be sized to supply capacity during the daylight hours PLUS charge up the BESS so that it can be used (typically) in the mid to late evening hours to supplement the fading PV. However, a typical electric utility may choose to also supplement the fading PV with other peak-demand assets as described in the last paragraph on the previous page.

Also note that the PV production in December and January (above table) is roughly half of the year-round average. However, the demand in December & January is likely to be well above the average due to the additional demand for heating and lighting. The only good news for my home-state (California) is that in November and December the hydro-electric production should also start to increase because the rains typically start to increase in October and November. Also, the wind production might increase slightly due to late autumn to early winter storms.

3. Design of PV-Plus-Battery System

Since 2010, utility-scale PV capacity has increased by over 500 GW globally, including over 38 GW of deployment in the United States. This increased deployment has been driven by a combination of rapidly declining costs, increasing interest in low-carbon energy, and a variety of policy-related incentives at different levels of government.[2]

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[2] Anna H. Schleifer, Caitlin A. Murphy, Wesley J. Cole, & Paul Denholm, National Renewable Energy Laboratory, Golden, CO, "Exploring the design space of PV-plus-battery system configurations… ," December 15, 2021, https://www.sciencedirect.com/science/article/abs/pii/S0306261921015890?via%3Dihub

The dramatic increase in PV generation on the U.S. bulk power system has reduced the value of additional PV capacity in some regions. In these regions, battery storage is becoming increasingly attractive for both enhancing grid flexibility and shifting PV generation out of already-saturated daylight hours (i.e., to hours with little or no solar resource). Stand-alone battery storage (i.e., battery storage sited by itself) can increase the ability to economically integrate additional PV capacity. However, coupling battery storage with PV can provide additional benefits, such as more efficient operation and cost savings relative to separately sited systems.

The objective of this work is to explore the design space of PV-plus-battery hybrid systems, accounting for a range of possible component sizes, and investigate how component sizing influences the value of these hybrid systems to the bulk power system in different locations and with evolving grid mixes over time. The focus of this work is on coupling types in which the PV and battery systems share a single inverter, or DC-coupled PV-plus-battery systems. DC coupling enables additional synergies between PV and battery systems, such as the ability to recover PV generation that falls outside inverter limits—including both upper bounds (i.e., energy that would be clipped by the inverter) and lower bounds (i.e., low-voltage PV generation during sunrise/sunset and at times with significant cloud cover). DC-coupled PV-plus-battery systems also have higher roundtrip battery efficiency when charging from the coupled PV (as opposed to charging from the grid). Finally, DC coupling enables the oversizing of available generation relative to the interconnection (i.e., PV and battery capacities that exceed the capacity rating of the shared inverter), thus allowing for increased utilization of the inverter and interconnection.

On the other hand, DC coupling introduces several unique challenges. First, DC-coupled systems require hybrid multiport inverters or extra DC-DC converters, both of which have until recently been expensive or difficult to procure. Second, DC coupling can limit output during high-value periods – when energy from both the PV and battery is available for various grid services, since both resources are subject to the shared inverter's capacity rating. Third, there is ongoing uncertainty around the permitting and interconnection processes for hybrids – especially for systems that can operate in multiple modes (e.g., electricity supply from PV or battery dispatch versus electricity demand when charging from the grid – and most market regions are currently establishing or modifying hybrid-specific processes. In some market regions, a coupled system can benefit from a more rapid, shared interconnection process; in others, interconnection may be allowed only if hybrid-specific requirements are met, such as the need for the telemetry that allows the grid operator visibility into the individual components…

This paper makes two original contributions to the literature on utility-scale PV-plus-battery hybrid systems. First, it examines the interactions between the solar resource potential in diverse locations and the technical characteristics of a wide range of PV-plus-battery configurations, including a greater range of inverter loading ratios (ILRs) than has been studied previously. To the authors' knowledge, no peer-reviewed study has yet evaluated PV-plus-battery systems with ILRs up to 2.6…

Second, it evaluates how these technology-related interactions further respond to changes in the grid mix over time, providing insight into the possible evolution of the highest-value DC-coupled PV-plus-battery configuration(s) through the use of marginal breakeven costs of incremental additions of PV and battery capacity.

To accomplish these goals, we combine the capabilities of several existing electricity sector models with different temporal and geographic scales to explore the economic performance of multiple DC-coupled PV-plus-battery configurations over a wide geographic extent and into the future. Our analysis quantifies their future energy and capacity values, based on simulated electricity prices that reflect evolving grid conditions projected through 2050…

4. Updating a Current Utility-Scale PV with BESS

As the global energy transition accelerates, utility-scale photovoltaic (PV) power plants are evolving from pure generation assets into flexible energy hubs. A major step in that evolution is the integration of Battery Energy Storage Systems (BESS).[3]

By retrofitting existing PV plants with BESS, asset owners and operators can unlock new revenue streams, improve grid compliance, and increase the overall value of their assets. However, integrating BESS into an operating solar site is not just a matter of dropping containers on-site—it requires careful technical design to ensure compatibility, performance, and long-term reliability.

At Detra Solar, we specialize in the technical design of PV and BESS infrastructure. In this article, we explore the key technical considerations for integrating BESS into existing PV projects—with a focus on the aspects where smart engineering makes all the difference.

When adding BESS to an existing PV plant, the physical layout and electrical architecture of the site must be carefully considered together. Layout design is more than just finding free land—it requires holistic analysis followed by optimized equipment placement for operational safety, maintainability, and cost. At the same time, the choice between AC and DC coupling fundamentally shapes both the layout and interconnection strategy.

4.1. BESS Placement: Centralized vs Distributed

The placement of BESS equipment generally follows one of two strategies, closely linked to the electrical coupling mode:

***Centralized BESS placement:** This approach locates all battery containers and their associated medium-voltage (MV) skids in a dedicated site area. It is typical for AC-coupled systems, where the BESS operates independently from the PV inverter and connects to the grid via its own inverter and transformer. Centralized layouts simplify maintenance, reduce trenching complexity, and support phased commissioning.*

***Distributed BESS placement:** This model is relevant primarily to DC-coupled systems, where battery units are electrically integrated upstream of a central inverter. While this setup can optimize energy capture—particularly by storing energy that would otherwise be clipped—it introduces layout and routing complexities. Distributed BESS is less common in retrofits due to the challenges of integrating with existing PV infrastructure.*

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[3] Ryszard Gornowicz, Energy Storage Specialist at Detra Solar, "Expert Insights: Upgrading Utility-Scale PV Projects with Battery Energy Storage Systems," June 25, 2025, https://www.pv-magazine.com/press-releases/expert-insights-upgrading-utility-scale-pv-projects-with-battery-energy-storage-systems/

4.2. AC vs. DC Coupling, Various Issues:

AC-Coupled Systems:

Technical: *Separate inverters for PV and BESS; systems are electrically independent.*

Practical: *Easier to retrofit; uses existing infrastructure with limited disruption.*

Economic: *Slightly higher equipment costs, but more modular and flexible.*

DC-Coupled Systems

Technical: *PV and BESS connect to the common DC bus inside the central inverter.*

Practical: *Usually requires significant modification of the existing inverter and LV auxiliary supply infrastructure*

Economic: *Potential for higher round-trip efficiency, clipping recovery, and lower CAPEX, but less suited for retrofits due to complexity.*

Key Layout Considerations:

Space constraints: *Is there enough room for battery enclosures, PCSs, MV Skids, and fire access zones?*

Topography: *Is the available area for BESS flat, or will it require extensive ground grading?*

Access for construction and maintenance: *Will there be sufficient clearance for crane access, delivery vehicles, and long-term operation?*

Shading sensitivity: *Will the new BESS infrastructure cast shadows on PV arrays?*

Integration with existing infrastructure: *How will the new system fit into the existing trench paths, fencing, access roads, and drainage systems, and how to plan it to minimize redesigns?*