WHITE PAPER

Choosing The Right Battery For Utility-Scale Solar-Plus-Storage Projects

To realize the value utility-scale solar and storage offers, utilities need to define the use case, determine ancillary services and locate the optimal location. This process will help identify the right solar, battery and storage technology option to achieve maximum returns.

Utilities have been capturing solar energy to create reliable power for more than two decades, and utility-scale solar continues to grow. The U.S. Energy Information Administration (EIA) estimates grid-scale solar facilities currently generate more than 60,000 gigawatt hours (GWh) of electricity and it is projected that utility-scale solar will account for almost two-thirds of all solar capacity by the end of 2021.

While solar power delivers clean energy and advantages for carbon dioxide emissions offset, the right energy storage system can help unlock grid reliability and stability for utilities around-the-clock.

Simplifying Solar-Plus-Storage

Energy storage can be used to capture surplus solar electricity generated during the day and discharge that energy to the grid in the morning or evening. This process smooths the output of a solar facility to lessen the impact of erratic solar production and bridge intermittent gaps when electricity need is high. The EIA reports that 869 megawatts (MW) of utility-scale batteries were in use on the electric grid at the end of 2018.
Storage systems convert electricity into other forms of energy, such as chemical potential energy in the case of battery storage systems, which can then be converted back to electricity on demand. Understanding the basic battery configurations and technologies is a good place to start in understanding the potential of solar and storage.

Ac-Coupled Vs. Dc-Coupled Systems

Solar panels produce direct current (DC) electricity, which an inverter then converts to alternating current (AC) electricity for consumer use to power devices. Battery energy storage systems (BESS) store DC electricity and also require an inverter to convert DC power to AC power. For solar-plus-storage systems, there are two primary configurations, each with different benefits and challenges:

AC-coupled, co-located storage: Solar and storage are located on the same site, either with separate interconnections or sharing a single point of interconnection to the grid. The connection to the grid, however, is via separate inverters on the AC side of those inverters (hence the name AC-coupled).

- **System advantages:**
  - Easier to retrofit to existing solar system installations.
  - Incrementally scalable to expand systems.
  - Possible to provide ancillary services to the utility/grid beyond solar shifting.

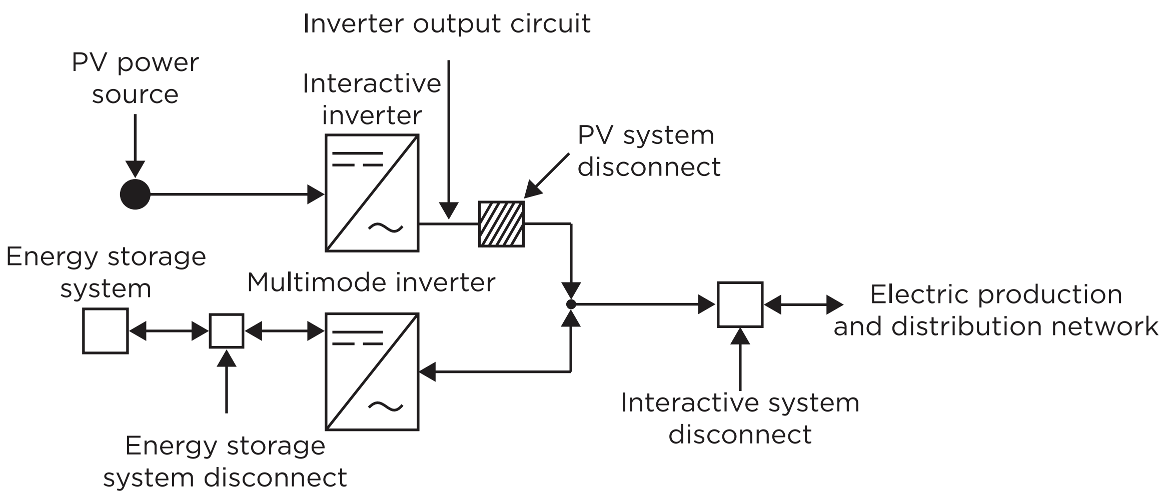

Figure 1: AC-coupled multimode system.

- Can be easier to augment the system in the future.
- Centralized battery system can simplify maintenance activities.
- Flexible contracting strategies.

- **System disadvantages:**
  - Requires installation of dedicated inverters, cable and other balance-of-system components that take up space and add cost.
  - Does not capture excess DC photovoltaic (PV) energy generated by the PV plant that exceeds the inverter capacity (DC clipping).

DC-coupled storage: Solar and storage are located on the same site and are coupled together on the DC side of the inverter. The solar and storage share the same inverter(s) and use the same grid interconnection.

- **System advantages:**
  - Cost savings using one inverter and other balance-of-system components for solar and battery conversion.
  - Captures excess DC PV energy that is typically lost to inverter clipping during certain production periods (DC clipping).
- **System disadvantages:**
  - Usually requires a DC-DC converter between the batteries and solar DC bus, which requires additional space and maintenance distributed throughout the solar arrays.
  - May have limitations on providing ancillary services to the grid.
  - Augmentation can be more difficult due to space limitations.
  - Not ideal for retrofitting existing PV systems.
  - Coordination with solar design and installation.

No matter the configuration, utilities can leverage solar-plus-storage system arrangements to achieve the same goal: provide stored renewable energy onto the grid when needed.

Battery Technologies

BESS rely on an energy storage technology to efficiently manage the storage and power output of energy to the grid. However, based on how the system will be used, not all battery storage technologies are equal.

Traditional battery technologies, such as lead-acid and nickel-based batteries, are proven in other, more common applications, but not necessarily ideal for large-scale solar applications. Lead-acid batteries, for example, are inexpensive but offer a short life cycle and poor energy density and are sensitive to ambient temperatures.

Lithium-ion battery systems are the most common, but based on the use case, other battery technologies such as flow batteries may be worth evaluating for solar-plus-storage projects, especially as the non-lithium-ion battery technologies mature and become more cost competitive.

Lithium-Ion Batteries

Commercially introduced in 1991, lithium-ion (Li-ion) battery technology is the most widely used for utility-scale energy storage. With a high energy density and relatively long

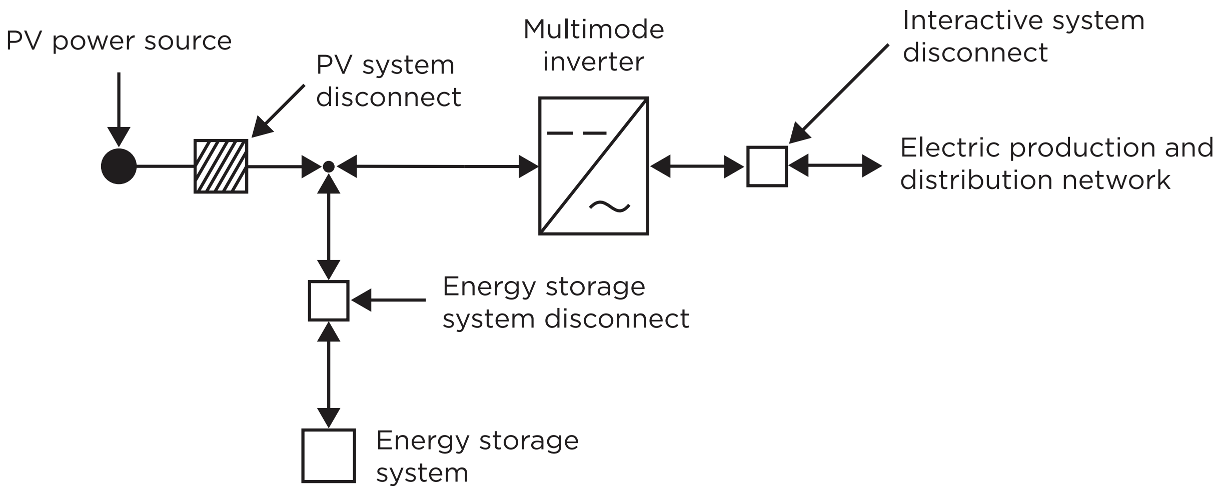

***Figure 2:** DC-coupled multimode system.*

life cycle, Li-ion batteries offer high round-trip energy efficiencies. This technology is seeing large manufacturing capacities and lower costs primarily due to its use in electric vehicle applications.

For storage periods around four hours, Li-ion batteries are very cost-effective. Likewise, Li-ion batteries can be custom configured for specific applications. Drawbacks to Li-ion technology include thermal runaway hazards, stringent HVAC requirements, as well as manufacturer limitations on charge/discharge cycles to maintain the warranty. There are several Li-ion battery types and manufacturers, and evaluation is needed to determine the optimal technology for solar-plus-storage applications, including cycle limitations, augmentation strategies and end-of-life disposal requirements.

Solar-Plus-Storage Project Framework

Identifying a utility's use case for a solar-plus-storage system is essential and determined by interconnection requirements and the payment structure agreed to by the energy off-taker. Establishing project goals, capabilities and economics is the preferred start before investigating specific solar-plus-storage technologies.

Define Operational Objectives

For utility-scale solar-plus-storage applications, determining the energy output objective and the battery use case is the first step in selecting the appropriate technology and system configuration.

Solar-plus-storage components use kilowatt-hours (kWh) to indicate energy output capability and kilowatts (kW) to denote instantaneous power output. Proper determination of these values for the AC and DC portions of the PV and BESS system is paramount to meet operational objectives without accumulating more upfront capital costs than necessary. Contractual obligations, such as power purchase agreements (PPAs), are key in determining the expected energy output, duration, and lifetime of the project and resulting augmentation strategies of the BESS.

The regulatory structure may prevent the solar-plus-storage system from performing some ancillary services. Understanding the required and allowable ancillary services, associated payment structures, and regulatory requirements of a specific project will aid in system configuration and component selection, including the suitability of an AC- or DC-coupled system.

For solar-plus-storage applications where the primary objective is solar energy shifting or arbitrage, the time-of-use (TOU) rates offered by the utility are essential in determining when to charge and discharge the BESS. These factors, in addition to project location, expected PV energy production and potentially ancillary services opportunities, are used to determine ideal project sizing specifications, such as the PV-to-BESS capacity ratio, DC/AC ratio, inverter quantities and equipment ratings. For example, since the DC-coupled solution can capture the DC clipped energy, DC-coupled solutions trend toward higher DC/AC ratios than AC-coupled solutions.

Other use cases for the BESS may be identified during this process and may point to an AC- or DC-coupled solution capability. For ancillary services such as frequency regulation or voltage/reactive power support, an AC-coupled BESS gives the most flexibility for the battery to operate independently of the solar. One consideration is whether this battery and the solar are the same site or separate sites. If the interconnection agreement

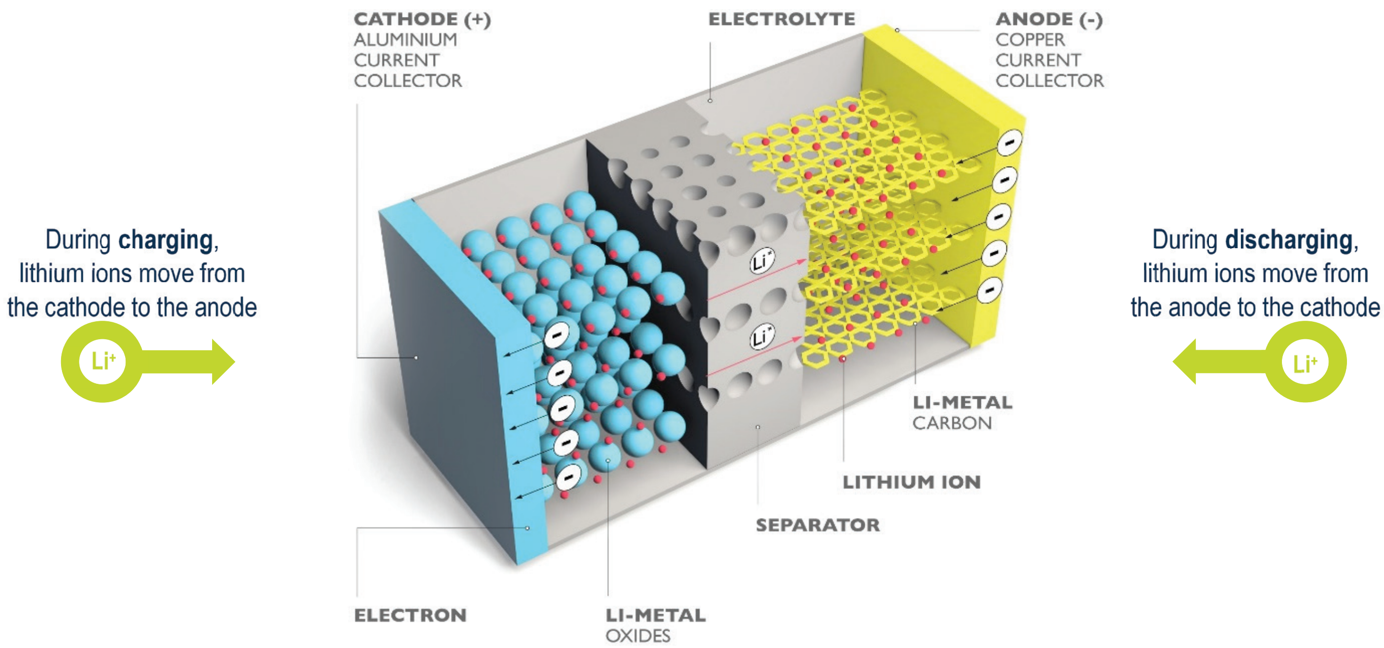

***Figure 3:** Charging and discharging process in lithium-ion batteries.*

is limited to the solar output, it may not be possible to discharge the battery at the same time the solar generation is high. This would limit the ability to provide ancillary services, or other grid services, independent of the solar shifting use case.

Aspects for Technology Selection

Greenfield solar installations typically offer project flexibility and present a great time to evaluate storage options, whether incorporated from the outset or added later. For brownfield sites, integrating storage with existing solar or renewable energy assets can be challenging but is certainly possible. Understanding limitations and how use case goals will be met requires careful evaluation.

A thorough evaluation of key project components early in development helps determine suitable technology and site location while identifying potential challenges:

- **AC- vs. DC-coupled systems:** Greenfield installations can, generally, accommodate either system but are often good candidates for a DC-coupled BESS with a PV facility. Brownfield sites require consideration of the use case, whether storage would be added initially or at a later date, and aspects of inverter compatibility with the necessary DC-DC converters.
- **Site and location:** Physical space requirements, site zoning and permitting requirements for BESS, power and communications and interconnection equipment must all be considered regardless of new developments or retrofit projects. While greenfield projects can typically offer more site planning flexibility, both greenfield and brownfield projects have several aspects to consider. Requirements to evaluate include whether storage will be added initially or at a future date, physical space allocation for BESS within the PV array, point of interconnection (POI) and equipment, switchgear and substation, auxiliary power needs, whether a BESS energy management system will be integrated with the PV plant or SCADA, and any physical access requirements. Typically, there are more hurdles and challenges for brownfield sites that point to an AC-coupled solution.
- **Power densities:** Greenfield and brownfield sites need consideration of whether a container or building design is the right approach and then identification of zoning and permit requirements, cost-effectiveness and siting location in relation to the PV array. BESS buildings are easier to locate near the collection substation or interconnect location for an AC-coupled solution. Container or purpose-built enclosure solutions can be more flexible and used for either AC- or DC-coupled solutions.
- **Interconnections**: A challenge for either project type, utilities need to evaluate interconnection requirements and impacts including fees, penalties and local utility limitations, whether a new interconnection request is required or an existing interconnection needs modification, and identifying if any monetary benefit exists (or will become available in the future) for energy storage installations.

While many sites can effectively accommodate utility-scale solar-plus-storage, project success is dependent on a thorough understanding of many different site characteristics and equipment requirements upfront.

Conclusion

Energy storage systems co-located with PV facilities provide benefits to utilities, facility owners and energy off-takers. However, close coordination is required between developers, owners, utilities and off-takers to fully understand the limitations and benefits of a solar-plus-storage facility, as well as the potential revenue that can be recognized by the facility owner.

Detailed analysis, coupled with experienced design and deployment of solar and energy storage projects, is essential to determine the optimal solution for a given location and realize a project's maximum, long-term benefit.

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