

**SOLAR
PLUS
ENERGY
STORAGE**

Comparing System Options



Energy storage for maximizing production and revenue from PV power plants: a systems overview

THE US currently has over 50 GW of installed utility-scale PV generation. With more than 45 GW of utility-scale PV projects in the pipeline at the beginning of 2021, the US is on track to grow total utility-scale PV capacity to over 100 GW by 2024.

Here we will examine the coupling of energy storage with PV by comparing three principle methods: **AC-coupled**, **DC-coupled**, and **Reverse DC-coupled** configurations. We will also consider all possible revenue streams of solar plus storage and their availability based on available systems for coupling storage.



Green Mountain Power 2 MW Solar Plus Storage



Solar Plus Storage

Revenue Streams



The addition of energy storage to an existing or new utility-scale PV installation allows system owners and operators the opportunity to capture additional revenues through:

CAPACITY FIRMING

Turn Solar Energy into a Dispatchable Asset

For certain time periods during the day the availability of storage gives the system operator the ability to bid firm capacity into merchant markets. That is storage makes PV generation a dispatchable revenue generating asset.

Depending on the available local energy market, this may translate to higher kWh rates for firm capacity during dispatchable periods.

ENERGY TIME SHIFTING

Utilize Generated PV Energy When Its Value is Highest

Energy Storage allows bulk energy shifting of solar generation to take advantage of higher PPA rates in peak periods, or to allow utilities to address daily peak demand that falls outside periods of solar generation.

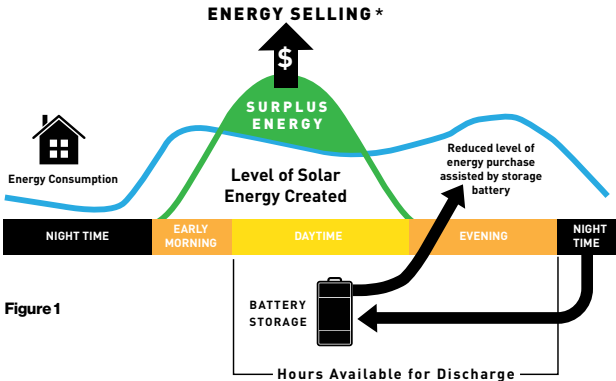


Figure 1

*The battery does not discharge any energy while selling the surplus solar energy.

CLIPPING RECAPTURE

Maximize Value of PV Generated Energy

Given common inverter loading ratios of 1.25:1 up to 1.5:1 on utility-scale PV (PV_{DC} rating : PV_{AC} rating), there is opportunity for the recapture of clipped energy through the addition of energy storage.

Using a simplified system for illustrative purposes, consider a $14MW_{DC}$ PV array behind a total inverter capacity of $10MW_{AC}$. **Depending on your location and type of racking, the total clipped energy can be over 1,000,000 kWh per year.**

With storage attached to the array, the batteries can be charged with excess PV output when the PV inverter hits its peak rating and would otherwise begin clipping. This stored energy can then be fed into the grid at the appropriate time. **Without energy storage these kWhs are lost and revenues stunted.**

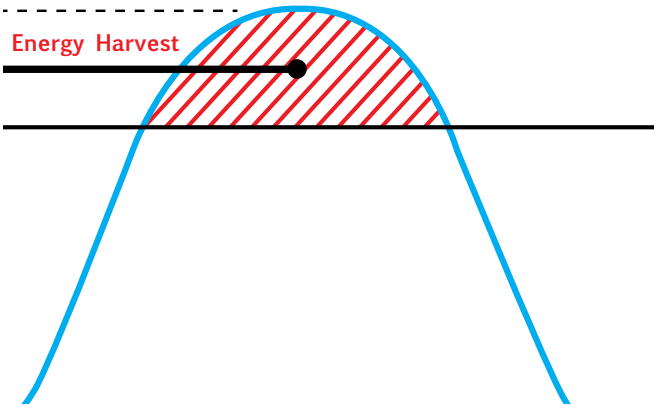


Figure 2: Clipping recapture opportunity on systems with high DC : AC ratios

SAMPLE 20 MW PV INSTALLATION
Inverter Loading Ratio = 1.45

Annual Lost Production:
1,923,256 kWh

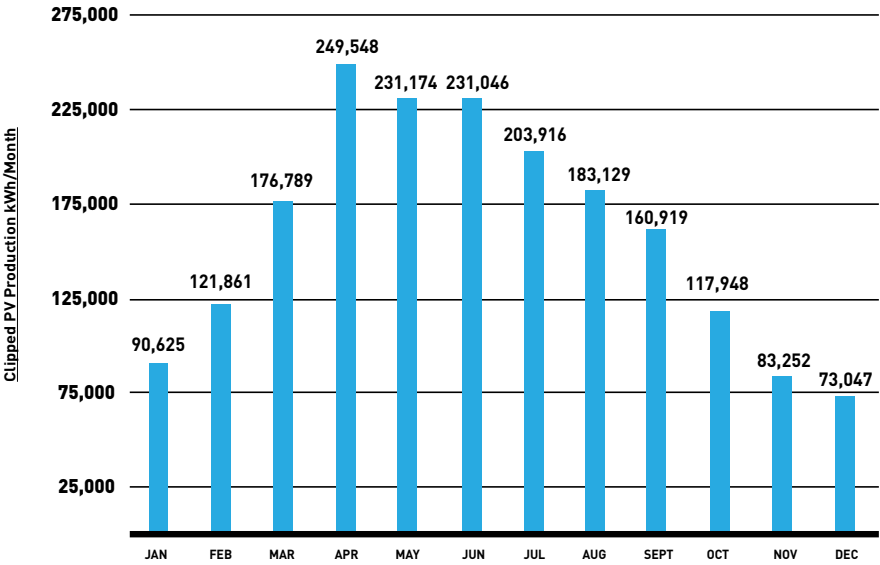


Figure 3: Graph of clipped energy over a year.

CURTAILMENT & OUTAGE RECAPTURE

Continuous Uptime and Revenue Generation

When storage is on the DC bus behind the PV inverter, the energy storage system can operate and maintain the DC bus voltage when the PV inverter is off-line for scheduled or unplanned outages. When the PV inverter is offline the energy from the array can still flow to the batteries via the DC-DC converter ensuring energy can be harvested for later use.

The same uptime capabilities apply when a large utility-scale array is curtailed by the ISO or utility. Curtailment is sometimes seen in areas of high solar penetration — such as California — when there is overall excess production on the grid. With a DC-coupled energy storage system, energy production can continue with energy being stored and available for discharge when curtailment ends.

LOW VOLTAGE HARVESTING

Make Money On The Edges

PV inverters typically require a minimum threshold DC bus voltage to operate. On a 1,500V_{DC} nominal system, this 'wake up' voltage may be around 500V_{DC}. As a result of this minimum voltage threshold, available generated energy in the morning and evening when voltage on the array is below the PV inverter 'wake up' threshold is not captured. **Adding energy storage through a DC-to-DC converter allows for the capture of this generated energy from the margins.**

This phenomenon also takes place when there is cloud coverage. In both cases this lost energy could be captured by a DC-coupled energy storage system.

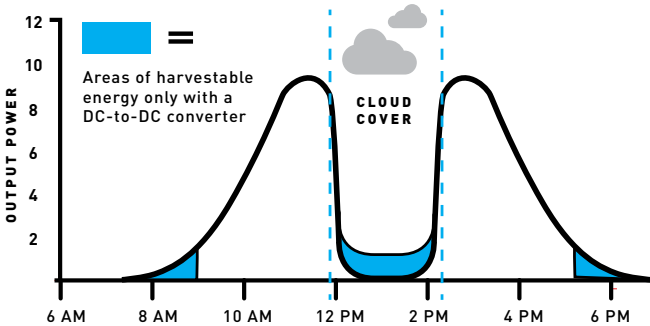


Figure 4

RAMP RATE CONTROL

Modulate Power for Continuous Grid Connection

Ramp rate control is often required by utilities and ISOs for PV and wind systems to mitigate the impact of a sudden injection of power onto the grid or a sudden loss of generation due to the intermittent nature of both generation sources.

A ramp rate of 1MW/minute, for example, has been required by HECO in Hawai'i to limit the rate at which a large array can come up to power or trail off in the event of cloud cover.

A storage system coupled with PV can monitor PV inverter output and inject or consume power to ensure the net output remains within the ramp requirements allowing for continuous energy injection into the grid. Additionally, with this ramp rate control benefit, energy otherwise lost when a PV inverter would self-regulate during a ramp up (by manipulating the I-V curve to curtail power output) can now be stored for later use.

SOLAR PLUS STORAGE SYSTEMS

**AC-Coupled
DC-Coupled
Reverse DC-Coupled**





AC-Coupled Solar Plus Storage

In AC-coupled systems there are two inverters, one for the battery and another for the solar PV system. **With this system configuration the power to grid can be maximized by discharging both the battery and PV at maximum power.** This configuration does pose integration challenges for microgrid operations. Dynapower offers AC-coupled solar plus storage at both behind the meter and utility scale levels.

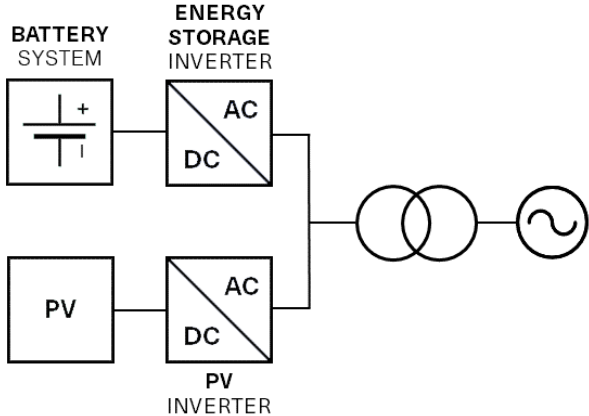


Figure 5: AC-Coupled Solar Plus Storage System



DC-Coupled Solar Plus Storage

The DC-coupled solution is a relatively new approach for adding storage to existing, and new construction solar projects.

Advantages of the DC-coupled approach include lower installation costs by reducing necessary equipment (one set of inverters, MV switchgear and other balance of plant costs), higher efficiency than AC-coupled systems, and increased PV energy generation — from clipping recapture and low-voltage harvesting. DC-coupled solar plus storage also allows for increasing the panel to inverter (DC/AC) ratio to much higher levels than solar only plants.

For more details on the DC-coupled power system for solar plus storage, please refer to Dynapower’s DC-Coupled Solar Plus Storage white paper.

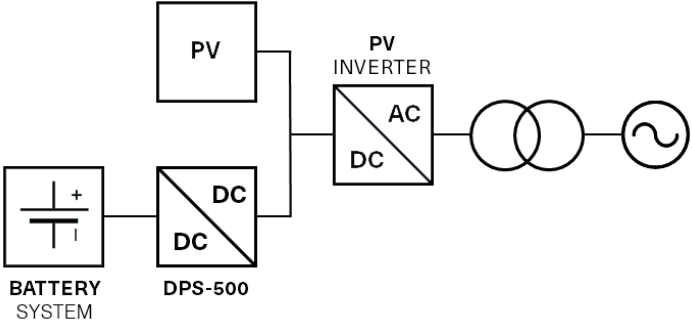


Figure 7: DC-Coupled Solar Plus Storage



Reverse DC-Coupled Solar Plus Storage

Reverse DC-Coupled PV+S ties a grid-tied bi-directional energy storage inverter with energy storage directly to the DC bus. PV is coupled to the DC bus through a DC-DC converter. The Reverse DC-coupled PV+S configuration allows you to operate in off-grid (microgrid) mode by virtue of the AC interface being a microgrid-capable storage inverter.

With a Reverse DC-coupled PV+S system, you enjoy the CAPEX, efficiency and revenue advantages of DC-coupling while enabling a microgrid application with battery backup power traditionally only possible with an AC-coupled configuration.

For microgrids connected to the electric grid and power markets, Reverse DC-coupled PV+S can also

unlock several value streams during times of grid connection including frequency regulation, arbitrage and bulk shifting.

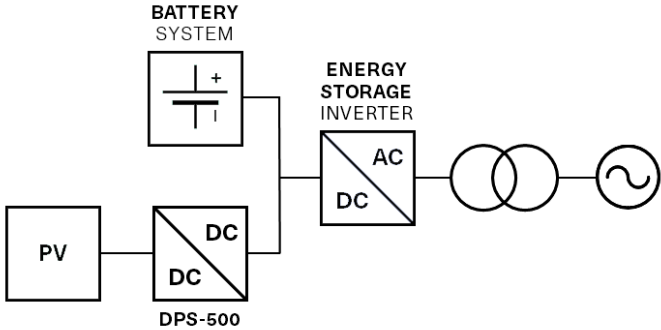


Figure 6: Reverse DC-coupled Configuration

AC-COUPLED / DC-COUPLED / REVERSE DC-COUPLED
System Comparison

	AC-COUPLED	DC-COUPLED	REVERSE DC-COUPLED
Capacity Firming	✓	✓	✓
Energy Time Shifting	✓	✓	✓
Clipping Recapture		✓	✓
Curtailment Recapture		✓	✓
Low Voltage Harvesting		✓	✓
Ramp Rate Control	✓	✓	✓
PV to Grid Efficiency	HIGH	HIGH	MEDIUM
PV to Battery Efficiency	LOW	HIGH	HIGH
Battery to Grid Efficiency	HIGH	MEDIUM	HIGH
Ease of Microgrid Integration	HIGH	LOW	HIGH
Ease of Retrofit to Existing PV	HIGH	MEDIUM	LOW

Dynapower has successfully delivered all three system architectures for our customers in both grid-tied and microgrid applications. When evaluating which of the system architectures is optimal, the options must be compared across a variety of metrics including cost, efficiency, reliability, and flexibility. With more than 15 years of experience and over 900 MWs of energy storage deployed worldwide, Dynapower can assist you in selecting the optimal system for your existing or new PV array.

