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POWERING A CLEANER PLANET™

DC-COUPLED SOLAR PLUS STORAGE

A Guide To Maximizing Production and Profit with a DC-DC Converter

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The United States Has Over

50GW

of Installed Utility-Scale Solar Capacity

Adding Energy Storage with a Cost-Effective DC-to-DC Converter will Maximize Production & Profits of the Installed Utility-Scale PV Base

Traditional storage plus solar (PV) applications have involved the coupling of independent storage and PV inverters at an AC bus, or alternatively the use of multi-input hybrid inverters. Here we will examine how a new cost-effective approach of coupling energy storage to existing PV arrays with a DC-to-DC converter can help maximize production and profits for existing and new utility-scale installations. This new approach leads to higher round trip efficiencies and lower cost of integration with exiting PV arrays, and at the same time opens up new use cases and revenue streams not possible with traditional AC-coupled solar plus storage.

DC-Coupled 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. Six distinct solar plus storage use cases are discussed below. DC-coupled storage allows project owners to access all six of these use cases, and, as compared with AC-coupling, three use cases are only available with the DC-coupled approach — clipping recapture, curtailment recapture and low voltage harvesting.

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. Without energy storage these kWhs are lost and revenues stunted.**

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. **Note that this ability to capture clipped DC output is only possible using a DC-coupled storage system.**

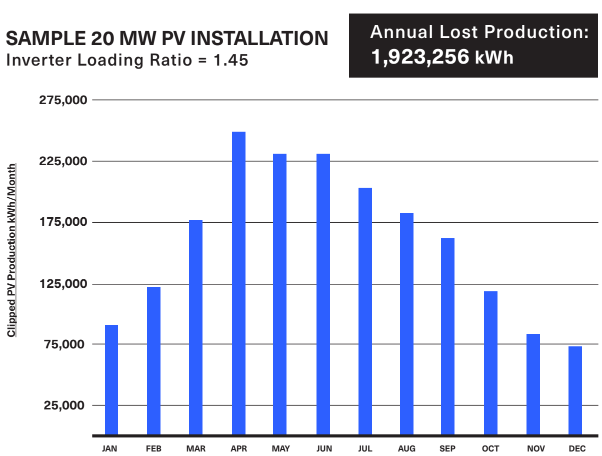


Figure 1: Graph of clipped energy over a year.

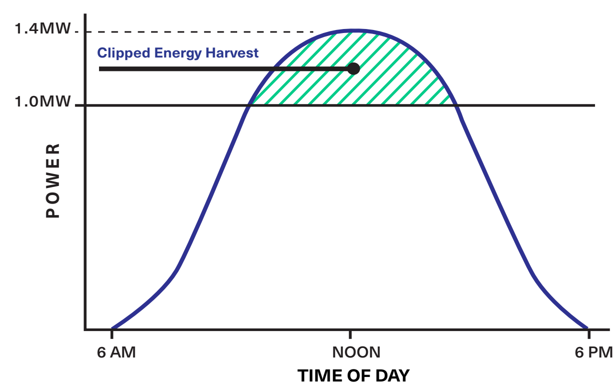


Figure 2: Graph of clipped energy over a day..

Clipping is a phenomenon where the DC-AC PV inverter has hit its peak AC output and therefore must drive the PV DC array voltage off of the maximum power point in order to effectively curtail the PV array. It is not possible to move or shunt this power to an AC-coupled battery system because doing so would force the PV inverter to exceed its rating to pass any excess PV energy onto the common AC bus.

Using a DC-coupled storage configuration, the DC-DC converter charges the batteries directly from the DC bus with the excess energy that the PV inverter cannot use. In the simple example of **Figure 2** where there is a 1MW AC inverter with a 1.4MW DC array, during times when the PV array is producing greater than 1MW DC, excess energy can be used by the DC-DC converter to charge the batteries, then discharged later when the PV output is low or when there is a peak demand on the grid for kWh production.

CURTAILMENT & OUTAGE RECAPTURE

Continuous Uptime

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 or curtailments. Additionally, when the PV inverter is offline or curtailed the energy from the array can still flow to the batteries via the DC-DC converter ensuring energy can be harvested for later use.

This benefit may be particularly valuable 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. As one example, a February 2017 memo from the California ISO warned that with high hydro capacity entering 2017, curtailment of solar and wind at any given time could be up to 6 to 8 GW. With a DC-coupled energy storage system, solar production can continue in that scenario with energy being stored and available for discharge when curtailment ends, mitigating system owner downside for both existing and future projects in such resource rich areas of the grid.

LOW VOLTAGE HARVESTING

Make Money On The Edges

PV inverters typically require a minimum threshold DC bus voltage to operate. As a result, 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-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. This capability is only available with a DC-DC converter that has voltage source capability.

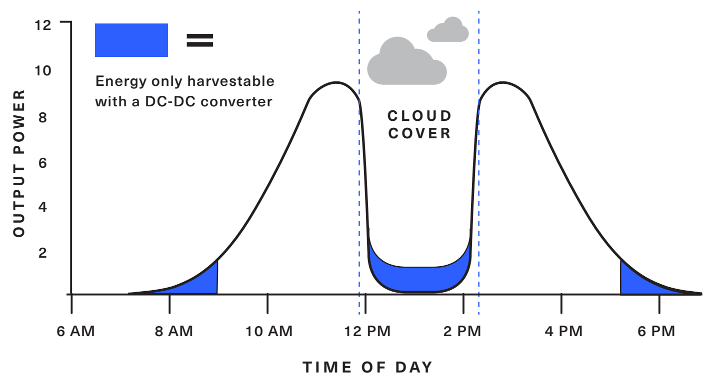


Figure 3: Graph of energy available with low voltage harvesting capabilities.

CAPACITY FIRMING

Turn Solar Energy Into A Dispatchable Asset

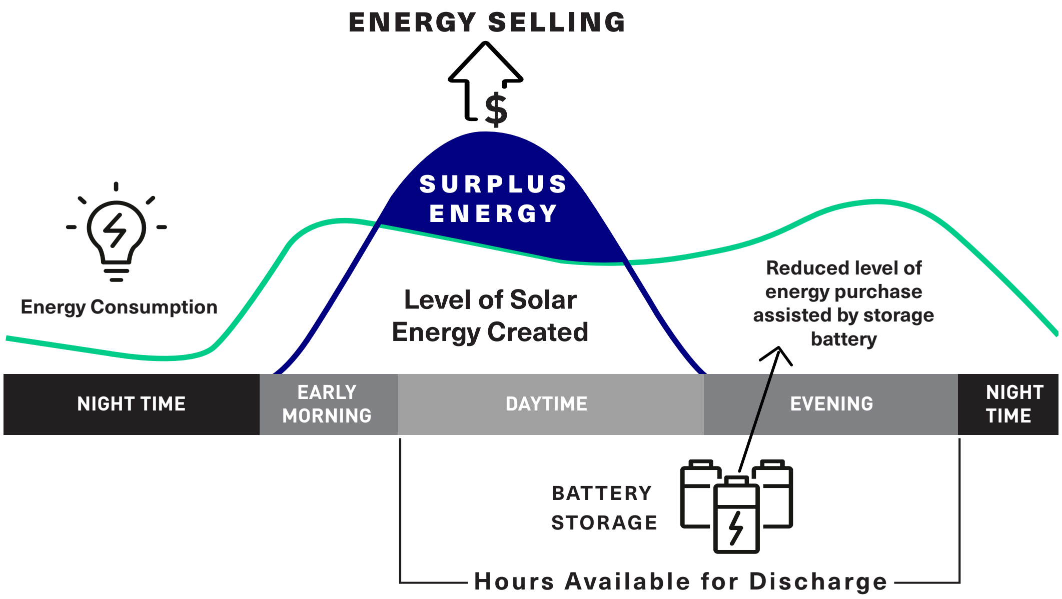
Adding solar to storage gives the system operator the ability to bid firm capacity into merchant markets. That is, storage makes PV generation a dispatchable revenue generating asset. If your storage system is fully charged entering the next 24-hour period, system owners can confidently bid into the day ahead capacity market at any time of day and with no weather contingencies. **Depending on the available local capacity market, this may translate to higher overall system revenue than if operated on a traditional flat $/kWh PPA rate structure.**

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.

Similar to capacity firming, energy time shifting is not unique to DC-coupled systems - however the reduced cost and increased efficiency of a DC-coupled system may make revenue opportunities such as time shifting and capacity firming more economically viable.



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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 Hawaii to limit the speed with 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, 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 be stored for later use.

That is, not only can the storage system provide a regulatory benefit during ramp up and ramp down (PV inverters alone can only modulate ramp up events), but there is some revenue recapture from the storage of the excess energy during ramp up.

Note that the ramp up phenomenon is much sharper on arrays with higher DC:AC inverter loading ratios. One of the desired effects of a large inverter loading ratio is the "boxier" output curve versus the traditional bell shaped curve associated with traditional PV systems with closer to a 1:1 DC:AC ratio. The potential negative is that for grid areas where the ramp up is regulated, there is greater potential loss of otherwise sellable kWh during the ramp up. Therefore, coupling PV with storage provides one more opportunity to optimize revenue from your utility-scale PV array.

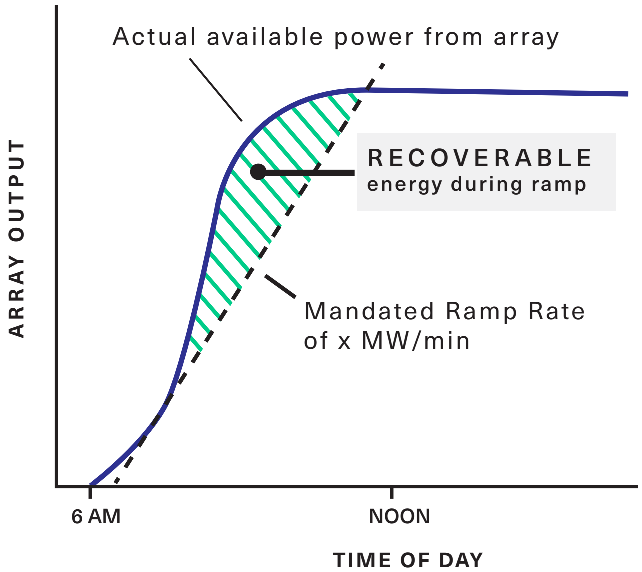

Figure 4: Graph of recoverable energy during ramp.

SYSTEM OPTIONS FOR COUPLING

The Case for Adding DC-Coupled Energy Storage

As noted above, there are three coupling system options for adding energy storage to new or existing solar installations — **AC-coupled, DC-coupled and Reverse DC-coupled energy storage**. Dynapower has extensive experience in developing, manufacturing and deploying inverters and converters for each of these options.

Here we outline the benefits of our latest solution — the DC-to-DC converter — which is particularly suited for adding energy storage to existing utility-scale solar arrays. The battery capacity (MWh) can be scaled according to the site use cases and project economics.

DC-to-DC Converters are the least expensive to install and can provide the highest efficiency and greatest revenue generating opportunity when adding energy storage to existing utility-scale PV arrays.

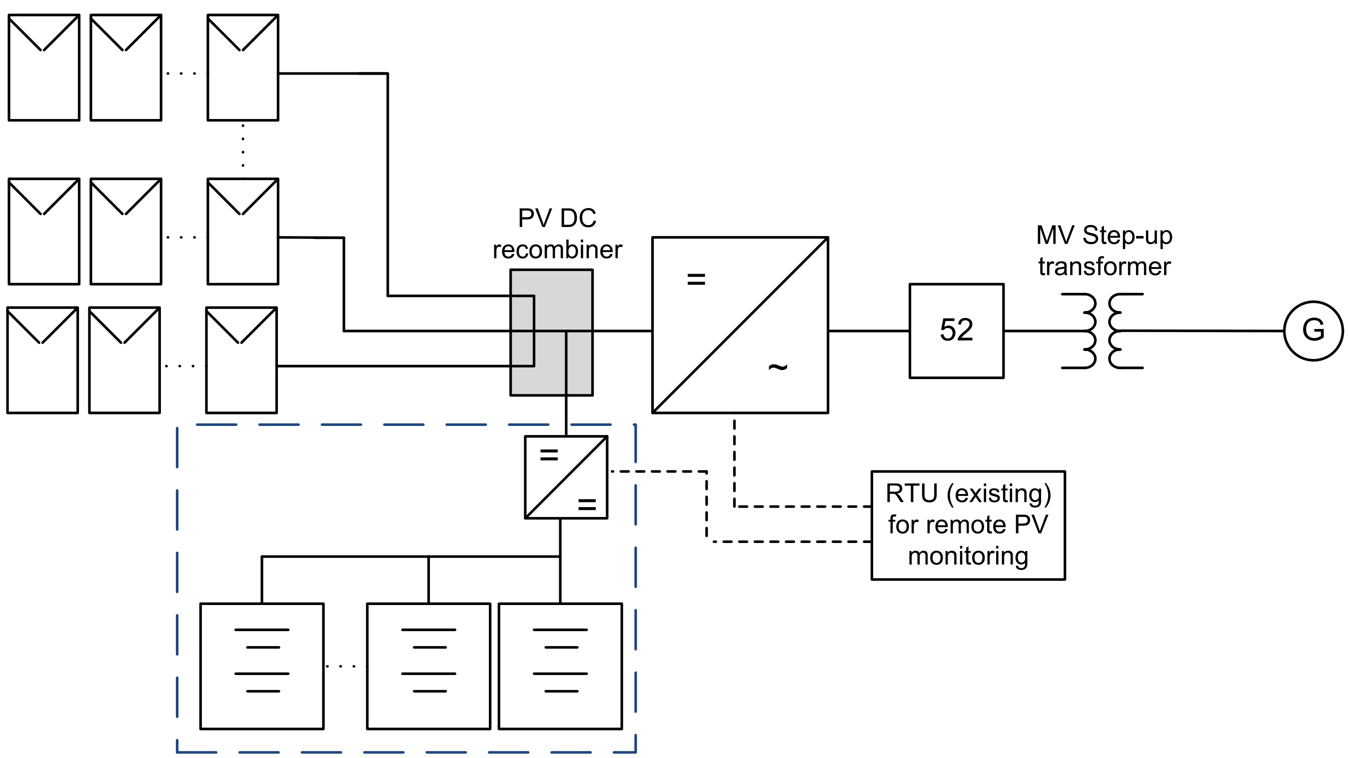

Figure 6: Illustrates the basic design of a DC-coupled system. In this set-up the storage ties in to the system behind the existing PV inverter and combines in parallel with existing PV strings at a recombiner. Depending on the size of the inverter and the use cases, designers can install multiple DC-DC converters in parallel on the DC PV bus.

FINANCIAL BENEFIT #1

Maximize all potential value streams

Of the previous outlined revenue streams available to PV with energy storage, the DC-coupled approach allows for revenues to be derived from all value streams — guaranteeing maximum value from an installed PV array. Not all revenue streams are available to AC-coupled inverter solutions. By virtue of tying in on the AC side of the PV inverter, AC-coupled solutions by definition cannot recapture clipped DC energy, for example.

	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

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FINANCIAL BENEFIT #2

Lower Installation and Regulatory Costs

Secondly, by adding energy storage on the DC PV bus, costs associated with adding energy storage can be greatly reduced. This includes equipment and EPC costs for AC switchgear, MV transformers and associated trenching. Additionally, because none of the system's AC characteristics change, there should be no need for a revised interconnection agreement or interconnection study. For developers familiar with the interconnection study process in many jurisdictions, there is a great benefit of not getting caught in a long interconnection review queue or tying up internal or external engineering resources to guide systems through the process. Likewise, depending on the off-taker, there may be no need to alter an existing PPA.

FINANCIAL BENEFIT #3

Greatest Possible Efficiency

A chief concern with energy storage design for utility-scale PV integration is optimizing for highest efficiency. As illustrated below, the efficiency achieved via a DC-coupled storage system is greater than for AC-coupled. This stems from the avoidance of funnelling power through two MV transformers in the charging process as is required by AC systems.

For the illustrative figures below we have even assumed a slight efficiency advantage in a DC-AC inverter over a DC-DC converter.

DC-COUPLED SYSTEM

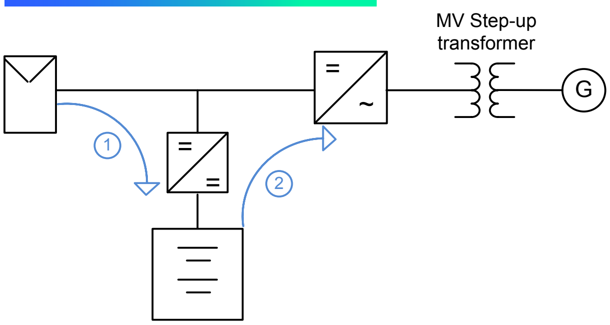

Figure 7: This figure illustrates the charge cycle (1) has single DC-DC conversion, while the discharge cycle (2) has DC-DC and DC-AC conversions and one transformer conversion. The net is 3 power electronic conversions and one transformer conversion in the round trip. Assuming the following efficiencies, the net round trip efficiency = 93.5% (98% DC-DC * 98% DC-DC * 98.4% AC-DC * 99% transformer.)

AC-COUPLED SYSTEM

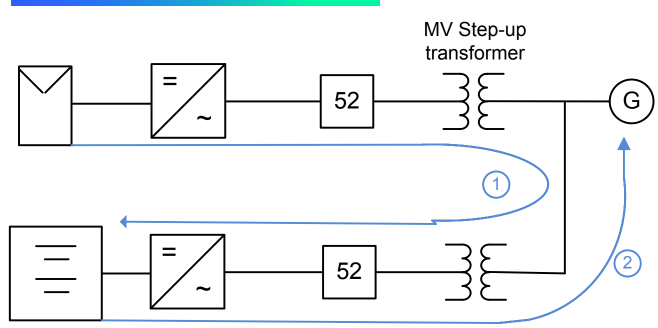

Figure 8: This figure illustrates an AC-coupled system where the charge cycle (1) has two DC-AC conversions and two transformer conversions and the discharge cycle (2) has a single DC-AC conversion and one transformer conversion. The net is 3 power electronic conversions and three transformer conversions in the round trip netting a total efficiency of 92.4%. (98.4% inverter * 99% transformer * 99% transformer * 98.4% inverter * 98.4% inverter * 99% transformer)

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FINANCIAL BENEFIT #4

Qualify for Tax Credits

The ability for a storage system to qualify for the federal PV investment tax credit (ITC) is based on the percentage of the battery charging energy that comes from the PV array. If charged energy from the array is less than 75% of the total for battery charging, then the battery system does not qualify for any ITC benefit. **With a DC-coupled design, the storage system can only be charged from the PV array so there is zero risk of ITC claw back and tax credits are made available to the owner.**

Furthermore, you eliminate the additional metering and controls needed with AC-coupled storage to verify that the batteries are charged from PV energy, further reducing CAPEX.

Conclusion

Dynapower recognizes that each PV installation has its own set of circumstances and considerations. As such we offer a full suite of options — AC-coupled, DC-coupled and Reverse DC-coupled — for coupling energy storage with utility-scale PV installations. The DC-to-DC option can be an attractive option for coupling energy storage with existing PV in many cases. Its ease and reduced cost of installation combined with its ability to bring online all additional value streams make it particularly attractive for the over 50GW of installed utility-scale PV.

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