YASKAWA
SOLECTRIA SOLAR

DC- AND AC-COUPLED PV AND ENERGY STORAGE SOLUTIONS

A DESIGN GUIDE

This document examines DC-Coupled and AC-Coupled PV and energy storage solutions and provides best practices for their deployment.

> In a PV system with AC-Coupled storage, the PV array and the battery storage system each have their own inverter, with the two tied together on the AC side.

> A DC-Coupled system ties the PV array and battery storage system together on the DC-side of the inverter, requiring all assets to be appropriately and similarly sized in order for optimized energy storage and power flow.

OVERVIEW

Mid to large-scale solar is a non-reversible trend in the energy mix of the U.S. and world. Due to the mismatch between the peak of solar energy generation and the peak demand, energy storage projects are essential and crucial to optimize the use of renewable resources.

Although the economic and environmental benefits of PV and Storage solutions have been examined widely, we feel a detailed design guide should be studied and discussed thoroughly to help the deployment.

1. PV SYSTEMS WITH DC- VS AC-COUPLED STORAGE

In a PV system with AC-Coupled storage, the PV array and the battery storage system each have their own inverter, with the two systems tied together on the AC side. The two systems are thus electrically separated, allowing a customer to size each separately. A DC-Coupled system on the other hand, ties the PV array and battery storage system together on the DC-side of the inverter, requiring all assets to be appropriately and similarly sized in order for optimized energy storage and power flow.

Both systems perform the same type functions, as far as the conversion of the DC PV and the control of active Common Coupling (PCC) are concerned. Both systems can be used for demand management, power quality management, and as a non-spinning reserve to the grid.

In an AC-Coupled PV and energy storage solution (pictured in Figure 1, left side), both inverters employed can push power and can absorb or supply reactive power at the same time. The AC-Coupled system can produce peak PV power at the same time as the bi-directional inverter is discharging the full battery power to the grid. Furthermore, the plant's ability to absorb or provide reactive power is the sum of both inverters combined, rather than just that of a single inverter in the case of a DC-Coupled solution.

In the AC-Coupled solution, both PV inverter and battery inverter can be chosen freely in their size. For example a 1 MW battery block could be paired with 10 x 1 MW PV inverters. It is the Plant Master Controller (PMC) that regulates energy flows in and out of each inverter and into the PCC, depending on the use case. It also manages the flow of reactive power, and assigns it to the inverter that has free capacity at the moment. AC-Coupled PV and energy solutions are employed as PV retrofits or where the storage component differs from the PV component widely in power rating.

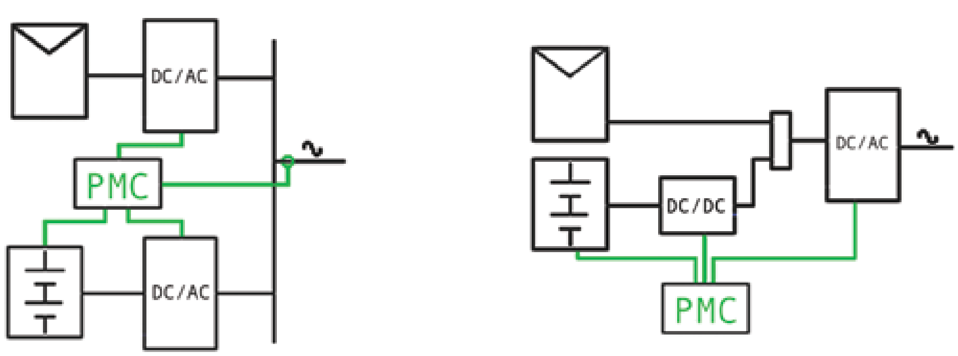

Figure 1: Schematic of a PV system with AC and DC-Coupled energy storage

The main advantage of the DC-Coupled energy storage solution is the ability to PV clip recapture with a higher DC/AC ratio.

However, In the DC-Coupled solution (pictured in Fig 1, right side), the battery and the solar array have to share the same inverter. Therefore, this solution has to be more selective with when each generation component can export power to the grid.

The main advantage of the DC-Coupled energy storage solution is the ability to PV clip recapture with a higher DC/AC ratio. Another major benefit is the smaller size of the inverter per PV Watt. With a DC-Coupled photovoltaic PV storage system, the DC/AC ratio goes as high as 2.5, allowing for a lot of PV power being fed through a relatively small inverter, whereas PV power gets lost in the summer with a PV inverter in an AC-Coupled system, starting from a DC/AC ratio of approx. 1.3.

Let us therefore have a closer look at how the DC-Coupled solution works (Figure 2). The PV strings, the inverter input, and the DC/DC converter are bussed together. Part of the power that is being generated during the day is not exported through the inverter (red), but redirected by the DC/DC converter into the battery on site (blue).

When the inverter has free capacity, such as at nighttime, that stored energy is freed up and fed back to the grid (Figure 3). If the site is subject to time-of-use pricing, the energy discharge can happen when power is most expensive and inverter capacity is left.

In addition to saving PV energy during the day, the converter and the battery also act as an energy storage for the PV power during a grid outage, where that power is lost in a traditional grid-tied system without storage or even in an AC-Coupled system. It is a design choice

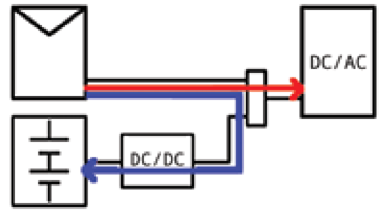

Figure 2: Excess PV power is charging the battery

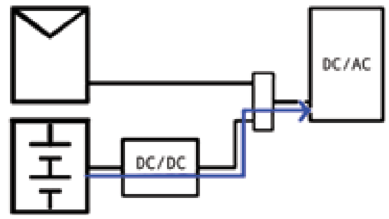

Figure 3: Battery depletion at night

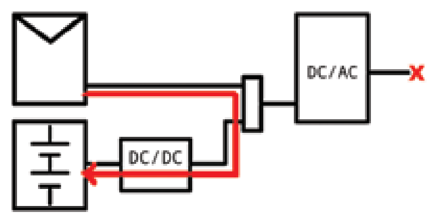

Figure 4: Battery charging during a grid outage

to be able to run the battery cooling system off the battery itself with a small separate inverter, so that continued charging can also take place in hot conditions, without a cooling down time after a grid outage has occurred.

The plant master controller switches between modes by communicating with both the inverters and the DC/DC converter in order to meet plant-wide goals. Power targets can be scheduled or sent by upstream grid operators. If time-of-use programs are in place, the plant controller can prioritize battery charging during the day to maximize the amount of energy to be discharged at a later time. If a plant operator desires a

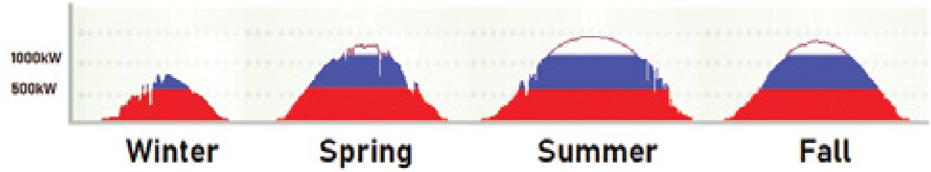

Figure 5: Performance of system with DC/AC ratio 2.5 through the seasons

Instantaneous grid demands, price signals, and utility tariffs are all factors that may be taken into account when selecting an operational mode.

site to hit a particular power target, the plant controller can capture excess PV generation in the battery system or discharge the battery to supplement PV generation, if that generation cannot meet the power target on its own. Instantaneous grid demands, price signals, and utility tariffs are all factors that may be taken into account when selecting an operational mode. Multiple systems can be aggregated and controlled as a fleet for larger sites.

During normal operation, the daily half sinusoid can be split in three parts: inverter capacity (red), DC/DC converter capacity (blue) and power excess (see figure 5). The excess power is wasted similar to an oversized PV array without storage and is much smaller (by the size of the DC/DC converter) than it would be with an AC-Coupled solution. The amount of loading of the DC/DC converter is called the DC/DC utilization ratio.

2. SIZING OF THE SYSTEM

Stringing the PV portion is done much like on a conventional system with storage. The string voltage has to match the input voltage window of the inverter, which in many cases will be the same as if no storage was used. The maximum open circuit voltage cannot exceed 1500 V in the coldest condition and the Maximum Power Point voltage cannot be under the operation threshold for the inverter. The total number of strings is a lot greater, due to the added capacity of the DC/DC converter. The total string currents all have to be safely combined on the common bus that is rated to carry the total load. See Figure 6.

The DC-Coupled system's dedicated DC re-combiner has a number (here 5) of DC inputs that matches the maximum number of combiner boxes that can be connected to it. It has a second type of fused input connection that connects to the DC/DC converter and a fused output that connects to the inverters.

43 Strings of I_{sc} = 9.14 A each (AC-coupled solution or traditional 500 kVA inverter	vs.	133 Strings of I_{sc} = 9.14 A each (DC-coupled solution, same 500 kVA inverter)

Figure 6: Comparison of 320 W modules (non-clipping)

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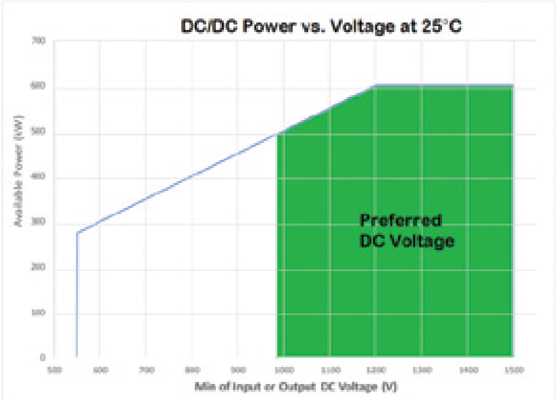

Figure 7: Power throughput capability of a typical DC/DC converter

When stringing the battery we have a lot more choices with a DC-Coupled energy storage system than with an AC-Coupled one.

The battery size (capacity) that is connected to the DC-Coupled system should be chosen such that a full day's energy charges the battery from, for example, 20% to no more than 80% SOC. Contact the battery manufacturer for their recommendations on optimal SOC range. The battery capacity may be additionally limited (as high as 50%) by various factors, such as degradation and seasonal fluctuations in energy production and temperature. Proper battery sizing must account for these limitations to ensure optimal performance. In particular, battery depth of discharge may need to be limited during periods of low solar hours to maintain full charge, and if measures aren't taken to heat batteries in colder months there may be additional capacity reduction. Too small of a battery can result in faster degradation or PV energy that is wasted. Too big of a battery can make the system economics unworkable.

When stringing the battery we have a lot more choices with a DC-Coupled energy storage system than with an AC-Coupled one, since a typical DC/DC converter can take input voltages for 550V to 1400V (see Figure 7).

However, the DC/DC converter is a current limited device and a higher battery voltage and higher PV voltage is therefore advantageous for a higher power throughput.

3. EFFICIENCY

A higher battery voltage is also advantageous for two efficiency reasons: First, the less work the DC/DC has to do boosting the battery voltage to a higher bus voltage, the more efficient it is and, second, the cabling losses are reduced, much like when choosing more panels in series when stringing a PV system.

The first portion of the system's efficiency calculation is straight-forward: All of the power during the winter and, up to the inverter's rating during the rest of the seasons, is simply inverted once. Latest commercial or utility-sized inverters have a CEC rating of 98.5%. However, inverters are typically forced to operate outside of their CEC weighing at full power, it can be assumed that it is running only at 98.0% during the daytime.

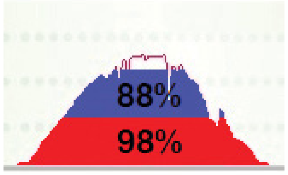

Figure 8: Efficiencies of a DC-Coupled storage system

The total system efficiency depends heavily on the "energy now" vs "energy stored for later" ratio of the system

Lithium-ion batteries have become the most widely used battery technology.

The remainder of the power needs to be stored in the battery temporarily until the inverter's capacity is freed up. Diverting power from the inverter to the DC/DC comes at an efficiency cost. The battery roundtrip efficiency is approximately 93% plus twice the DC/DC conversion loss of 98.2% equals 98.2% x 93.0% x 98.2 %, and then times the 98.0% inverter efficiency to get the power out to the grid = 87.9%. That means that getting the power out directly to the grid in real time is 10.1% more efficient than sending the same power at a later point in time.

The total system efficiency obviously depends heavily on the "energy now" vs "energy stored for later" ratio of said system. In the northeast of the United States that ratio may be 70%/30% and therefore the mixed, weighted system efficiency may be 95.0%.

4. BATTERY

The choice of battery is key to ensure an affordable, reliable, and efficient energy storage system.

Compared to Zinc-hybrid batteries and Redox-flow batteries, Lithium-ion (Li-ion) batteries have become the most widely used battery technology, for their versatility to handle small scale applications as well as grid-scale applications requiring megawatts of power for hours at a time. Lithium-ion batteries are also more efficient.

A few key things are easy to be missed while planning the system:

Operational Temperature

During the cold winter months in the northern latitudes, care has to be taken to heat the batteries sufficiently. No charging is permitted below freezing temperatures, because of the reduced diffusion rates on the anode of Li-ion batteries. In the summer heat the Li-Ion batteries have to be cooled at cabinet temperatures above 50°C, usually by means of a fan, in order to avoid losses in longevity.

Snow Emergency

In the winter, the array may be covered in snow for several days. A smart algorithm in the PMC recognizes this situation and makes sure that the plant wakes up anyway and the battery is ready for

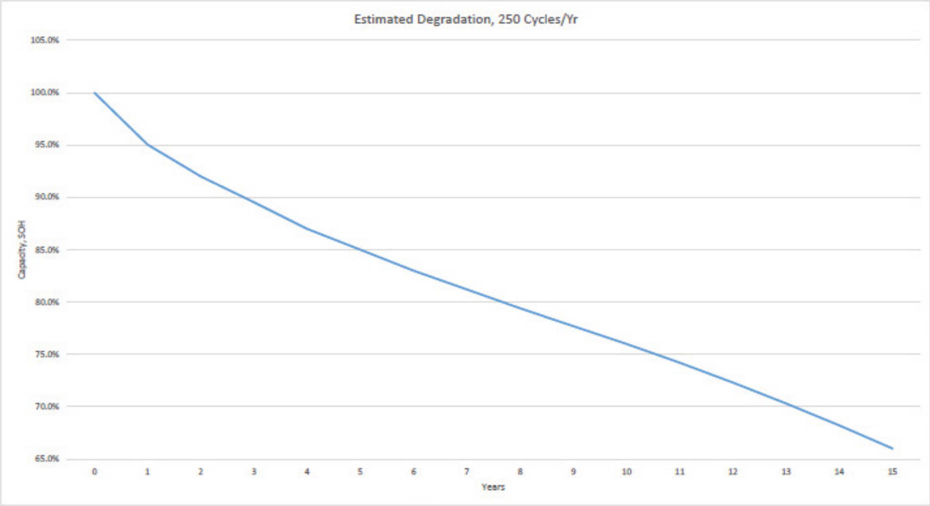

Figure 9: Example Battery Aging

operation, even if little or no voltage is present on the terminals of the PV array. This important feature allows the user to guarantee portions of the total capacity to the utility as a non-spinning reserve, even in a snowstorm.

Battery Aging

A Li-ion battery will always age, due to its nature of innate chemical reactions, so careful examination of the battery datasheet on capacity vs. years or charging/discharging cycles is critical to ensure it meets the requested performance. See Figure 9 for example battery aging data.

Battery manufacturers may provide these degradation curves for their products.

5. CODES/STANDARDS APPLICABLE TO STORAGE SYSTEMS

The codes and standards applicable to energy storage products and systems are intended to safeguard persons and property from hazards that could arise from the use of such systems. The table below provides a summary of the most common codes and standards that apply to energy storage equipment and systems.

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SOLAR INVERTER SAFETY	
UL 1741SA **Inverters, Converters, Controllers and Interconnection System Equipment for Use With Distributed Energy Resources**	These requirements cover inverters, converters, charge controllers, and interconnection system equipment (ISE) intended for use in stand-alone (not grid-connected) or interactive (grid-connected) power systems. Interactive inverters, converters, and ISE are intended to be operated in parallel with an electric power system (EPS) to supply power to common loads.
BATTERY SYSTEMS SAFETY	
UL 1973 **Batteries for Use in Stationary, Vehicle Auxiliary Power and Light Electric Rail (LER) Applications**	These requirements cover battery systems as defined by this standard for use as energy storage for stationary applications such as for PV, wind turbine storage or for UPS, etc. applications.
SYSTEM-LEVEL COMPONENTS COMPATIBILITY AND SAFETY	
UL 9540 **The Standard for Safety of Energy Storage Systems and Equipment**	This standard covers energy storage systems that are intended to receive and store energy and provide electrical energy to loads or to the local/area electric power system (EPS) when needed. This is a system standard, where an energy storage system consists of the energy storage mechanism, power conversion equipment and balance of plant equipment. This standard evaluates the compatibility and safety of these various components integrated into a system.
SYSTEM INSTALLATION SAFETY REQUIREMENTS	
NFPA 70 National Electrical Code Article 706 Energy Storage Systems	This article applies to all energy storage systems having a capacity greater than 1kWh, including systems that are stand-alone and interactive with other electric power production sources. The National Electrical Code provides system and equipment installation requirements to ensure the safety of persons and property.

Table 1: Codes and standards that apply to energy storage equipment

From a reliability and longevity point of view, an important thing to consider is at which time of the day to run off of the battery system.

6. SYSTEM RELIABILITY

Compared to a traditional PV system without storage, three new elements are introduced: the battery (and associated Battery Management System BMS), the DC/DC converter and the Plant Master Controller (PMC). Naturally the corresponding total mean-time-between-failure (MTBF) is going to be lower and more repairs have to be planned over the life of the system. For certain failure modes of the battery or the DC/DC converter, it is crucial that the plant is allowed to operate just on solar power alone until the faulty part in the storage branch is repaired. This does not require the entire plant to be taken down due to a problem with the energy storage system. New battery vendors pop up almost monthly and their BMS and state-of-charge (SOC) predictor may not be ready for prime time. It is therefore crucial to choose your battery vendor not just on price, but also on history, service and support. For the DC/DC converter and the inverter the story is similar. Sourcing equipment from a reputable vendor is important. Most PV inverter vendors give an MTBF that is updated for battery storage applications, with up to twice the run time.

From a reliability and longevity point of view, an important thing to consider is at which time of the day to run off of the battery system. MTBF has a direct correlation to the temperature inside the enclosure where the electronics for the inverter are located. The lower the temperature, the greater the MTBF, while the higher the temperature, the lower the MTBF is. See Table 2 for a "typical" 166kW string inverter

Inverter Temp. (°C)	MTBF (Hours)
25	335537
30	300960
35	264012
40	237217
45	209093
50	181206
55	155921
60	134225
65	112352
70	94020
75	82555

Table 2: Example MTBF with increasing inverter temperature

Therefore, from a reliability point of view, if the inverter runs for roughly 13 hours off of the PV panels on a hot summer day and then at sunset it immediately switches to Battery operation, it is more demanding for the inverter from a reliability/MTBF point of view than first waiting a few hours for the inverter's internal temps to cool off.

The reason for this is: If an Inverter has been operating all day, at the end of the day, even though the outside ambient temperature might have cooled off substantially, the internal enclosure temperature will still be high for at least 2-3 hours after the inverter stops processing power. The thermal mass of larger components like heatsinks, DC bus capacitors, Inductors/magnetics and metal parts will retain the heat for several hours. Because of the inherent relationship between MTBF and temperature, it would be better, if the battery operation would start after the inverter has had a chance to cool. This is something to keep in mind when deciding at which time of the day to discharge the battery. If your particular system must run off of the battery system immediately at

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Electrical stress in a battery system can happen when the battery is charged too rapidly or at a voltage that is too high.

It can also happen when the battery is overcharged or discharged too rapidly.

the end of the day, while the inverters are still pretty hot, it's important to follow all the inverter manufacturer's preventive maintenance schedule to make sure you get the highest longevity out of your hard working inverters.

For example, if a fan is not working properly or the air intake is clogged, the inverter will run at elevated temperatures for longer than it was designed to and this will shorten the life of the inverter.

Failure Modes

The DC/DC converter and Inverter have solid protection circuits to minimize catastrophic failures. Because the PMC is only a logic device and doesn't generate a lot of heat, it should have a pretty high MTBF. Electrical stress in a battery system can happen when the battery is charged too rapidly or at a voltage that is too high. It can also happen when the battery is overcharged or discharged too rapidly. Too many electrical stress events on the battery system will reduce the life of the battery system and in some extreme cases may cause the battery to start a thermal event.

Because Lithium-ion batteries have shown they can ignite long after they have been damaged —hours, days, or even weeks later, it's critical to have a solid and reliable fire suppression system so that if a fire starts in the battery, it doesn't spread to nearby components of the system.

The Heila EDGE plant master controller can be configured to apply a protection and alarm scheme to ensure safe operation of a system. Extreme temperatures, high or low states of charge, grid outages, hardware failures, shorts, and faults detected by the assets will prompt the PMC to take protective actions and alert site owners and operators.

For example, a battery with a very low state of charge will be shut off, while allowing any PV power to continue exporting to the grid. If multiple plants exist on a single site, the site-level coordinating controller will ensure system targets are met through some combination of all plants, adjusting setpoints for individual plants according to the health of each asset. For example, if a certain plant has a faulted battery storage system and cannot export as much power as it could otherwise, the remaining fully functional plants will be commanded to export additional power to make up the difference in order to achieve the site target.

7. ADVANCED GRID SUPPORT FEATURES

Inverters are listed to UL 1741 Supplement A and Supplement B that include a variety of advanced grid support features. The intent of these features is to provide temporary assistance to the local electrical distribution network in the event of a fault or other grid abnormality. These features also help avoid adverse system performance on the distribution network that can often occur when the highly variable power output of a PV system rapidly changes. By offering some support functions, grid operators can rely on these feature sets to help maintain system voltage within acceptable limits and will oftentimes allow certain distribution networks to accept interconnection of significantly more distributed generation compared to networks that do not have these features available.

Section Number	Description
SA8	Anti-Islanding Protection-Unintentional Islanding with Grid Support Functions Enabled
SA9	Low and High Voltage Ride-Through
SA10	Low and High Frequency Ride Through
SA11	Normal Ramp
SA11	Soft-Start Ramp
SA12	Specified Power Factor
SA13	Volt-VAR Mode [Reactive Power Priority]
SA14	Frequency-Watt
SA15	Volt-Watt
SA17	Disable Permit Service
SA18	Limit Active Power

Table 3: List of grid support functions for UL 1741 Supplement A

Voltage ride-through permits the inverter to stay connected if the line voltage measured by the inverters deviates too much from nominal.

There are 10 different features included as part of UL 1741 SA. Prior to these functions being available, inverters were required to have very narrow regions of acceptable voltage and frequency operation. Any disturbance on the grid would cause the inverters to turn off and wait 5 minutes after the system stabilized to nominal conditions before reconnecting. As the amount of inverter based distributed generation increases, the harder it is to overcome the effects from loss of generation following an abnormal condition. If a distribution network has a significant PV capacity, a small fault unrelated to the PV systems can trigger a shutdown of all PV sources connected to the network. These small disturbances can have major impacts if the inverters cannot provide temporary support to the distribution network. Instead of simply turning off every time there is a grid disturbance, the ride through features allow the inverters to support the local network until the disturbance resolves itself or to buy enough time for the network to activate other slower acting protections.

Voltage ride-through permits the inverter to stay connected if the line voltage measured by the inverters deviates too much from nominal. The frequency ride-through feature offers the same benefits but for deviations in frequency.

The automatic control function Frequency/Watt (Figure 10) allows real power (watts) to be injected or absorbed into the system from DERs based on deviations in transmission and distribution system frequency. In this case the inverter will use a set of user-defined control parameters to automatically absorb or inject real power into the system. In under-frequency conditions, real power is injected to the local power distribution system from the inverter(s) to raise the utility system's frequency.

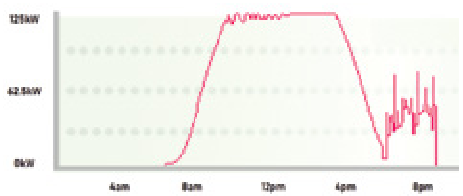

Figure 10: Discharging and charging graphs and frequency response support. Through SolrenView. www2.solrenview.com.

In over-frequency conditions, real power is absorbed from the local power distribution system to lower the utility system's frequency.

The grid support function set also includes three types of reactive power support: fixed power factor, Volt-VAR control, and reactive power priority. The system operator can configure the inverters to operate in one of these modes at a time. Since anti-islanding protection relies on the inverter's ability to vary the reactive power output, some inverters on the market may not be able to simultaneously provide anti-island protection functions and reactive power support. It is important to note that the Yaskawa Solectria inverters are configured to provide anti-islanding protection when these reactive power support functions are activated.

The main benefit of reactive power support is that reactive current in large networks can have a significant impact on the local voltage. This feature can become a critical necessity when large amounts of PV are connected to a feeder. The variable output can cause large variations in local voltage that can add a strain to voltage regulation equipment and cause disturbances to other customers on the network. Reactive current interacts with the inductive nature of distribution wires and can help adjust the local voltage up or down depending on the need.

The main benefit of reactive power support is that reactive current in large networks can have a significant impact on the local voltage.

Generally speaking, an inverter that exports reactive current to the grid will push the local voltage up, and inverters that absorb reactive current from the grid will help pull the local voltage down. The real current output of the inverter will interact with the resistive nature of distribution wires and normal power production will often cause a local voltage rise. The reactive power features of the inverter can counteract this voltage rise and help bring the local voltage to within acceptable tolerances.

Fixed Power Factor

In this example, the local area voltage will often exceed 5% above nominal when the inverters are operational and exporting power to the grid. The voltage is pushed higher the more power the inverters contribute to the grid. When the static power factor feature is enabled, the reactive current will counteract the typical voltage rise and allow the plant to operate within voltage limits regardless of power output. It doesn't take a lot of power to achieve this effect. A 500 kW inverter operating at 0.97 power factor will effectively reduce the real power output to 485kW, but in doing so the inverter will absorb 121 kVAr from the system and allows export vs. tripping due to high voltage. The 15kW is not lost, as it can be directed to battery during the 0.97 power factor operation.

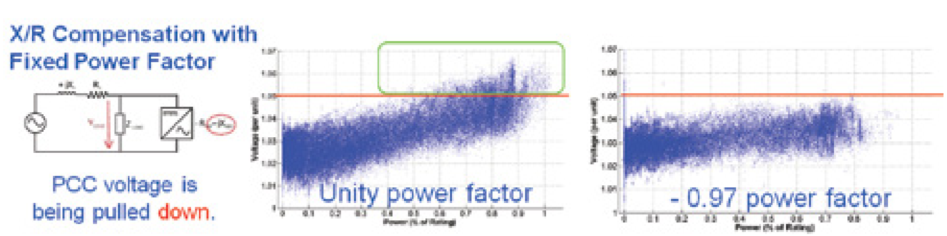

Figure 11: Power Factor Compensation

Volt-VAR not only helps keep the local distribution network voltage within tolerances, it can also significantly reduce the variability in voltage keeping it more constant throughout the day.

Reactive power output configures the inverter to dedicate output current towards achieving a target reactive power output.

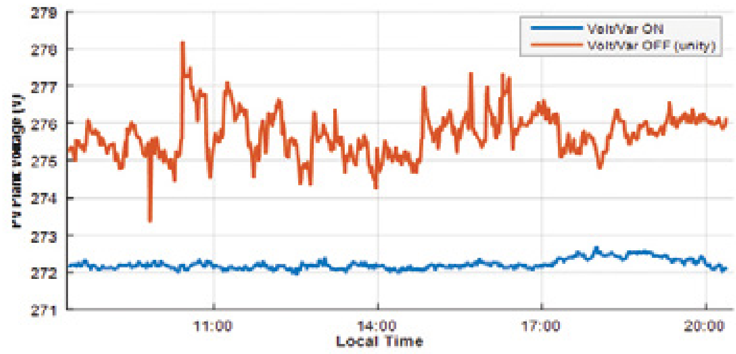

Figure 12: Volt-VAR

Volt-VAR

The second method of reactive power support is an automatic control function named Volt-VAR. In this case the inverter will use a set of user-defined control parameters to automatically vary the reactive current in proportion to how much the voltage deviates from nominal. Small deviations call for a small amount of reactive current, and large deviations call for maximum reactive current. Volt-VAR not only helps keep the local distribution network voltage within tolerances, it can also significantly reduce the variability in voltage keeping it more constant throughout the day.

In this example, the orange line is the output of an inverter with no reactive power features enabled. The voltage often exceeds the 5% over voltage tolerance to maintain grid operation standards and the variability of the voltage has large rapid changes throughout the day. The inverter output in blue has the Volt/VAR function enabled. Not only does the average system voltage decrease to acceptable levels, the variation in voltage through the day is maintained within a very tight range. The inverters are less likely to cause a high voltage trip condition, which would reduce overall production.

Reactive Power Output

The third option for reactive power support is reactive priority mode. This mode configures the inverter to dedicate output current towards achieving a target reactive power output. Whatever output power is not contributing to the reactive power target is the real power output.

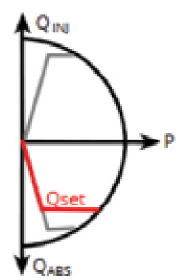

Figure 13: Reactive Power Output

At low current output, the inverter will produce significant reactive power output and minimal real power output. Once the inverter current output achieves the reactive power set point Qset, the inverter will hold the reactive power output at that setpoint and current beyond what is necessary to maintain that setpoint is delivered as real power. This feature allows the inverters to act similar to a switched capacitor bank, voltage regulator, or static var compensator. By varying the reactive power setpoint, grid operators can

The PVS-500 DC-Coupled energy storage system is ideal for new projects that include PV that are looking to maximize energy yield, minimize interconnection costs, and take advantage of the federal Investment Tax Credit (ITC).

control how much reactive power is generated or absorbed by the inverters and can be used to help regulate system voltage. While this feature may not be very useful to an independent distributed generation owner, a utility or grid operator will certainly value the ability to dispatch vars on demand. This feature is incredibly impactful once energy storage is involved, as four quadrant power is available to a utility or grid operator at any time while also avoiding the costs of dedicated voltage regulation equipment.

The Heila EDGE plant master controller can be configured to automate the enabling of these advanced grid support features and prevent conflicting modes from being enabled on an inverter simultaneously. For example if the local area voltage exceeds 5% above nominal when the inverters are operational and exporting power to the grid, the Heila EDGE controller could automatically enable static Power Factor Mode to allow the plant to operate within voltage limits regardless of power output. Additionally, in this case if an operator then enables reactive priority mode, the Heila EDGE could automatically disable Static Power Factor mode to prevent any ambiguous or conflicting mode states on the inverter.

8. WHAT YASKAWA SOLECTRIA SOLAR OFFERS

Yaskawa offers two different 500kW systems for battery energy storage, the PVS-500 for battery storage DC-Coupled with a PV array, and the ACS-500 for battery containers.

Each of these products includes three XGI 1500 166kW inverters, a DC combiner that distributes the DC inputs to the 3 inverters, a fused AC panel that collects the output of the three inverters, and plant control hardware provided by Heila Technologies.

The PVS-500 DC-Coupled energy storage system is ideal for new projects that include PV that are looking to maximize energy yield, minimize interconnection costs, and take advantage of the federal Investment Tax Credit (ITC). The components related to charging and discharging of the inverters are all managed with hardware on the DC side of the inverters. The DC charge controller provided by Dynapower, the DPS 500, acts as an intermediary between the MPPT voltage operation of the inverters and the charge/discharge voltage point of the batteries.

The ACS-500 AC-Coupled energy storage system is an excellent choice for new projects that don't include PV, for existing PV plants that want to add energy storage capabilities without disturbing the existing inverters, and for projects where the batteries cannot be easily collocated near the PV inverters. The ACS-500 includes the same inverters as the PVS-500, a DC combiner to distribute the battery power to the three inverters, a fused AC panel to combine the output of the three inverters.

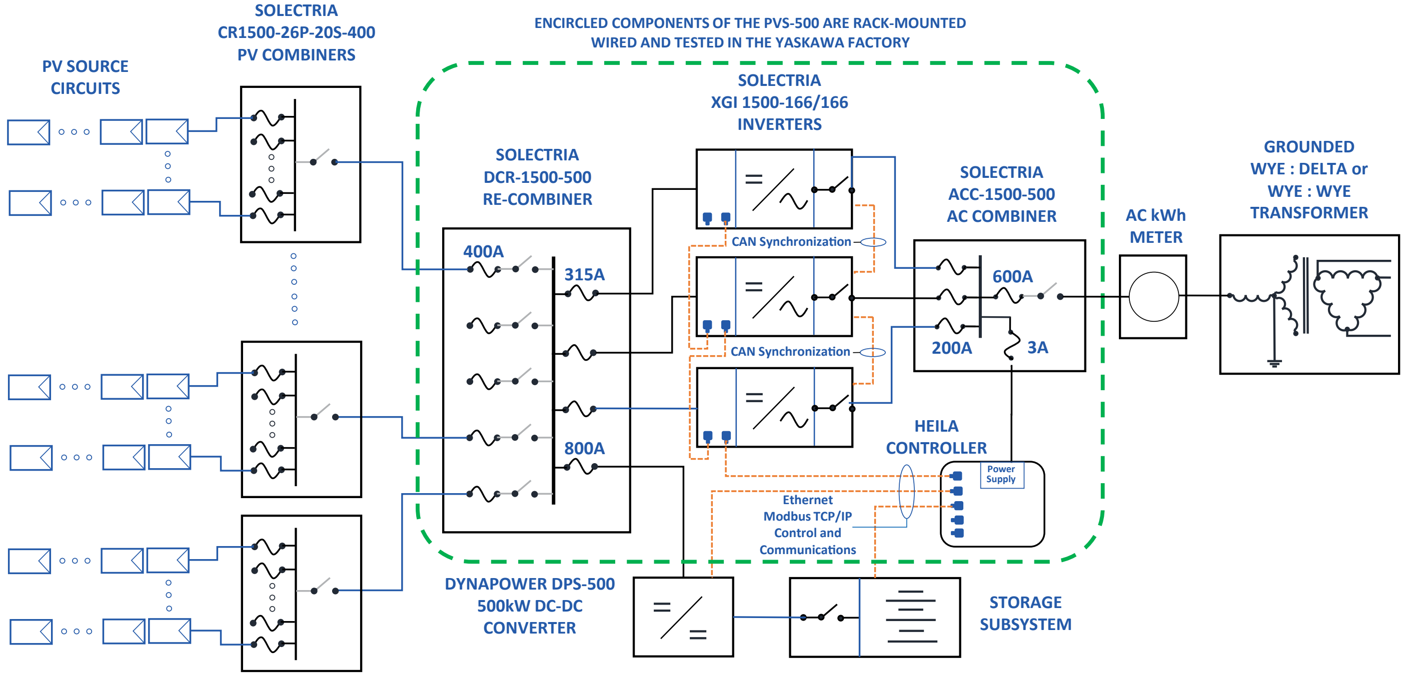

Figure 14: PVS-500 DC-Coupled Storage

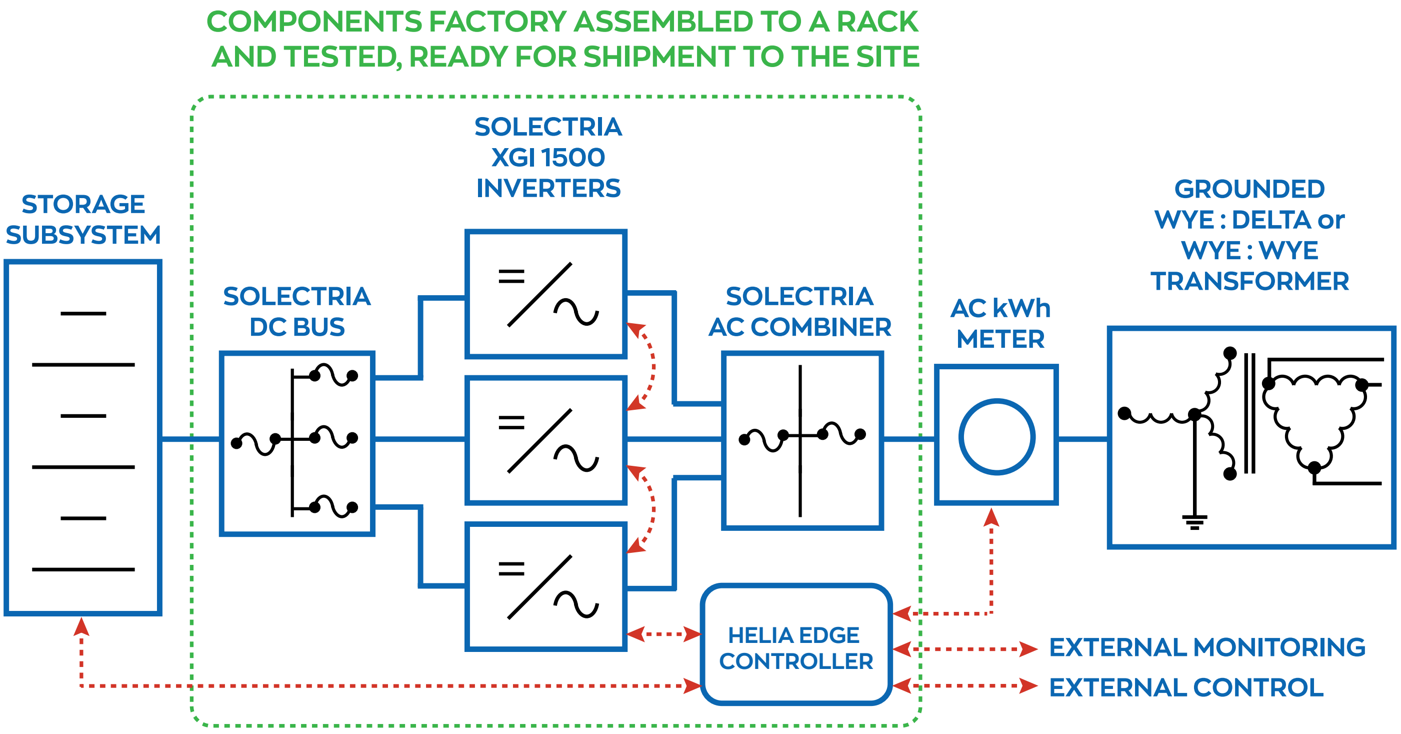

Figure 15: ACS-500 AC-Coupled Storage

PVS-500

- Maximize energy yield
- Simplified interconnection
- Lower power electronics cost
- PV Peak (recapture)
- Retain tax incentives

ACS-500

- Implement storage without PV generation
- Add storage without disturbing existing inverters
- Projects where batteries cannot be located near PV inverters

YASKAWA SOLECTRIA SOLAR

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This white paper is the result of the collaboration between Yaskawa America, Inc. and Heila Technologies.

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Yaskawa Solectria Solar is a wholly-owned subsidiary of Yaskawa America, Inc. and the largest inverter manufacturer based in the USA, with headquarters in Lawrence, MA, and world-class production facilities in Buffalo Grove, IL and Oak Creek, WI. Solectria's products include inverters ranging from 25kW to 250kW, string combiners and web-based monitoring for all size solar systems. All of Solectria's three-phase utility inverters are made in the USA with global components and meet the Federal Acquisition Regulations (FAR) definitions of a Commercial Off-The-Shelf (COTS) item. This also qualifies our Solectria inverters as domestic end products, compliant with the Buy American Act (BAA). Solectria is backed by Yaskawa, with over 100 years of power electronics and inverter experience and continues to build the highest quality solar inverters and provide new innovations for the marketplace.

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