Application Note

AC Coupling

using the OutBack Power Mojave™ Inverter

Objective of this Document

This application note explains a technique called AC Coupling, whereby a non-storage-based grid-dependent inverter (GDI) can be connected with an energy storage system (ESS) like OutBack Power's Mojave™ inverter. This provides energy storage for both retrofit and new photovoltaic (PV) systems plus storage applications.

Introduction

Adding storage to a GDI with the Mojave™ inverter provides backup power and energy management that would not otherwise be possible. Connecting OutBack Power's AC coupling system with a GDI utilizes a frequency shifting technique ("Freq/Watt") that safeguards battery bank overcharging by closely regulating voltage and current limits. Advanced sense circuits and software rapidly increase and decrease the inverter output frequency providing a well-regulated power output from the GDI. The result is an industry-leading, high-performing AC coupled system that can both extend the life and protect the battery bank from overcharging.

The Mojave™ inverter's advanced grid management can also significantly reduce utility bills by regulating the grid connection so expensive utility rates can be mitigated or avoided altogether. OutBack Power's legacy inverter systems, as well as many competing AC coupled inverters, did not have the battery charging performance that would allow daily battery cycling without compromising battery life. Many of the lead acid battery types could tolerate a few days or even a couple of weeks per year of poorly regulated battery charging. However, that is not the case with the advent and popularity of lithium batteries that require much tighter voltage regulation. The Mojave™ ESS with its high-performance, high-cycle lithium battery, can handle the AC coupled daily cycling that is required for extended backup, sophisticated energy management and even off-grid applications, providing a much shorter return on investment for a solar-plus-storage ESS.

Enhanced Battery Protection

The Mojave™ inverter's advanced internal power flow does not only provide valuable grid management capabilities. It also provides enhanced battery protection over the classic H-bridge design that many battery- based inverters are using, including OutBack Power's legacy inverters. When grid-connected in the "pass through" mode that includes both the export and import of power to/from the grid, the inverter is regulating current, while the utility is regulating the voltage. In an off-grid mode when disconnected from the utility, the inverter must then regulate the voltage as the new power source, while the current is regulated by load demand.

Since the H-bridge design is bidirectional for battery charging as well as inverted AC to power loads in the off-grid mode, excess power from the GDI will flow backwards against the intended direction when the battery is full and there is not enough load demand to consume it. This can lead to overcharging of the battery, which is a potentially hazardous situation. There are various methods to overcome that backward flow to the battery when it is full. The various methods include: blackout relays to open the current path to the battery, diversion loads to consume the extra energy and a frequency shift technique that the Mojave™ inverter also employs to curtail the output of the GDI.

The Mojave™ inverter also has a very fast-reacting Freq/Watt circuit that provides very good battery voltage regulation, allowing for three-stage lead-acid battery charging. Additionally, the Mojave™ inverter employs a nulling circuit that senses when the battery is full — either through the depletion of the charge timers, return amps, state-of-charge (SOC) readings, or some combination thereof — and then uses the battery shunt to "null" or zero the current going into/out of the battery. This circuit ensures that the battery is not overcharged, but ready to discharge if load demand requires it. This function not only provides additional protection, but increased performance as well.

Theory of Operation — Live Grid

Figure 1 shows the current path for a normal GDI from the PV panels through the inverter, to the main service panel and on out to the grid. In a typical GDI application, power produced from the PV array is consumed by loads connected to the main service panel with excess power going out to the grid. However, with grid loss the GDI has no way to synchronize itself to the grid, a requirement for operation — so it shuts down and is unable to use any renewable energy (RE) from the PV array.

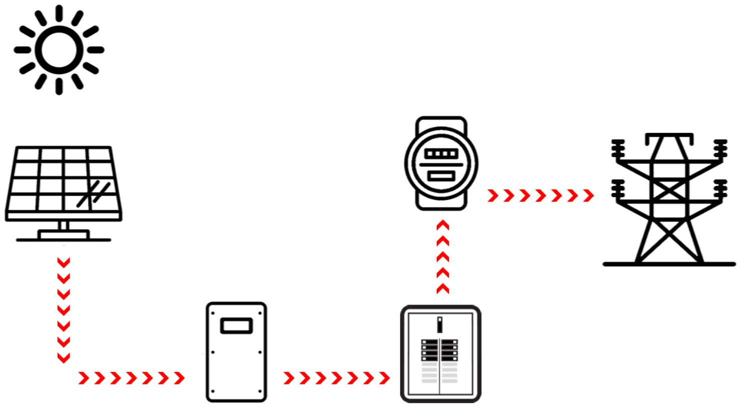

Figure 1 – Normal GDI Power Flow

By connecting (coupling) the output of the GDI to the Mojave™ inverter output (see Figure 2), the Mojave™ inverter can act like a grid source during a power outage. The GDI can synchronize to this source and process power from the PV array to a backup load panel. The backup load panel is required so loads can be powered from either or both inverters without back feeding the main panel during a grid outage (see next section on Grid Outage operation). Figure 2 shows the new current paths from the PV array which now includes the backup load panel, the battery bank, as well as main service panel loads. RE will continue to the power grid if any excess PV power has not been consumed onsite.

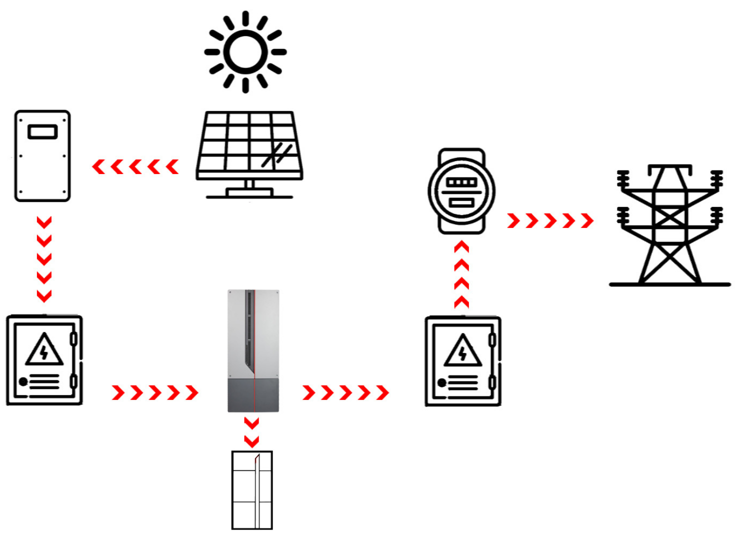

Figure 2 – GDI Power Flow with Active PV

IMPORTANT:

The Mojave™ inverter can AC couple up to 7.6 kVA of the GDI output power. Any combination of either the GD inverters or the PV arrays must be sized no larger than 8 kW. Exceeding this number can cause unexpected behavior and poor performance, as the Mojave™ inverter is not rated to handle more than this amount of power.

IMPORTANT:

In a live-grid AC-coupled application, the Mojave™ inverter does not export power. It simply acts as a conduit for the GD inverter to export power. Also note that the Mojave™ inverter has no control over the operation of the GD inverter while both are on-grid. The GD inverter will deliver the maximum available power unless installed and programmed otherwise. If it is necessary to reduce the exported power, see the GD inverter literature for appropriate settings and installation instructions.

In addition to passing GDI current to the main service panel, a separate parallel current path to charge the battery bank from PV power is possible if either the ***Refloat*** or ***Rebulk*** charging voltages are reached. However, with a live grid and no PV available, the backup load panel and battery charging (if needed) will be powered from the grid as shown in Figure 3 (unless the Mojave™ inverter's ***Charge from grid limit*** setting has been set to zero to prevent battery charging from the grid).

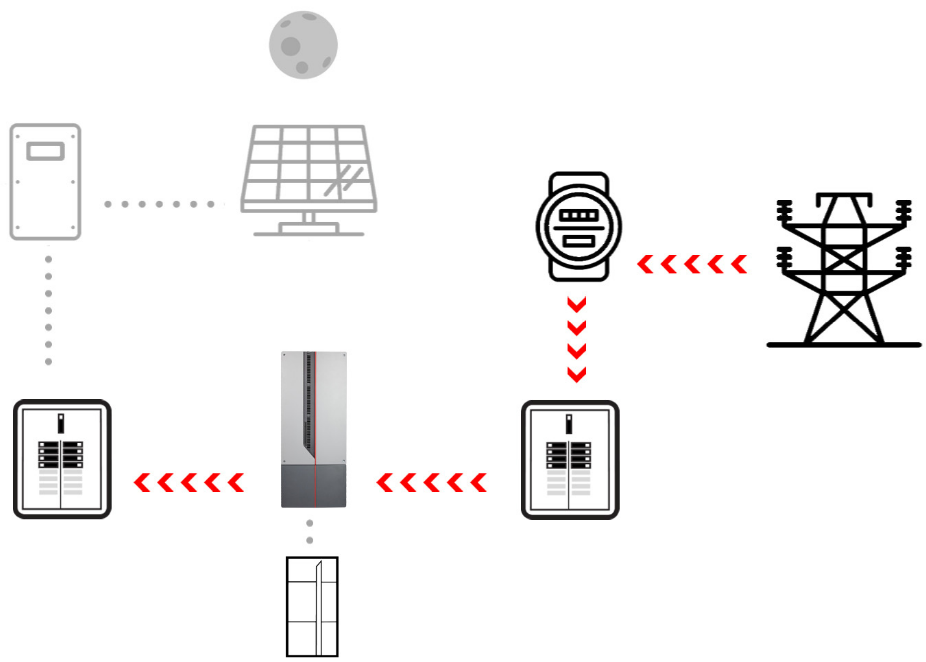

Figure 3 – GDI Power Flow without PV

Theory of Operation – With Grid Outage

During a grid outage when the sun is shining, the Mojave™ inverter becomes an AC source to which the GDI can synchronize (Figure 4). This allows the PV power to flow to the backup panel's protected loads, as well as charge the batteries if the GDI is generating more power than can be absorbed by the loads.

Figure 4 shows all possible current flows, the paths of which can change depending on several factors. If the PV generation can satisfy the backup panel and battery charging loads, then PV power flows in those two directions. If the backup panel load demand exceeds the GDI power generation, then the Mojave™ inverter will stop charging the battery (if Absorb or Float charging is active) and invert DC power from the battery bank and contribute current to the backed-up loads in parallel with the GDI.

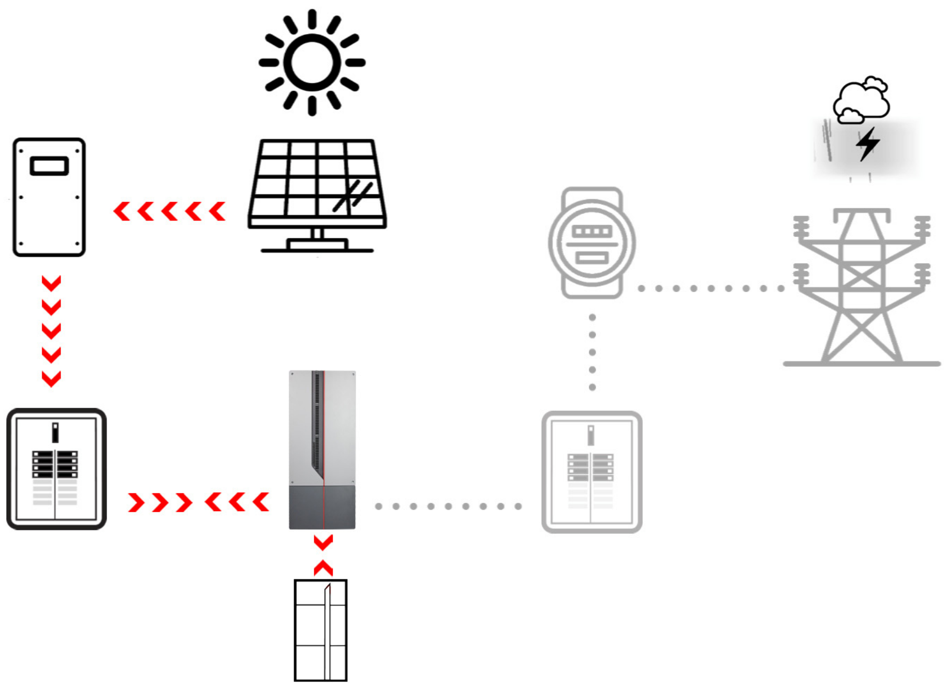

Figure 4 – AC Coupled current flows with sufficient load or battery charging demand

If the batteries become fully charged and the load demand falls below the GDI power production, then that excess energy will be curtailed using Freq/Watt regulation. When the battery voltage raises more than 0.4 volts above the active charging voltage target, then the Mojave™ inverter begins to shift its output frequency above 60 Hz until the battery voltage starts to level or drop off, but not above 64.5 Hz. The inverter's frequency shift regulation will also be enabled if the DC charge current coming back onto the battery bank exceeds the ***Max charge current*** setting.

> **EXAMPLE**: There is a grid outage and the Mojave™ inverter becomes the new AC source for the GDI which then delivers 3400 watts to the load. The load then drops to 1,000 watts, meaning the other 2400 watts (50 Adc at 48 Vdc) will come back through the Mojave™ inverter to the battery bank. If the 50 Adc GDI charging current is less than the ***Max charge current***, then it will continue delivering charge current to the battery bank. If greater than the Max charging limit, the Mojave™ inverter output frequency will start to rise until the GDI reduces its output if Freq/Watt compliant, or just go offline if non-Freq/Watt compliant. If the Mojave™ backfeed current to the battery bank stays below the ***Max charge current***, but the battery voltage eventually rises above the active voltage target (Absorb, Float or Sell), then frequency shift will also be enabled.

There is a significant installed base of non-Freq/Watt legacy GDI products that will simply go offline and wait to reconnect for the time specified by the local jurisdiction (usually 5 minutes in North America). Newer Freq/Watt compliant inverters conforming to UL 1741 SA or SB, will actually "feather" back their output to allow some degree of charging regulation to the battery bank. Depending on the difference between load demand current and GDI output current, this feathering back of the GDI output will usually prevent shut down of the Freq/Watt compliant GDI.

NOTE*: Not all UL 1741 SA/SB compliant GDI products react as fast as others, so the degree of voltage regulation can vary amongst these inverters. Load demand, battery bank size and present SOC will also factor into the degree of regulation.*

Should the GDI go offline, then the Mojave™ inverter is powering the loads as in the backup mode of operation. See Figure 5. After the reconnect time period, the GDI will try to reconnect to the Mojave™ inverter's output voltage where the cycle would repeat again until the load or battery charging demand increases, or PV production goes down, or some combination thereof.

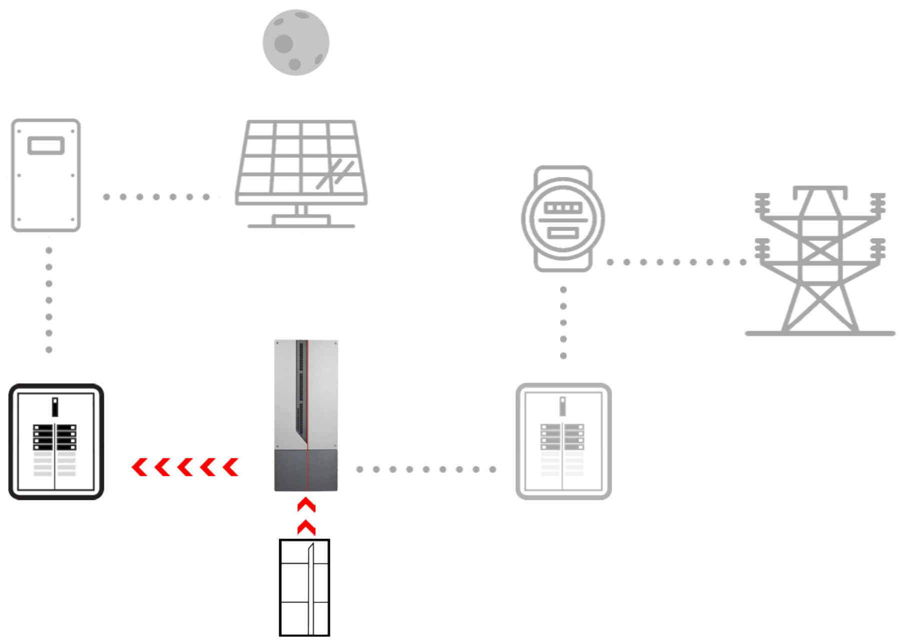

Figure 5 – Off-grid current flow due to PV loss or GDI power overcharging battery bank

Once PV production is gone for the day, the Mojave™ inverter will power the loads in the backup mode until the sun returns the next day, or the battery bank reaches low battery cutout (LBCO) for lead-acid batteries (or ***Min SOC*** if the Mojave™ ESS is in use). If the battery bank reaches LBCO, then the Mojave™ inverter can no longer power the backed-up loads or be a voltage source for the GDI to start again and recharge the batteries. The Mojave™ inverter will continue to discharge the batteries during LBCO as the inverter standby mode still uses power even when disconnected from the loads.

To recover the Mojave™ lithium battery, connect an AC source to the Mojave™ **GRID** or **GEN** inputs, and begin AC coupling PV power through the GDI again. More details about the Low SOC Recovery procedure can be found under **Battery Troubleshooting** in the *Mojave™ ESS Operator's Manual*.

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Solution

Hardware Connections

Setting up the GDI for AC Coupling operation with the Mojave™ inverter requires a connection between the AC outputs of the two inverters. This connection is normally made in the backup load panel which is shown below in Figure 6.

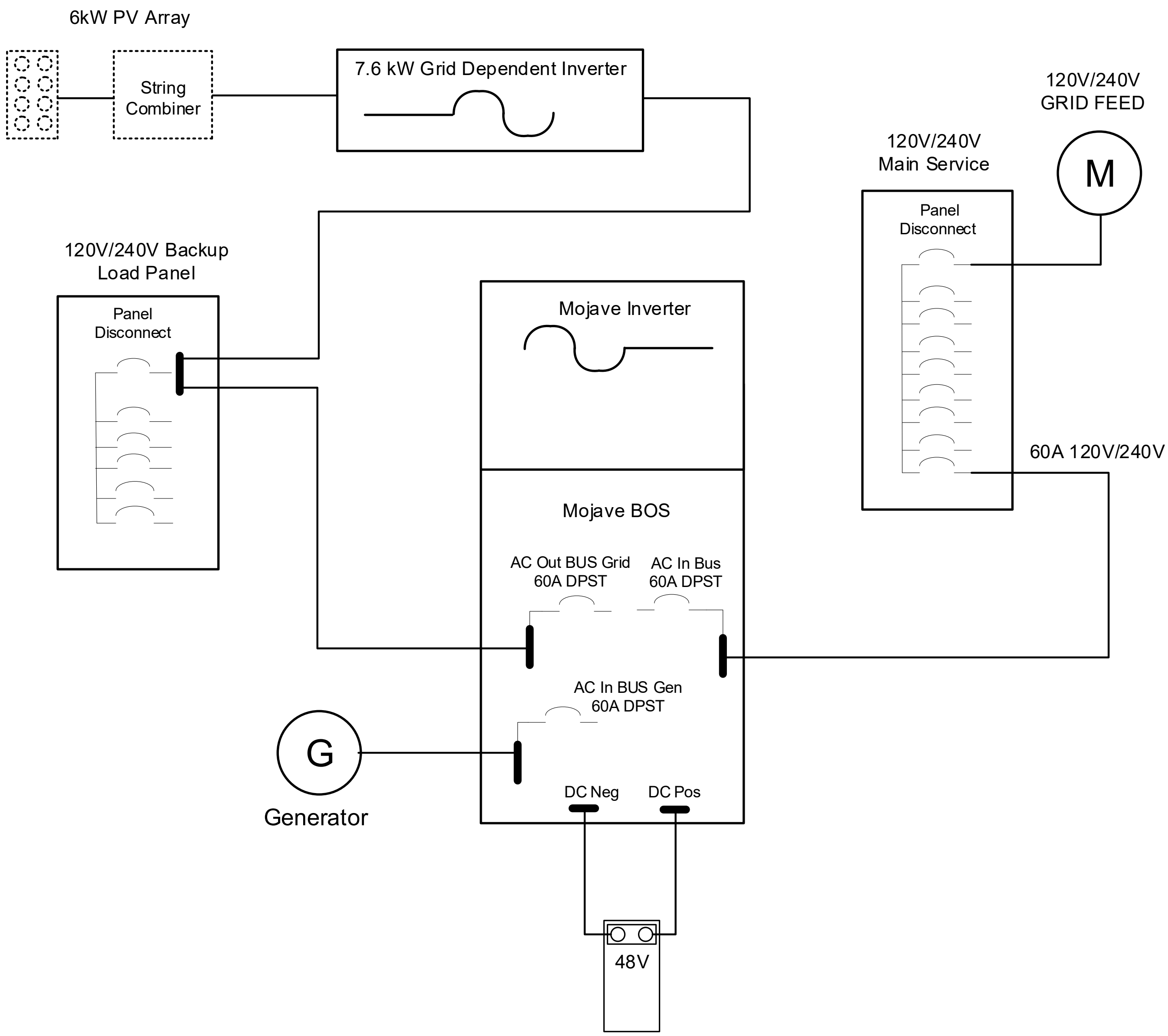

Figure 6 – Single line diagram of GDI inverter connection to Mojave™ inverter

Procedure

Programming Mojave™ Inverter Settings for AC Coupling

1. Program the **Inverter** settings as described in the *Operator's Manual* per the application requirements. See the *Smart Grid Management* applications note for examples of grid management such as time of use (TOU), grid important limit (peak shaving), no grid charging, and whole house self-consumption using external current transducers (CT).
2. Program the **Battery** settings by selecting one of the whitelisted batteries on the ***Battery Model*** drop-down menu. For batteries not listed on the drop-down menu, set the ***Min*** and ***Max SoC*** settings per the battery manufacturer's recommendations and/or personal preference for backup power capacity. Set ***LBCO*** to optimize the battery bank's cycle life and to prevent complete discharge of the batteries. Accurate settings for the ***Absorb end amps***, ***Charge efficiency***, and ***Temperature compensation*** are essential to achieve maximum battery capacity, performance and longevity of the batteries.
3. Program the **Grid** settings as described in the ***Operator's Manual*** per the application requirements. Select the appropriate ***Grid Profile*** per the local utility's connection agreement.
4. If a generator will be used, the **Generator** settings can be programmed as described in the *Operator's Manual*. It is important that the generator be connected to the generator input ***only***. Never connect to the generator to grid input!

   The generator connection is made through a 60 Aac DIN mount circuit breaker (not supplied, but available from OutBack Power). The generator circuit breaker can be installed on the same DIN rail as the **AC GRID INPUT** and **AC OUTPUT** circuit breakers in the Mojave™ inverter's wiring compartment.

Setting up the GDI for AC Coupling

1. Set the GDI Grid Profile to the local utility's recommendation. If the site is in California or Hawaii, then use those settings as appropriate. Some GDI products have grid profile settings that allow Freq/Watt control such as IEEE-1547-2018, which is also Freq/Watt compliant. Some older products are IEEE-1547-2003 and will abruptly shut off the GDI when it reaches 60.5 Hz. For better-regulated off-grid charging, program the GDI using a Freq/Watt-compliant grid profile.
2. Many utility jurisdictions don't allow RE export, or the RE production credits are so low that RE export is not desired. Therefore, most modern GDI products will have non-export modes whereby RE production can be self-consumed on-site.

   Please note: the Export limit setting of the Mojave™ inverter is unable to control RE exporting when AC coupled. The ***Export limit*** setting is only valid for DC coupling RE production from the DC input through the inverter's active power circuits to the AC input. DC coupling is not currently implemented with the Mojave™ inverter.

Summary

The Mojave™ inverter's high-performing power regulation provides superior charging and battery protection than many other AC coupled RE storage solutions. The ToU scheduling coupled with its ability to prevent charging from the grid, and other energy management features, makes the Mojave™ inverter a utility friendly solution, with higher utilization of stored energy for faster system payback.

Power grids are becoming more unpredictable with the increased frequency of utility shutdowns, as well as more utilities utilizing expensive rates to reduce peak demand. Adding the Mojave™ ESS to an existing grid-dependent inverter will provide secure and cost-effective power.

About OutBack Power

OutBack Power is a leader in advanced energy conversion technology. OutBack Power products include true sine wave inverter/chargers, maximum power point tracking charge controllers, and system communication components, as well as circuit breakers, batteries, accessories, and assembled systems.

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