Application Note

AC Coupling with Time of Use (TOU) using the Mojave™ Inverter

This application note explains how to set up a connection technique called AC coupling. In AC coupling, a non-storage-based grid-dependent inverter (GDI) can be connected with an energy storage system (ESS) like the Mojave inverter from OutBack Power™. This note also discusses Time of Use (ToU) with the Mojave inverter for utilizing onsite renewable energy during expensive peak demand rate periods.

Introduction

Adding storage to a grid-dependent system with the Mojave inverter provides backup power that would not otherwise be possible. Connecting an AC-coupled system with a GDI utilizes a frequency-shifting technique that safeguards overcharging of the battery bank 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 a high-performing AC-coupled system. This is particularly true in the case of a Freq/Watt-compliant GDI that responds to closed-loop control.

The Mojave inverter's advanced grid management can also significantly reduce utility bills by regulating the grid connection so that expensive time-of-use rate periods are avoided. After entering the time window of the rate period to be avoided, the inverter does the rest. Additionally, some utilities do not allow grid charging of the storage system batteries. For these applications, the Mojave inverter's ***Charge from grid limit*** can be set to zero.

The aforementioned cases assume the renewable energy (RE) site has a net metering agreement with the local utility that exports any unused power back to the utility grid. The AC coupling technique that has been discussed is only implemented when the grid is down. However, some site owners are unable to obtain a connection agreement. In other cases, the RE export credit is so low that by need or preference, the site owners would like to self-consume all available RE.

Since the Mojave inverter's output and input are connected only through the internal grid relay, it's not possible to manage the GDI output when grid-connected — only when the system is off-grid, using frequency shifting. Therefore, any self-consumption or non-export function when grid-connected will need to be managed by the GDI itself. In this situation, when the grid is live, the Mojave inverter is basically a copper wire between the GDI output and the grid.

Theory of Operation – Live Grid

Figure 1 shows the current path for a normal GDI from the photovoltaic (PV) panels through the inverter, to the main service panel. and on out to the grid. In a normal 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 RE from the PV array.

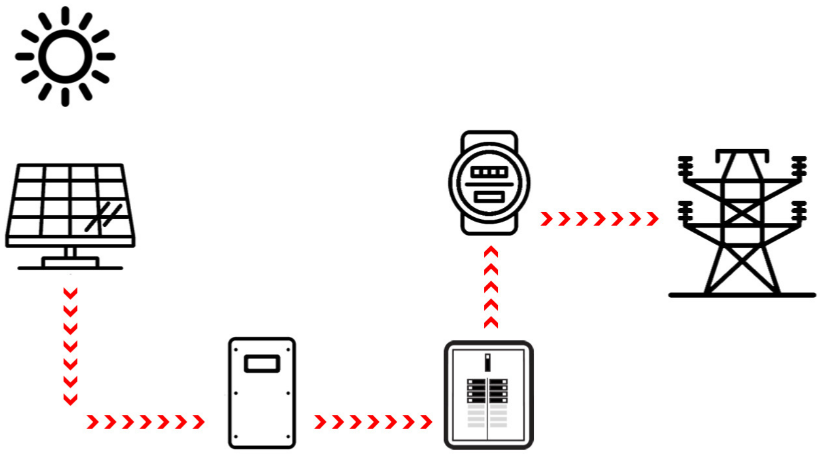

Figure 1 – Normal GDI Power Flow

By connecting (coupling) the output of the GDI to the Mojave inverter's output, Figure 2, the Mojave inverter can act like a grid source to which the GDI can synchronize. The system can 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 backfeeding 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 out to the utility grid if any excess PV power has not been consumed onsite.

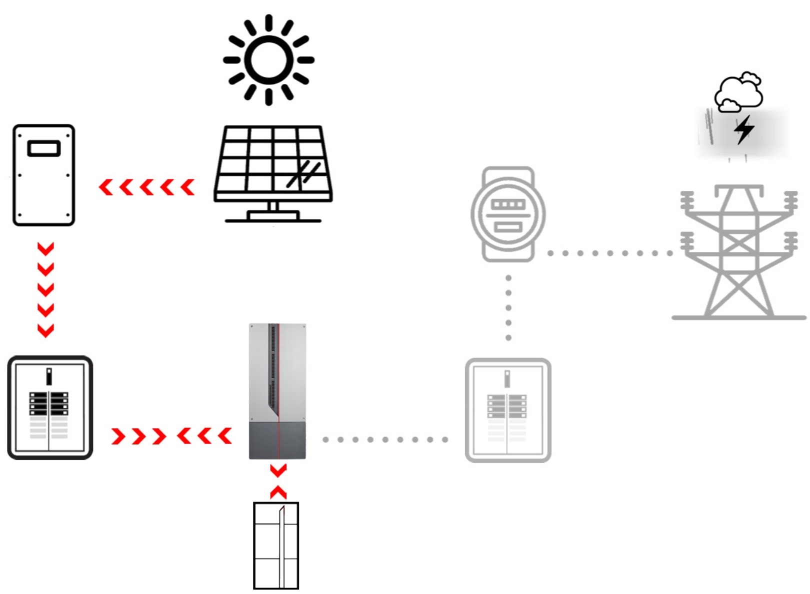

Figure 2 – GDI Power Flow with Active PV

In addition to exporting GDI current to the main panel, a separate parallel current path to charge the battery bank from PV power can exist 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 ***Charge from grid limit*** has been set to zero.

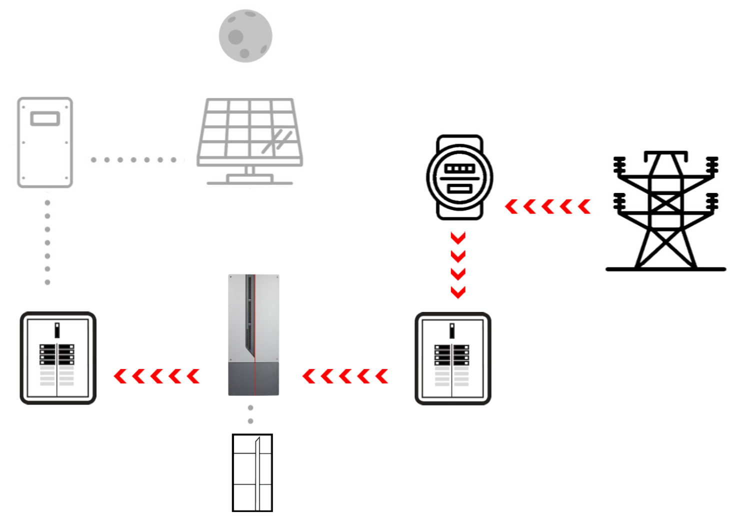

Figure 3 – GDI Power Flow without PV

Theory of Operation – With Grid Outage

During a grid outage when the sun is shining, the Mojave becomes an AC source to which the GDI can synchronize (Figure 4). This allows the PV power to flow to the backup panel's connected 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 different 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.

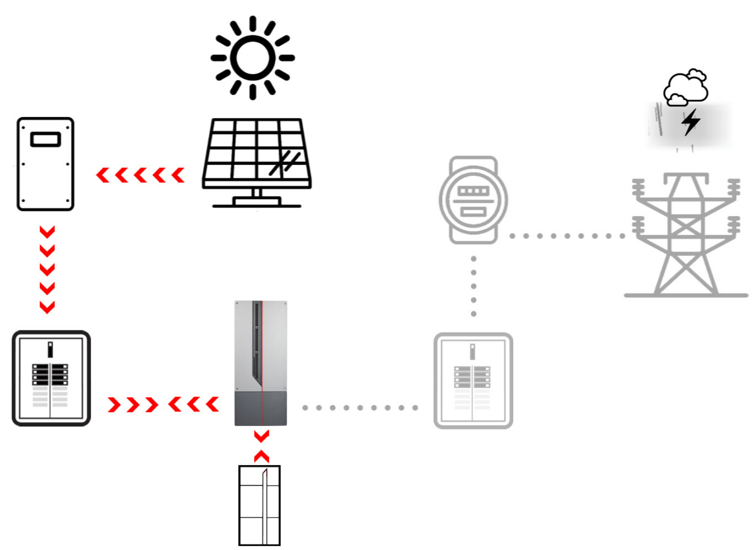

Figure 4 – AC-Coupled Current Flows with Sufficient Load or Charging Demand

If the batteries become fully charged and the load demand falls below the GDI power production, then the excess power from that production will flow back through the Mojave inverter in an unregulated charge to the batteries. 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 maximum charging limit, then it will continue delivering charge current to the battery bank. If greater than the maximum charging limit, the Mojave inverter output frequency will start to rise until the GDI reduces its output if Freq/Watt compliant. If non-Freq/Watt compliant, the GDI will just go offline. If the backfeed current to the battery bank stays below the charge limit, 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 just 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 may 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.

Should the GDI go offline, then the Mojave inverter will power the loads as indicated 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.

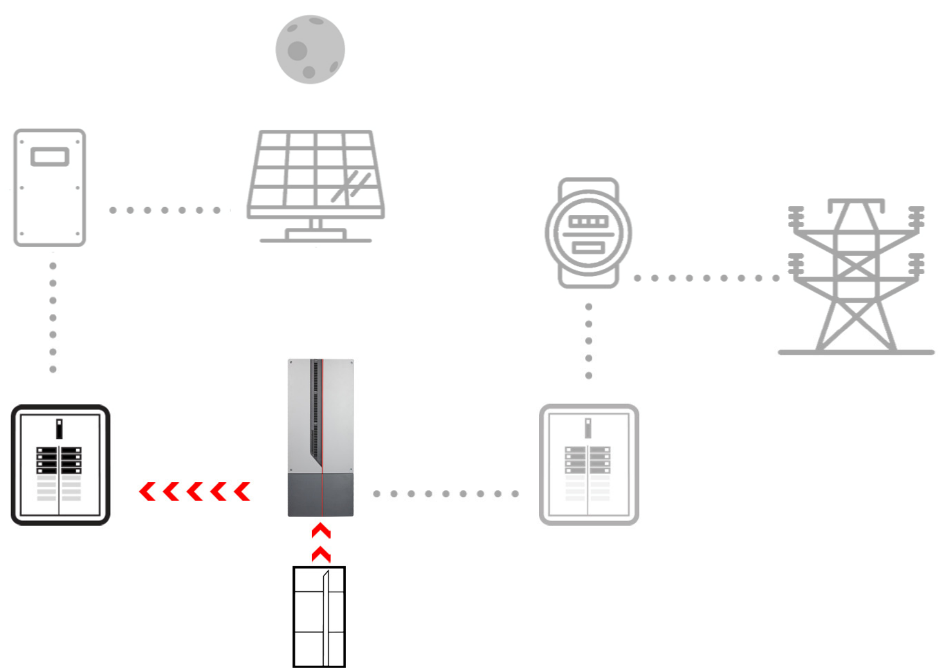

Figure 5 – Off-Grid Current Flow due to PV Loss or GDI Power Overcharging Battery Bank

Once PV production is gone for the day, the Mojave inverter will power the loads in the backup mode until sun returns the next day, or the battery bank reaches the inverter's low battery cutout (LBCO) voltage. If the battery bank reaches LBCO, then the inverter can no longer back up the loads. It also can no longer be a voltage source for the GDI to start again and recharge the batteries. However, 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 batteries, a DC charging source must be connected to the battery bank in order for the system to recover and begin normal operation again.

✓	**NOTE**: The Mojave inverter can AC couple up to 7.6 kVA of the GDI output power.

Solution

Hardware Connections

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

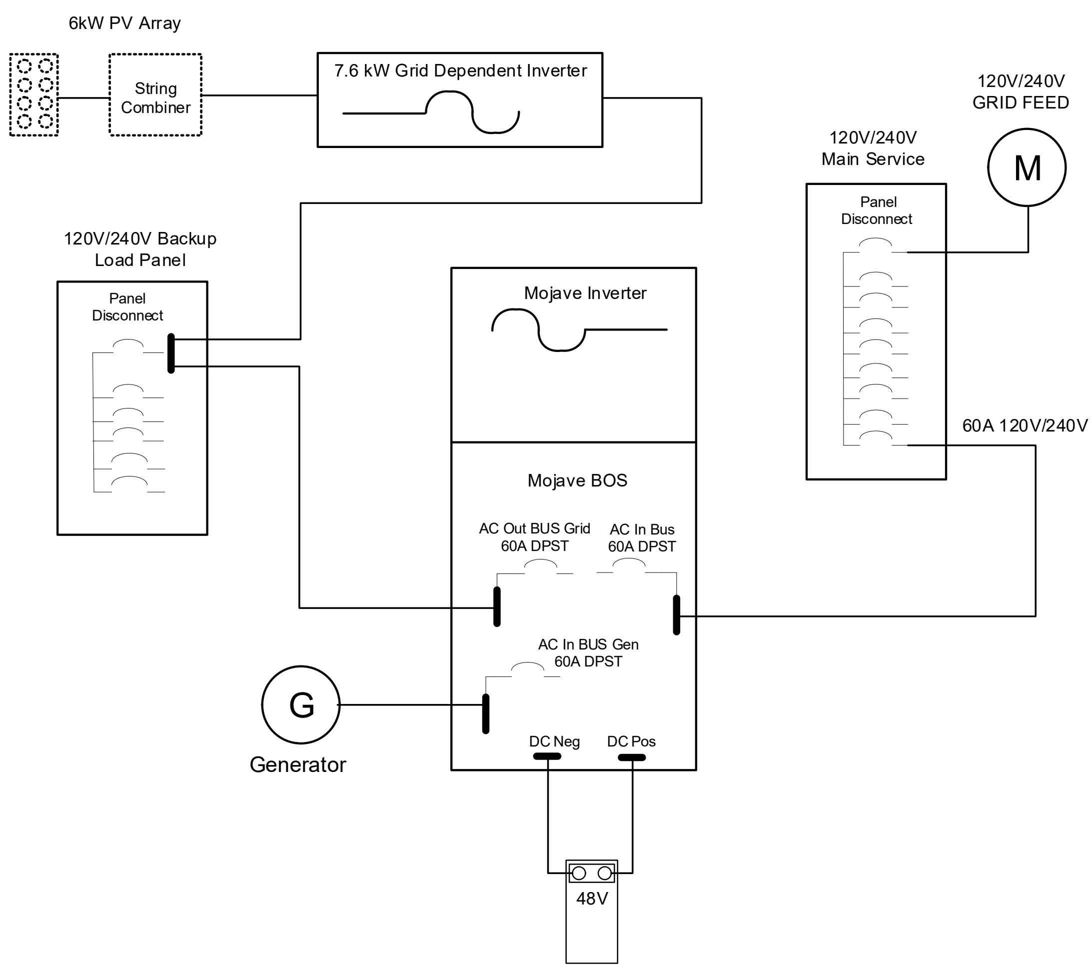

Figure 6 – Single line diagram of GDI inverter connection to Mojave inverter

Procedure

Programming Mojave Inverter Settings for AC Coupling

1. Log into the Mojave inverter UI. Then click on the **Settings** view and select the appropriate tab for the settings: **Inverter**, **Battery**, **Grid**, or **Generator**.
2. Program **Inverter** settings as described in the *Mojave Inverter/Charger Operator's Manual* per the application requirements.
3. If the Mojave lithium-ion battery is in use, install the CANbus cable and the Mojave inverter will auto-detect the battery and load the appropriate settings. With other battery types, program the **Battery** settings per the application requirements and the battery manufacturer's recommended charge settings. Set the ***Min*** and ***Max SoC*** settings per 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. Accurately setting the ***Absorb End Amps***, ***Charge efficiency*** and ***Temperature compensation*** is essential to achieve maximum battery capacity, performance and longevity of the batteries. See the *Operator's Manual* for more details on all these items.
4. Program the **Grid** settings per the application requirements. Select the appropriate ***Grid Profile*** per the local utility's connection agreement. Enable ***External CT*** if being used. Leave the **Export limit** and **Import limit** settings at their default settings. The ***Charge from grid limit*** can be set to zero if charging batteries from the grid is not desired or allowed. See the *Operator's Manual* for more details on all these items.
5. If a generator will be used, the **Generator** settings can be set as described in the *Operator's Manual*. It is important that the generator be connected to the **GEN** terminals ***only*** (never connect to **GRID** terminals) Connect using a 60A DIN mount breaker (not supplied, but available from OutBack Power). The breaker can be installed on the same DIN rail as the **GRID** input and **LOAD** breakers in the Mojave BOS.

If ToU is desired, see **Setting up the Mojave inverter for ToU** on the next page.

Setting up the GDI for AC Coupling

1. Set the Grid Profile on the GDI to the recommendation of the local utility company. If the inverter site is in California or Hawaii, then use those settings as appropriate. The default for all other areas is IEEE-1547-2018, which is also Freq/Watt compliant. Some older GDI products are IEEE-1547-2003 and will abruptly shut off the GDI when it reaches 60.5 Hz. To have better regulation for off-grid charging, program the GDI using the default of IEEE-1547-2018 if that is an option, or select one of the HI or CA settings. Initial testing by OutBack Power has shown that a GDI with 62 Hz high-frequency-limit utility profile settings will produce the best regulated charging for off-grid operations.
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.

NOTE:

The ***Export limit*** setting of the Mojave inverter is unable to control AC-coupled RE exporting. ***Export limit*** 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.

Setting up the Mojave inverter for ToU

1. Log into the Mojave inverter UI. Then click on the **Settings** view and select the **Inverter** tab just below.
2. The **Inverter** tab will reveal a list of settings. Changing the sixth setting down titled ***Simplified ToU*** from ***Disable*** (default) to ***Enable*** will reveal four available ToU time periods as shown in Figure 7.
3. Peak rate periods can be set to ***Daily***, ***Weekday***, or ***Weekend***. Select the expensive rate period(s) and ***Start*** and ***Stop time***s during which the backed-up loads will be powered with stored RE.
4. The external current transducers (CT) can be added so that ToU energy flow from the battery can include the main panel loads. See Figure 8.

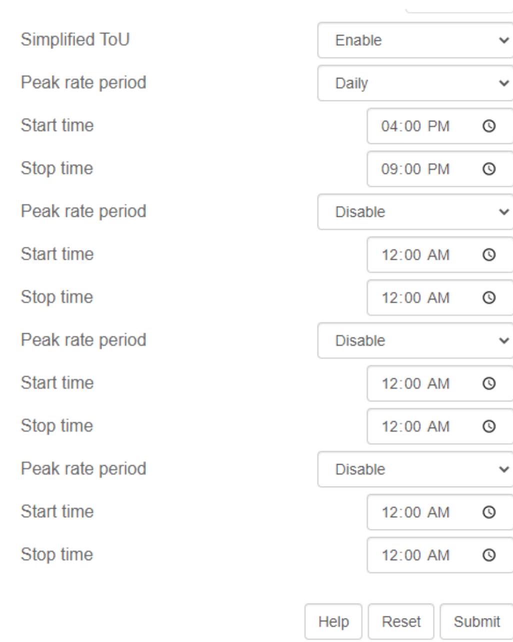

Figure 7

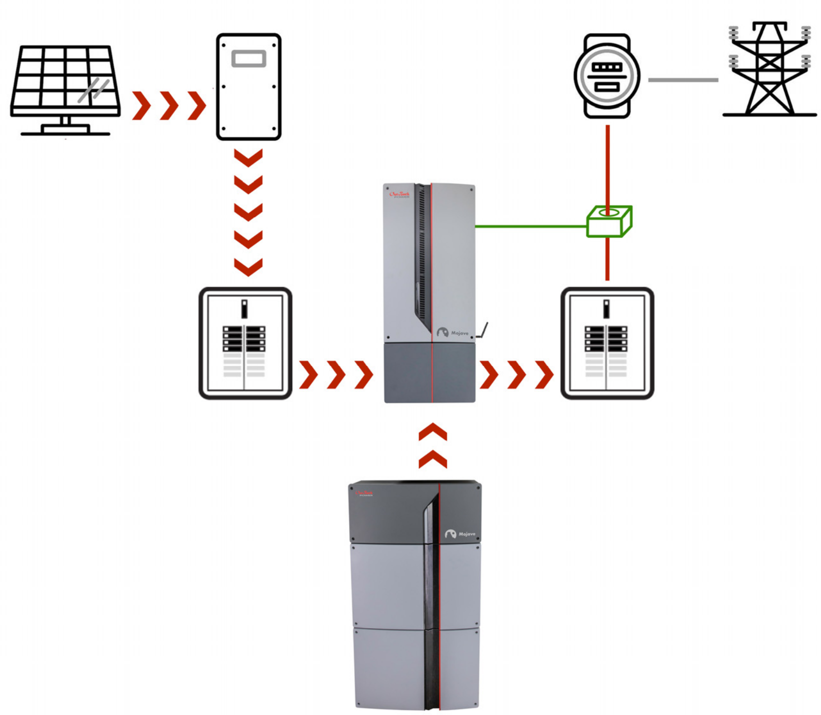

Figure 8 – ToU Power Flow with Current Transducers

ToU Example using California's Pacific Gas and Electric (PG&E) Summer Rate Schedule

PG&E's rate schedule is shown in the table below. Note that rates can be even higher if the site is over the utility baseline amount. The Peak period is the most obvious candidate for ToU. Not only because it is the highest rate period, but also most homes will use the bulk of their day's electricity during this time, resulting in the greatest savings.

Rate Period	Time	Days of Week	Rate in cents per kWh
Peak	3 PM to 8 PM	Monday to Friday	$0.42 ($0.49 if > baseline)
Part-Peak	Noon to 3 PM and 8 PM to 10 PM	Monday to Friday	$0.30 ($0.37 if > baseline)
Part Peak	5 PM to 8 PM	Saturday and Sunday	$0.30 ($0.37 if > baseline)
Off-Peak	All other times including holidays		$0.22 ($0.30 if > baseline)

However, there are some tradeoffs to consider before deciding which rate periods should be used. The battery bank's usable capacity (usually 50% DoD for lead acid [LA] and 80% for lithium [Li]) should first be calculated. A typical site with minimum backed up loads of (for example) a refrigerator, light circuit and a receptacle circuit might use 16 kWh in a 24-hour period. In this case, the battery bank's overall nameplate capacity would be sized to 32 kWh for LA, or 20 kWh for Li.

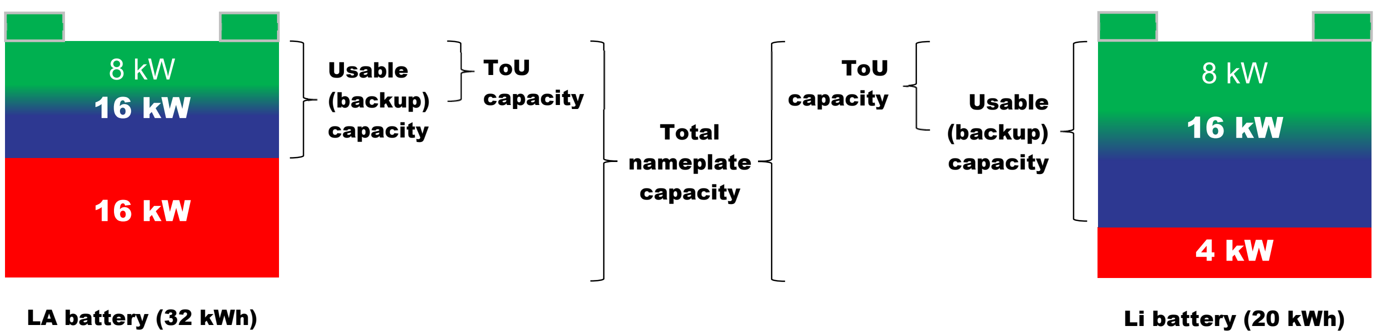

Figure 9 – Capacity Levels for Batteries

If half the 24-hour kWh is used from 5 PM to 8 PM, then there are two approaches to take.

First approach would be to set the Mojave inverter ***Min SoC*** with a consumption of 8 kWh (75% SoC for LA, 60% SoC for Li) which reserves 50% of the usable 16 kWh battery capacity as shown in Figure 9. This additional reserve is in case a power outage occurs before the battery bank is recharged. If an outage does occur before the batteries are recharged, then some load shedding may have to be done until the sun comes out and recharges the batteries. If the grid outage continues, then the system should provide adequate power for the home if usable battery bank capacity equals 24-hour load demand.

A more conservative approach would be to increase the battery bank with another 8 kWh of energy storage. In this example, a 50% larger usable capacity battery bank will power the backed-up loads completely during the Peak ToU period and still have a 24 hours of backup power should a grid outage occur before the batteries are recharged. While this does increase the cost of the most expensive component in an RE Energy Storage System (ESS), there are additional benefits.

The first is that an extra 50% usable capacity will not only guarantee 24 hours of emergency backup, but will provide as much as 36 hours of backup should the outage last more than 24 hours.

The second benefit is in the case of some cloudy days being mixed in during the outage. The extra reserve will increase chances of making it through the night until the sun comes up again without having to shed loads. Additionally, the resulting (more shallow) daily ToU discharges increases longevity of the battery bank significantly, especially if using LA batteries.

Some site owners may choose to have multiple days of usable capacity and could choose to include Part-Peak rate periods as well to increase the payback on their ESS. The example in Figure 10 shows the Mojave inverter ToU rate periods set for both Peak and Part-Peak rate periods using PG&E's rate schedule from the table on the previous page.

> **NOTE**:
> The 8 PM to 10 PM period could have been combined with the first 5 PM to 8 PM period, but was shown separately for clarity.

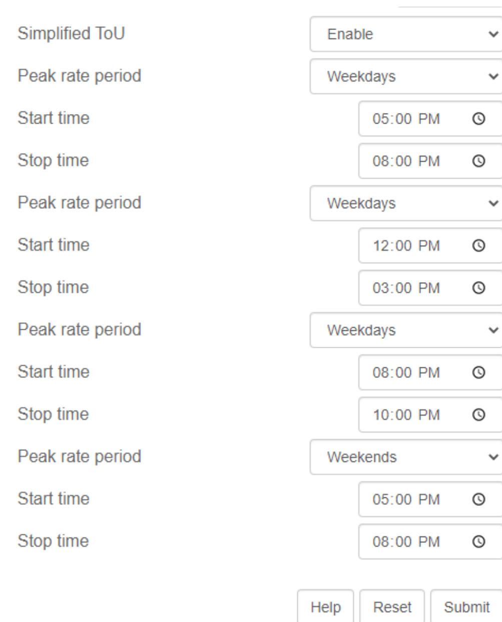

Figure 10

Summary

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

With the increased frequency of utility shutdowns, and more utilities utilizing expensive rates to reduce peak demand, adding an energy storage system like the Mojave product to an existing grid-dependent inverter will provide secure and cost-effective power. This is especially true now that power grids are becoming more unpredictable.

About OutBack Power

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

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