Using Inverter Input Modes for Smart Grid Management

Some battery based grid connected inverters from OutBack Power have a unique collection of functions designed to optimize utility power usage for OutBack customers. This application note will show how to configure the Radian and FXR class inverters for various power conversion applications including:

- Backup Power for Grid-Connected Systems
- Selling Excess Power to the Utility Grid
- Avoiding Expensive Time-of-Use Surcharges
- Limiting Peak Demand Charges
- Optimizing Self-Consumption

BACKUP POWER FOR GRID CONNECTED SYSTEMS

The first step in sizing a backup power application is to start with the electrical loads. The basic backup system for most homes would include power for a refrigerator, lighting, and some receptacles for powering small appliances and entertainment systems. Table 1 shows a typical load profile and the amount of energy in watt-hours (Wh) required to run them over a 24-hour period.

Table 1

Calculating Average Daily AC and DC load										
LOADS	**QTY**	**x**	**WATTS**	**=**	**Total WATTS**	**x**	24 Hours	**=**	**AVG Wh/Day**
CF Lights	**6**	**x**	**17**	**=**	**100**	**x**	**16**	**=**	**1,600**
Refrigerator	**1**	**x**	**1,000**	**=**	**1,000**	**x**	**6**	**=**	**6,000**
Receptacle Load Circuit	**1**	**x**	**600**	**=**	**600**	**x**	**16**	**=**	**9,600**
AC TOTAL WATTS					**1700**	**AC AVG DAILY LOAD**			**17,200 Wh**

Using the 17,200 watt hours (17.2 kWh) in Table 1, and a battery depth-of-discharge (DOD) of 80%, we would need a battery bank with a capacity of 21.5 kWh to back up the loads for 24 hours. Quite often a DOD of 50% is used in battery-based off-grid systems since a shallower discharge extends the life of the battery. However, 80% DOD can be used for backup applications since the battery bank will only be cycled a few days per year, or a week or two at the most, and going with a deeper DOD means a smaller battery bank. In the example above, 50% DOD for a 17.2 kWh energy demand would equate to a 34.4 kWh battery compared to 21.5 kWh for 80% DOD.

The next step is to translate energy demand from kWh into battery amp-hours (Ah) since that is how battery storage capacity is commonly measured. Using the load profile above and a 48-Vdc nominal battery bank, divide 21,500 Wh by 48 Vdc. The result, 448 Ah, is the minimum size battery bank for this application. Since the energy demand is based on a 24-hour rate, then the battery Ah for the same discharge rate of 24 hours should be used as the battery capacity (Ah) will vary depending on how fast it is discharged (see table below). Using the OutBack batteries listed in the table below, two strings (four 12 Vdc batteries in series for each string) of the EnergyCell 220GH batteries could be used for a total of 432 Ah and be slightly under our estimate. If we wanted to be more conservative, then we could choose to use three strings of the EnergyCell 170RE batteries for a total of 471 Ah.

Table 2

Discharge Hours	**EnergyCell 170RE**	**EnergyCell 200RE**	**EnergyCell 200GH**	**EnergyCell 220GH**
	Rated Ah	**Rated Ah**	**Rated Ah**	**Rated Ah**
1	**89.1**	**103**	**120**	**133.5**
3	**114.2**	**132**	**148.5**	**166.2**
4	**120.6**	**139**	**154.8**	**173.2**
8	**137.0**	**158**	**168**	**188.8**
12	**145.3**	**168**	**176.4**	**198**
20	**153.8**	**178**	**191**	**214**
24	**157.0**	**181**	**189.6**	**216**
100	**170.0**	**200**	**200**	**220**

To size the inverter, we use the total watts column in Table 1. This is the maximum power the inverter would need to deliver to the loads if they were all running at the same time. The ambient temperature affects inverter conversion efficiency at 1% per degree C above 25°C. If the worst-case temperature is 40°C, then the inverter needs to be derated by 15%. Some loads also have power factor (see OutBack *Power Factor* applications note for more information) with a common "rule of thumb" derate of at least 10% for power factor (PF). While many homes may have a 90% PF or better, PF is not an easy thing to measure. Using 80% PF (20% derate) could be a more conservative approach, especially if there are a lot of motor loads and high energy electronic loads. So if the derate of 15% for temperature and 10% for PF is combined, that gives a total derate of 25%. To get the minimum inverter size for this example, divide the 1700W from Table 1 by 0.75 (25% derate) which means a 2266VA inverter is the minimum size for this application.

There are two Radian/FXR input modes for backup applications; ***Backup*** and ***UPS***. The ***UPS*** input mode is essentially the same as the ***Backup*** input mode, except that the power modules never go into standby so they can be switched on faster with the transfer from utility power to battery power.

OFFSET FUNCTION

An important thing to note about ***Backup*** and ***UPS*** modes is that they only become active with the loss of grid input. Any renewable DC energy will go unused other than that which is used to keep the batteries charged. The other input modes discussed below use some form of a built-in "Offset" function which allows renewable or stored energy from the DC side to be used to power loads or send energy to the power grid. With the Offset function, renewable energy will almost always be fully utilized and not go to waste. However, all input modes will provide backup power with the loss of an AC source whether that input mode uses the Offset function or not.

The main concept behind Offset is that it blends renewable, or stored energy from the DC side with power from the grid. The trigger points at which the blending occurs is mostly dependent on user settings, and by default, the Offset itself is always enabled with the input modes; ***Grid Tied***, ***Mini Grid*** and ***Support***. However, Offset can be disabled by changing the inverter Grid Tied setting (not the ***Grid Tied*** input mode) to Disable. Firmware revisions after version 001.005.000 change the setting name from Grid Tied to Offset Enable to avoid confusion with the ***Grid Tied*** input mode.

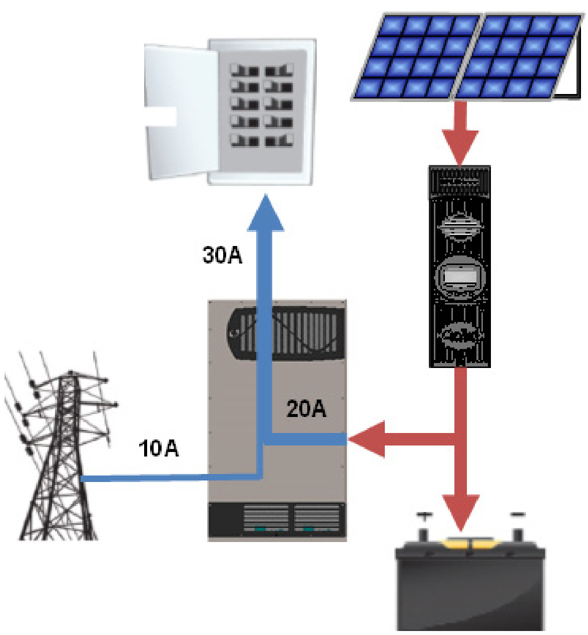


Figure 1 - Offset Current Blending Function

Figure 1 shows an example of how the Offset function is inverting 20A from the DC side and blending it with 10A from the AC grid-side of the inverter to meet the 30A demand from the load panel. Note that some amount of charging current will always be diverted to the batteries before going to the inverter as even a "full" battery draws about 2% of its amp hour rating when a charging voltage is applied. More details on the Offset function can be found in the *Offset Functionality* application note on the OutBackPower.com website.

SELLING EXCESS POWER TO THE UTILITY GRID

The vast majority of DC to AC grid tied inverters move excess DC power from photovoltaic (PV) arrays to the utility power grid once the site's local power demand has been met, as illustrated in Figure 2.

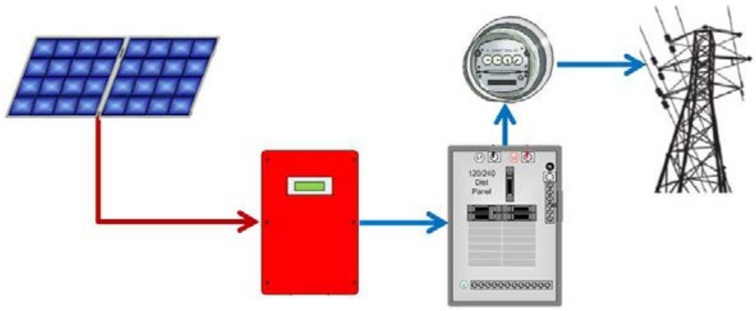


Figure 2 - Grid Tied Inverter Current Flow

Historically, battery-based inverters were mostly for off-grid or battery backup applications. Battery-based inverters from OutBack have since evolved into a grid/hybrid design that can sell excess power to the grid, as well as provide backup power when the power grid is down. The components and energy flow in a grid/hybrid inverter system are shown in Figure 3.

When the grid is active, DC current flows from the PV array to a DC to DC converter called a charge controller, then to the battery bank. Once the battery bank is charged, the DC power is converted to AC. The AC power is consumed by the critical loads connected to the output of the grid/hybrid inverter, then passed to the input side of the inverter where it is consumed by loads connected to the main panel. If the PV production should fall short of the critical load demand, whatever PV power is available is blended with grid power (Offset function) to satisfy load demand. If there is excess PV power, then it is passed on to the grid which effectively spins the meter backwards and provides what is known as net metering, or reduction in the metered utility charges. Some utilities provide additional renewable energy production credits in some form of a feed-in tariff program that can vary widely depending on the local state and utility policies.

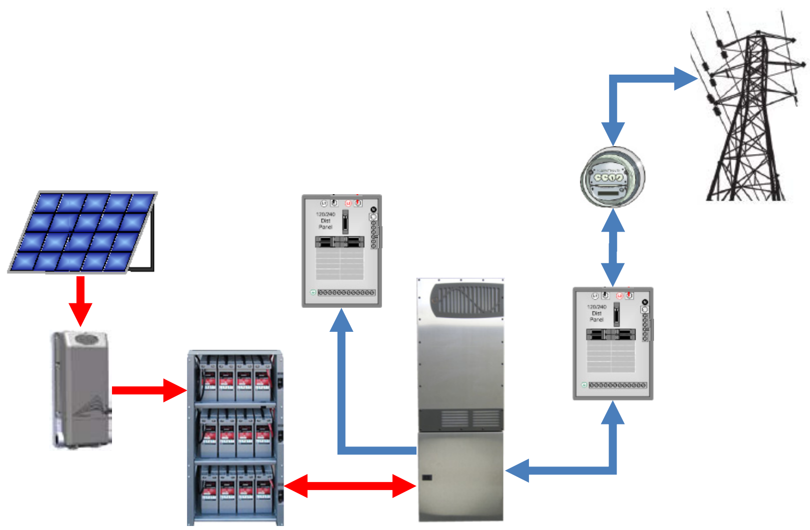


Figure 3 - Grid Hybrid Inverter Current Flow

When the grid goes down, the main load panel (to the right of the inverter in Figure 3) will also lose power but the critical loads panel (to the left of the inverter in Figure 3) will continue to power loads from energy stored in the batteries and/or from the PV array. The batteries will continue to power the loads throughout the night, and will recharge in the morning when the PV array starts producing power to take over powering the critical loads while recharging the batteries.

Specific settings for the ***Grid Tied*** input mode can be entered using the MATE3 system display Profile Wizard, or can be done manually with guidance from the programming section of the MATE3 literature.

While most site owners have opted for the more cost-effective grid-tie inverter, many have been surprised when the PV panels are unable to produce power when the grid is down, since the grid-tie inverter needs an AC source to synchronize to in order to produce power. As mentioned, the grid/hybrid inverter produces its own AC source from energy stored in the batteries. It isolates itself from the grid during a power outage using an internal transfer switch, and can power critical loads connected to a backup subpanel panel while the power is out (panel on left in Figure 3).

If it is known from the beginning that a site is subject to frequent or extended power outages, or if there is a desire for secure power in areas that could experience extreme weather, then it is more cost effective to add the grid/hybrid system from the beginning than to add in as a retrofit later. More information on how to retrofit a grid-tied inverter system for storage can be found in an application note titled, "*AC Coupling Grid-Tie Inverters With OutBack Battery-Based Inverters*" on the OutBackPower.com website.

AVOIDING EXPENSIVE TIME OF USE SURCHARGES

Many utilities struggling with how to deliver enough energy during peak demand times have turned to time of use (TOU) surcharges to discourage their customers from using unnecessary loads during these peak usage times. Peak demand times usually include 4pm to 7pm or later with per kilowatt charges running 200 to 300 percent of off-peak periods. Some utilities also have a morning TOU surcharge, and may add weekend and seasonal peak periods as well.

As the solar peak typically runs from about 10am to 4pm (more or less depending on seasonal variation) adding a local solar generation system will not do much if anything to reduce TOU charges without some kind of energy storage system. As the solar peak does not line up with peak demand periods for many solar sites, the surplus PV power being generated during this time can be stored in the OutBack grid/hybrid inverter's battery bank for use at a later time.

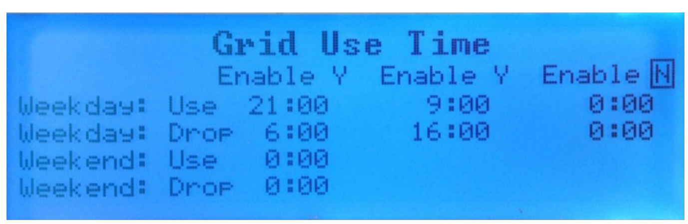


Figure 4 - Grid Use Timers

The OutBack MATE3 has up to three grid use timers for weekdays and one grid use timer for the weekend. The Use and Drop settings determine the actual connection times to the grid. The

Use period defines the beginning time of the grid connection. The Drop setting determines the time at which the critical load panel running from the OutBack inverter is disconnected from the grid and uses the batteries to power the loads. Any other grid-connected load panels not connected to the output of the OutBack inverter will continue to run from the grid and will not be affected by this function.

The Grid Use example in Figure 4 shows the power will get dropped at 6am, reconnected at 9am, dropped again at 4pm (16:00), and then reconnected again at 9pm (21:00). This will keep the loads connected to the critical load panel at zero consumption from the grid during 6-9am and 4-9pm when TOU charges are highest. Note that the third weekday and weekend timers have been disabled by setting both the Drop and Use times to midnight (0:00), but could also be enabled to add yet more time periods to be off-grid and continue savings from TOU charges.

LIMITING PEAK DEMAND CHARGES

Utilities need to provide maximum power capacity equal to the worst-case scenario where all their customers were to be demanding power to their highest peak that would occur in a month. This usually happens during the typical peak demand times in the morning or afternoon, but many utilities will calculate their peak demand charges to the largest 15-minute peak load demand for each of their utility customers whether it occurred during the peak demand times or not and is usually on top of time of use charges if they also apply. In some cases only commercial customers are charged an additional peak demand charge.

If you are paying peak demand charges, there is a mode of operation with OutBack inverters that will allow you to reduce it. This input mode is called ***Support***. The incoming power from the grid can be set to a maximum limit, then supported with DC power from batteries and PV to meet the rest of the load demand. For example, if the incoming utility current limit is set to 15 amps and the electrical load in the house increases to 25 amps, then 10 amps from the battery bank would be blended with the 15 amps of utility power to satisfy the 25 amp load demand.

This blending of grid power with DC power is also a form of the Offset function, but the trigger is the AC Input Current Limit setting whereas Offset in the other input modes uses one of the battery voltage charging targets (Equalize, Absorb or Float) or the Sell RE voltage setting for its trigger to blend grid power with DC power.

OPTIMIZING SELF CONSUMPTION OF RENEWABLE ENERGY

While the ***Grid Tied*** input mode will self-consume available PV with any excess being exported to the power grid, and Grid Use Timers can self-consume PV power on demand for any given time slots during the day, the ***GridZero*** and ***Mini Grid*** Input Modes more fully optimize self-consumption without any PV power going to the grid or otherwise become stranded on the array.

Applications for full self-consumption include sites where the local utility does not allow connection agreements with PV based inverters, or where the site owner wants to become mostly off-grid, with the utility providing the occasional make-up power, acting like a backup generator for when the PV array cannot satisfy all of the site's load demand.

DECIDING BETWEEN GRIDZERO AND MINI GRID OPERATING MODES

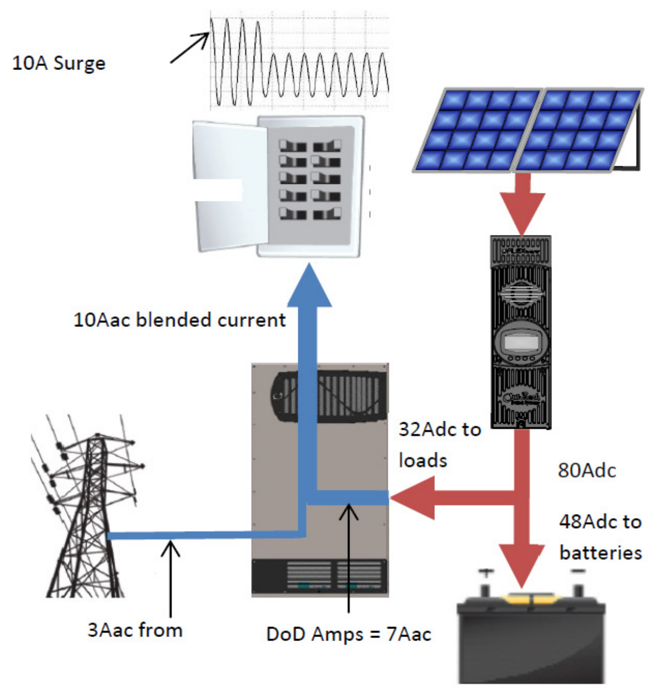
GridZero With Peak Support

With ***GridZero***, the inverter sees every load as an opportunity to displace grid power with the customer's own generation. The inverter's output follows the load, up to a customer-selected upper limit, and will use the customer's battery down to a selected lower limit, to replace expensive utility power with less expensive power from the customer's battery and PV.

The figure below shows how a 10A surge at the load panel is satisfied by 7 Aac from the DC side of the inverter which is blended with 3 Aac from the grid. There will always be 1-2 Aac drawn from the grid to insure no "leakage" from the inverter to the grid where grid export is not allowed. Otherwise, any additional load current beyond the 1-2 amps will come from the DC side up to the DoD amps current limit; in the example below the setting is 7A. Once load demand goes beyond the 7A setting, then additional current from the grid will be blended with renewable energy (RE) from the DC side of the inverter.

GridZero – Peak Support

- Active Renewable Energy (RE) and stored energy are "dosed" to the load up to the rate set by DoD amps.
- Pulls power from the grid when load surges above preselected limits.
- Allows the inverter to service larger load panels
- The battery's contribution decrease as DoD volts is reached (backup power reserve limit).



Pros

- Maximizes RE for self-consumption
- Minimizes grid use
- Limiting rate of battery discharge can decrease wear on battery and increase capacity
- Settable DoD Volts to maintain reserve power for outages
- Smaller system can be used with larger load panels
- Streamlined utility interconnect process (HECO's Customer Self Supply option)

Cons

- May not use all available RE during periods of low load demand and/or high RE production
- Battery cannot be charged with grid power

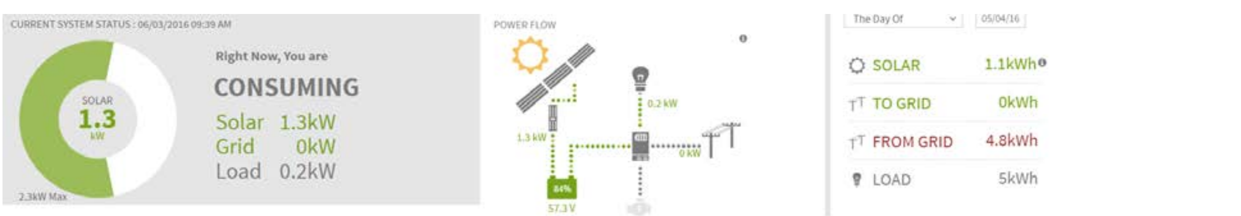
Sizing Considerations

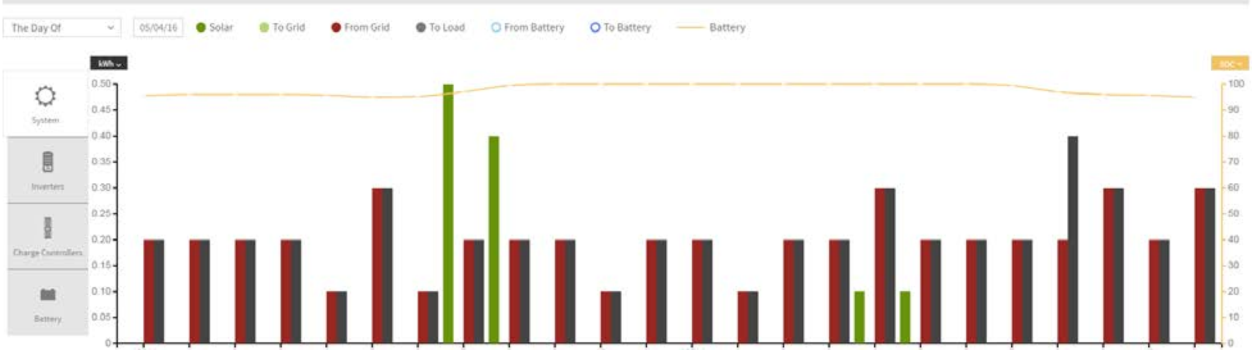
- 50-60 amps pass through current per inverter
- PV array watt hours should be greater than daytime load watt hours to charge batteries
- PV array amps cannot exceed maximum battery charging amps
- Battery Type Recommendations
  - o OutBack Power Nano Carbon (NC) batteries
  - o Any high cycling lead acid battery
  - o Lithium Ion (high cycle life and rapid discharge/charge capability)

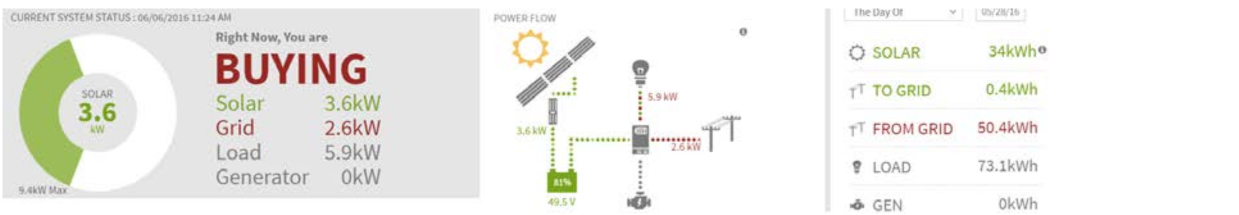
The two graphs below illustrate performance differences between two systems that are both operating in the ***GridZero*** mode. The bars represent a 24 hour period midnight to midnight. The system in the top graph has a 200W load throughout the day with occasional peaks during the day (black bars are load, red bars are from grid). Since the minimum grid draw is around 1-2 amps, the grid is able to handle most of the load demand except for some occasional peaks where the solar kicks in to help service the load (green bars).

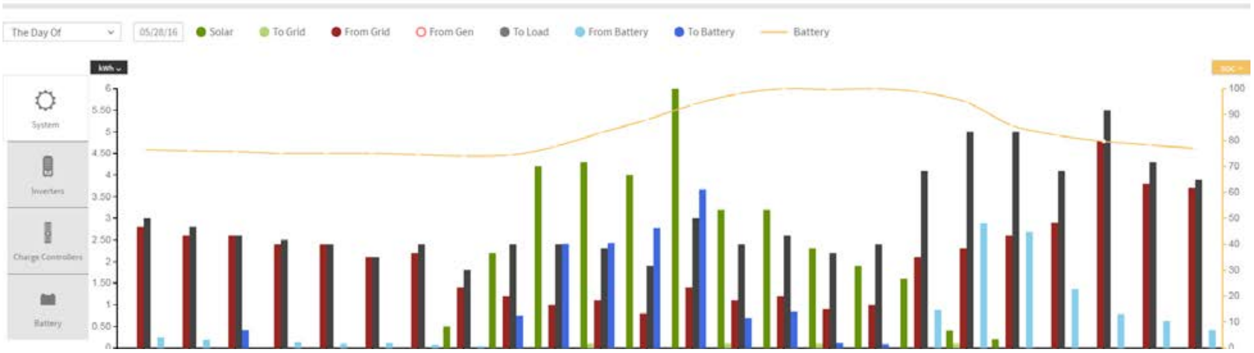
The other system in the bottom graph shows far more solar being harvested and delivered to both the load and for recharging the battery bank (dark blue bar). Then in the evening time, the solar energy stored in the battery during the day is being used to help power the evening load demand (blue bars).

NOTE: The ***GridZero*** mode of operation is for single inverter systems only. Multi-inverter systems are not supported for ***GridZero*** operation.



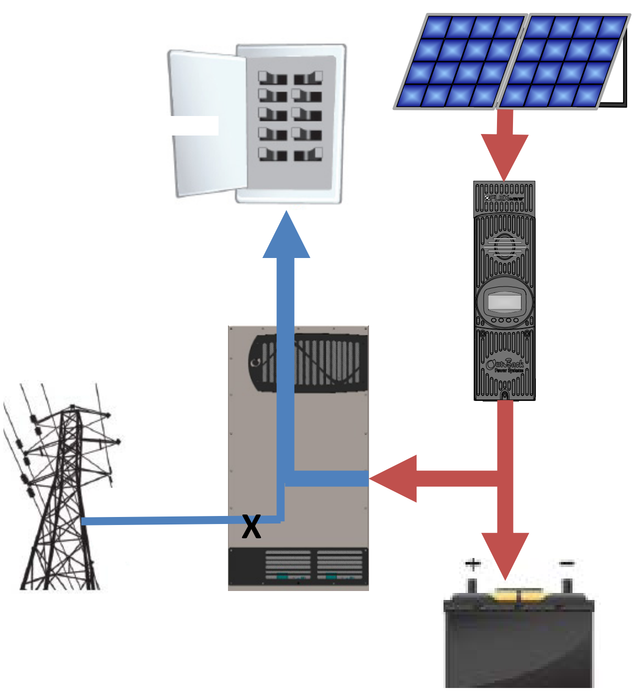


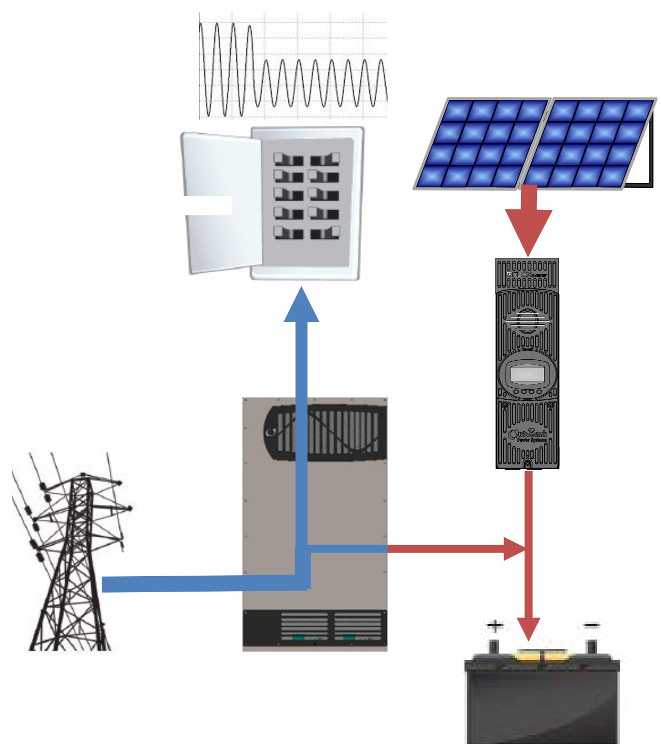




MINI GRID OR "GRID AS A GENERATOR"

Mini Grid is for site owners that want to live like they are off-grid where RE is satisfying nearly all of their power needs, but want the safety net of the grid for days when RE production is not high enough to satisfy load demands. Essentially the grid is acting like the generator that a true off-grid site would use during periods of low RE production.





Operating as an Off-Grid System

Operating like Grid as a generator

Mini Grid – an Off-Grid System that uses the grid like a generator

- Maximizes RE for self-consumption
- Runs like an off-grid system using the grid like a generator
- Grid powers loads only when batteries are low
- Will not restrict battery discharge amps
- Batteries can optionally be charged from grid when low
- Grid connect voltage user selectable
- Connect delay user selectable
- Battery will discharge until Grid Connect setting for the delay period – loads are then powered from the grid
- Batteries will charge from the grid if Charger is On, then disconnect from grid on Float and charge timers are zero
- If Charger Off, batteries must be recharged with RE

Pros

- Maximizes RE for self-consumption to minimize grid use
- Can use the grid like a generator for “off-grid like” use
- Settable DoD reserve power
- Will power loads from grid when RE is not available
- Charging from grid is optional
- Utility notification only (Rule 14H Appendix II-B)

Cons

- RE watts must be larger than load watts to stay in balance
- DoD discharge amps rate cannot be controlled
- Battery charging from grid can reduce RE self-consumption benefit

Sizing Considerations

- 50 Aac Pass Through per Radian
- PV Array watt hours ≥ daytime + night time load watt hours to charge batteries
- PV array amps cannot exceed maximum battery charging amps without curtailing charge controller output(s)
- Battery banks sized for more than one day autonomy could take a long time to recharge depending on ratio of PV array to battery bank
- Battery Type Recommendations
- OutBack Power AGM Nano Carbon (NC) Battery
- Any high cycling lead acid battery
- Li Ion (lots of cycles, rapid charge/discharge OK)

The graph below representing a 24 hour period of ***Mini Grid*** operation shows the grid (red bars) powering the loads in the early morning hours until about 8am, and how the solar energy at 6am is reducing grid power while charging the batteries until about 9am when the loads are completely powered by solar until about 5pm when the batteries (light blue bars) take over until about 8pm, when the system is reconnected to the grid until the sun comes up the next morning.

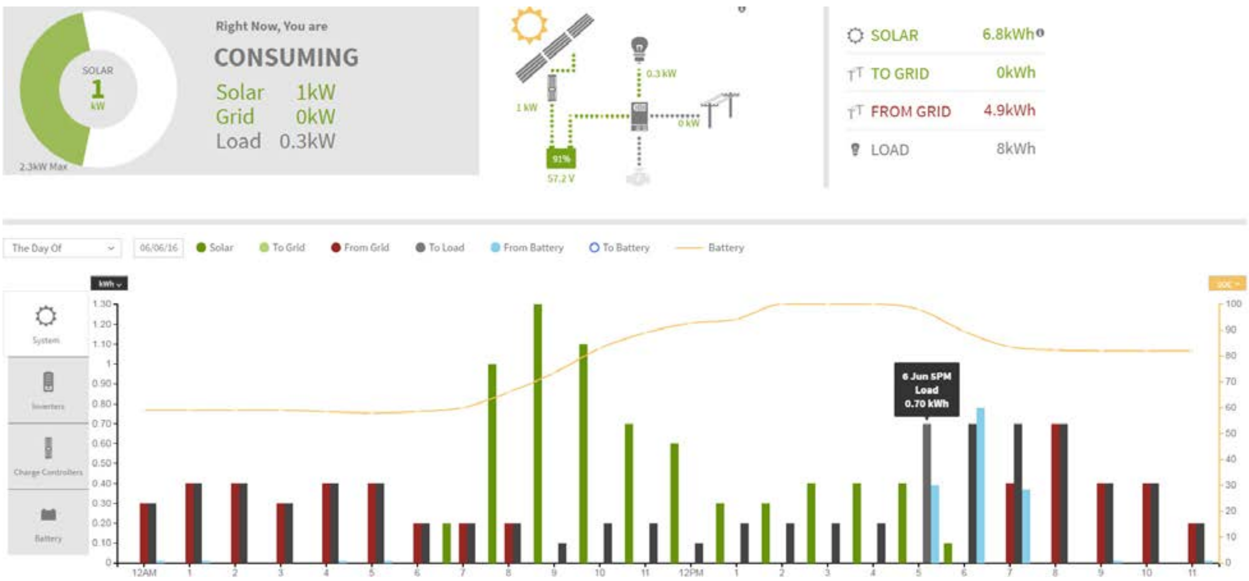


Table 1 – Summary of Radian/FXR Input Mode Functions

	Grid Tied	***Support***	***Grid Zero***	***Mini Grid***
Sells To Grid	√			
Charges Batteries From Grid	√	√		Optional
Uses PV To Offset Power From Grid	√	√	√	√
Uses PV To Charge Batteries	√	√	√	√
Limits DC Discharge Through Inverter			√	
Grid Use Timers	√	√	√	
Must Have More RE kWH than Load kWh			√	√
User Settable Low Battery Limit	√	√	√	√
Has Maximum Current Limit From Grid		√		
Blends Grid Power With RE During Peaks			√	

About OutBack Power Technologies

OutBack Power Technologies is a leader in advanced energy conversion technology. OutBack 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.

Other

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