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.

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 442 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	103	124	138
3	114	132	154	172
4	121	139	160	178
8	137	158	170	190
12	145	168	181	203
20	154	178	191	214
24	157	181	194	221
100	170	200	210	250
	**Ah Capacity @ 77F (25C)*			

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 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 a2266VA inverter is the minimum size for this application.

There are two inverter input modes for backup applications; Backup and UPS. The UPS input mode is similar to 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 automatically. This is not programmable. More information about Offset can be found on the OutBack Power website in the *Offset Functionality* application note.

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 1.

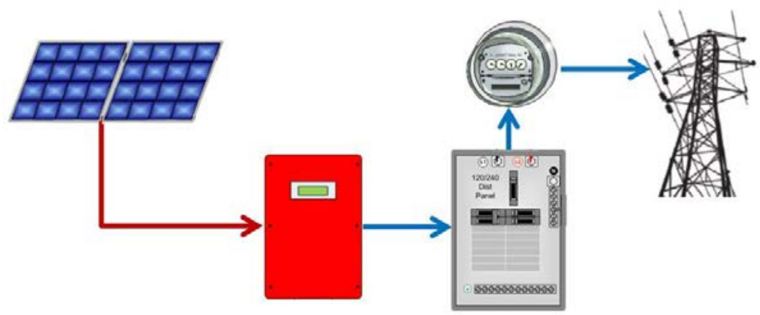

Figure 1 - Grid Tied Inverter Current Flow

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 2.

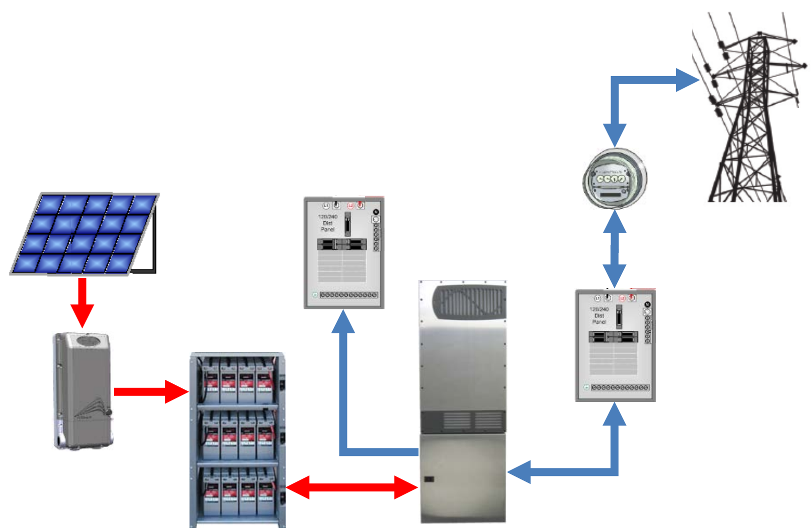

Figure 2 – Grid/Hybrid Inverter Current Flow

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.

When the grid goes down, the main load panel (to the right of the inverter in Figure 2) will also lose power but the critical loads panel (to the left of the inverter in Figure 2) 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 user interface Configuration Wizard, or can be done manually with guidance from the programming section of the MATE3 Owner's Manual.

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 2).

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.

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.

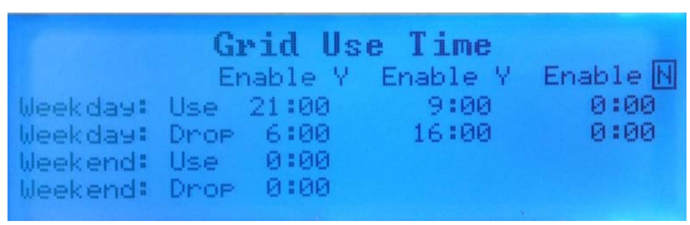

Figure 3 - Grid Use Timers

The Grid Use example in Figure 3 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.

IMPLEMENTING SMART GRID MANAGEMENT WITHOUT ADDING A BACKUP LOAD PANEL

For those that are primarily interested in selling energy back to the grid, or are wanting to minimize utility bills through peak demand and time of use charge reductions, and don't want to install a backup load panel, that is a viable option. The AC output of the inverter can just be left open circuit, or can be wired to a convenience outlet installed in the load center to power some small loads in the event of a grid outage. This can simplify and reduce the cost of the installation if the benefit of backup power isn't desired and a single receptacle outlet is all that is needed.

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 Grid Zero 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.

Grid Zero Mode

Grid Zero is designed to self-consume and utilize PV power at a controlled rate with load peaks being supported using power from the grid. The grid never charges the battery, but will always pull a minimum of 1 Aac from the grid to ensure no power from the inverter is "leaking" back onto the grid input. The flow rate of PV power and/or battery power is determined by the DoD Amps setting, in amps AC. By restricting the flow of DC power, the inverter is able to supply a base amount of energy to the loads, while only blending grid power with DC power when load demand is high or surging. Having a consistent discharge of the DC power provides a more predictable load curve to match up to the available PV power.

Also, the battery acts as a buffer both for days of excess PV power as well as days with less, and there is a DoD Volts setting to be sure the system always has the level of backup desired by the site owner. Having a PV power based generation system will always have some level of unpredictability, but the problem of having load variation coupled with PV power variations can create a system with highly variable performance. Grid Zero solves this problem by helping reduce the over/under performing system by bringing more balance to self-consumption.

Having a system with fewer highs and lows of performance is only one benefit of Grid Zero. Some utilities have ended feed-in tariff (FIT) incentives, or have even disallowed battery-based inverters that charge from the grid. Grid Zero should therefore make it possible to have a utility connection no matter what the rules, as batteries are never charged from the grid and the 1A minimum power draw from the gird ensures that power is never exported.

Here are some guidelines for Grid Zero to optimize its operation in your application:

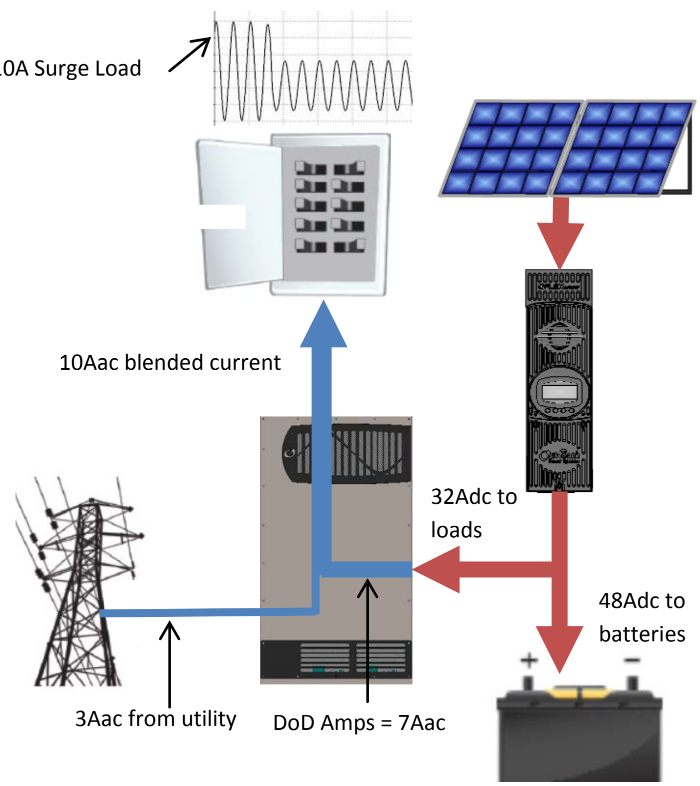

Figure 4 - Grid Zero Current Paths

1. Use a battery that is designed for daily cycling. Flooded lead acid batteries are usually best, but Lithium Ion (Li Ion) batteries also have a high cycle life. OutBack EnergyCell RE batteries can also be used, but use a minimum C20 discharge rate (500 W or about 10 Adc per string), otherwise a slower discharge rate could significantly reduce cycle life. So for three strings of OutBack 200RE batteries about 1500 W minimum AC load, or 30 Adc is best.
2. Be sure the RE kWh exceeds the load kWh or the batteries may be chronically undercharged as the batteries compete with the loads for power to recharge themselves. The RE kWh minus the load kWh must equal enough charging current during the RE period to properly charge the batteries.

3. The RE kWh must be more than the load kWh, but not so much that the maximum battery bank charging current is exceeded. For example, a 4kW Radian with a 4kW PV array into an FM80 charge controller will produce a maximum current of 80 Adc. If the DoD Amps is set to 7 Aac, this would result in a 32 Adc draw from the DC bus (minimum suggested per guideline #1), which leaves 48 Adc for charging the battery bank. This is too much for a single string of OutBack 200RE batteries, and a little on the high side. It is all right for two strings, and just about right for three strings. If a larger array is going to be used, then Li Ion batteries would be a good choice as they can be charged and discharged rapidly with very little consequence.

Mini Grid Mode

The normal operation of Mini Grid is for the inverter and loads to be disconnected from the grid and power the loads with PV power and/or stored energy from the battery. Unlike Grid Zero, the rate of discharge from the battery is not controlled. Grid power is not blended with PV power unless it's Offseting while charging the batteries. However, similar to Grid Zero, the Mini Grid mode works best when there is more PV power kWh than load demand kWh as it only connects to the grid when the battery hits a user selectable low-battery setting. As long as there is adequate active PV power and stored PV power in the batteries to power the loads, then Mini Grid will never connect to the grid. If the low battery setting is reached for the delay period specified, then the Radian and FXR connects to the grid and it will power the loads. If the Radian and FXR charger is turned on, then the batteries will complete a full charge cycle from the grid (a partial charge cycle can also be specified). The inverter will not disconnect from the grid until adequate PV power is available, achieves one of the three DC voltage targets (see Offset application note). If the Radian and FXR charger is turned off, then the grid will power the loads on reaching the low-battery setting, but will not charge the batteries from the grid. The Radian and FXR will not disconnect from the grid and start powering loads with PV power until adequate PV power is available for charging the batteries and powering the loads. Follow the same guidelines battery sizing guidelines listed above under Grid Zero.

Table 1 – Radian and FXR inverter Input Mode Function Matrix

	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			√	

This application note has shown how to configure the Radian and FXR class inverters for the smart grid management of site based solar generation to minimize utility bills, increase self-consumption and contribute to a healthier power grid. The power conversation modes are summarized by application in the table below.

Application	**Mode**
Backup Power for Grid-Connected Systems	UPS and Backup AC input mode
Selling Excess Power to the Utility Grid	Grid tied mode
Avoiding Expensive Time-of-Use Surcharges	Grid tied mode + Grid use timers
Limiting Peak Demand Charges	Support Mode – AC Input Mode
Optimizing Self-Consumption	GridZero Mode