AC Coupling Grid Tie Inverters With OutBack Battery-Based Inverters

Overview

This application note will show how to add battery storage to a grid-tied (GT) inverter that is limited to photovoltaic (PV) solar conversion only when the utility grid is active. By adding a battery-based (BB) inverter like those from OutBack, the GT inverter can remain active with a grid outage as the OutBack inverter becomes the new AC source to which it can synchronize. This allows the GT inverter to continue converting DC power from the PV array to usable AC power for the site's local electrical loads.

Adding energy storage through AC coupling: For the owners of the more common grid-tied, grid-dependent inverters, there is a way to tie in a battery-backup inverter system using a method called *AC Coupling.* It typically requires adding a load center with circuit breakers and electrical connections for the building's critical loads. This allows a point at which the GT inverter and the BB inverter to "couple" and share their energy to the loads. In a normal mode of operation with grid power available, the energy from the PV array flows through the GT inverter to the critical load panel, with any excess energy flowing through the load panel to the BB inverter, and on out to the grid (see Figure 2).

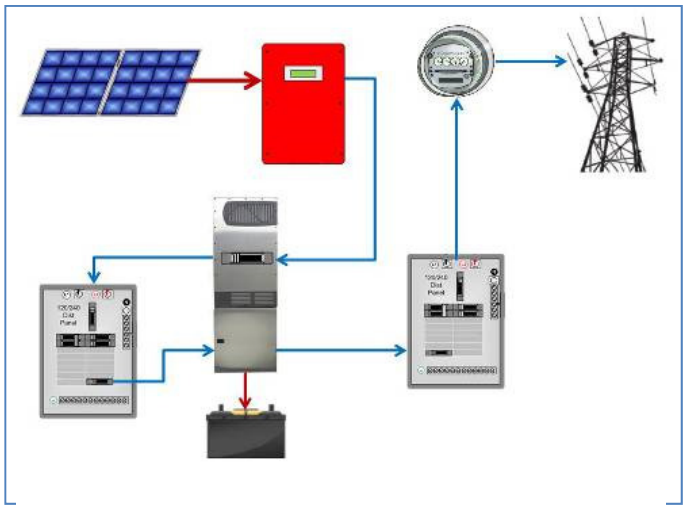


Figure 2 – Current path when grid is present.

When grid power is lost, the BB inverter activates an internal transfer switch which opens its connection to the grid. This keeps the inverter from trying to power other homes on the grid, as well as keeping energy off the power lines so utility workers don't get shocked. The BB inverter also provides a power source to the GT inverter that keeps it online and "inverting" the DC power to AC power for the critical loads (see Figure 3). When the sun goes down and the PV power is no longer flowing through the GT inverter to the loads, the power stored in the batteries will now provide power to the critical loads panel until morning (see Figure 4 on the next page).

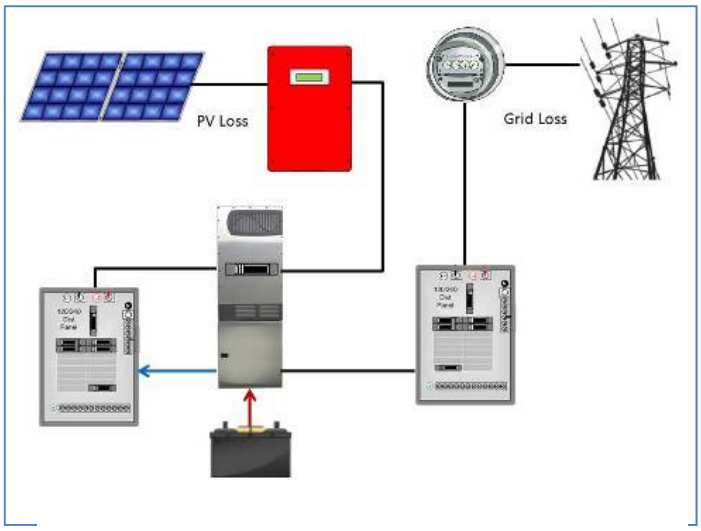


Figure 3 – Current path when grid power is lost.

When the sun comes out the next day, the system reverts to the power flow as shown in Figure 3, with any extra energy used for recharging the batteries. If no excess energy is available, then some manual load-shedding (divesting of less critical loads to prioritize the most critical, such as lighting and refrigeration) may be necessary through the turning-off of the critical load panel connected devices until the batteries are charged. If the critical loads are absolutely essential and load shedding is not an option, then adding a generator to the backup system can satisfy the critical load demand while charging the batteries.

One might ask: “why not just add the generator and forget about the BB inverter?” That might be a viable option for some, but there are some important things to consider before making that decision.

1. The generator will need to run the ***entire*** time that electrical energy is demanded by the building’s loads, perhaps 18-24 hours per day. Aside from the noise factor, many low-cost generators require frequent maintenance, and are very inefficient at low power output.

2. As an example, higher efficiency can mean the difference between filling up a 5-gallon gas tank once a day versus once a week if the generator is tied into a battery-based backup system that is running the generator just a couple of hours a day.

3. In a BB inverter system augmented with generator power, the batteries can greatly extend generator run-time as the same fuel will go a lot further since the generator does not need to run 24/7.

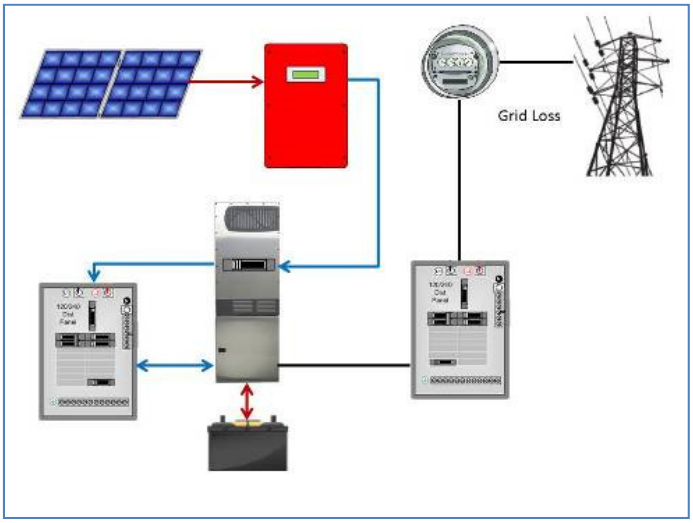


Figure 4 – BB inverter current path with both PV and Grid loss.

Typical AC-Coupling solutions and tradeoffs: Like any solution, the devil is in the details, and AC-coupling a GT and a BB inverter together is no different, especially if one wants a “one size fits all” solution for all applications. That “one size fits all” package usually includes one or more diversion loads, possibly a blackout relay or some other method to take the GT inverter offline to prevent it from overcharging the batteries on the BB inverter when the GT inverter produces more energy than what is demanded by the load panel. And it requires a lot more upfront design to be sure all devices in the system can handle all possible conditions.

Some battery-based inverter manufacturers attempt to simplify their AC coupling implementations by “dithering” or altering the frequency of their power to the GT inverter outside its operational window of 59.3 to 60.5 hertz. This will effectively shut off the GT inverter should excess PV energy start to overcharge the BB inverter batteries and is a simpler solution than using a blackout relay, thereby saving the cost of the relay. However, in many instances frequency dithering prohibits the use of a generator as the generator frequency is not always stable enough for the GT inverter to synchronize to. Even if it synchronizes, there is a risk of back-feeding and damaging the generator in low or no load conditions. In most cases, a manual transfer switch will be required to isolate the generator from the GT inverter if one is to be used.

It should also be noted that the “one size fits all” AC coupling solution really needs diversion loads to divert any excess energy in systems that either have too much PV power and/or too small of a battery bank which could put dangerous charge levels into the batteries. While it can be argued this energy can be used to heat water or run pumps, that “benefit” often comes when not necessarily demanded, and if the diversion load can no longer accept the available energy, the GT inverter must still be shut down. In addition to the complexity, diversion load implementations can also be expensive, requiring undesirable invasive installations which can make this design a poor choice for those who want simplicity and cost control in their AC coupling system. The extra expense of all the associated control and coupling hardware plus adding a more expensive inverter/charger often means skimping on energy storage with lower-grade batteries and enclosures, lowering overall system performance and utility.

OutBack's AC Coupling solution: Another approach is to keep things elegantly simple by outlining some basic sizing and operational guidelines. Typically, a simple BB inverter, a battery bank, and a remote-operated relay can be added to an existing GT inverter system to tie in the building's available PV power with the critical loads during grid loss. The rest of this article discusses an advanced electro-mechanical solution from OutBack Power with an option for automatic generator control if desired. A single line diagram outlining OutBack's solution can be found at the end of this application note.

The OutBack control circuit consists of the two OutBack inverter Auxiliary (AUX) ports; one controlling a remote operated circuit breaker (ROCB) acting as a "blackout" relay for the GT inverter, and the other to control an optional generator. This cleaner, more compact component design allows the safe lock-out of the GT inverter when the batteries are full, and also keeps the GT inverter locked out if an optional generator is started and running in the system. Integrated with a more advanced, smarter inverter/charger — such as OutBack's Radian series with dual AC inputs and advanced generator features — the result is a system that achieves higher performance at a lower effective cost. The detailed load center and control wiring diagrams can be found at the end of this application note.

In addition to the ROCB and relay devices, a new AC coupling function has been added to the MATE3 user interface. This function uses temperature-compensated charging set-points, will disconnect the GT using the ROCB when the battery voltage is 0.8 VDC above the battery voltage to protect the batteries, and will reconnect the GT inverter when the battery voltage is 0.4 VDC below the current temperature-compensated charging set-point.

Other smart features of the AC Coupling MATE3 function include a regular 15-second check of the high battery set point in the event the occupants manually close the ROCB when it should be open, and will re-open the ROCB to ensure the batteries are not overcharged through user error. Another feature is the MATE3's checking for an active grid when the ROCB has an open command, so if the grid power returns while the ROCB is open then the MATE3 will re-close the ROCB and allow the GT to return to selling to the grid.

Notable features of the OutBack GSLC175-AC-120/240 AC Coupling solution include:

- UL-1741 end-to-end — when used with an OutBack battery rack, the entire system is certified specifically for this application, ensuring fully-compliant operation.
- Split-phase design — more easily integrated into standard household wiring without costly, inefficient transformers.
- Simple installation — only one additional programming step and four new field wire connections.

NOTE: The aforementioned AC coupling solution using the OutBack AC coupling load center, is intended for a single Radian inverter used with comparably powered grid tie inverter(s). While designs using more than one Radian and AC coupled load center are feasible, the additional complexity of design and maintaining system balance goes beyond what OutBack Power is able to support. Please contact a qualified professional for design and ongoing support of large AC-coupled systems.

Solution

System Requirements

- Can be used on 48V battery banks only.
- The prewired GSLC AC Coupling load center is for use with the Radian inverters only.
- FXR single and dual inverter AC coupled systems are possible but do not come prewired. It is recommended to use the prewired FLEXpower systems as the panel knockouts will accommodate the ROCB blackout relay. The FLEXnet DC (FN-DC) battery monitor and its relay will be required as part of the system if used with a generator. FXR system wiring is shown in Figure 10 at the end of the application note.

Following are a few guidelines on how to size the system and interact with the two types of inverter systems.

Guideline Number One: The GT inverter power should not exceed 75% of the OutBack inverter rating.
This guideline ensures that the GT inverter does not overwhelm the charging circuitry in the OutBack inverter if the load demand goes to zero and all available GT inverter power is flowing to the OutBack inverter. For example, the 8 kW rating of the Radian inverter would dictate a GT inverter no bigger than 6 kW.

Guideline Number Two: Match PV Array Amps to Maximum Battery Charge Amps
Under normal operating conditions when the grid is present, an BB inverter/charger will keep the batteries in a "float" charge. However, when the grid is lost, the inverter is no longer in control of the charging current going into the battery, so any remaining power not needed by the loads will flow back through the bidirectional H-bridge circuit of the BB inverter into the batteries in an unregulated charge. Therefore, PV to battery bank sizing should be examined closely before finalizing a design.

Table 2 illustrates the relationship between PV array size and the maximum charging current for a typical battery bank using OutBack 200RE AGM batteries. For a single battery string, the 31A from the 2 kW array (calculations assume 75% array efficiency for a 48V battery bank) is well below the 53A maximum charging current, but a 4 kW array at 62A would exceed the maximum charge current. While the 93A from a 6 kW array would not exceed the 106A maximum charging current for a two string battery bank, charging the batteries at a lower charge rate than the maximum will significantly increase the usable capacity of the battery bank. Using a more conservative sizing approach will also help protect the batteries from the overcharging effects of an unregulated charge when load demand drops below the output level of the PV fed GT inverter.

Typically, most site owners will want available power to last at least a day so the batteries can get refreshed on a daily basis. The last column in Table 2 shows the available energy for the different battery string sizes at the C/24 discharge rate to 80 percent DOD. The kWh number for each battery string size can be used to match up with a 24-hour load demand that is normally calculated at the system sizing and design stage.

PV Array kW max (STC)	PV Charging Amps (Based on 75% efficient array)	Number of 200RE Battery Strings	Available Capacity at C/24 rate with 80% DOD
2 kW	31 Amps	1 string: 53 A Max	6.9 kWh
4 kW	62 Amps	2 strings: 106 A Max	13.9 kWh
6 kW	93 Amps	3 strings: 159 A Max	20.8 kWh

Guideline Number Three: PV array production should match combined load and battery charging demand. This ensures that either the daily load demand or battery charging doesn't exceed the power from the PV array. The energy flow diagram below in Figure 5 shows how much energy is required from the array to power the loads and simultaneously charge the batteries while the sun is shining. The 3 kWh going into the batteries represents the night time load demand that needs to be replaced during the day when the sun is out. As peak load demand and available charging currents will also affect the system energy balance, those factors should also be considered when designing the system.

And even with the PV array sized for minimal winter sun hours, an optional generator may still be needed to supplement PV energy shortages when load shedding will not be adequate compensation, or when medical and emergency equipment requires firm power.

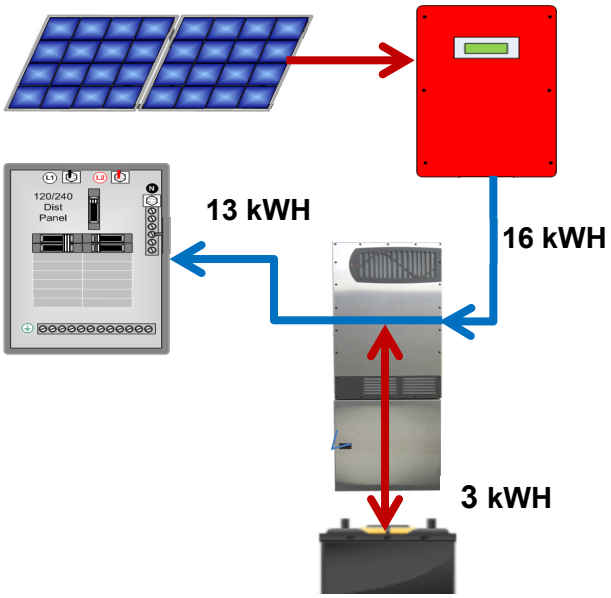


Figure 5 – System Energy Balance.

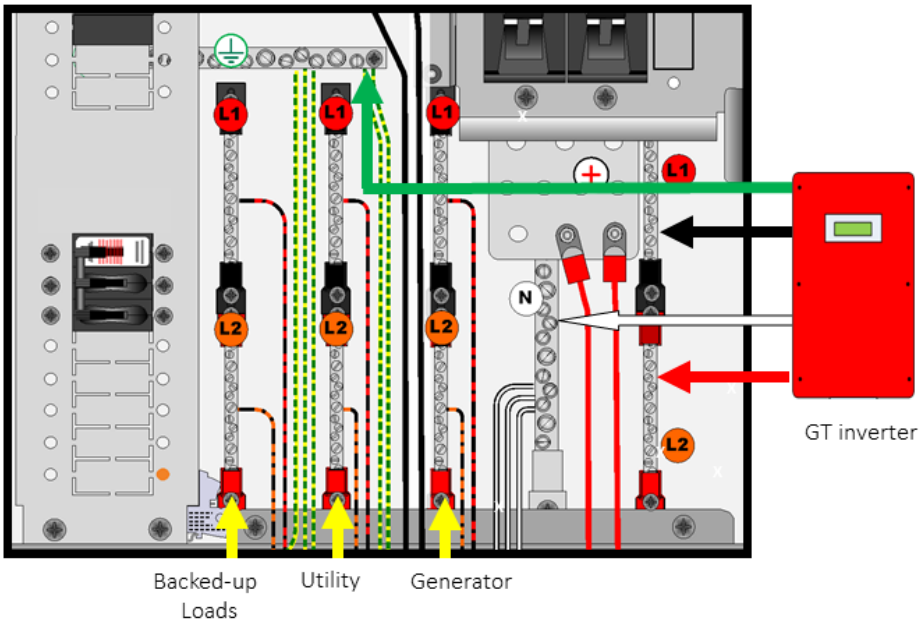
Installation Procedure

Audience

This application note provides instructions for the physical installation and wiring of the OutBack Power AC coupling solution. These instructions are for use by qualified personnel who meet all local and governmental code requirements for licensing and training for the installation of electrical power systems with AC and DC voltage up to 600 volts. This product is only serviceable by qualified personnel.

Radian System Layout and Interconnections

1. Mount the OutBack Radian inverter, its corresponding GSLC load center, critical loads panel (CLP) and battery bank in close proximity, preferably in a secure location.
2. Make the AC interconnections between the GT inverter, CLP and the OutBack inverter inside the GSLC load center as shown in Figure 6.



3. See Figure 7 for interconnections between the ROCB control relays and the inverter Aux Ports. The 18 AWG twisted pair wires are coiled inside the GSLC prewired load center. The green pair goes to the 12V Aux and the orange pair goes to the Aux Relay.

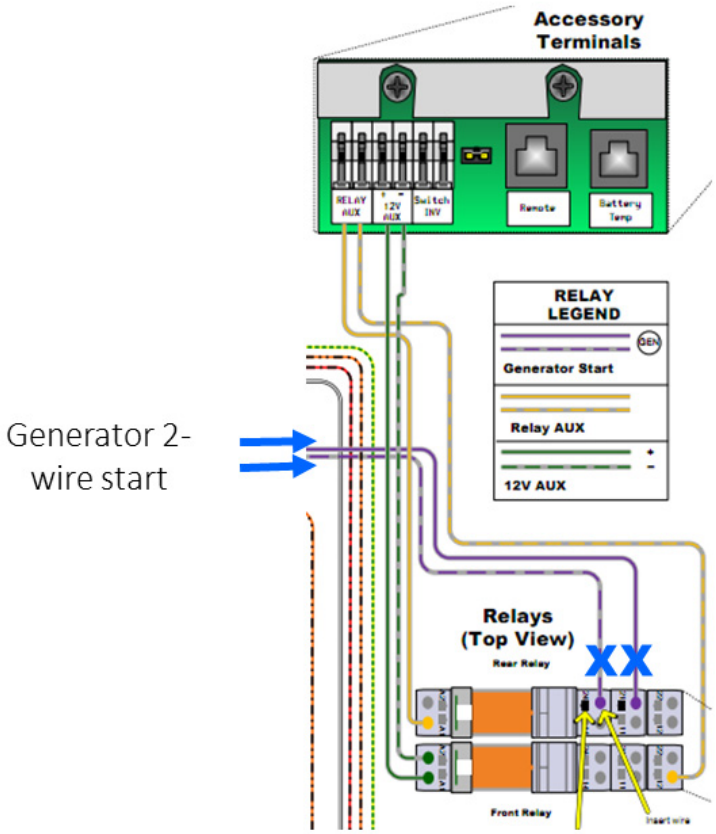


Figure 7 – Control relay to inverter and generator wiring.

4. Make remaining battery, optional FN-DC battery monitor, and any other required connections per instructions in the AC Coupling load center Quick Start Guide.

AC Coupling with OutBack FXR Inverters

System Programming

1. Press the LOCK key, and enter the 141 password, then select and run the Profile Wizard (formerly Configuration Wizard). Step by step instructions can be found in the Programming Guide. Optionally, the system settings can be programmed manually if the installer is experienced programming the OutBack Power system settings.
2. Additional settings required for proper AC coupling operation.
    a. Set the AC Input mode to Grid Tie under the Settings/Inverter/Grid AC Input Mode and Limits. Even though the inverter does not have any DC-coupled energy to push back to the grid, this mode allows proper monitoring of current direction, especially when the PV power from the GTI is going back to the grid and charging batteries simultaneously.
    b. Navigate to Settings/Inverter/Grid-Tie Sell and set ***Grid-Tie Enable*** to ***Yes***, and the ***Sell Voltage*** equal to the ***Inverter Float*** voltage setting. This will prevent cycling of the ROCB should an OutBack inverter Float cycle end with ***Sell Voltage*** set to a lower setpoint than Float which then gets interpreted as an overvoltage to turn off the ROCB during the batteries self-discharge time.

c. Set the ***AC Coupled Control*** to ***Yes*** under the Settings/MATE3/AC Coupled Control menu.

d. Navigate to Settings/Inverter/Auxillary Output, and set to ***Remote*** if implemented. Otherwise set to ***Gen Alert*** with the ***High*** and ***Low*** settings to their extreme to prevent the Inverter Aux function from being triggered and interfering with MATE3 AC Coupling Aux control.

e. Navigate to Settings/Inverter/Auxillary Relay, and set to ***Remote*** if implemented. Otherwise set to ***Gen Alert*** with the ***High*** and ***Low*** settings to their extreme to prevent the Inverter Aux function from being triggered and interfering with MATE3 AC Coupling Aux control.

f. If the AC coupled system is functioning mostly as a backup power system as intended, then programming Float time on the short side of the battery manufacturer's recommendation will reduce unnecessary extended charging of the battery bank.

AC Coupling Recommendations and Precautions

Lithium Ion Batteries

Due to risk of unregulated charging when load demand drops below GT inverter energy output, Lithium Ion (Li-Ion) batteries are not normally recommended for AC coupling applications. Not all Li-Ion chemistries are the same, however, and some are much more forgiving to overcharging or have a fast acting BMS for protection. Even some of the more volatile chemistries (usually the ones with oxide in the name) have active cooling to reduce the risk of thermal runaway. OutBack Power recommends discussing safety and warranty concerns with the Li-Ion battery manufacturer before making a final decision on battery type for the AC coupling installation.

Daily AC Coupling Applications

The OutBack Power single Radian/FXR or dual FXR inverter solution is only recommended for the few days or maybe couple of weeks per year backup power application. We do not provide design review or technical support for multiple inverter AC coupled applications (except for dual FXR), or OutBack Power inverter systems that are intended for daily AC coupling, meaning grid loss, or off-grid applications where the OutBack inverter is acting as the grid source to the GTI full time.

However, experienced AC coupling designers have put together "full time" AC coupled systems using diversion loads to prevent unregulated current flow through the inverter and onto the batteries, but even so, it's most likely that the battery bank will have a reduced life span.

Perhaps a better alternative would be to DC couple the array into a 300V or 600V charge controller that could be switched to a battery based inverter during power outages. The energy efficiency will also be much higher with a DC coupled system versus an AC coupled system.

Grid Tie Inverter Compatibility

OutBack Power has successfully tested our AC coupling solution on SMA, Enphase and SolarEdge inverters. SolarEdge does not support blackout relay solutions, but has something called a Power Reduction Interface Port that can be used instead of a blackout relay to take the inverter offline.

The main problem surrounding compatibility has to do with how the GT inverter performs its source impedance test to make sure it is connected to the grid and not some other unqualified source like a generator. One technique used is to insert a little "notch" at the peaks of the voltage waveform and if the source can push down the notch, then there is a strong enough AC source for the GT inverter to sync with. If the notch remains, then the GT inverter will not sync with the AC source. Some GT inverters employ a frequency shift technique where if successful, then the AC source is too weak and the GT inverter will disconnect. This is another reason why Guideline One stated above is important. If the GT inverter is too close to, or exceeds the OutBack inverter power rating, the OutBack inverter does not have enough power to push down the notch or overcome the frequency shift.

Optimizing System Balance

A typical DC coupled grid hybrid system will often undersize the battery bank to help keep down costs as the main objective is to sell power back to the grid, or at least net meter (offset) the electric bill through self-consumption, or "spinning the meter backwards" by exporting excess power to the grid.

However, in an AC coupled system, it can be helpful to oversize the battery bank to act as an energy absorbing buffer during times of excess PV power when load demand drops off during sun hours. Another alternative that may be more cost effective than oversizing the battery bank, would be to employ a diversion load to absorb the extra energy during peak PV power/low demand periods that might otherwise stress the battery bank during periods of unregulated charging.

If the loads — including battery charging — are at or below the peak PV power being produced, then oversizing the battery bank or employing a diversion load will not be necessary.

Retrofitting Radian and FXR Inverters

OutBack also offers an AC Coupling kit, part number GS-IOB-AC-120/240, that can be used for retrofitting existing Radian or FXR inverters (photo of typical ROCB kit installation at right). For FXR inverters it's recommended to install the ROCB in three unused circuit breaker spaces of the FLEXpower (FP) AC load center along with the DIN rail for mounting the two relays. The Radian inverter has both a 12V auxiliary (AUX) port and dry contact relay for the generator start, but the FXR inverter only has the 12V AUX port. The FN-DC battery monitor is recommended for battery monitoring and charging control for every OutBack system so the dry contact relay in the FN-DC can be used for AC coupling applications requiring a generator. The kit comes with installation instructions or they can be downloaded as ROCB Installation Instructions on the OutBack website under Products/Inverter-Chargers/Radian Series/GS Load Centers.

Figure 8 – AC Coupling kit installed in FP2 load center with dual FXR inverters.

Summary

Overall, this AC Coupling solution from OutBack has considerable advantages: it is easy to size, easy to install, does not require external hardware, and is less expensive than most other solutions. It uses intelligent controls and provides back-feed protection if a generator is part of the system. The OutBack solution provides backup power for existing grid-tied inverter systems up to 6 kW that won't leave all that PV power stranded on the roof the next time disaster strikes. When implemented using the OutBack Radian-series inverter, the result is higher-performance and greater reliability in a more compact, cost-effective package, enabling the user to invest in higher-quality energy storage and thoroughly optimizing their renewable energy system.

Figure 9 below shows a simplified single line diagram of the AC coupled system. The drawing shows the generator option which is not required if daily sun is expected or critical loads can be shed until more sun is available.

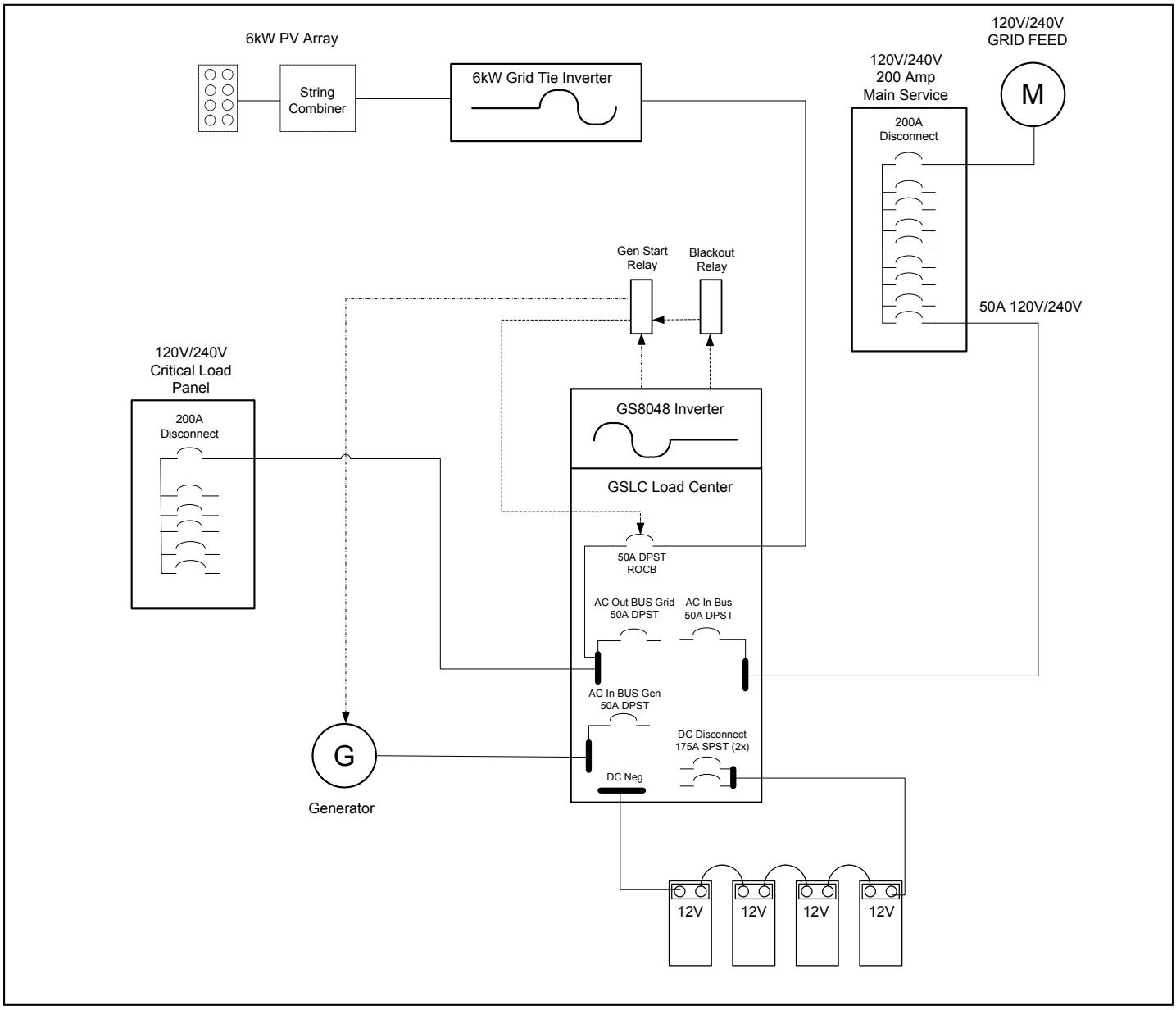


Figure 9 – Single line diagram of an OutBack Radian inverter AC coupled to a grid-tied inverter.

Figure 10 below is a detailed wiring diagram of the Radian GSLC175-AC-120/240 GSLC load center. Field wiring lands on the terminal bus bars as designated below with "X". If desired, a two-wire generator start can be connected to pins 21 and 24 of the 48V relay.

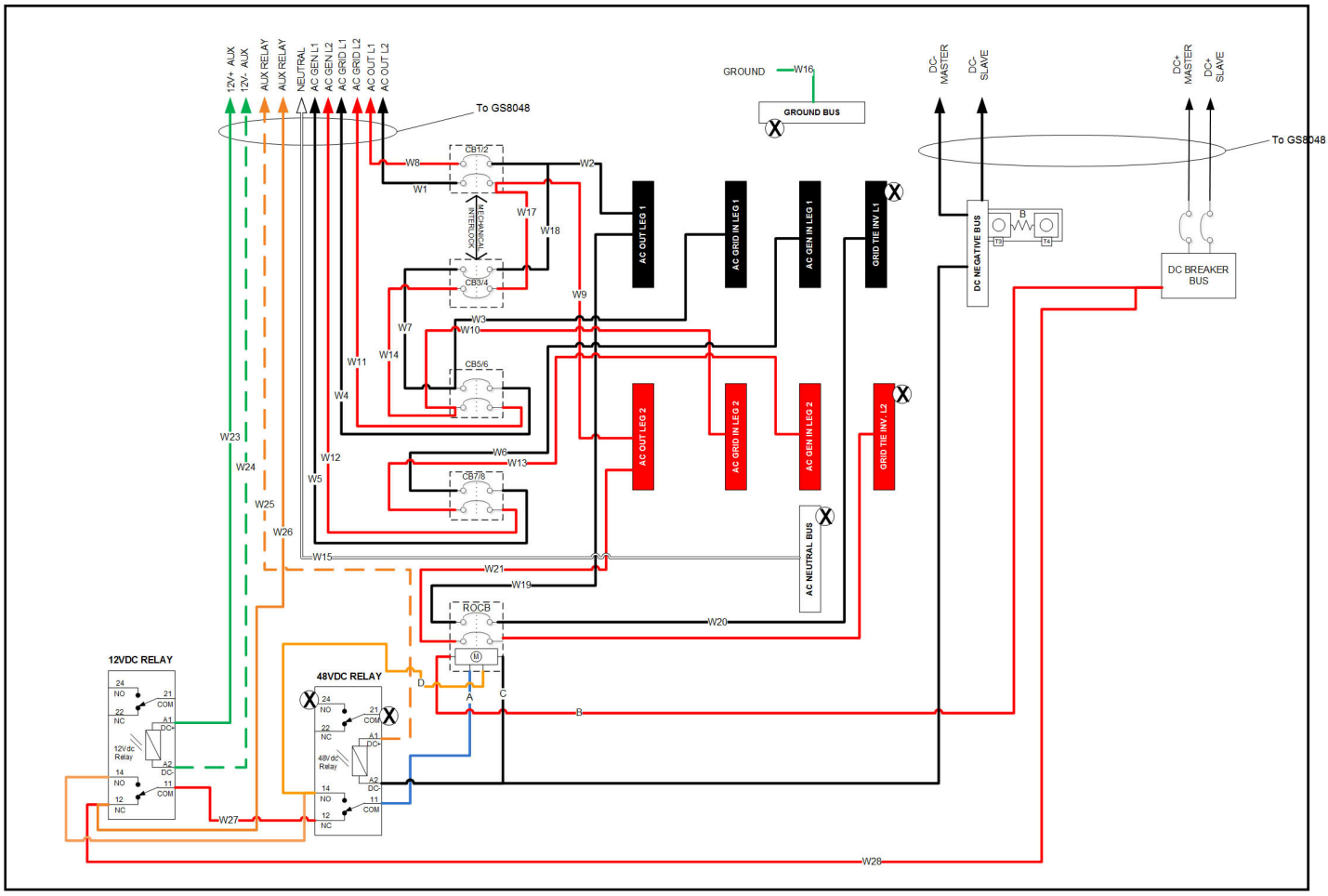


Figure 10 – Detail diagram of the Radian GSLC175-AC-120/240 GSLC load center wired for AC coupling. Field connections designated with "X".

Figure 11 below is nearly identical to Figure 10 above except for the internal wiring labels showing the destination as landing on the FP FXR inverters rather than the Radian GS inverter. Field wiring lands on the terminal bus bars as designated below with "X". If desired, a two-wire generator start can be connected to pins 21 and 24 of the 48V relay.

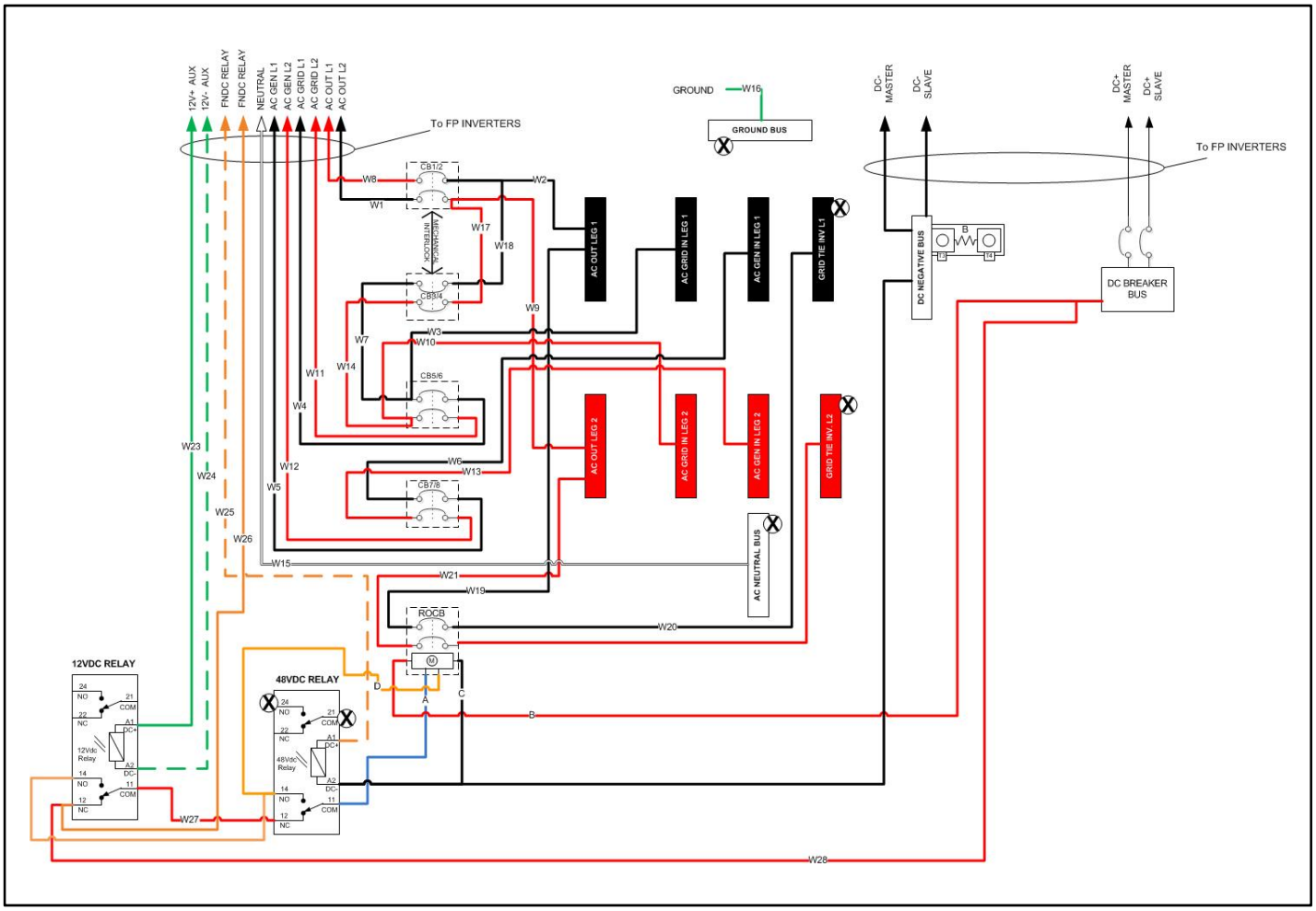


Figure 11 – Detail diagram of the FP FXR load center wired for AC Coupling. Field connections designated with "X".

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.

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