OutBack POWER™ an EnerSys company

Application Note

A Simple and Cost Effective Solution to Meet NEC 690 Compliance with the FM100 AFCI Charge Controller

Introduction

A number of significant changes in the last few NEC 690 code cycles have made compliance challenging for photovoltaic (PV) power electronics manufacturers and integrators alike. Changing definitions for ground fault, arc fault, array boundaries, controlled conductors and disconnects all contribute to a meandering road of solutions.

OutBack met this challenge head-on with the new FLEXmax 100 AFCI. This industry-leading charge controller platform carries the strongest implementation for NEC 690 compliance, on and off the grid. With up to 6000 watts of power conversion (7000 watts of connected PV), the 300V PV input and 100A output provides the most flexibility for module/string combinations over a wide variety of PV module power ranges.

This application note will first show how the FM100 charge controller maximizes deployable power for a cost-effective PV-plus-energy storage installation. It then examines how this charge controller has the lowest system component count and greater ease of installation to meet NEC 690 compliance.

FM100 AFCI Advantages

Higher Voltage and Current - Flexible String Sizing

The output power of a given charge controller is the product of the maximum output current, 100 amps in this case, and the battery voltage. Some charge controller designs employ higher PV inputs without increasing the output current, which is ineffective. While a higher input voltage results in fewer, longer input strings, the controller will only convert that added energy if the output current is increased to match.

For example, the OutBack FLEXmax 80 was designed with an ideal input power to output power ratio. This 80-amp charge controller will always have a maximum string configuration of three PV modules in series due to the 150 V_{OC} input limit, and possibly only two if high power modules are used in a cold environment. It set a benchmark at its introduction to the market for many charge controllers developed since.

Here are how some common competitive charge controllers stack up against the industry standard FM80 and the new FM100 AFCI based on a 320W PV module with a V_{OC} of 40.8V and a battery voltage of 57V.

PV Charge Controller	V_{OC} Max	V_{OC} Operating	Max Modules in Series	Max # of Strings	Max Watts Connected	Max Watts Operating
FM80 4000W/80A	150V	145V	3	4	3840	3840
FM100 6000W/100A	300V	292V	7	4	6720	5700
Comp 1 6600W/100A	240V	187V	4	5	6400	5700
Comp 2 4000W/55A	298V	250V	6	2	3840	3135
Comp 3 4800W/80A	600V	550V	13	1	4160	4160

Comp 1 - 240 V_{OC} input limit (187V operating) with 100A output – Up to four modules in series per string for continuous operation (V_{OC} 163.2) and five strings. The 187V V_{OC} operating limit significantly limits series string sizes.

Comp 2 - 250 V_{OC} input limit with 55 A charging output – Up to six modules in series, but only two strings in parallel are reasonable due to the low output power (55A @ 57V).

Comp 3 - 600 V_{OC} input limit with 80 A charging output – Up to 13 modules in a single series string but can only charge at 80A, which reduces the maximum possible output power from 4800W to 4160W. Adding a second string would increase the output power, but then the high 600V controller is not really necessary, as adding a second string only requires a 300V controller.

FM100 AFCI – 300V V_{OC} input limit with 100A charging output – Unlike the other charge controllers, the FM100 AFCI has ***both*** a high input V_{OC} and a high output current to deliver the largest amount of PV power with the most flexible string configurations. The controller's integrated rapid shutdown function, ground fault detector interrupter (GFDI), and arc fault circuit interruption (AFCI) also provide the simplest configuration of NEC 690 to meet the aforementioned requirements.

Battery Sense Leads - Improved Charging Accuracy

Most charge controllers measure battery reference voltage at the internal battery terminals, which becomes problematic with systems employing multiple charge controllers. Voltage drop (from the charge controller's internal terminals across the cables to the batteries) creates a discrepancy between the measured voltage and the actual battery voltage at high and even moderate current levels.

In each charge controller, this discrepancy can cause inaccuracies in system behavior and calibration. In systems with multiple charge controllers, the cumulative effect of these voltage discrepancies can cause certain controllers to artificially reach charging targets sooner than others and stop producing energy. This, among other issues caused by imprecise voltage measurements, reduces uptime and total energy harvest.

Battery sense leads (Fig. 1) overcome this problem. The sense wires carry almost no current to the high impedance voltmeter inside the charge controller, and therefore have virtually no voltage drop across them. For multiple charge controller systems, battery sense leads may be daisy chained using ferrule terminals or run separate pairs to each controller.

Some charge controllers that lack battery sense leads allow the user to calibrate the internal battery terminals to the battery bank voltage. Unfortunately, this requires calibration at commissioning and regular maintenance by a skilled technician. Variations in current levels between controllers can still be problematic. The battery sense leads on the FM100 eliminate this problem and ensure that multiple charge controllers with multiple arrays are synchronized for maximum production.

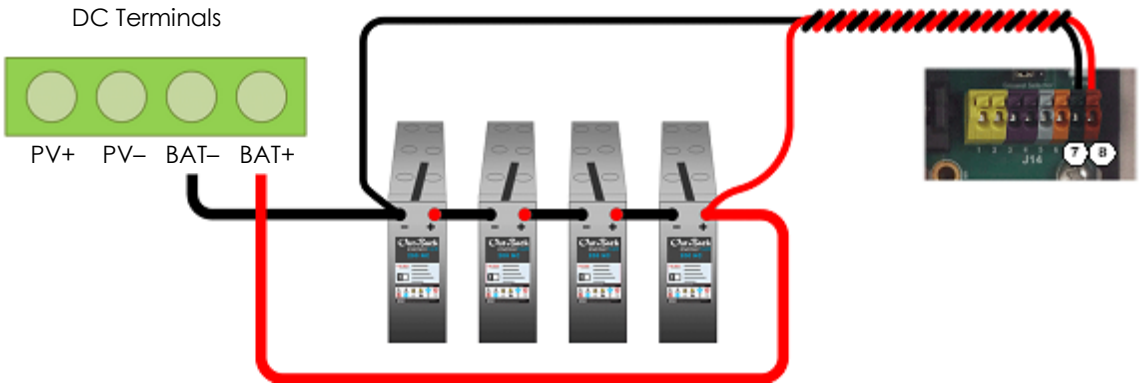
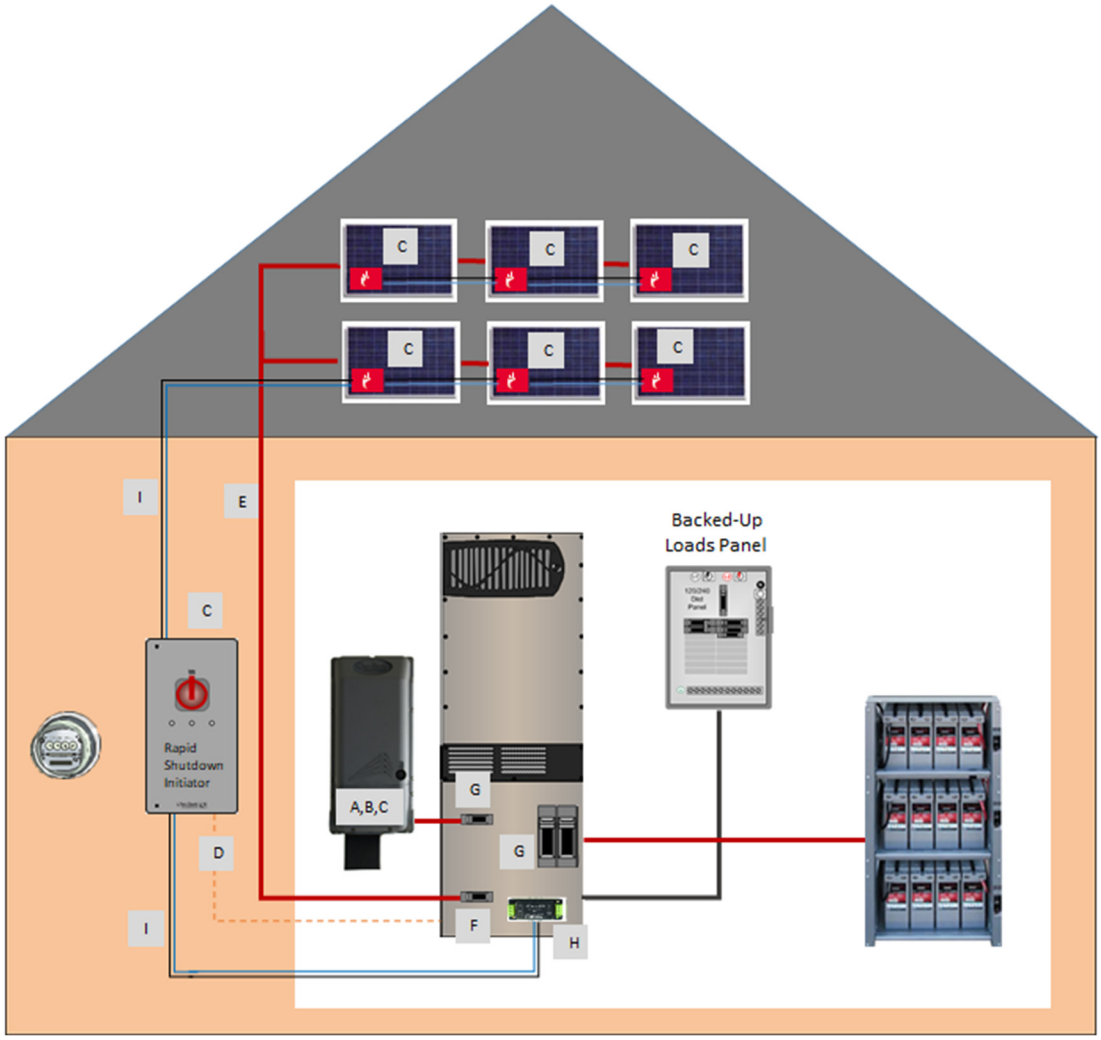


Figure 1 - Battery sense leads prevent unintended curtailment of parallel charge controllers

FM100 AFCI NEC 690 Compliance

The FM100 AFCI employs industry-leading technology to meet the most recent 2017 code compliance with regards to GFDI and AFCI detection and interruption, rapid shutdown, and related disconnecting means. Systems that use the FM100 AFCI require no additional GFDI nor AFCI equipment. This makes it the most cost effective, easy to install, and low maintenance controller on the market for NEC 2014 and NEC 2017 compliant systems.

Figure 2 on the next page shows a typical 2017 NEC 690 compliant installation. While this example depicts an NEC 2017 compliant system, all NEC 2014 requirements are met by 2017 code cycle implementation. OutBack's 2014 solution requires the ICS Plus combiner box with a large, expensive contactor, two arc fault sensing devices and a circuit board, all of which must be placed within ten feet of the PV array. The OutBack 2017 solution eliminates the expense of the 2014 ICS Plus combiner and its wiring and installation costs, making the 2017 solution far more cost effective and convenient regardless of whether the installation must be 2014 or 2017 compliant.



FM100 NEC 690 Compliance

A. 690.5 Ground fault protection
B. 690.11 Arc fault protection
C. 690.12 PV rapid shutdown component
D. Optional rapid shutdown to inverter so backup panel is dead when utility power is disconnected (RSI J3 relay to Inv. On/Off).
E. Controlled conductor
F. 690.13 PV disconnect
G. 690.15 Disconnecting means for DC sources
H. 48Vdc to 24Vdc power supply
DIN mount, P/N PWRSPLY-24
I. 24Vdc power

Additional NEC 2017 compliance options are detailed on the following pages.

Figure 2 - Typical 2017 NEC 690 Compliant OutBack System

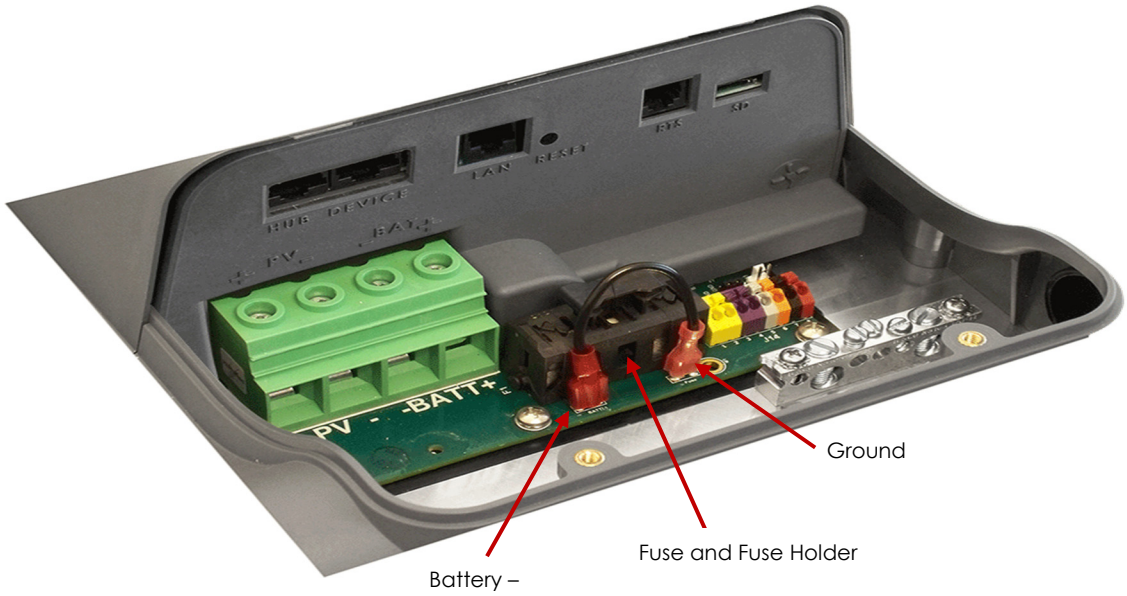


Figure 3 - Ground fault detection

Ground Fault Detection

The FM100 AFCI uses an internal fuse and jumper system for ground fault detection as opposed to the external GFDI breaker used by the FM60/80 legacy charge controllers. The jumper is connected to the system ground on one end and DC negative on the other. This provides an electrical bond from ground to DC negative with a 0.75A 600V ground fault fuse in series. In multiple charge controller systems, the jumper is left in place in all controllers, but the fuse is removed from all controllers except one. For positive grounded systems, all jumpers and fuses are removed. See the FM100 manual for more complete information regarding positive grounded systems.

Arc Fault Detection

Arc fault detection is the latest NEC 690 code compliant feature to be integrated into the FM100 charge controller. This means the ICS Plus combiner box with arc fault detection is no longer required for the FM100 to be NEC 690.11 arc fault compliant. Many PV array configurations will only require two PV strings, but even if three or four strings are required, the much less expensive FLEXware FWPV6 combiner box may be used.

No arc fault detection circuit can claim total immunity from false trip events. However, OutBack has taken special care to develop arc fault detection that is immune to false tripping *and* fully tested and listed to UL requirements for detecting unsafe arcing. To that end, a dual algorithm approach to arc fault detection was implemented. Each algorithm has great detection capabilities, but each is also susceptible to some level of error. However, OutBack's tests showed that the algorithms will not falsely trip together, making a double-positive detection a "high confidence" trip, while single-trip detections are ignored.

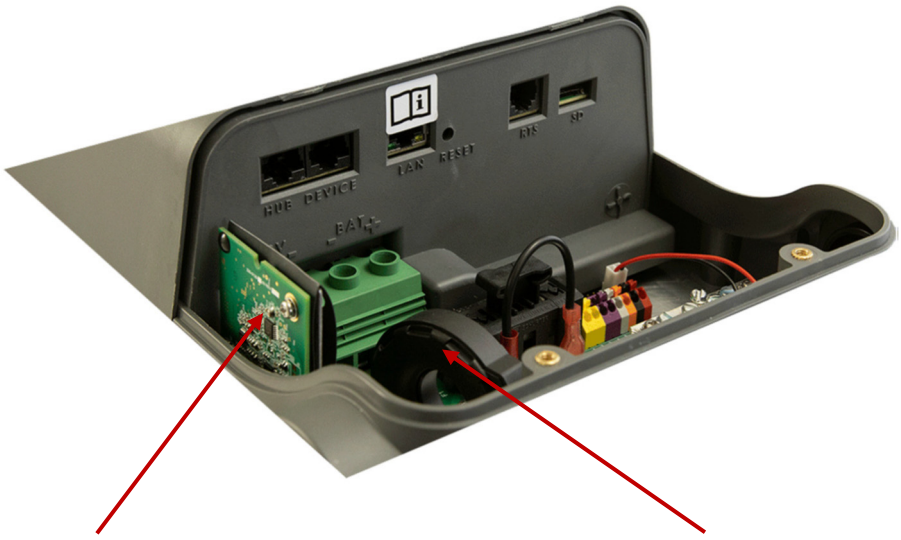


Figure 4 – Arc fault detection components

Rapid Shutdown

The 2017 Rapid Shutdown function can be implemented two ways. Both use the IMO FireRaptor module level power electronics (MLPE) with OutBack components. The easiest and least expensive is to use the FireRaptor shutdown switch and 24V supply with a 24V DPDT relay switch from OutBack as shown in Figure 5 below. When the FireRaptor switch opens, the 24V power is removed from both the Fire Raptor modules as well as the 24V DPDT relay. The open relay contacts will put the FM100 into rapid shutdown. The OutBack connected inverter will also turn off via the connection to the Inverter On/Off jumper. This solution can power up to 40 Fire Raptor MLPE devices, which is enough for most dual FM100 installations.

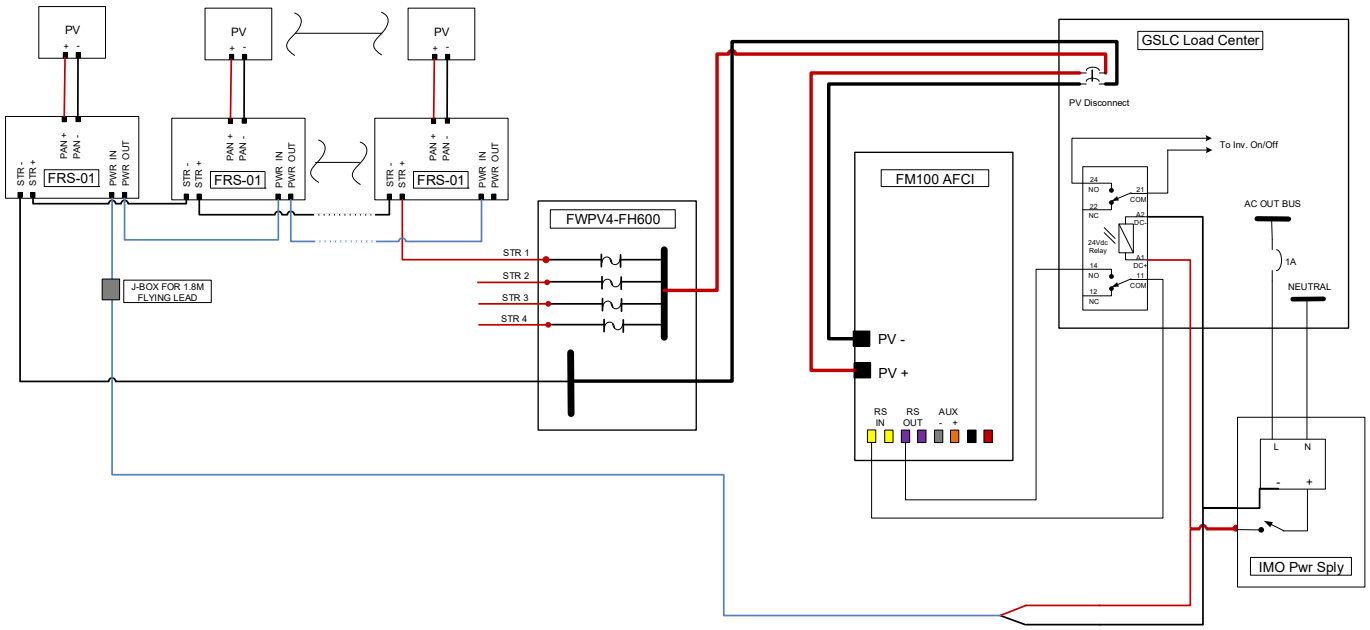


Figure 5 – Rapid Shutdown using IMO Fire Raptor MLPE devices and power supply with OutBack 24V DPDT relay

The second option, for installations requiring more than 40 FireRaptor MLPE devices, involves the OutBack RSI and the OutBack 24V 1200mA power supply. This power supply can power up to 114 FireRaptor MLPE modules. This solution is shown in Figure 2 on page 4, and in more detail in Figure 6 below. In this solution, the 24V supply powers the RSI as well as the FireRaptor modules. When the RSI shutdown is initiated, the 24V power is removed from the FireRaptor modules. Simultaneously, the RSI J3 contact puts the FM100 into a rapid shutdown state. The controller's external "daisy chained" RSI terminals can be connected to the inverter On/Off jumper to keep the OutBack inverter in the off state as well.

With either solution, when the FM100 AFCI is in the rapid shutdown state, it will then reduce the controlled conductor on the PV input side to less than 30V in less than 10 seconds. **Since the FM100 AFCI employs a double redundancy circuit, a confirmation output is not required for its UL PV Rapid Shutdown Equipment (PVRSE) listing.**

All FireRaptor components required for these solutions can be purchased with OutBack part numbers through a local OutBack Power distributor.

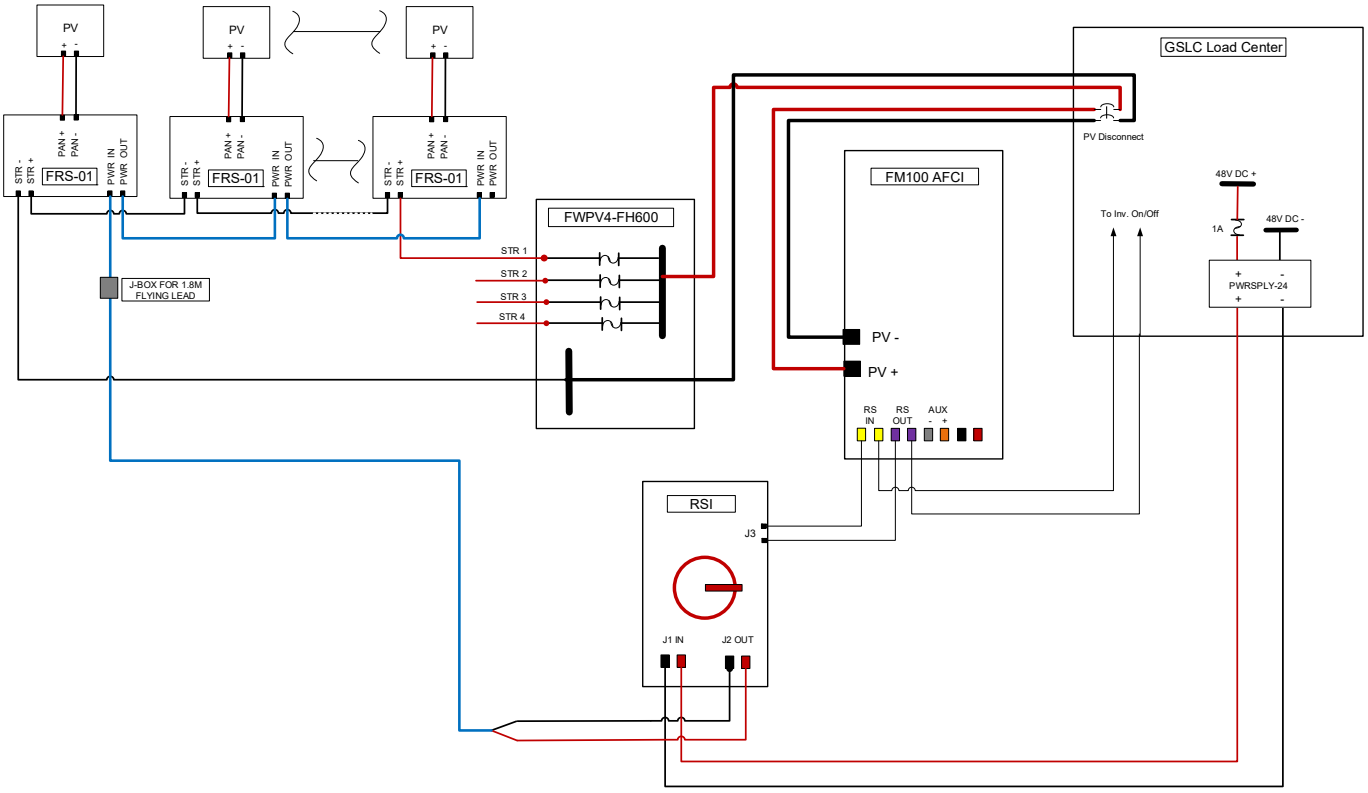


Figure 6 – Rapid Shutdown using the OutBack RSI and 24V power supply

OutBack has also tested the TS4-R-S module for compatibility. A drawing for this rapid shutdown solution is shown in Figure 7 below. It works the same as the previously described solution using FireRaptor and the OutBack RSI where the RSI shutdown mode will put the MLPE devices into rapid shutdown. With the loss of 24V power, the J3 connector will shut down the FM100 AFCI. The charge controller's parallel rapid shutdown terminals can be connected to the OutBack inverter On/Off.

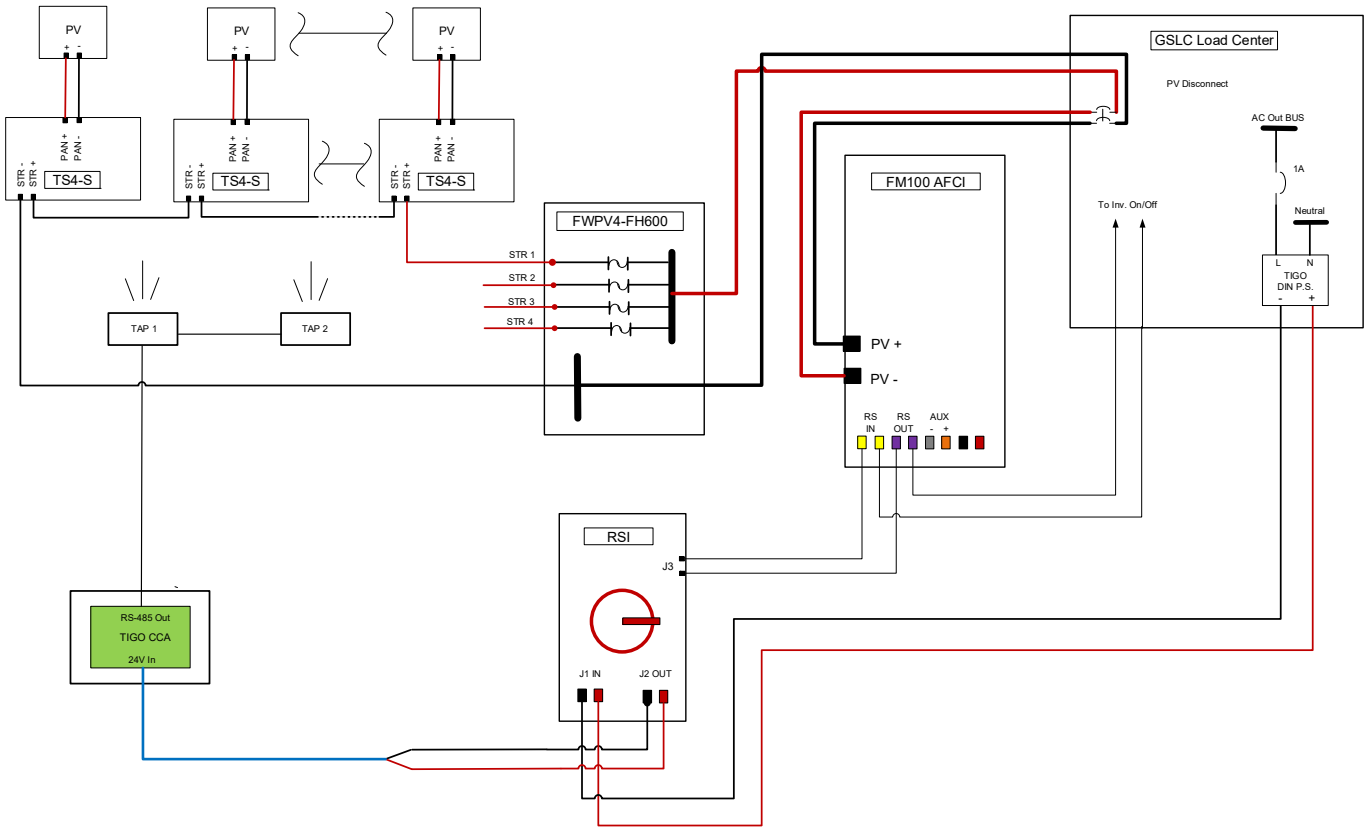


Figure 7 – 2017 Rapid Shutdown solution for Tigo MLPE devices and CCA Outdoor kit with OutBack RSI

Summary

The FM100 AFCI is the most comprehensive, cost effective solution for 2014 and 2017 NEC 690 compliant installations, and offers industry leading performance for storage-based PV generation and inverter systems.

Frequently Asked Questions

Q: Does the FM100 AFCI work in SGIP and in HECO territory?

A: Yes, it meets all CEC and Hawaii Energy Company requirements and listings.

Q: Why not a 600V charge controller?

A: Some MPPT charge controllers increased input voltage without increasing the output current. This requires a bigger, 600V enclosure and higher-voltage, higher-cost components without increasing the power the array can send to its batteries or loads. The only advantage of 600V is longer PV circuits.

The FM100 was upgraded to 300V input for longer circuits and smaller conductors AND an output current of 100A. The combination of 300V input voltage and 100A output current at 60V+ battery voltage provides the best combination for string sizing. In addition, the OutBack warranty on 7,000 connected watts of PV permits larger arrays for strong "shoulder" performance year-round, and increased output for winter months.

Q: Why choose the FM100 AFCI over the FM80?

A: Most popular charge controllers, like the FM80, were designed before the current arc fault, ground fault and rapid shutdown requirements started. OutBack made the FM100 AFCI the most cost-effective controller available for 2014 and 2017 NEC systems by eliminating the costs of the external balance of system material and its installation.

Consider the many other programmable features of the FM100, and it is the clear choice for developed and developing markets.

Q: How does the FM100 AFCI have 7,000W PV input and 6,000W charging output?

A: The FM100 AFCI will operate safely and efficiently with input from arrays up to 7,000W of nameplate power at 300VDC. The output is based on 100A of current at the battery charging voltage.

The output may exceed 6,000W when the battery voltage exceeds 60V, but 6,000W is the maximum continuous output on most 48V battery banks.

Q: What are the best markets for this product?

A: This product is popular in all major renewable energy markets including Europe, Africa, Latin America, Southeast Asia, and North America.

Q: Does the FM100 AFCI have remote battery voltage sensing capability?

A: Yes, it comes standard. OutBack highly recommends using it instead of relying on each controller's internal measurement at the battery connection terminals. High-current cable voltage drop can affect that internal measurement. It also requires regular recalibration.

Proper use of the battery voltage sense leads provides the exact same voltage reading to every charge controller in a given system. This ensures each charge controller will maximize its array output without the risk of one controller disabling another in parallel due to voltage target differences.

Q: Do I have to use the voltage sense wires?

A: No, but OutBack highly recommends using the voltage sense function for increased accuracy without regular recalibration. Proper use of the battery voltage sense leads provides the exact same voltage reading to every charge controller in a given system. This ensures each charge controller will maximize its array output without the risk of one controller disabling another in parallel due to voltage target differences.

Q: Can I daisy chain the voltage sense wires?

A: Yes, but only if using an appropriately sized ferrule-type connector to connect to each controller's terminals. Otherwise, simply use a twisted wire pair to connect the battery bank to the battery sense terminals of each FM100 in the system.

Q: Do I need to calibrate the FM100 AFCI voltage?

A: Voltage calibration is required if not using the remote voltage sense function. It is required if the system depends on the internal FM100 AFCI voltage readings.

Q: Is there a limit to how many units I can have in a system?

A: A HUB10.3 will accept up to ten devices for monitoring and programming. However, if the installation requires monitoring of the FM100 AFCI controllers on current shunts, the HUB's tenth port will be occupied by the FLEXnet DC. This means the limit is nine controllers on one current-monitored array.

Q: What batteries did OutBack use for testing?

A: The FM100 AFCI works with all 24, 36 and 48V flooded and sealed battery banks. It was also tested with SimpliPhi, Blue Ion and Discover lithium-ion batteries.

Q: Does it work with other lithium-Ion batteries?

A: The FM100 AFCI is currently tested only with SimpliPhi, Blue Ion and Discover batteries.

Q: How does OutBack plan to address module level shutdown?

A: The FM100 AFCI is currently compatible with IMO FireRaptor, Tigo TS4-R-S, and Tigo TS4-R-F.

Q: Any issues with nuisance tripping with the Tigo or FireRaptor MPLE modules?

A: OutBack recommends only IMO FireRaptor and Tigo TS4-R-S to avoid this problem. Tigo-O modules and other "optimizers" may cause nuisance trip events.

Q: With the ICS PLUS, I reset AFCI nuisance trip events by turning Solar ON & OFF. How do I reset AFCI nuisance trips on the FM100 AFCI?

A: To reset an AFCI fault on the FM100 AFCI, cycle the battery power to the charge controller. **See the manual for arc fault troubleshooting details**.

Q: Does OutBack have any module level optimizers?

A: Not at this time.

Q: What is the length of the FM100 AFCI warranty?

A: 5 years.

Q: Can I replace control boards in the FM100 AFCI?

A: Only the AFCI, GFDI, and fan components will be field serviceable. All other repairs must be done at the OutBack service center.

Q: Where do I get replacement GFDI fuses?

A: Order them using OutBack part number SPARE-045

Q: Can I mix FM100 AFCI controllers with FM80 controllers?

A: OutBack does not recommend it. See the application note on this topic for details.

Q: Can I upgrade an older FM100 to the arc fault version?

A: No, the original FM100-300VDC cannot be upgraded **to include AFCI.**

About OutBack Power

OutBack Power 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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Other

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