Shock Hazard in a safe enclosure?

A legal shock hazard?

Have you ever turned off all the sources of power to an enclosure and still found a hazardous voltage inside? This is a very possible situation with Battery Based Solar Systems using current "approved" equipment. While I have warned about this possibility in the past, I recently encountered a real life situation that demonstrated this electrocution hazard. Approved equipment can present a life threating situation, why would this be allowed?

There are several factors that create this hazard, so I will need to set the stage for the reader to understand the issue. Also, keep in mind that for the most part, the code has always assumed a central generation – grid distributed system. This is much different from locally produced power with several sources of power and different hazard potentials. Battery based renewable energy system also use very different and specific equipment that electricians and inspectors are generally not familiar with.

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The issue in a nutshell

Current Battery Based Charge Controllers incorporating ground fault protection, either integrally or via a ground fault breaker do not work in conjunction with a solidly grounded/bonded renewable energy system. The use of these approved charge controllers requires removing or not installing the solid negative to equipment bond since the ground fault protection would not work and there would now be two negative to equipment/ground bonds. There are also issues when multiple charge controllers are used in an installation. If multiple charge controllers are used and the integral protection in a charge controller is used in one controller, the other charge controllers now depend on the one that has the ground fault protection enabled. For the purposes of this discussion, the term ground will refer to both equipment bond and system grounding.

Power Sources in a Renewable Energy System

Before we get into the details, it is important to identify the power sources as there are usually several in a battery based system.

1. The individual solar strings (usually 3 in series, though other configurations are also used)
2. The Solar array(s) as a unit(s) (typically 4 strings each)
3. The Battery bank(s)
4. Other renewables, such as wind or hydro
5. Generator
6. Possibly the Grid
7. Inverter taking AC power and charging the batteries and the inverter taking DC power and inverting it to AC power

Grounding & Bonding

A. System Ground

Code rule 64-064 does not require System grounding for system voltages below 50 Volts. This would normally mean that renewable energy systems do not require a system ground to earth. (This is somewhat irrelevant in that most modern systems have an inverter installed. The AC output of this inverter is required to have a system ground, which then effectively earth grounds all the equipment on the DC side as well, since the inverter case and typically the breaker boxes and other equipment bond all the metal enclosures of all the equipment anyway.)

Solar Arrays typically operate above the 50 Volt limit even though the system voltage at the battery and inverter level are at 48 Volts or less. This means that solar arrays need to have the negative grounded. A 3 string array will typically operate at around 90 Volts DC with open circuit voltages as high as about 140 Volts. Arrays that have more modules per string would have a potential open circuit voltage approaching 600 Volts DC.

64-064 requires ground fault protection for the renewable energy DC supply circuits that are over 50 Volts and it allows for the grounding of the circuit to be via the ground fault protection device. So what happens in installations that have multiple charge controllers? Presumably, this rule would not allow for the integral ground fault protection to be used, but would have to rely on the GFI breaker type. This would also limit the number of charge controllers to 4 with the current equipment.

64-064 also does not permit the duplication of the grounding path

B. Equipment Bond

64-070 requires that the removal or disconnection of the equipment will not interrupt the bonding continuity.

64-070 appendix B has some notes on this. Basically, equipment bonding is required even in 12 and 24 volt systems so that protective devices can operate. It also indicates that in order to prevent shock and fire hazards, "it is important that the bonding continuity be maintained even when the equipment is removed".

14-010 – the intent of this rule is that if there is a dangerous fault, the fault needs to be automatically opened. This is really a common sense item and a basis for many of the rules in the code.

With current equipment we cannot meet both 64-064 and 64-070 at the same time

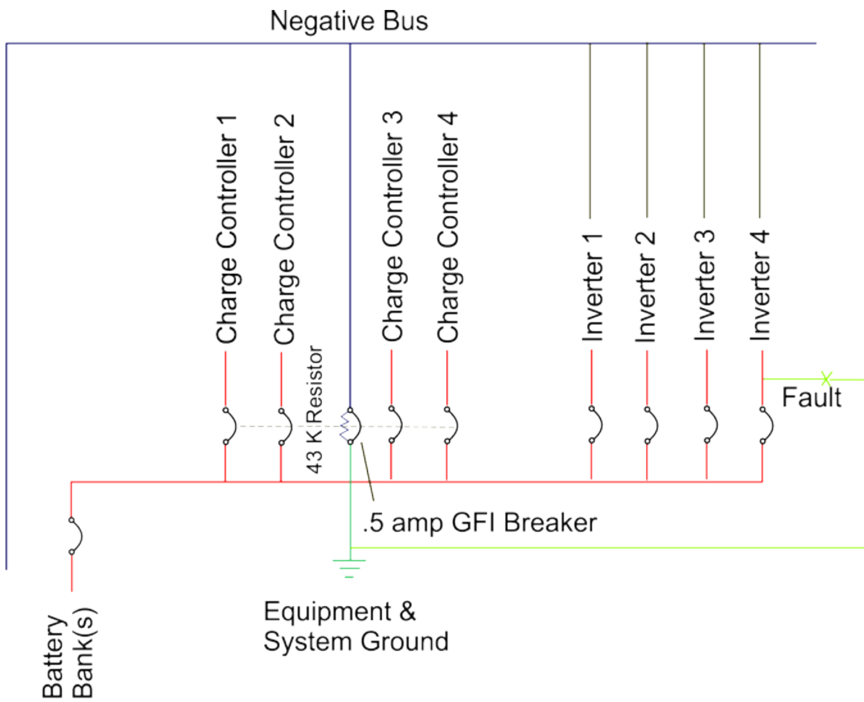
Equipment

A. Disconnects

The code requires that all ungrounded conductors from a renewable energy source have a disconnect, and it specifically lists several items as an example.

B. Ground Fault Breakers for charge controllers

This diagram shows a GFI breaker being used for 4 charge controllers and what would happen if a fault occurs in another part of the installation. Here a positive to equipment enclosure fault would result in current flow from the positive of the battery, through the fault, then proceeding through the ½ amp breaker back to the negative. This would trip the ½ amp breaker and, through the common trip, also trip the charge controllers. The fault would not be able to be cleared and you would then have the battery voltage present on the equipment case in relation to the negative of the battery. This would then have a normally grounded conductor (negative) with a voltage potential on it in relation to the equipment enclosure. Opening the circuit breaker would also open the negative to ground bond and leave only a high resistance bond that would not be able to interrupt a fault current.

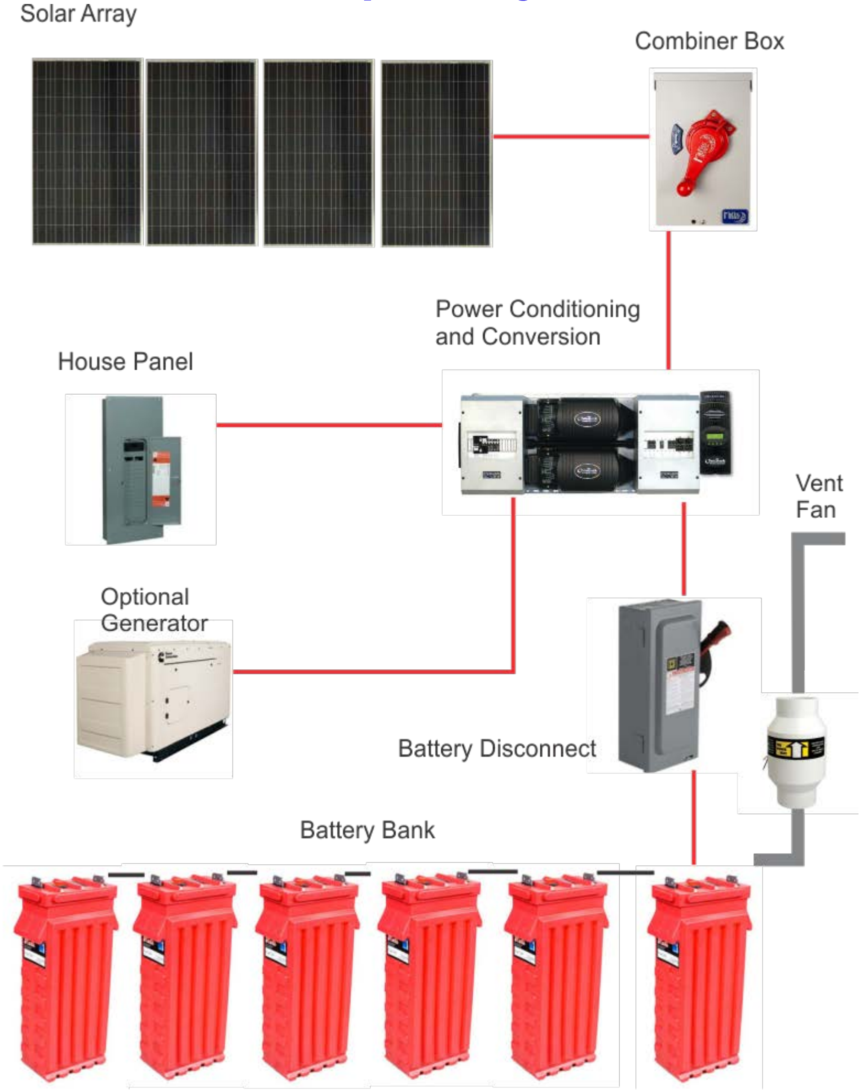


C. Ground Fault Protected Charge Controllers

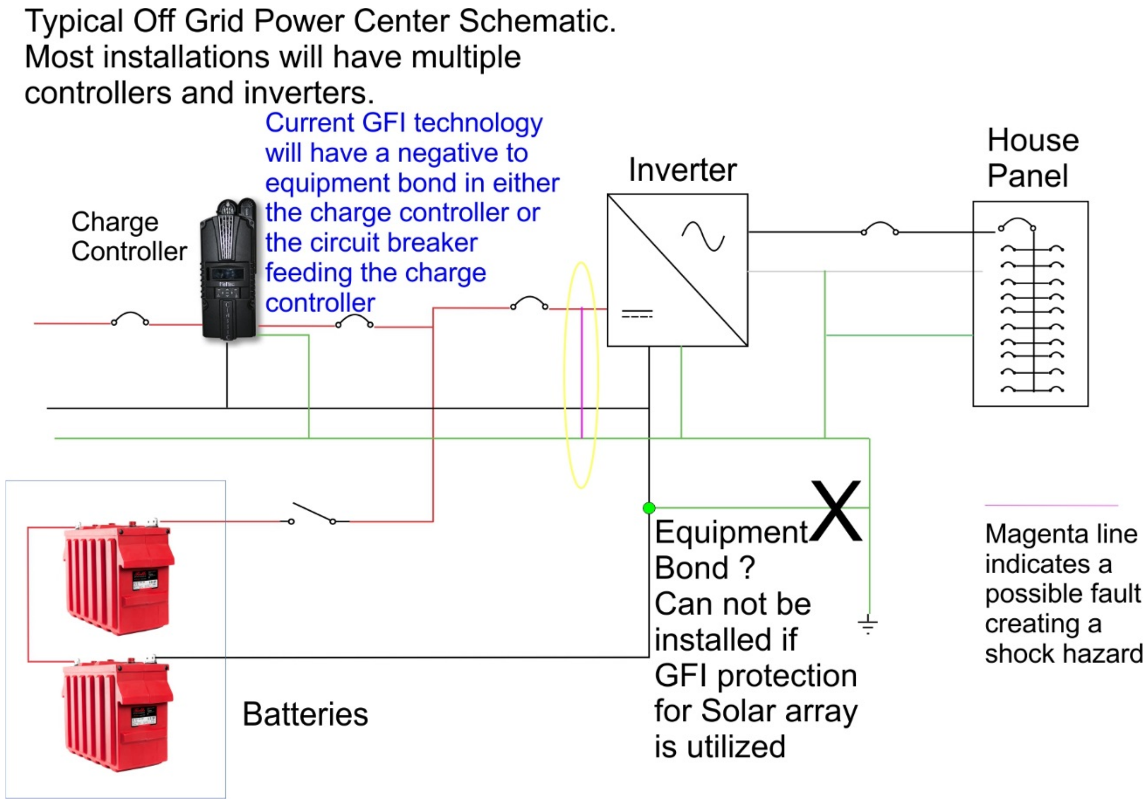
Integral protection by a charge controller operates much the same way. It may or may not have a resistor bridging the fuse. Removal of the charge controller then removes the negative to ground bond.

Wiring Layouts

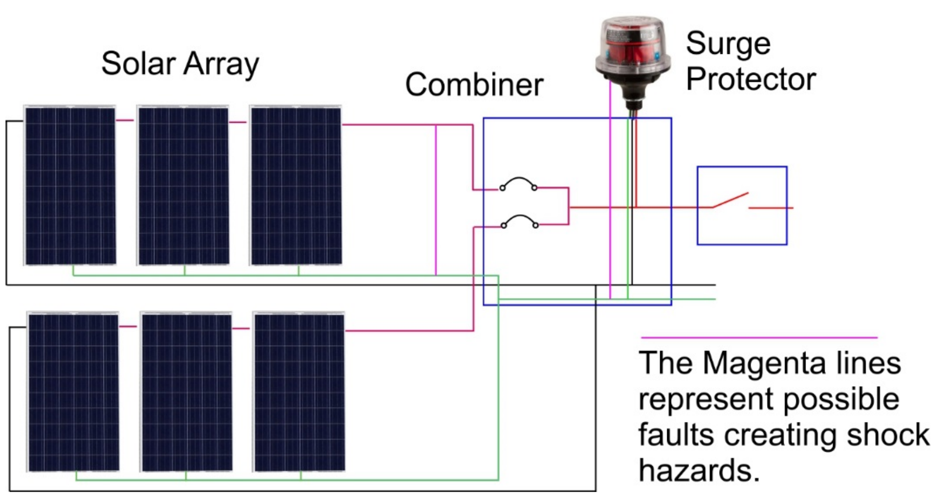
A. Overall simplified Diagram



B. Fault at the power center



C. Fault at the Solar Array

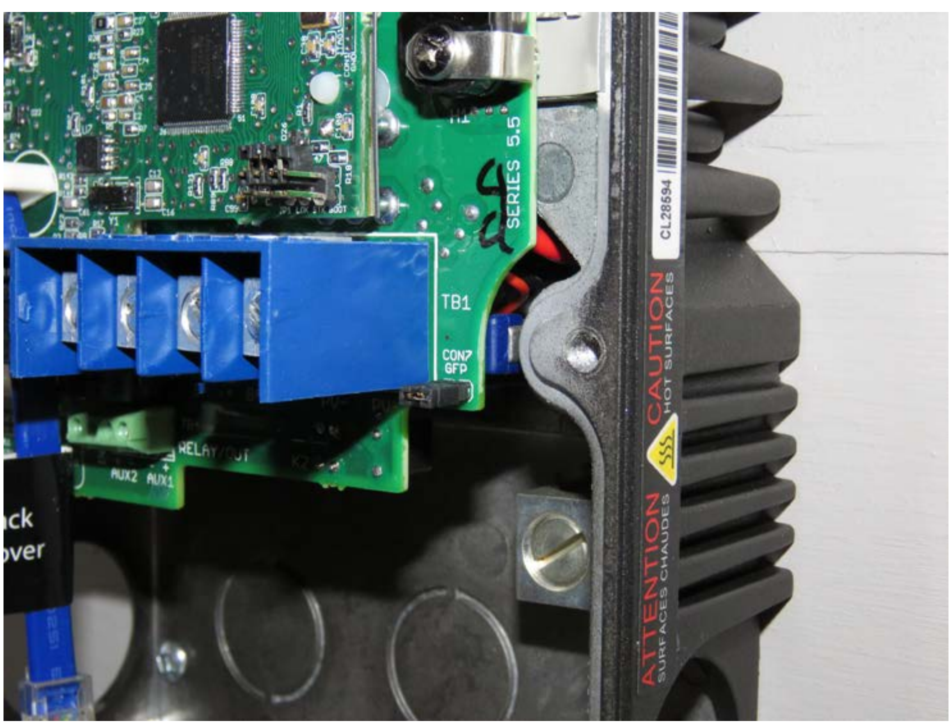


This is a much more dangerous situation than the fault at the power center as the voltage that is present between the normally grounded conductor (negative) and the equipment enclosure can be lethal. This is the situation that I encountered recently. I turned off all the disconnects for the various supply sources into the power center wiring. I then checked voltages between various points to make sure that there were no energized conductors. The result? 100 Volts DC from negative to equipment enclosure!

Upon further investigation, I found that the surge protector was imposing this voltage on to the equipment enclosure. Depending on the specific charge controller and number of modules in series, this voltage could be several hundred volts DC! So even with the Photovoltaic output circuit disconnect open, the dangerous voltage still existed. This same situation could occur with a short or even relatively high resistance path to ground from the positive wire from a series string of modules.

Surge Protective Devices

Surge protective devices are frequently installed at the combiner box. Surge protective devices clamp the voltage between positive and ground and between negative and ground. The issue then is that the surges that are suppressed between either positive or negative to ground would be clamped through the GFI device if the system does not have a solid negative to ground bond. The jumper that is used in charge controller type ground fault protection is usually a very small jumper, in this case, the little jumper just to the right of the blue connection block labeled CON 7 GFP. So we bring the surge right through very delicate circuitry in the charge controller.



Conclusion

The current approved equipment creates a very dangerous shock hazard in certain fault conditions when the ground fault protection is enabled or used, whether it be a ground fault breaker or integral ground fault protection in a charge controller. Since the solid negative to equipment case bond is not there, faults occurring in other parts of the system cannot be cleared, thus producing a dangerous situation. As stated above, with the current equipment, we cannot meet both 64-064 and 64-070

I would suggest that until charge controllers are available that will work with a solidly grounded DC system that ground fault protection for the solar arrays not be enabled because of the hazard that is presented by this equipment. We need to have a solid negative to equipment bond in the DC power center regardless of system voltage. This is a workplace hazard and it is our duty to protect workers from such a hazard.

I would also suggest that the location of the ground fault protection for future equipment needs to be much closer to the source of the problem. Having ground fault protection at the charge controller is much like building ground fault protection into a power consuming device rather than, as we have in AC wiring, the ground fault protection is at the supply end of the wiring. What I mean is this. The solar array is the power source, therefore, the conductors from the solar array need to be de-energized as close as possible to the source, so that the hazard is eliminated. Currently, a path to ground and subsequent shock hazard such as the one that I encountered would continue to exist even if the ground fault equipment de-energizes the charge controller.

One more final suggestion is that even though cost should not be the primary factor, safety should be, the equipment to meet the code rules should be reasonably priced. If it is not, we will have an even greater number of people installing systems themselves and not installing the equipment properly. It will also increase the number of systems that are installed without electrical permits. This is just human nature.