Grounding Basics: Stationary Systems

Grounding Made ~~Simple~~ Simpler

The subject of grounding is a complex, multifaceted subject, that is often treated as an after-thought but needs to be considered from the beginning of the design and build process of any DIY Solar/Battery Project.

This is Part 2 of a 4-part series on grounding Basics.

1. **AC & Household**
   Part 1 covers the basics of grounding for household AC systems. Even if you are familiar with house wiring, it is suggested that the reader review this paper to become familiar with the terminology concepts and practices of grounding.
2. **Stationary Systems(This Paper)**
   Part 2 introduces the grounding principles of DC wiring, inverters and multiple power sources.
3. **Solar Panels**
   Part 3 is a short overview of how to properly ground the frames and mounting racks of Solar arrays.
4. **Mobile Systems**
   Part 4 goes through designing the grounding scheme that addresses the unique situations encountered in a mobile system.

Each of the 4 parts are written to be usable and understandable as a stand-alone paper. However, to get a broad understanding of grounding and grounding principles, it is recommended that all 4 papers be read.

Grounding in stationary Solar Systems

Solar arrays and batteries introduce several complexities to the grounding system. This paper will go through some of these complexities as well as how they are handled.

All of the terminology discussed for AC circuits in Part 1 are the same for DC circuits.

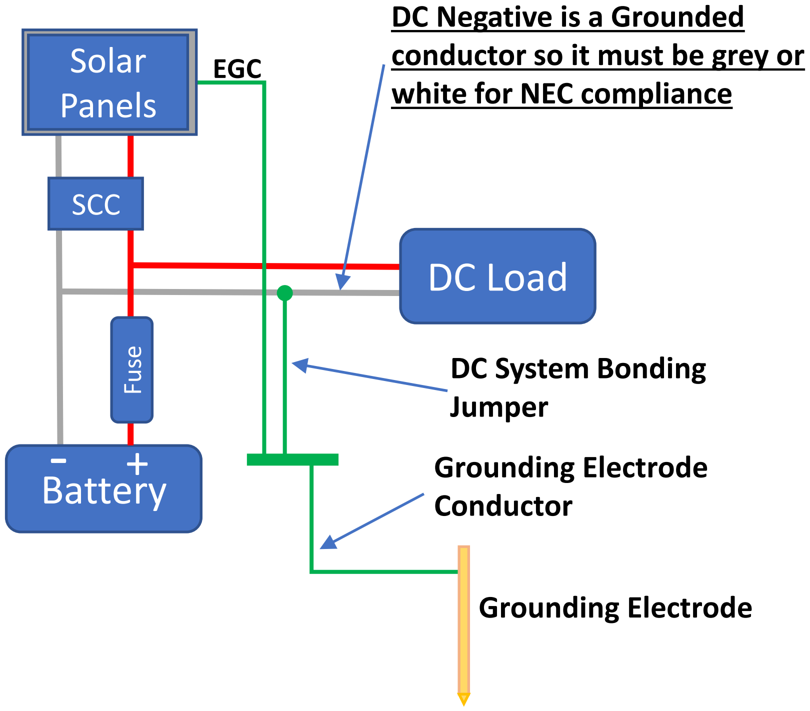
- **Earth Ground -** This is a point that is electrically tied to the earth. Usually this is done with a copper rod that is driven 8' into the ground.
- **Bonding -** Bonding is electrically tying one conductor to another. This term is often used to describe connecting earth ground to AC Neutral or DC Negative or tying an Equipment Grounding conductor to a non-current carrying metal component.
- **Equipment Grounding Conductor** (**EGC**) – A conductive path that is part of an effective ground-fault current path and connects normally non-current-carrying metal parts of equipment together and to the system grounded conductor (neutral conductor) or to the grounding electrode conductor, or both.
- **Grounded Conductor -** This is a normally current carrying conductor that is bonded to ground. In household AC wiring the neutral wire is a Grounded conductor. IF DC negative is 'grounded' then DC Negative becomes a Grounded Conductor.
- **System Bonding Jumper –** This is a conductor between Ground and a current carrying conductor at the source. For US residential utility power, the AC source is the Utility transformer, so this is done by the utility, not on the customer premise. When there is a separately derived AC source such as an inverter in an off-grid set-up, there must be a System Bonding Jumper at/in the inverter. If the DC circuit is grounded, a single DC System Bonding jumper is used to tie to ground.
- **Main Bonding Jumper –** This is a conductor between the AC Neutral and Ground that is typically found in the main breaker box in the US. This re-establishes ground reference because the utility does not supply a grounding conductor to the house.

DC circuits: Bonding, Earth Ground and Equipment Grounding conductors

The NEC states that Bonding between DC and ground is optional (but recommended) for DC systems that operate at less than 50 volts while systems that operatee at voltages of 50V or more are required to be bonded to Ground. Just like AC Neutral Bonding, DC Bonding to Equipment ground should only occur in on place on the DC Circuit.

<u>The reasons for bonding DC to ground are the same as the reasons for bonding AC Neutral to ground: Neutralize static or induced charge.</u> Consequently, I recommend bonding DC to ground even if the system runs at less than 50 volts. (Warning: there are some inverters that specifically say not to tie DC negative to Equipment ground, but they are the exception, not the rule)

The NEC does not specify if the positive or negative branch should be used as the Grounded line. In my experience, the negative branch is most commonly the one bonded to ground but the positive branch is sometimes used. For this paper, it is assumed the negative branch is the one to be bonded to equipment ground. (DC Negative becomes a **Grounded Conductor)**



We do not typically run a ground conductor with the DC power lines, yet our DC equipment often has equipment ground points. These ground points should all be tied to an Equipment Grounding Conductor (EGC) and ultimately to earth ground. Use NEC Table 250.122 (Appendix B) for sizing the grounding conductors. Just like for AC Grounding, all of the equipment grounding conductors should rout back to one point for bonding to ground.

IMPORTANT: **For NEC compliance, all grounded conductors must be grey or white. Therefore, if DC negative is bonded to ground, it must be grey or white….Not Black.**

Bond DC circuits to the ground point after the BMS

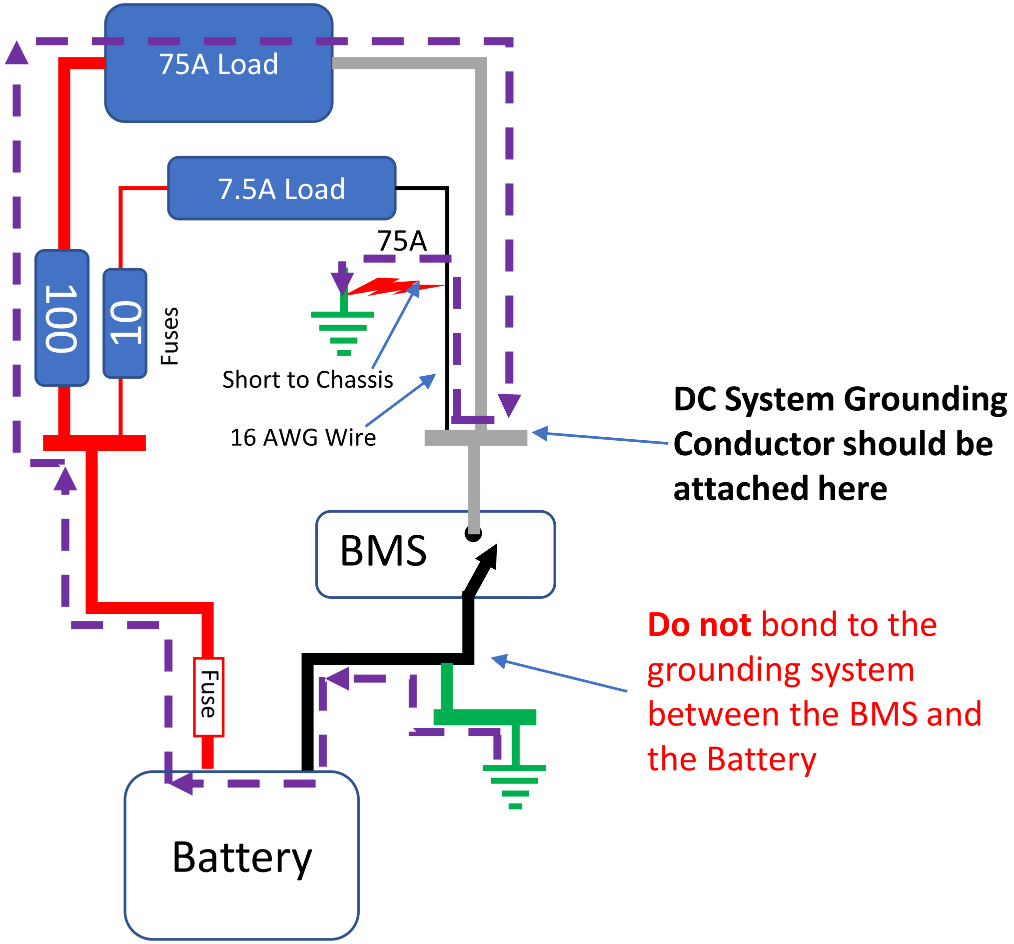
Most FET based BMSs are positioned in series with the most-negative cell of the battery bank. In this case the DC negative to equipment ground bond should not be between the battery and BMS.

The figure to the left shows both a safety issue and a functional issue with bonding DC neg to ground between the BMS and the Battery.

1. Safety Issue
   If the BMS disconnects the battery, a short to ground on a small wire could cause a large amount of current that the fuses would not stop and the wire can not handle. This is a significant fire safety issue.

2. Functional Issue
   Even if the short did not cause a fire, it is allowing current to flow even though the BMS has tried to turn it off. This circumvents the cell protection offered by the BMS.

3. Functional issue
   A third issue (not shown) is that in a mobile system, people often use chassis as a negative return conductor. If this is done and the bond is between the battery and BMS, the BMS can not shut off the current.



Grounding Systems with Both AC & DC

Since the inverter is the transition between AC & DC it is critical to know what it does internally in order to properly design your system.

- When there is both AC and DC circuits, the grounding system for AC and DC should be kept separate everywhere except at one point.
- Since inverters tie the AC Equipment grounding conductors to the inverter case ground lug, tying the DC grounding system to the Inverter grounding lug also ties the DC grounding system to the AC grounding system. In that case, no further connection between the AC and DC grounding systems is needed (Figure 1 & Figure 2)
- If there are multiple grounding electrodes, they must follow the same rules as outlined for Grounding Electrodes on AC systems
- If the inverter has an AC System Bonding Jumper between equipment ground and AC Neutral, there should *not* be another AC system bonding jumper elsewhere. (Figure 1)
- If the inverter does not have an AC System Bonding Jumper, there should be an AC System Bonding or Main Bonding jumper elsewhere in the system. (Figure 2)

Figure 1

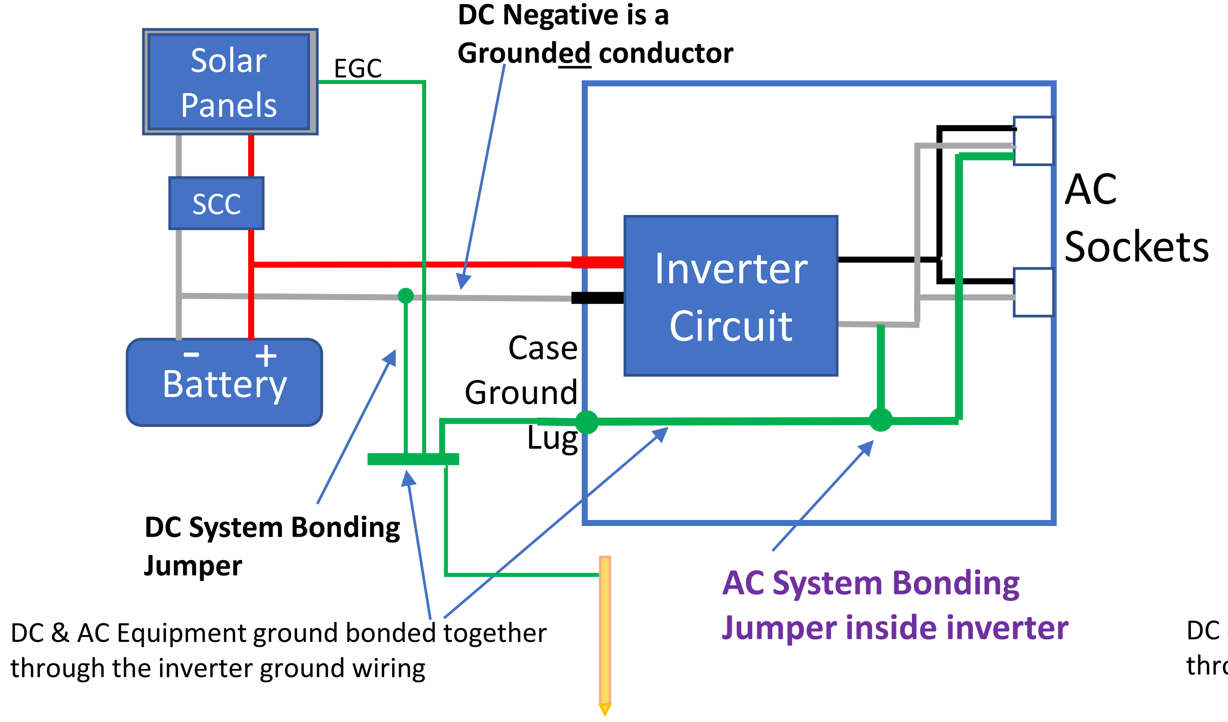
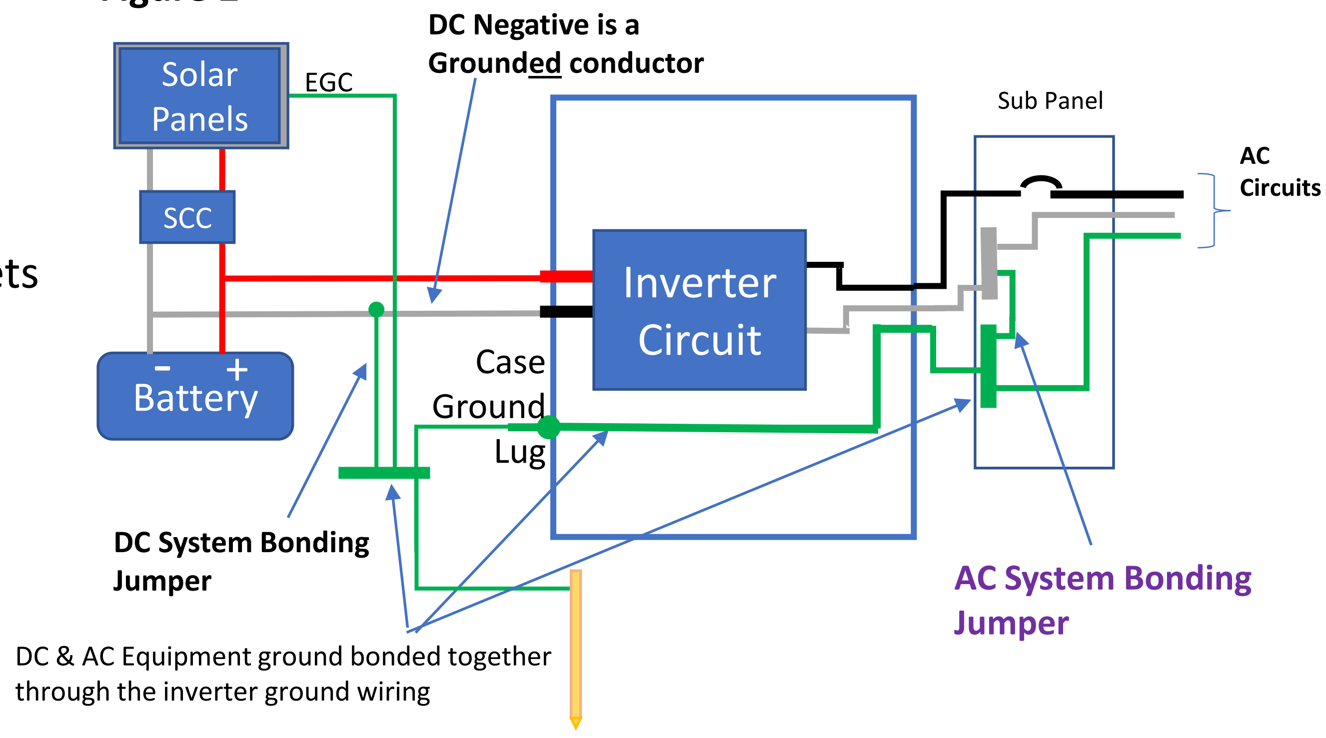


Figure 2



A note about Inverter Grounding similarities and differences.

Unfortunately, different inverters can handle ground differently so there can be no simple statement on how to handle grounding for all inverters.

Of the inverters I have looked at, the commonalities I have seen are:

- They all have a case grounding lug
- They all tie the AC-out Equipment Grounding Conductor to the case.
- Inverters that have an AC in (Such as inverter-Chargers) all tie the AC-in Equipment Grounding Conductor to the case.

Warning: The above are my observations of several different inverters and inverter brands. There is no guarantee all inverters will be the same.

However, there are several critical differences between inverters.

- Some Inverters have a bond between AC Neutral and Ground. Some don't.
- Some inverters that have AC-in will dynamically switch on a N-G bond only when they are not getting AC-IN. Some don't.

Note: Some all-in-one inverter products have built in Ground-fault protection.   Be sure to read the manual carefully because these units may already tie the DC circuit to the grounding system and an additional connection between the DC and Ground system may create problems.

<u>It is important to find out how your specific inverter handles all of this in order to set the system up correctly.   Unfortunately, the manuals and spec sheets for many inverters do not describe what the inverter does so it can be difficult to find out.</u>

The following resource on the DIY Solar Forum shows the best available information on how several popular inverters handle ground internally.
https://diysolarforum.com/resources/grounding-details-for-specific-make-model-of-inverters.156/

Switching Multiple AC Sources: Generators and Inverters

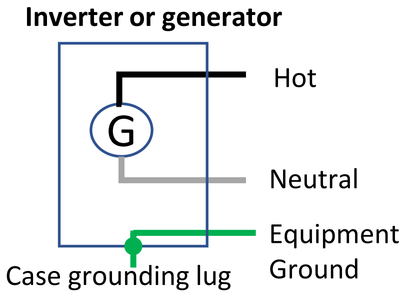
The Bond between AC Neutral and Equipment Ground must be at <u>only</u> one place. If there are multiple sources such as the Grid, an AC Generator and an AC Inverter, the 'single bond' rule still applies so special switching may be necessary

First, we need a new definition: **A Separately Derived AC power source** is simply one that ties Neutral to Equipment Ground. In this context, the 'power source' could be an inverter or a generator. (Figure 2)

To use a generator or inverter as a backup power source, we must have a switch that safely switches from our normal power source to the back-up source.

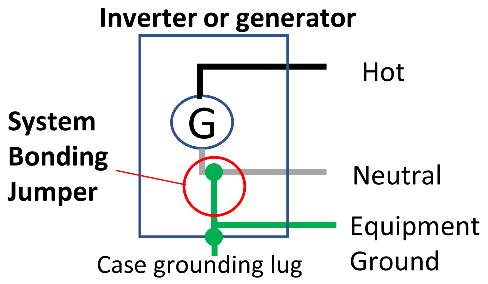
Clearly, the hot wire must be switched and in the case of a Non-Separately derived source, that is all that is needed.(Figure 3) However, if it is a Separately derived source, both the Hot and Neutral must be simultaneously switched in order to maintain the 'single bond' rule (Figure 4)

Notice that in both cases, the equipment Grounding conductors are <u>not</u> switched.



Non-separately Derived Source

Figure 1



Separately Derived Source
Figure 2

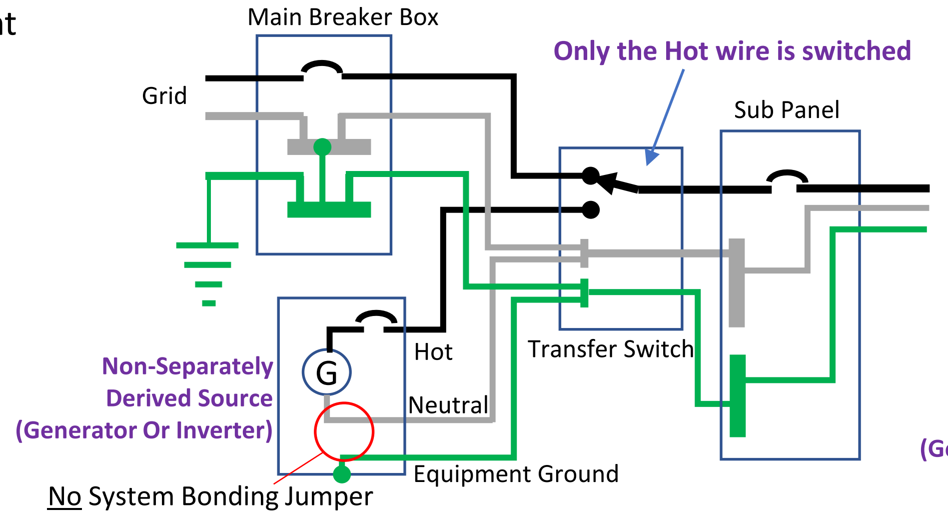


Figure 3

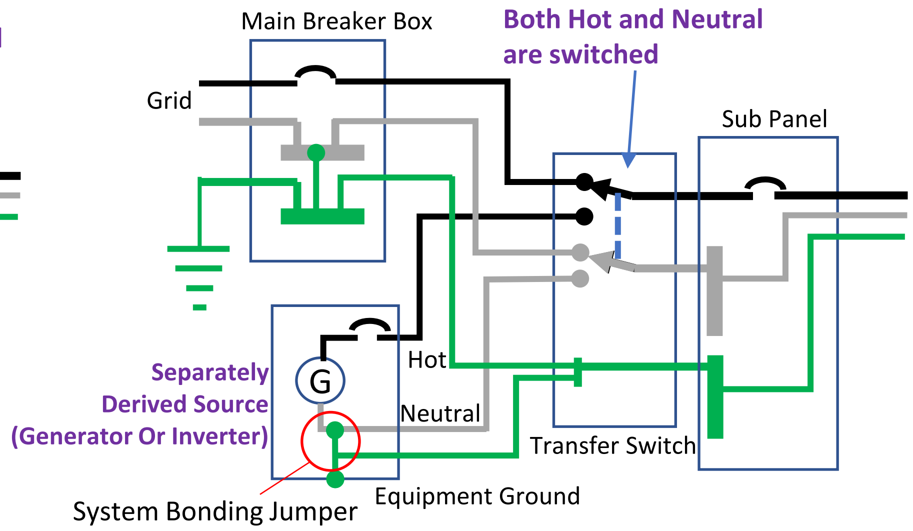


Figure 4

Switching Multiple AC Sources: Generators and Inverters (Continued)

If both AC sources do not tie Neutral to Ground, then a Neutral-ground bond must be established elsewhere. In the diagram below, neither the generator nor the inverter has a Neutral-Ground bond, so one is added at the sub panel. Also notice that if both AC circuits do not have a Neutral-Ground bond, then only the Hot wire needs to be switched.

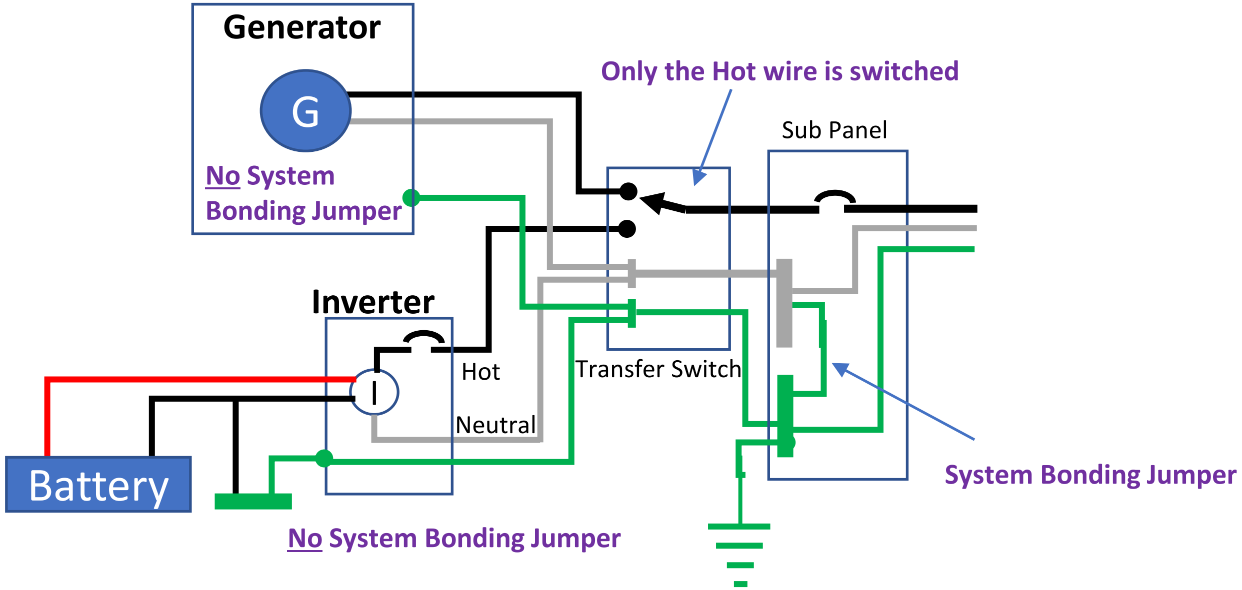


Figure 3

Multiple AC Sources: Inverter-Chargers

Inverter chargers have the transfer switch function built in and therefore must properly manage the tie between neutral and ground. Furthermore, inverter-chargers typically switch from battery to external AC power in a seamless manor. Consequently, the internal switching can be quite complex. The diagram below shows a conceptual diagram of how it works.

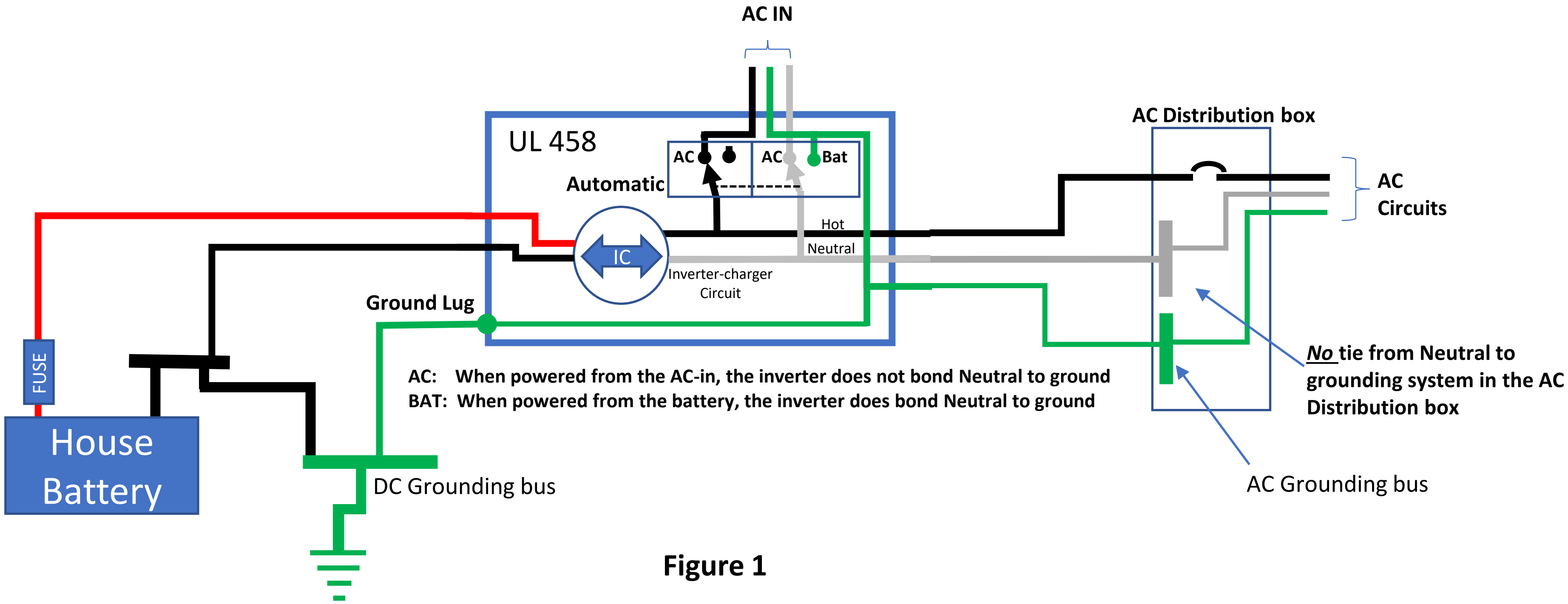


Figure 1

However, not all inverter-chargers do the internal N-G bond switching as shown above so managing the bond must be done in other ways. Understanding how the selected inverter-charger handles the Neutral-Ground Bond is critical to get the set-up correct.

Multiple AC Sources: Inverter with transfer switches.

Some inverters have a built-in automatic transfer switch. In the example below, the inverter does *not* manage the Neutral-Ground bond so it is added in the AC Distribution Box. In this example, the generator should not have a N-G bond either

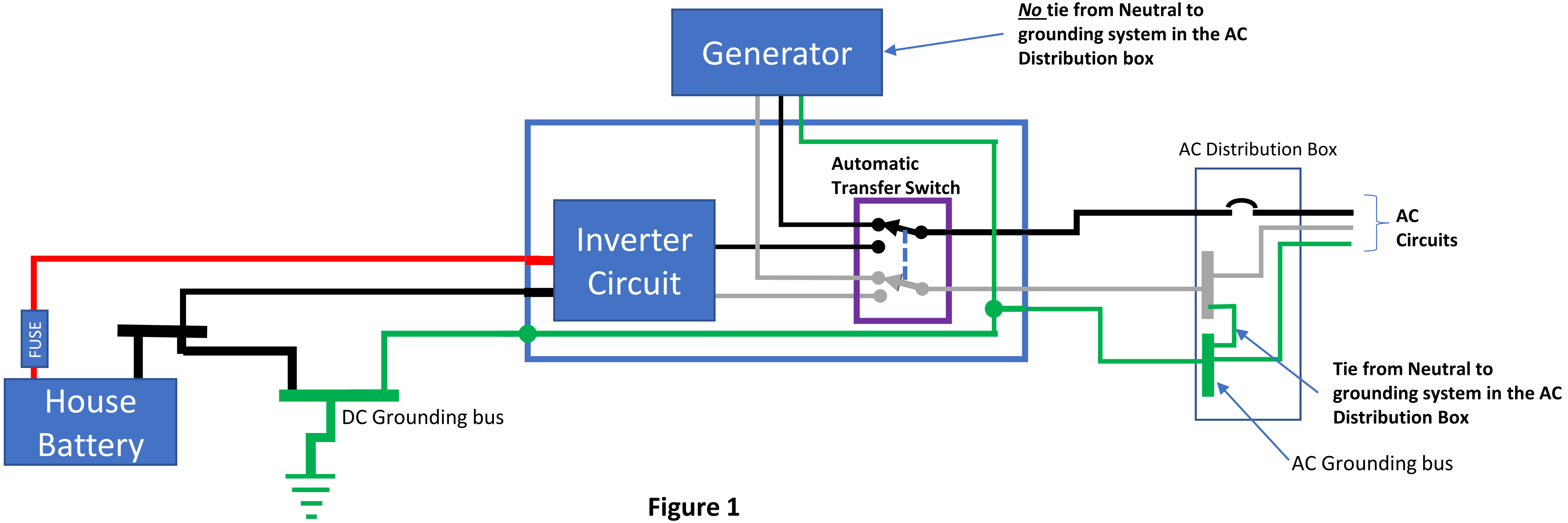


Figure 1

Other inverters/transfer-switch handle things differently. Be sure to understand the inverter you select and set up the N-G bond appropriately.

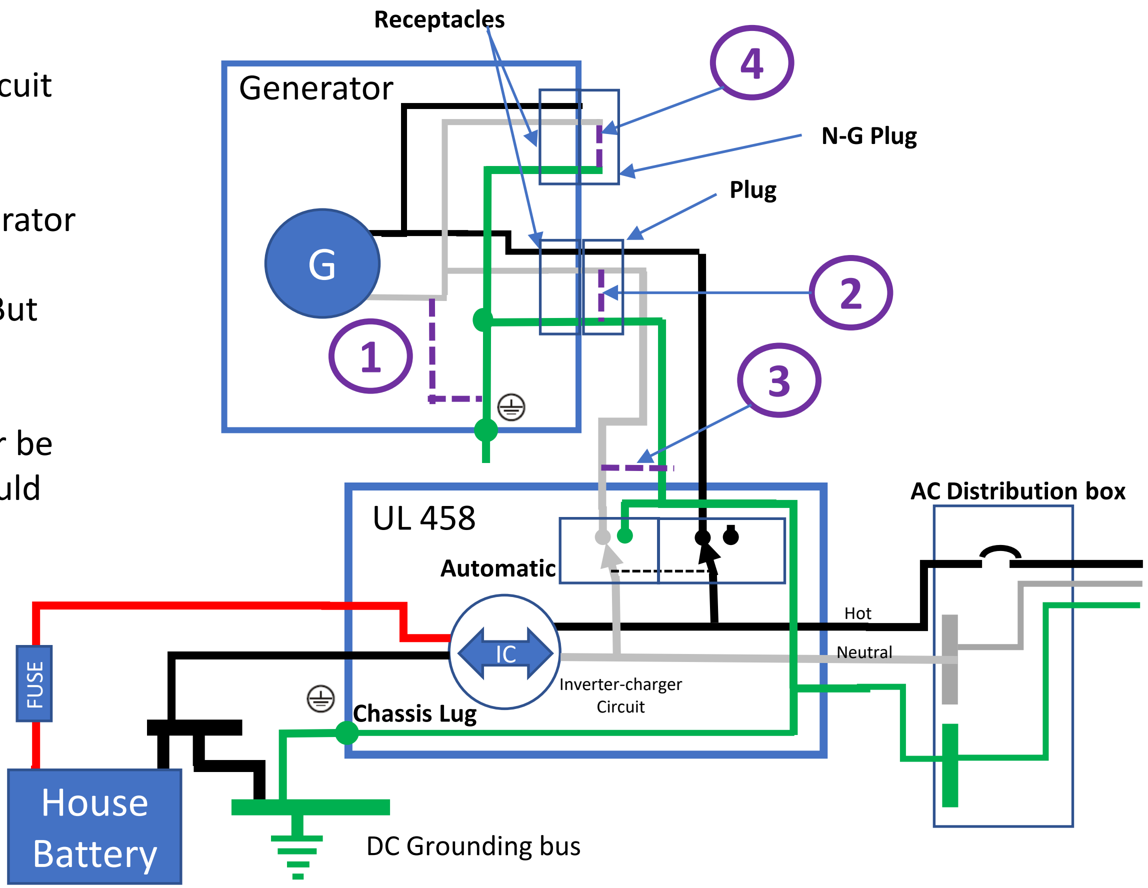
A note about Neutral-Ground bonds in portable Generators

It is important to know if your generator has a Neutral-Ground bond. In the US, most (but not all) portable gas generators sold do *not* have a neutral-ground bond. Instead, the generator design expects there to be a N-G bond elsewhere in the system. In fact, some inverter-generators will not even turn on if it is plugged into a system without a N-G bond.

For some systems it is fine if the generator does not have the N-G bond. However, many systems will expect an NG bond on the generator circuit. As an example, if you have a UL 458 listed Inverter-Charger, it expects an AC input source that has this bond. (The design center for UL-458 is for plugging into a standard grid AC source that has the bond). In that case, the generator needs to have the N-G bond.

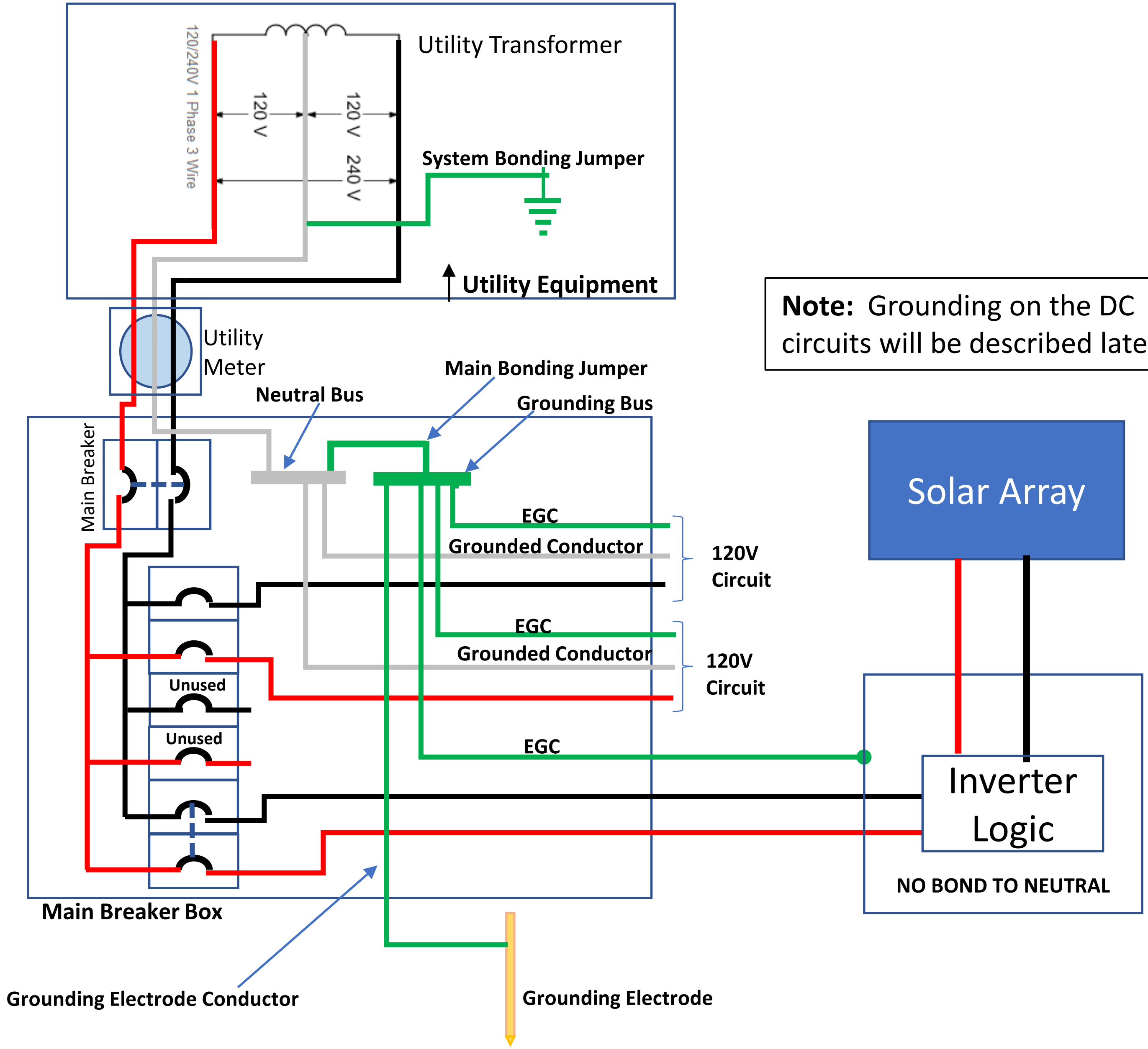
There are several places a Neutral-Ground jumper can be added to the generator circuit
Warning: Only do ONE of the following

1. On some generators, it is possible to install a jumper someplace inside the generator
2. It is possible to install a jumper inside the plug that plugs into the generator…. But that plug should never be plugged into 'shore' power
3. A jumper can be added at the input to the inverter, but the system should never be plugged into shore power with that jumper in place. (Technically, the bond should be at the source, but this would still work)
4. An N-G plug can be used on a second plug on the generator. This plug is 'just' a connection between the Neutral and ground pin inside a plug.
https://www.amazon.com/gp/product/B07F4R7BDL/
This is handy because it makes it easy to use the generator both ways… but be sure the plug is only in place when appropriate.



Multiple AC Sources: Grid Interactive Inverter)

A grid interactive inverter has many requirements including grounding.   The main requirement around grounding is that since both the grid and the inverter are supplying power at the same time, the inverter can <u>not</u> be an independently derived source. (The inverter can NOT bond neutral to ground)



Note: Grounding on the DC circuits will be described later.

Warning: There are many critical requirements for the safe installation and operation of a grid-interactive inverter and grounding is just one small part of the total set of requirements.

Solar Panels and Solar Charge Controller.

The metal frames and metal mounting racks for solar panels are highly susceptible to static charges. They are also susceptible to imposed voltages/currents due to nearby lightning strikes. These issues can cause safety issues and equipment damage. Consequently, it is important to properly ground the frames and mounts of solar panel arrays.

For more on Solar Panel grounding see the resource "Solar Panel Grounding" at the DIY Solar Forum Resource Section.
https://diysolarforum.com/resources/grounding-made-simpler-part-3-solar-panels.160/

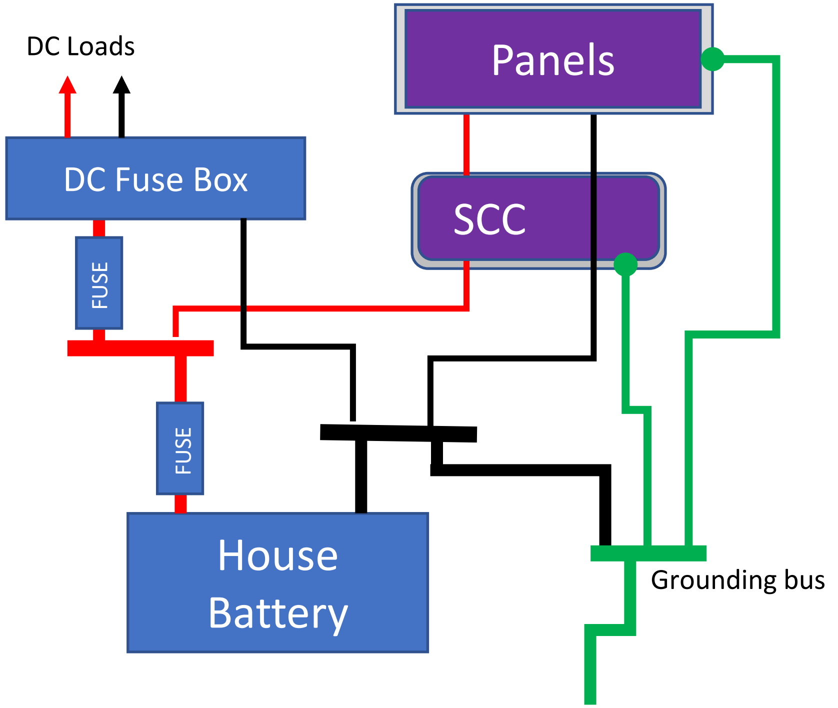
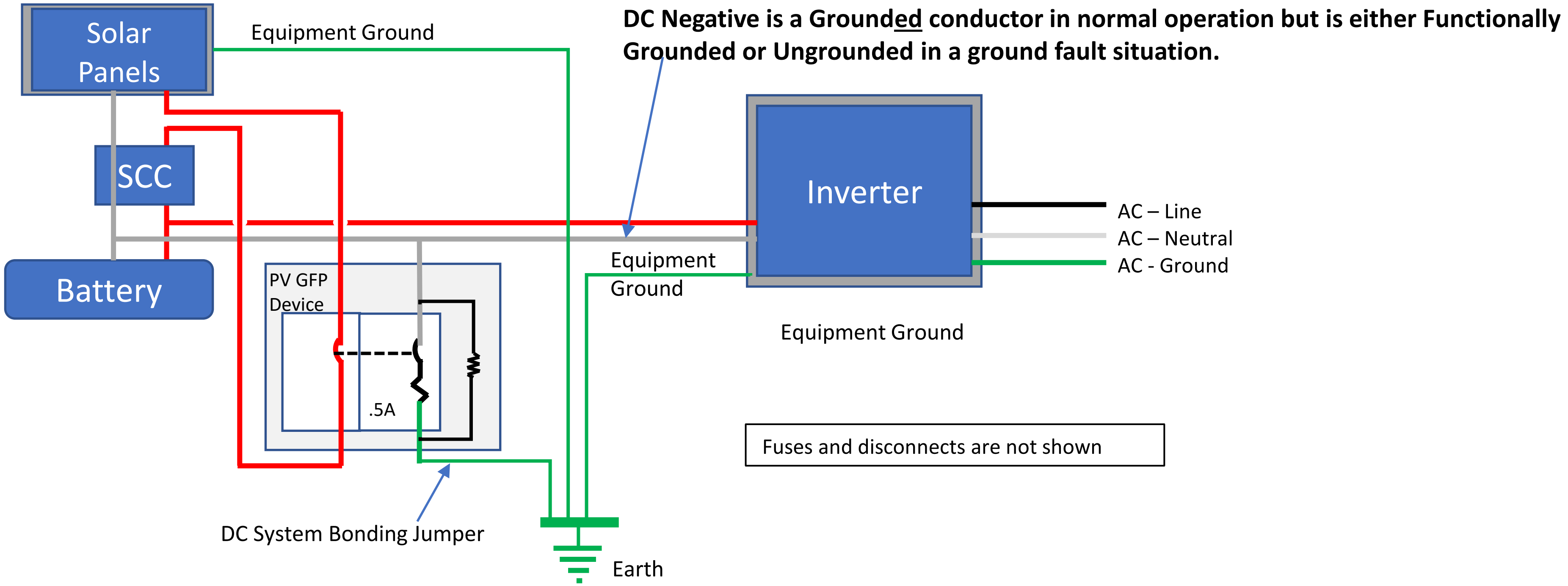


Figure 1

Special Case: PV Ground Fault Protection and DC bonding to Equipment ground.

The rules for bonding DC circuits to equipment ground apply to Solar Panel Array circuits, but there is a special situation that should be pointed out. Normally, it is not appropriate to put a switch, fuse or breaker in a grounding circuit. However, some PV Ground Fault Protectors use a ~.5A-1A circuit breaker or fuse in series with the system bonding jumper to detect ground faults. In this case, if a ground fault occurs and the breaker trips, the DC circuit is no longer solidly grounded. In the diagram below, once the circuit breaker opens, the DC is grounded though a resister and at that point it is a 'functionally grounded' circuit. If the PV GFP device does not have the resister, the DC becomes 'ungrounded' when the breaker trips. Both with and without the resister are acceptable solutions to meet NEC requirements for grounding and for Ground Fault Protection.



For more information about PV Ground Fault Protection solutions, see the resource at:
https://diysolarforum.com/resources/ground-fault-protection-on-solar-panel-arrays.148/

A note about ground loops. **(When it comes to grounding, more is not always better)**

The circuit in figure 1 shows a ground loop that could be inadvertently created in a system (Figure 1). At first glance there does not appear to be an issue with this. In fact, chances are very high the system will supply power as intended. However, the loops form antennas that can either broadcast or receive noise.

Systems with inverters are notorious for broadcasting radio frequency noise, and the culprit is often ground loops like shown below. This noise can affect other circuits or, more likely, radio systems like AM, FM, CB, HAM, WiFi and Bluetooth. Consequently, you might find you can't tune in your favorite 70s disco station… (Oh wait…that is a good thing. I need a better example ☺)

The chances are very high the system won't be affected by received noise with one possible exception: In a lightning storm, there can be very high electro-magnetic pulses that would impose a high pulse surge current on the ground loop. If the pulse is high enough, it can impose currents on nearby circuits and create damage to the electronics that would otherwise be protected by their metal case.

To fix this, simply remove the extra connection between the AC and DC grounds (Figure 2)

Figure 1

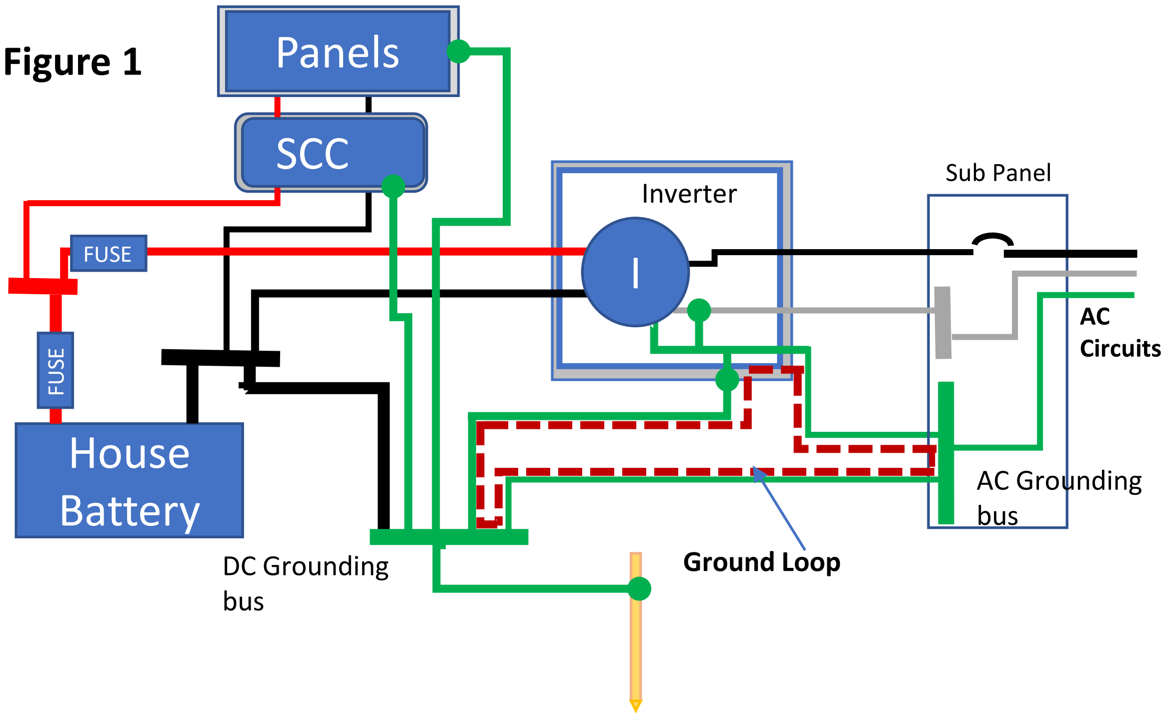
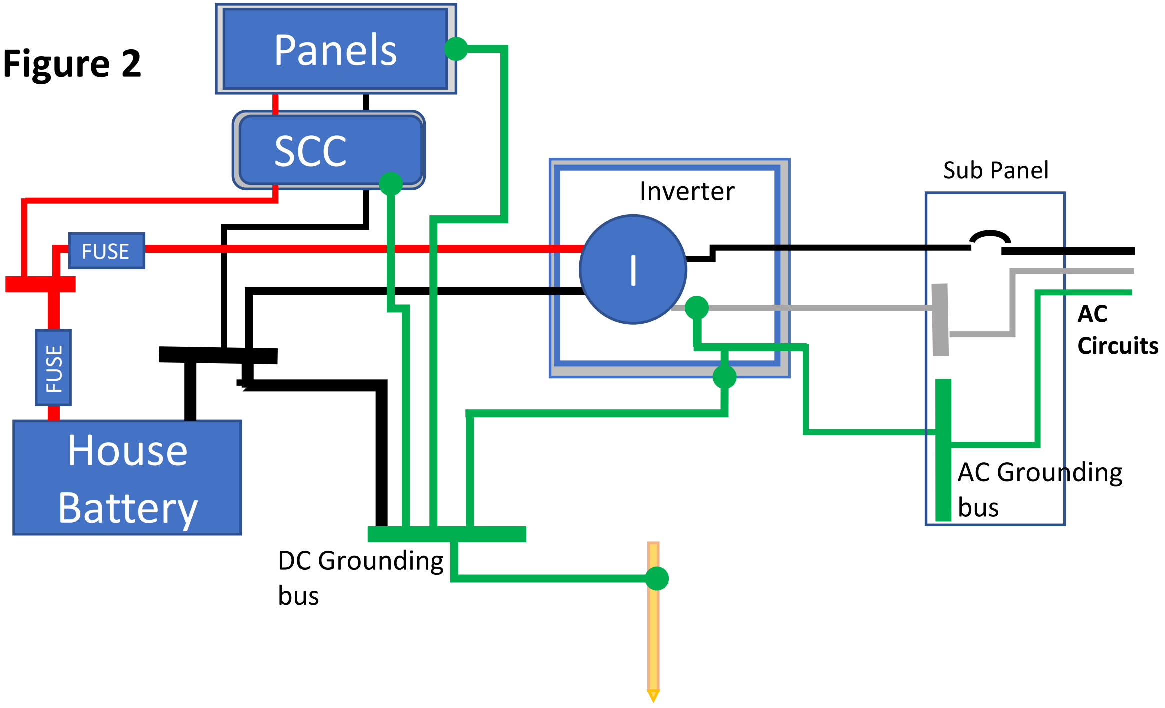


Figure 2



Appendix A: NEC Table 250.66

International Note
The sizing requirements for the grounding electrode conductor may be different outside the US

Grounding Electrode Conductor for Alternating-Current Systems Alternating-Current Systems

Size of Largest Ungrounded Conductor or Equivalent Area for Parallel Conductors (AWG/kcmil)		Size of Grounded Conductor or Bonding Jumper* (AWG/kcmil)	
Copper	Aluminum or Copper-Clad Aluminum	Copper	Aluminum or Copper-Clad Aluminum
2 or smaller	1/0 or smaller	8	6
1 or 1/0	2/0 or 3/0	6	4
2/0 or 3/0	4/0 or 250	4	2
Over 3/0 through 350	Over 250 through 500	2	1/0
Over 350 through 600	Over 500 through 900	1/0	3/0
Over 600 through 1100	Over 900 through 1750	2/0	4/0
Over 1100	Over 1750	3/0	250

1. If multiple sets of service-entrance conductors connect directly to a service drop, set of overhead service conductors, set of underground service conductors, or service lateral, the equivalent size of the largest service-entrance conductor shall be determined by the largest sum of the areas of the corresponding conductors of each set.

2. Where there are no service-entrance conductors, the grounding electrode conductor size shall be determined by the equivalent size of the largest service-entrance conductor required for the load to be served.

This table also applies to the derived conductors of separately derived ac systems.

For Aluminum GEC conductors, see installation restrictions in 250.64(A).

Appendix B: NEC Table 250.122

Table 250.122 Minimum Size Equipment Grounding Conductors for Grounding Raceway and Equipment

Rating or Setting of Automatic Overcurrent Device in Circuit Ahead of Equipment, Conduit, etc., Not Exceeding (Amperes)	Size (AWG or kcmil)	
	Copper	Aluminum or Copper-Clad Aluminum*
15	14	12
20	12	10
30	10	8
40	10	8
60	10	8
100	8	6
200	6	4
300	4	2
400	3	1
500	2	1/0
600	1	2/0
800	1/0	3/0
1000	2/0	4/0
1200	3/0	250
1600	4/0	350
2000	250	400
2500	350	600
3000	400	600
4000	500	800
5000	700	1200
6000	800	1200

Note: Where necessary to comply with 250.4(A)(5) or (B)(4), the equipment grounding conductor shall be sized larger than given in this table.

*See installation restrictions in 250.120.

International Note

The sizing requirements for equipment ground may be different outside the US

Corrections

Feedback, corrections and suggestions are welcome. You can post them in the comment section for the resource at the following link.

https://diysolarforum.com/resources/grounding-made-simpler-part-2-stationary-systems.161/

Updates to this document can be found there as well.

About the author

I am *not* a licensed electrician.

I have a degree in electrical engineering. I know a lot about electrical wiring, solar systems and batteries from both personal experience and on-line research. I have studied a lot of the NEC code but do not consider myself an expert on it.

I gladly share my knowledge for free, but you should not consider my advice as 'professional' advice.