A SunCam online continuing education course

Solar Power Part V

Installing Systems - an Introduction

by

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COURSE DESCRIPTION

This course is basically a detailed type of course for contractors and professionals that work closely with contractors or monitor the installations... a guide of what's behind all those component covers, how they are connected, grounded, protected, what goes where, etc. It includes installation considerations that many contractors simply aren't familiar with or don't worry about in their haste to complete the job and get paid.

Note: The course assumes that you have a working knowledge of Solar Photovoltaic (PV) design and are familiar with the terminology and components found in a typical system. ***If not, you should take the SunCam courses "Solar Power Design for Small Structures, An Introduction" first and "Solar Power Systems - Inspecting and Evaluating" if you are only inspecting or are responsible for the supervision or construction management.***

This course is intended to provide an introduction to the installation of a solar PV system for a small structure. The design and basic explanations of a solar power system are not included in this course but are found in the first two courses. Obviously, we can't cover the installation of all the products manufactured today but we will cover a complete **off-grid** solar system installation that can be used as a reference for the different products available today.

Solar powered professional offices

Seek the experience of others

Never stop seeking the advice of others. Technology is changing and changing rapidly. New products are constantly being developed and improved.... smaller, more efficient, more capable, cheaper, etc. As in most cases involving design and construction, drawing a line on a sheet of paper is considerably different than actually building what that line represents. Engineers have earned a good reputation... *or not*... depending on how well the plans are designed. Just because the contractor got a permit from the Building Department doesn't mean it can be constructed as designed. Once the ink is on the paper, it's only a theory. Only when it's built that way does it become fact. Otherwise, it becomes just another field-modified design.

Likewise, when a contractor says "That's not the way we do it" doesn't mean the engineer is wrong. Saying "That's not the way we do it" really means "That's not the way we've done it *previously"*. And it doesn't mean that the design is necessarily wrong either. But then, we don't build cars like we did a hundred years ago either. There's always a different way... better, cheaper, faster, or improved. And... *sometimes*... it becomes a case of "If the engineer had only done this, it would've saved thousands of dollars and would've been completed last week!"

And the same applies to designs for a solar power installation. There are some things that must be done a certain way and there are some that can be done multiple ways. Generally, it's better to state what needs to be done rather than "how" to do it... as long as the final result is correct. *For the engineer*, much can be learned about "better design" by watching, doing, and discussing. Likewise, *for the contractor*, much can be learned about new products and new or different techniques by discussing it with the engineer. So... which are you and what reputation do you want? Or are you finished with learning from others?

SAFETY FIRST

As I have told many I've instructed over the years... *"It's Safety First or it's First Aid... your choice."* While a single solar cell only produces about 0.5 volts, a single solar panel can produce about 50 volts and 8.5 amps... or more... depending on the panel specifications. Just eight of those panels, when installed in two arrays, can produce

over 200 volts and 17 amps! The point is... if you don't know what you're doing, you can get hurt... seriously hurt! And solar panels don't have an off switch. If light is getting to the solar cells, they ***are*** producing electricity... regardless of whether they're connected to anything or not. So keep a deep respect for electricity anytime you're handling electrical components with exposed wires or connections or working in damp/wet locations.

WORDS OF CAUTION

Before we begin, let's quickly cover a few basic safety rules to keep you out of harm's way.

1. If you personally don't have electrical experience, enlist the aid of someone who does. This is not a time for learning by trial and error. And mistakes can be costly for hospital care or replacement parts.

2. Always assume the circuit you're about to work on or check is ***HOT*** until ***you*** verify that it's not. That means you will need to check every electrical source in the system. What are those systems? Remember, there are three potential sources... the solar panels, the batteries, and the grid tie switch (if you have one). Every one of these sources needs to be disconnected from the system anytime you're working on the system wiring. If just one of these is connected and you don't know it, you will be *shocked* when you find out!

3. If you're working on a pitched roof or a ladder, ensure that you are safely secured. Like the saying goes... "It's not the fall that gets you, it's the sudden stop at the end."

WHAT'S NEEDED

For any installation, you will need the following tools and materials *and*... the knowledge of how to use them safely.

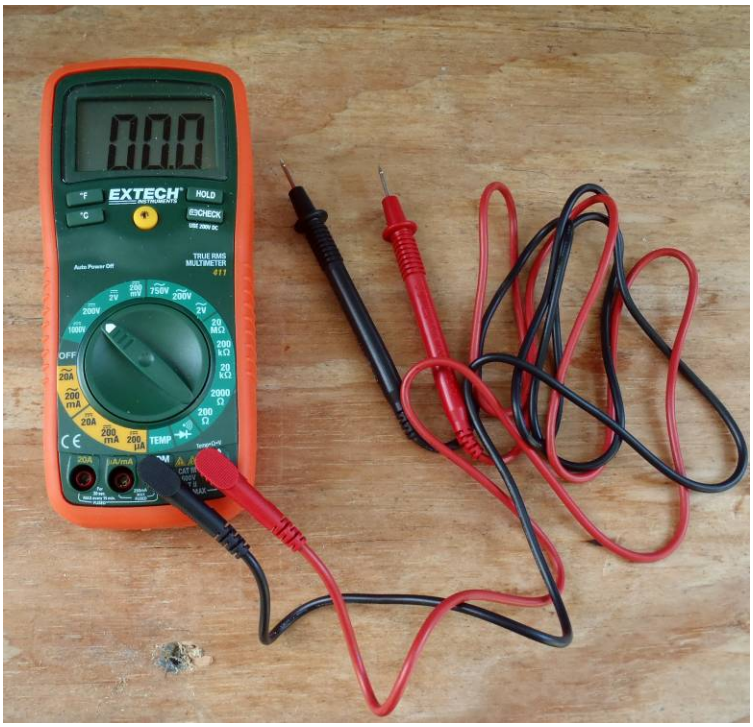
1. The solar system design plans

2. All required building and electrical permits

3. Power company approval if installing a grid-tie switch (not covered in this course)

4. Materials
    a. Solar components (panels, combiner, inverter, controller, etc.)
    b. Wiring (various gauges)
    c. Conduit
    d. Fasteners
    e. Zip ties
    f. Grounding lugs
    g. Grounding rod
    h. Bolts/Screws/Nails (various sizes)

5. Tools
    a. Wire crimper
    b. Wire cutter
    c. Wire stripper
    d. Drill and bits
    e. Stud locator
    f. Screwdrivers
    g. Saw
    h. Level
    i. Inclinometer
    j. MC4 key
    k. Hammer
    l. Tape measure
    m. Socket wrench set
    n. Chalk line
    o. 20A multi-meter



20-Amp multi-meter

THE COURSE PROJECT

To keep the course simple enough to avoid unnecessary confusion, we will use the solar system installed in this remote maintenance shop pictured below. It is a small system which is good since it will have fewer wires and connections that can become confusing. However, it does have all of the basic components... solar panels, PV combiner, surge protector, electrical disconnects, inverter, batteries, and the service loads. Hence, a complete off-grid solar powered system.

An off-grid solar powered shop and fire fighting water well

As stated previously, there are many manufacturers and each manufacturer has many products. This course will be covering the installation of the following products:

XRS rail mounts
Suntech solar panels
MidNite Solar PV combiner
Morningstar charge controller
Morningstar monitor meter
MidNite Solar disconnect
SunTech inverter
MidNite Solar surge protector
12-volt Batteries

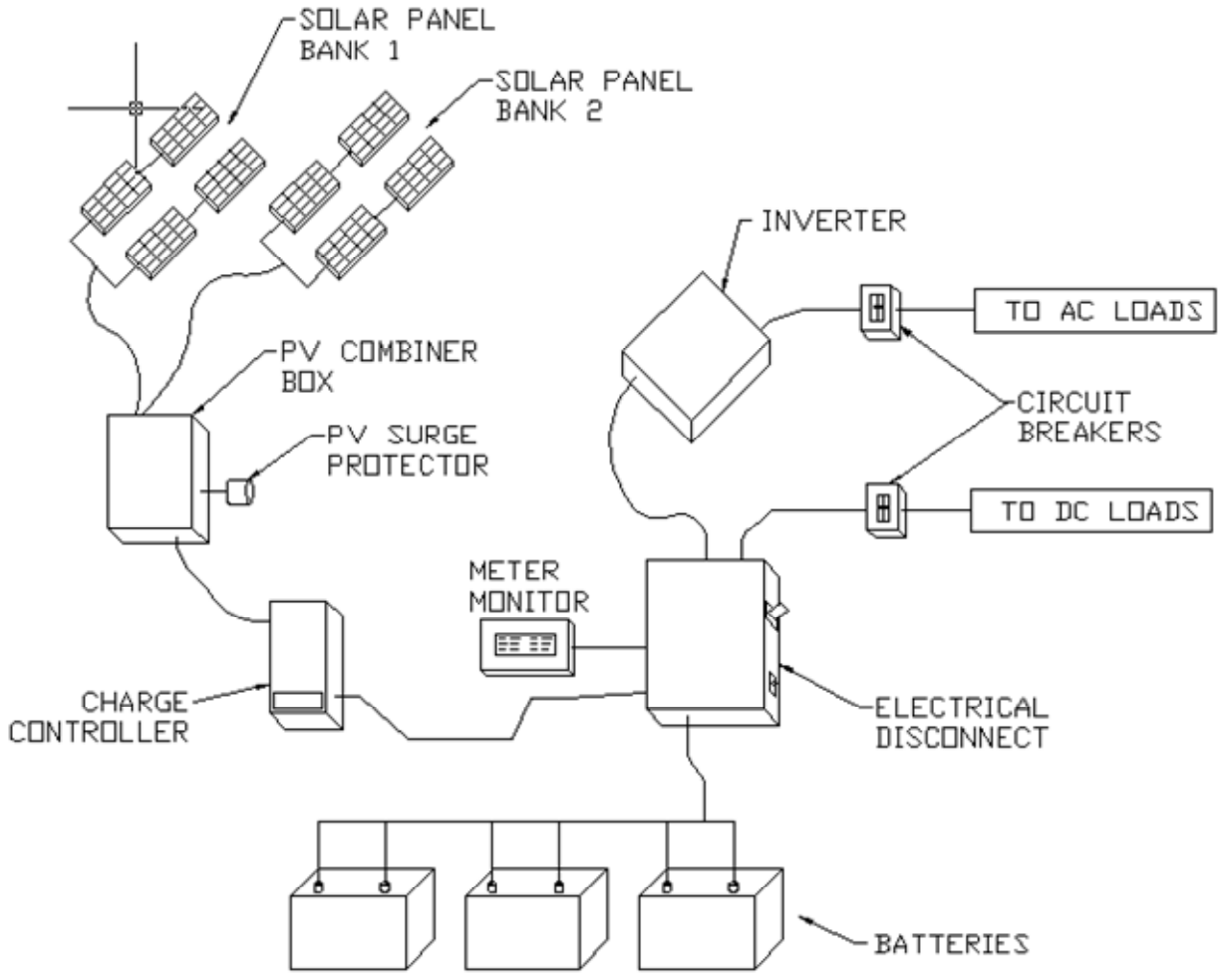
Note that all components should be UL Listed and compatible with solar installations.

Though these are the specific products we will cover in this course, the connections and installation procedures will be similar for the other manufacturers. Regardless of the manufacturer, all solar panels will have a positive lead, a negative lead, and all will require a grounding connection. Likewise, all inverters will have similar input, output, and grounding connections. So the specific manufacturer is unimportant as long as it meets the solar design specifications.

The one exception is the installation of the various solar panel mounts. Our solar panels will be fix-mounted on rails which are installed on a roof which is distinctly different from using pole mounts or ground mounts. We also will not be covering the installation of one-axis or two-axis tracking mounts which is significantly different. However, the fixed ground mounts installation procedures are pretty straight forward and should not pose a problem for you. Just recognize that ground mount installations, because of the electrical hazards, should be fenced or otherwise protected.

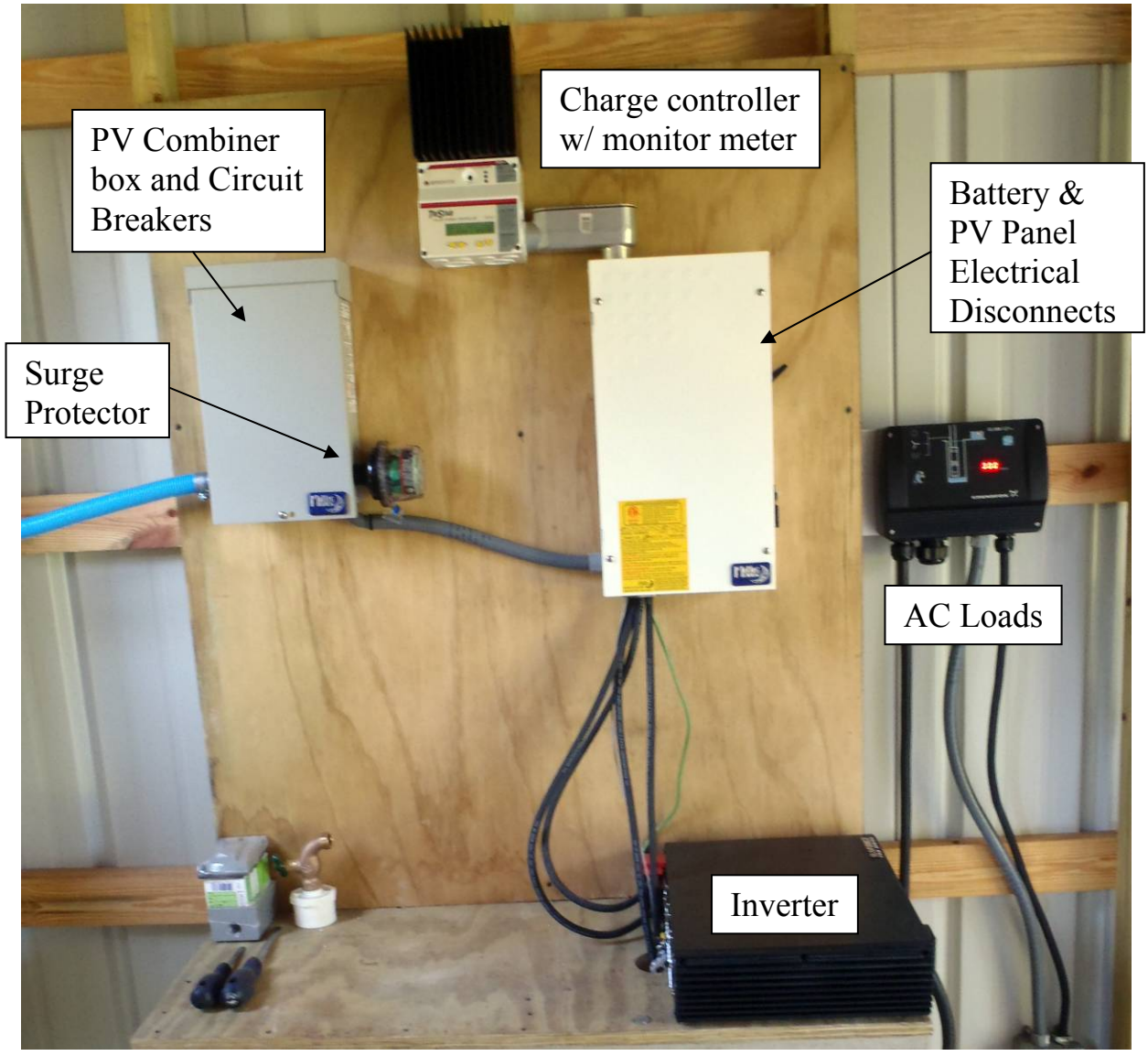
SOLAR POWER SCHEMATICS

A basic PV schematic was provided in the introductory course. However, many systems will include multiple solar arrays, a PV combiner box, a surge protector, an electrical disconnect, and circuit breakers. And these are the components that we will install for this course. The system schematic that we will use for this installation is the following...



OFF-GRID PV SCHEMATIC

The photo below shows this schematic wired up and installed on a wall. The major components have been noted for comparison with the schematic on the previous page.



Note... the system batteries are located below the Inverter and therefore are outside of the area pictured above

THE INSTALLATION SEQUENCE

There is no mandatory sequence for the installation of a PV system. However, many prefer to begin with the solar panels and work their way along the current path. However, I recommend installing the solar panels and their wiring during the more temperate or "dry" hours of the work day regardless of whether that is morning or afternoon. Since you're working outdoors when installing the solar panels, choose a time that provides the most comfortable conditions so as to avoid rushing to get out of the weather. You will get a much higher quality installation by doing this.

For this course, we will be following the current path so we will start with the installation of the solar panels or, more specifically, the solar panel mounts.

INSTALLING THE SOLAR PANEL MOUNTS

Most solar arrays are mounted on a roof for two primary reasons... they don't use any additional land area and they avoid many of the obstructions which cast shadows. For roof-mounted panels, safety is a critical element because of the hazards of falling. So ensure you take the necessary precautions with footwear, ladders, existing electrical wiring, etc. when installing a solar power system. Follow your plans for the roof layout in determining the placement of the roof anchors for the mount rails. A chalk line works great in laying out the rail locations and verifying that there are no conflicts prior to drilling holes in the roof.

The plans should specify the number of anchors, their spacing, and the size of the anchor screws or bolts. The anchors must always be installed into the framing structural members and not to the roof sheathing. Always verify the rail spacing with the solar panel manufacturer's specifications. Many require the rails to be placed near the ends of the module but within 1/4 to 1/8 of the module length. For this course, the installation is using IronRidge XRS rails mounted on a metal roof with wood roof trusses.

If you are combining two rail sections to make a longer rail, this is best done on the ground unless you happen to be installing them on a flat roof. The rails are anchored using lag screws or bolts into the trusses below at the manufacturer's recommended

spacing for the applicable wind loads. The IronRidge rails are rated for 90-150 mph winds and snow loads depending on the anchor spacing. The anchors must be properly sealed against leaks using a code-approved product. And some installers will also add a sealant over each anchor connection once the roof installation is completed.

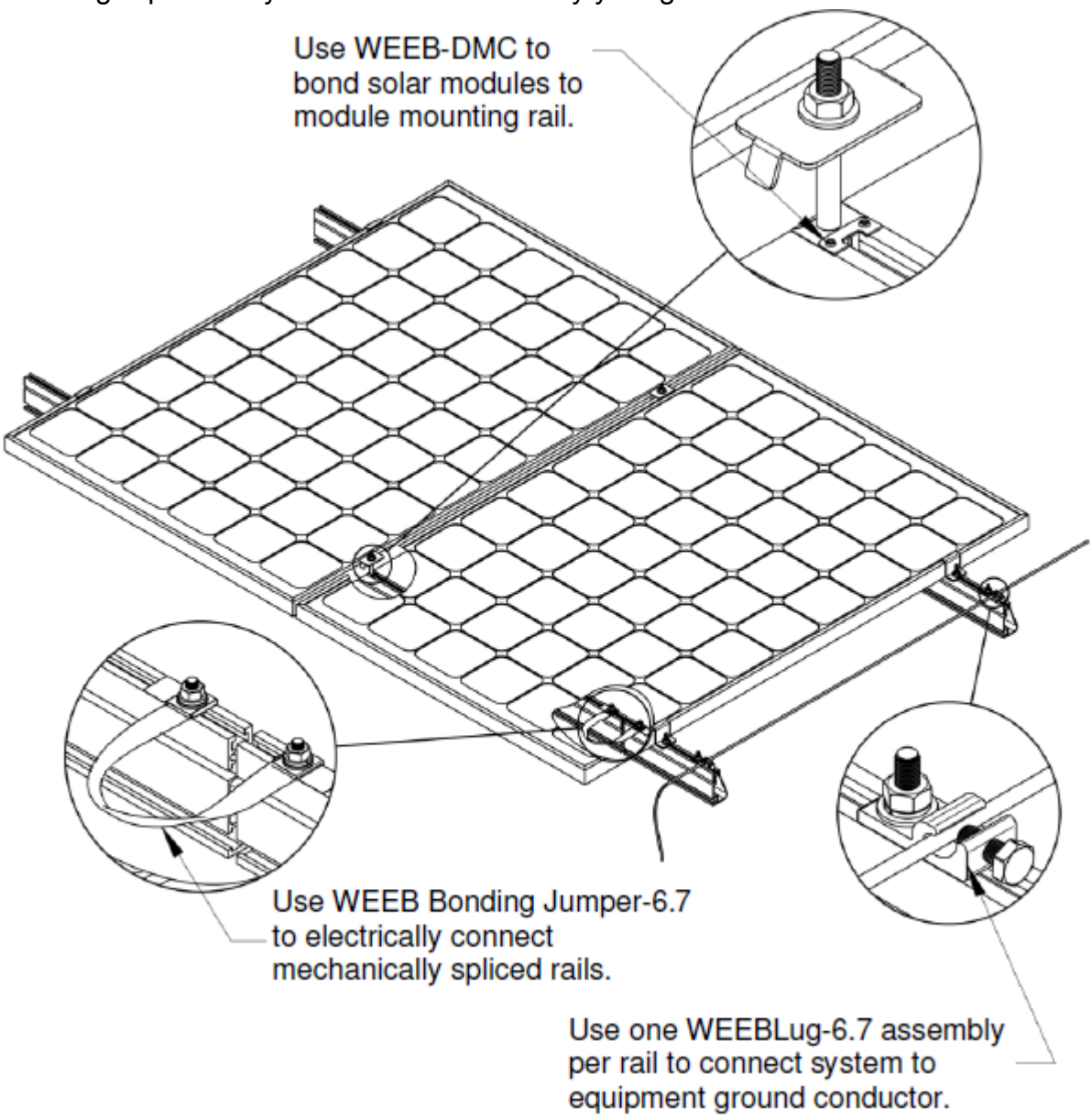
Once the anchors are installed, the mount rails are attached. For the XRS rail system, the rail mounting bolts slide into the appropriate channel of the rail and then are bolted to the anchors. It is recommended that the lower rails be attached using the higher mount attachment point such that the bottom of the rail is 2 inches above the roof. Why? The two-inch spacing will keep the rails from catching leaves and debris and creating a dam during rainfall events. If you use the lower attachment point in the bracket slot, the rails will end up being about a half inch above the roof which will definitely trap leaves and debris. See the photo below showing this situation.

> ***TIP:*** *This is one of those installation techniques that many contractors fail to consider. Note that temporarily mounting the rail close to the roof during installation will help to keep tools and parts from sliding off and possibly injuring people, pets, or vegetation on the ground. Just remember to raise the lower rail once the roof installation is complete.*

XRS rails with upper and lower mount brackets installed. The end caps must be installed after the solar panels are attached.

If two rails are being bolted together to create a longer mount rail, the rails must be connected with WEEB grounding clips or another approved grounding connection. A

cautionary note is that each WEEB clip can be ***used only one time***. If a clip is removed for any reason, it must be discarded and a new clip used to insure there is a positive ground connection. Visit http://www.we-llc.com/Datasheets/104-0404-000039_V5.pdf for more detailed information on the proper installation of the WEEB grounding clips. Use your multi-meter to verify your ground connections.



WEEB clips for the IronRidge rail mounts by Wiley Advanced Renewable Technology (we-llc.com)

If you need to install more than one array on the roof, ensure there is proper spacing between the rows of panels such that one row will not shade any portion of the next row of panels. And remember to account for the change in sun angles and shadows during the year.

Inclinometer showing 30° roof angle

Use an inclinometer to check the mount rails for the proper angle. It's easier to correct now than after the solar panels are attached. With the rails securely anchored and their angle verified, the panels can now be installed.

INSTALLING THE SOLAR PANELS

The panels are delivered pre-assembled with a permanently attached junction box with two wires that typically terminate in standardized PV connectors (one male and one female). Don't forget that even right out of the box, *they will start generating power as soon as they are exposed to sunlight.* And since they do, it's the perfect time and place to test them for both voltage and amperage.

> ***TIP:*** *It's much easier to test solar panels on the ground in a convenient location than on the roof or after they're mounted on a pole.*

← *Junction box, wiring, and specs on back of solar panel*

Solar panel specifications →

Panel Specs: On the back of the solar panel next to the junction box will be a label with the panel's PV specifications. Using your multi-meter, confirm each panel's performance with the listed specifications for the short-circuit amperage (I*sc)* and the open-circuit voltage (V*oc)*. The readings will not match the listed specifications exactly since the specifications are stated for industry Standard Test Conditions (1,000 Watts per square meter solar irradiance, 25°C cell temperature, air mass equal to 1.5, and ASTM G173-03 standard spectrum). So unless you have the exact irradiance levels and temperature, your numbers will vary... higher or lower... depending on the amount of sunlight and the current temperature. If your readings are significantly lower than the

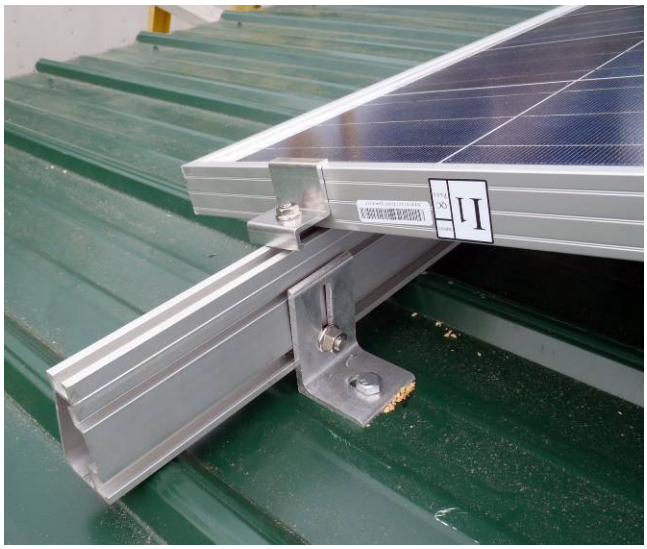
listed specifications, you need to determine why before you spend time mounting the panel only to have to remove it later. And *Murphy's Law* will cause the faulty panel to be in the least accessible location possible! Not familiar with Murphy's Law?... you will be!

Drain holes: Many of the manufacturers provide their panels with junction boxes that have drain holes. If you're installing one of these, ensure the panel is installed with the junction box located at the higher end when mounted to allow the drain hole to function properly. If not installed properly, the drain hole may allow rainwater to fill the junction box sufficiently to short out the circuitry.

Mounting the solar panels: Once the solar panels have been tested, they may be mounted to the XRS rails using the supplied fasteners. The bolt heads will slide into the top slot in the rail. You will need two bolts between every two adjacent panels... one on each rail. Slide all of the bolts to their approximate locations for ease of installation and add the WEEB clips to the appropriate bolts. Carefully place the first solar panel into position, place the clamp on the bolt, and install the nut to securely hold the solar panel in place but do not over-tighten. Once the first solar panel is in place, the remaining panels can be easily mounted using the previously mounted panel as a guide for the next panel.

Close-up views of the installation of the solar panel, bolt, clamp, and nut

Once the last solar panel on the rail is installed, use the special end clamp to securely hold the panel in place. Now return and check each bolt in the string for proper torque. And then add the rail end caps to finish off the run.



Terminal end clamp

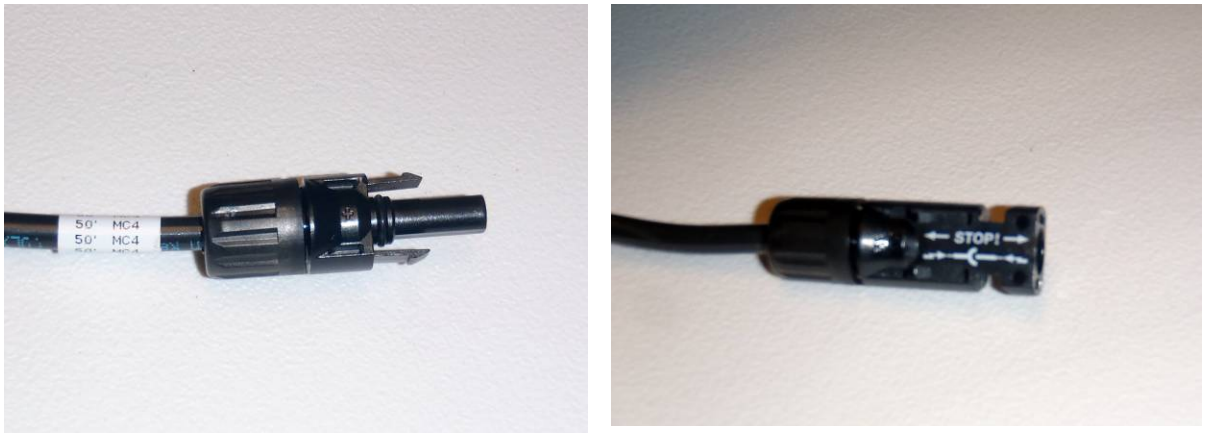
Now that the panels are securely fastened to the roof, you can begin making the wiring connections.

The finished installation of the solar panels

WIRING:

> ***TIP:*** *Before beginning to work on any of the wiring, I recommend covering all of the solar panels with an opaque material... a blanket, black plastic sheeting, etc... anything to keep the sunlight from reaching the solar cells and generating electricity, especially if anyone assisting in the installation is unfamiliar with PV systems. Once the wiring has been completed, the covering can be removed for the system testing.*

The panel wiring consists of two wires about three feet in length... one positive and one negative. Each is terminated with either a male or female connector which helps minimize improper connections. There are five manufacturers of the connectors used in the USA but typically the connectors will be by Multi-Connector (MC4) or Tyco. Both are locking connectors that require a special “key” to disconnect them which comply with the NEC code requiring that solar wiring connectors not be capable of being opened or disconnected by hand without a tool. This explains the need of the MC4 key in the Needed Tools list earlier.



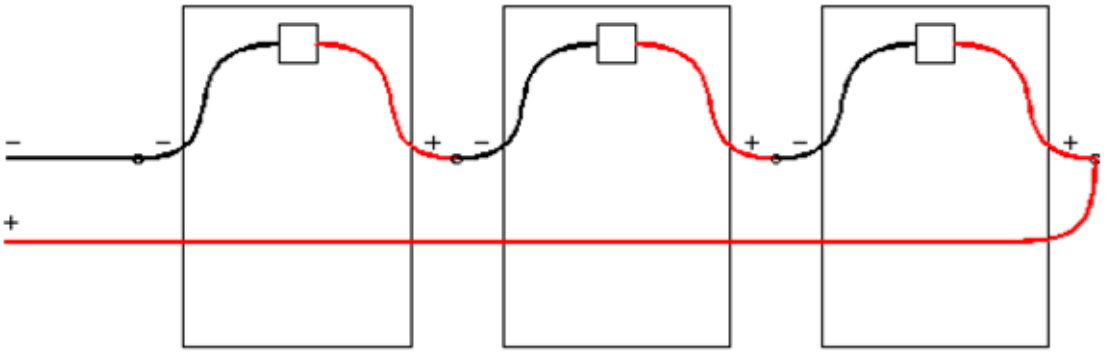
Male and Female ends of MC4 cables

Typically, you will be wiring the panels together in strings of 2-10 panels (the number of panels determined by the design) connected in series to increase the voltage. These connections will be made positive to negative between adjacent panels with the end panel having a wire running full length to the other end to make a complete loop. These

two ends may then be combined with another string in the PV Combiner Box to make a parallel connection to increase the amperage.

> ***TIP:*** *Order a long MC4 extension cable that you can cut to the proper length from the array connections to the PV combiner box or junction box. You can then use the MC4 male and female ends to connect to the appropriate solar panel plugs.*

The cut ends will be marked as to which is positive and which is negative and then wired directly into the PV combiner box. This makes for quick and easy wiring connections between the array panels and the combiner box without a lot of unnecessary splicing and wiring connections. This is just another installation technique to provide good secure connections that many contractors use.



PV Panel Array Wiring

Now that the wiring of the panel arrays has been completed, you need to make the remaining grounding connections. Note that each solar panel frame must be properly grounded and the grounding must be completed in accordance with the local codes, regulations, and manufacturers' requirements. Typically, a bonding or toothed washer is required when making the grounding connection to the solar panel frame. All of the grounding connections must have a continuous electrical path to a grounding rod. Use your multi-meter to verify you have a good ground path from end to end. And the ground wire must be sized for the maximum amperage of the system from the panel to the grounding rod.

If you're using non-metal junction boxes in the array wiring, remember to maintain the grounding path *across and through* the junction box with tested grounding connections.

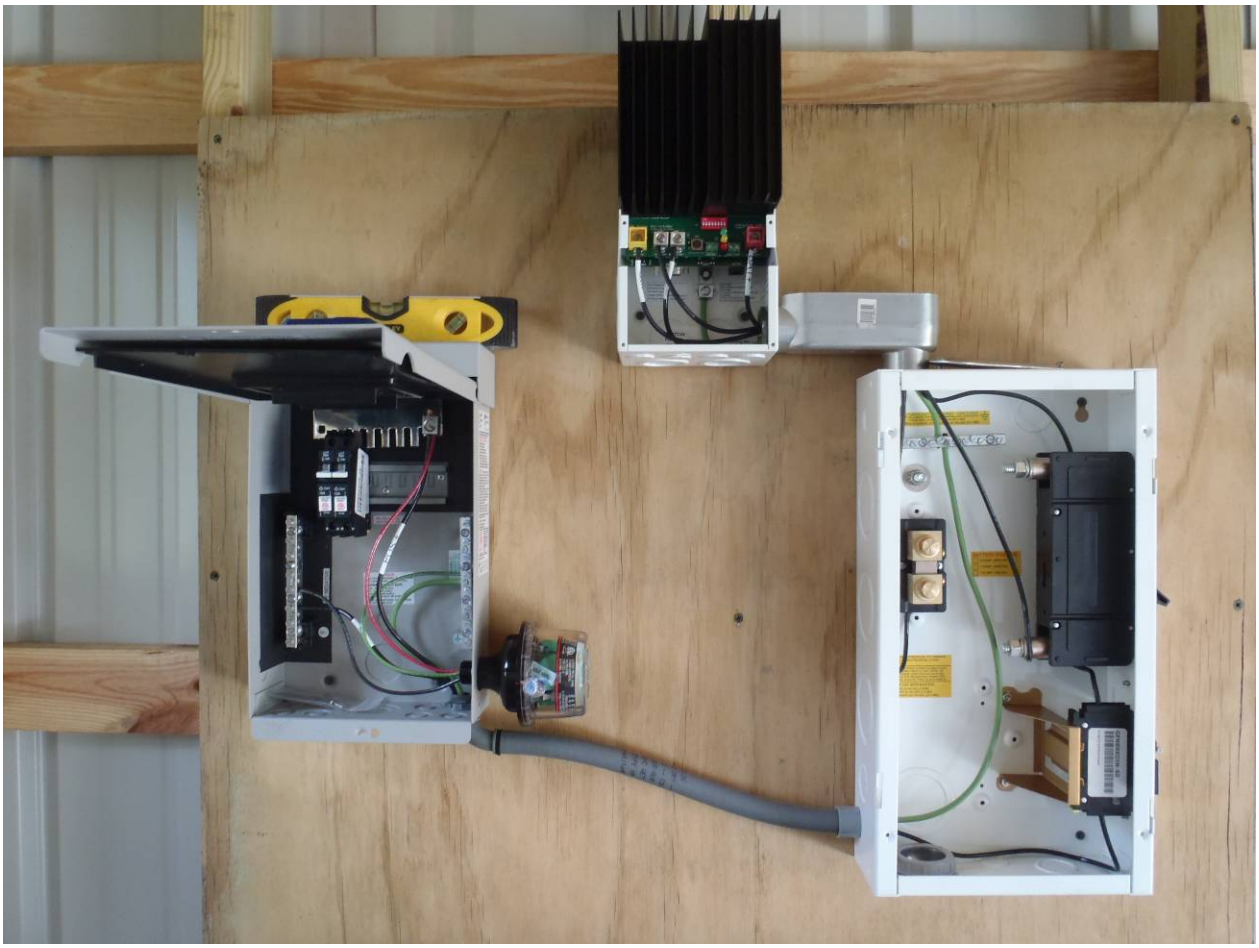
While the solar panel wiring is weather-resistant and UV protected, it is not animal-proof... birds, squirrels, rodents, etc. Even for small installations, placing the wiring within conduit, can save you headaches, time, and money in the future. Refer to NEC Article 690 and 230 for proper conduit sizing. If using conduit for this, remember to consider the diameter of the MC4 plugs.

If installing a solar array on a metal roof, use high-heat wiring and insulation because the heat on a metal roof can reach extreme temperatures in full sun during the summer months.

MOUNTING THE SOLAR SYSTEM COMPONENTS

You will want to locate the system components in a location that minimizes the wiring runs from the solar arrays, is easily accessible (both for installing and for maintenance), is well ventilated, is dry, and is secure from kids or pets. Plan out your layout for each of the components to ensure there is adequate room for each of the components and the interconnecting wiring. Trust me... you don't want to do this twice and induce errors in the installation from partially removing something and then forgetting to reconnect it or discovering the wiring is too short to reach the component where it needs to be located. So, plan ahead. It's time well spent.

Most of the components are intended to be installed on a wall but some... like inverters... may need to be installed on a shelf, table, or cabinet. Also, recognize that many of these components are surprisingly heavy so the wall will need to be structurally sound. Trying to mount these on sheetrock just isn't going to work. At a minimum, you will need to mount the PV Combiner Box, the Charge Controller, the Electrical Disconnect Box, and perhaps a Monitor Meter so you will likely use a 1/2 or 5/8 inch plywood mounting board. You may also want to provide a sturdy shelf or table for the inverter and/or the batteries. If you're planning on installing new AC or DC Breaker Boxes or a second PV Combiner Box, you're going to need even more room.



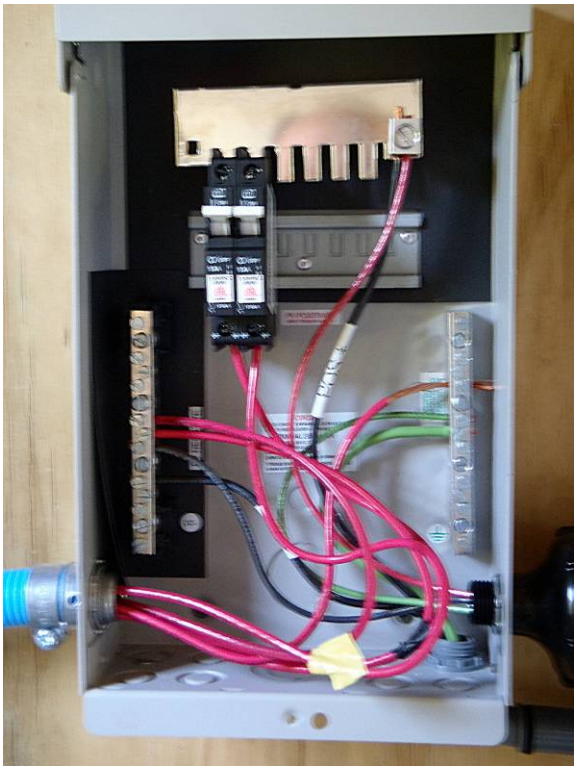
Initial configuration of PV Combiner box, Electrical Disconnect Box, and Charge Controller. The Monitor Meter attached directly to the Charge Controller in this installation.

The installation above did not include a new AC or DC Breaker Box since the inverter included two AC outlets and one AC connection terminal which were sufficient for the intended uses. However, we will still discuss the installation of the Breaker Boxes.

PV COMBINER BOX WIRING

A PV combiner box is not a requirement in small structures but is recommended because its use allows you to isolate each solar array for troubleshooting or solar panel replacements. It also provides a convenient test location of the solar array performance and the wiring from the array to the combiner box.

There will be three wires from each array... positive, negative, and ground. Each array's positive wire will be connected to a DC circuit breaker (sized for the maximum amperage of the array). The other end of the circuit breaker will be to the positive bus bar (upper center in photo below). Make sure each array and its corresponding circuit breaker is properly labeled for ease in future troubleshooting or repairs.



PV Combiner Box wiring

The negative wires will be connected to the negative bus bar (lower left in photo). Each array will have a wire connected to the negative bus bar.

The third wire from the array is the ground wire which is attached to the ground bus (lower right with green wires).

Unfortunately for the contractor, in the photo above, red wiring was used for everything coming from the PV panels on the roof and he simply marked the ends of each wire as positive, negative, or ground. Then in other areas, he used all black wires. This practice should not be permitted. During the construction inspection, the contractor was required to replace the wiring with industry standard colored wires.

Once the wires from the solar arrays are connected properly inside the PV Combiner Box, the circuit breakers can now be used to independently disconnect the electrical power from each solar array from the rest of the system. The system ***voltage*** can also be checked with a multi-meter now. For the rest of the installation, test only the voltage but do not test the amperage using a small multi-meter. Just remember to uncover the panels for the testing and then re-cover them after the tests are complete.

SURGE PROTECTOR WIRING

The Surge Protector is your insurance for a trouble-free solar system, especially for an off-grid application. The Surge Protector has three wires that need to be connected and the PV Combiner Box is the ideal location for its installation. Just use one of the knock-out plugs on the side to mount the surge protector on the PV Combiner box. Then, just as with the solar panel wiring, connect these three wires to the positive bus, the negative bus and the ground bus. Red goes to the positive bus, black goes to the negative bus, and green goes to the ground bus. That's it... you're finished with the surge protector installation and wiring! For the MidNite Solar surge protectors, simply rotate the surge protector such that the LEDs are easily visible since this is the owner's verification that the surge protector is operating and protecting the system.

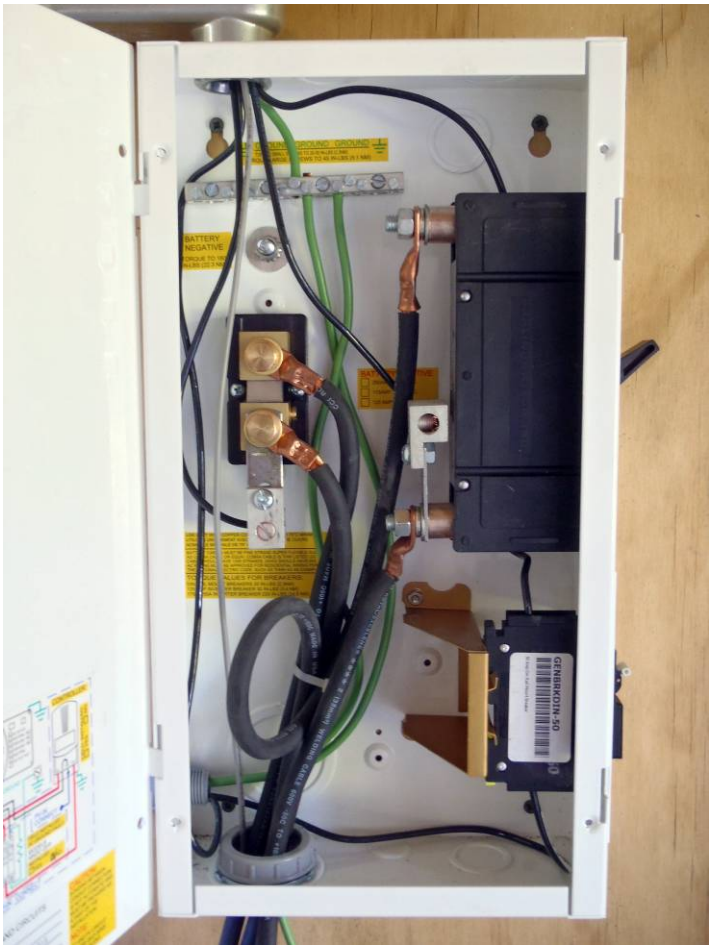
Surge protector and shown mounted

ELECTRICAL DISCONNECT BOX

Next up is the Electrical Disconnect Box. You will now install three wires (from the positive, negative, and ground buses in the PV Combiner box) and run them to the Electrical Disconnect box.

The PV positive wire will connect to the Master Solar Panel Disconnect switch (lower right in photo below). Then connect a new positive wire to the other terminal of the Master Solar Panel Disconnect Switch and run it to the Charge Controller.

The PV negative wire will simply run through the Electrical Disconnect Box not connecting to anything and continue on to the Charge Controller.

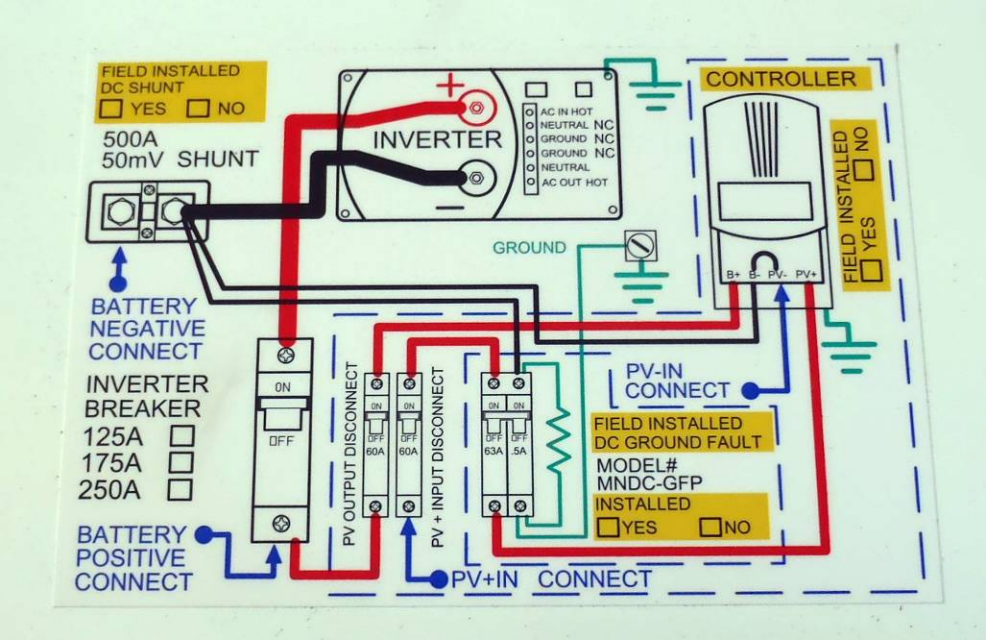


Electrical Disconnect Box wiring

The PV ground wire will connect to the ground bus in the Electrical Disconnect Box (upper left). Then run a new ground wire from the ground bus to the Charge Controller. Now run a new ground wire to the Inverter.

Next run a battery cable from the Battery Bank's positive terminal to the lower terminal on the Master Battery Disconnect Switch... after you ensure the Master Battery Disconnect Switch is in the **OFF** position. From this same Master Battery Disconnect Switch terminal, run a wire to the Charge Controller. Then run another battery cable from the upper terminal of the Master Battery Disconnect Switch to the "positive battery" terminal on the Inverter.

Now we run a battery cable from the Shunt (left center) terminal to the "negative battery" terminal on the Inverter. From this same Shunt terminal, run a wire to the Charge Controller. Next, we add another battery cable from the second Shunt terminal to the Battery Bank's negative terminal.



Electrical Disconnect Box wiring diagram provided by the manufacturer

This completes the wiring inside the Electrical Disconnect Box. But don't close it up yet as we still need to run a battery sensor wire from the Charge Controller to the Batteries through this box. At this point, verify that both the Master PV Disconnect switch and the Master Battery Disconnect switch are in the OFF position. Again, test your connections with a multi-meter. And give your wiring a few tugs to ensure they are secure. Just because the torque screw is firm doesn't mean the wiring is secure.

CHARGE CONTROLLER WIRING

We can now start on the Charge Controller wiring. We have already run 2 PV power wires, 2 battery power wires, and a ground wire to the Controller. We just need to connect those and add some additional wires now.

Behind the panel of the Morningstar TS-45 MPPT Charge Controller

Connect the positive PV power wire to the Solar Positive terminal (which is conveniently colored yellow for the sun on the upper left side) and connect the negative PV power wire to one of the Negative terminals immediately adjacent to the Solar Positive terminal (it doesn't matter which one).

Then connect the Battery power wire to the Battery Positive terminal and connect the negative Battery power wire from the shunt to the other unused Negative terminal.

Next, connect the green ground wire to the Ground terminal (center of photo).

Now we can run the Remote Temperature Sensor wires through the Electrical Disconnect Box to the positive terminal on the Battery terminal. It will be connected at the same battery terminal as the battery cable coming from the Electrical Disconnect Box. The sensor terminals are not polarity sensitive so simply connect one wire to each terminal (located immediately adjacent to the red Battery terminal)
.
Next, we connect the ribbon cable from the TS-M-2 monitor meter to the Meter Bus Port. This makes for a quick clean connection for the monitor meter in this installation. Many monitor meters will require multiple wiring connections.

The Charge Controller wiring is now completed but before we can close it up, we need to set the configuration DIP switches (red box with switches in upper center of photo). For the Morningstar TS-M-2, the DIP switches set the system voltage, the type of batteries used, battery equalization setting, and the Ethernet Security setting. The settings below will give you an idea as to what these settings are for since they are similar to other manufacturers.

DIP Switch	Function
1	Not used (future use)
2-3	System voltage
4-6	Battery charging & set points
7	Battery equalization
8	Ethernet security

If your Charge Controller also has DIP switches, you will need to refer to the Owner's Manual for the proper switch settings for your particular installation.

Once again, it's time for the multi-meter to verify all of your connections. Now we can close up the Charge Controller which, in this case, the Monitor Meter itself just happens to be the cover for the Charge Controller.

MONITOR METER WIRING

The Monitor Meter may be an independent meter or it may be specifically made for a particular Charge Controller... as in this case. However, if it is an independent meter, the required connections are easily made but you must follow the manufacturer's installation instructions closely. There will be wires that need to be connected to the batteries, solar panels, Shunt terminals, and ground. Again, follow the manufacturer's instructions. The connections aren't difficult but obviously require a little more effort and time than simply connecting a ribbon cable to a matched Charge Controller as with the Morningstar TS-M-2 monitor meter. Some will require that you purchase additional shunts especially if you are intending to monitor multiple inverters. Additional shunts also mean additional wiring. Fortunately, most charge controllers in use today include a very capable meter.

BATTERY CONNECTIONS

The battery location was selected for its close proximity to the Inverter and for its easy access for maintenance and monitoring. Its location is also in a dry location... after all, we are dealing with a lot of amps and we all know water and electricity are a "thrilling" combination. Additionally, ensure the area is well ventilated even if you're using sealed batteries. The reason is the batteries will be replaced one day and if they are replaced with flooded batteries, the ventilation will be crucial. If the location is not ventilated, post a warning sign in **clear view** stating that only sealed batteries are permitted for use due to the lack of ventilation.

And if your particular system requires... say, for example, 24 batteries... do you have sufficient area for them? You may need to perform some quick calculations of the area you will need for the batteries. And don't forget that the batteries have to be maintained, so you will need to provide access to each battery and that takes up space, too. Using racks can help minimize the total floor space but there's a significant cost for racks strong enough to hold these heavy batteries. But, racks do make it easy to access the batteries for routine maintenance.

A dry easily accessible location for the batteries

As noted above, there are two cables and one wire running from the Battery Disconnect Box to the batteries that need to be connected. The positive wire from the Battery Disconnect Switch is run to the Battery Bank's positive terminal. The "common" or negative cable from the Shunt terminal is run to the Battery Bank's negative terminal. And then the third wire, the battery sensor wire from the Charge Controller, is also run to the Battery Bank's positive terminal. As you remember, the battery sensor wire is used to monitor the battery's temperature for more efficient charging by the Charge Controller so ensure it's not located near a hot or cold air source that will distort its readings.

Refer to the design plans for the proper battery array wiring... series, parallel, or a combination. In this particular installation for a small load requirement, the batteries are connected in parallel to maintain a 12-volt system but doubling the amperage. So the positive terminal of one battery is connected to the positive terminal of the other battery with the appropriately sized battery cable. Likewise, the negative terminals of the batteries are connected to each other with a battery cable. Verify the battery array voltage but ***NOT*** their amperage... unless you have a meter capable of handling their rated amperage which, in many cases, is hundreds of amps.

INVERTER CONNECTIONS

The Inverter connections are next up on the "To Do" list... *if* you're going to need AC power. If you don't, you can skip this section but... even for installations that were DC only, it's not long before you get a call about adding AC power to it. So, you may still want to review this section after all....

You should select a location near the Electrical Disconnect Box and the batteries because the electrical cables from the Electrical Disconnect Box to the Inverter and the batteries will be large and expensive. Additionally, the location needs to dry and easily visible to monitor its performance.

There will be two cables and one wire coming from the Electrical Disconnect Box that will need to be connected to the inverter. The positive cable from the Battery Disconnect Switch will be connected to the Inverter's positive terminal. The negative cable from the Shunt terminal will be connected to the Inverter's negative terminal (see photo below).

DC Connections in the rear of the SunForce Inverter

The ground wire (the third wire) from the Electrical Disconnect Box will be connected to the Inverter's ground terminal. Then another ground wire will be run from this ground terminal to the building's AC Electrical Panel Box.

The front of the SunForce Inverter has the AC connections providing 120-volt power to the building's AC Electrical Panel Box. An electrical cable will be run from the AC connection to the building's AC Electrical Box and sized for the maximum output of the Inverter. This Pure Sine Wave Inverter was selected for this installation because it also has two circuit breakers and a DC power port included.

The front panel of the SunForce Inverter has four 120-volt AC outlets, one 12-volt DC outlet, and one wired 120-volt connection point (the large cable on the left side of the photo)

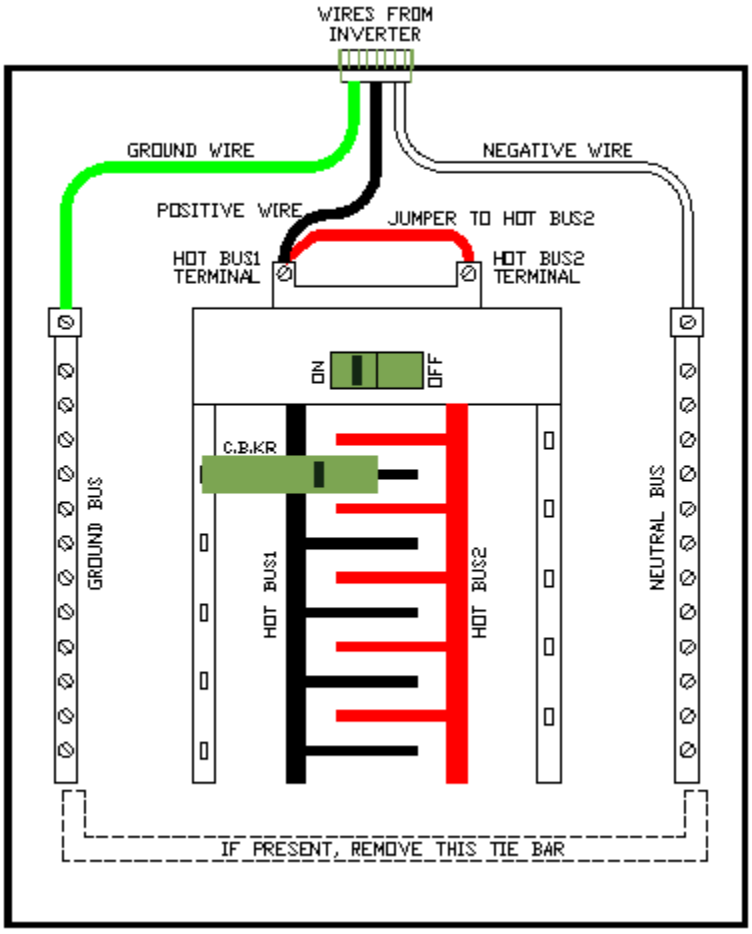
Note that every Inverter is different and some Inverters will have both input (DC) and output (AC) connections at the rear panel of the Inverter. Just ensure the cables are connected to the correct terminals and that the Inverter is properly grounded per the manufacturer's specifications.

AC BREAKER BOX

The main electrical panel (the breaker box) will have the three wires from the Inverter coming into the panel box. The positive wire will be connected to ***both*** of the two hot bus terminals by using a jumper wire... assuming you are using only a single inverter that is supplying 120 volts. Note that a jumpered wiring arrangement will not provide 220 volt service. If you need 220 volt service, you will need a second inverter and... another solar array. See the diagram below the photo.

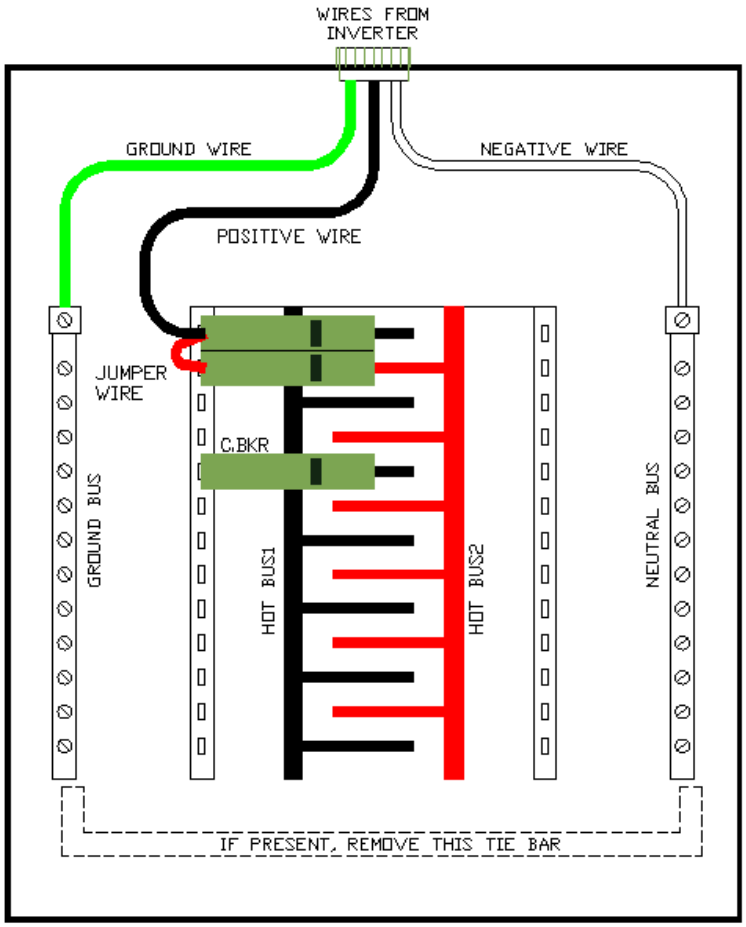
Circuit Breaker Box

The negative wire will be connected to the neutral or common terminal. And, finally, the ground wire will be connected to the ground bus terminal.



Circuit Breaker Box wiring – Note the Breaker Box may or may not have a main disconnect switch

If there are no Hot Bus terminals, you will need to install a circuit breaker to act as the positive terminal and the main panel breaker as shown in the photo below. Simply install two circuit breakers ***adjacent*** to (above and below) each other and then run the positive wire to both terminals on the circuit breakers. The positive power from the inverter will now feed through these two breakers to feed Hot Bus1 and Hot Bus2.



Circuit Breaker Box wiring using circuit breakers to feed both Hot Bus bars

In the photo above, the power from the Inverter enters the box and runs to the top circuit breaker. Then a short jumper wire is run to the adjacent circuit breaker below it. These two circuit breakers will act as your Main Disconnect Breakers. (In the diagram, the two circuit breakers located below them are the load breakers.)

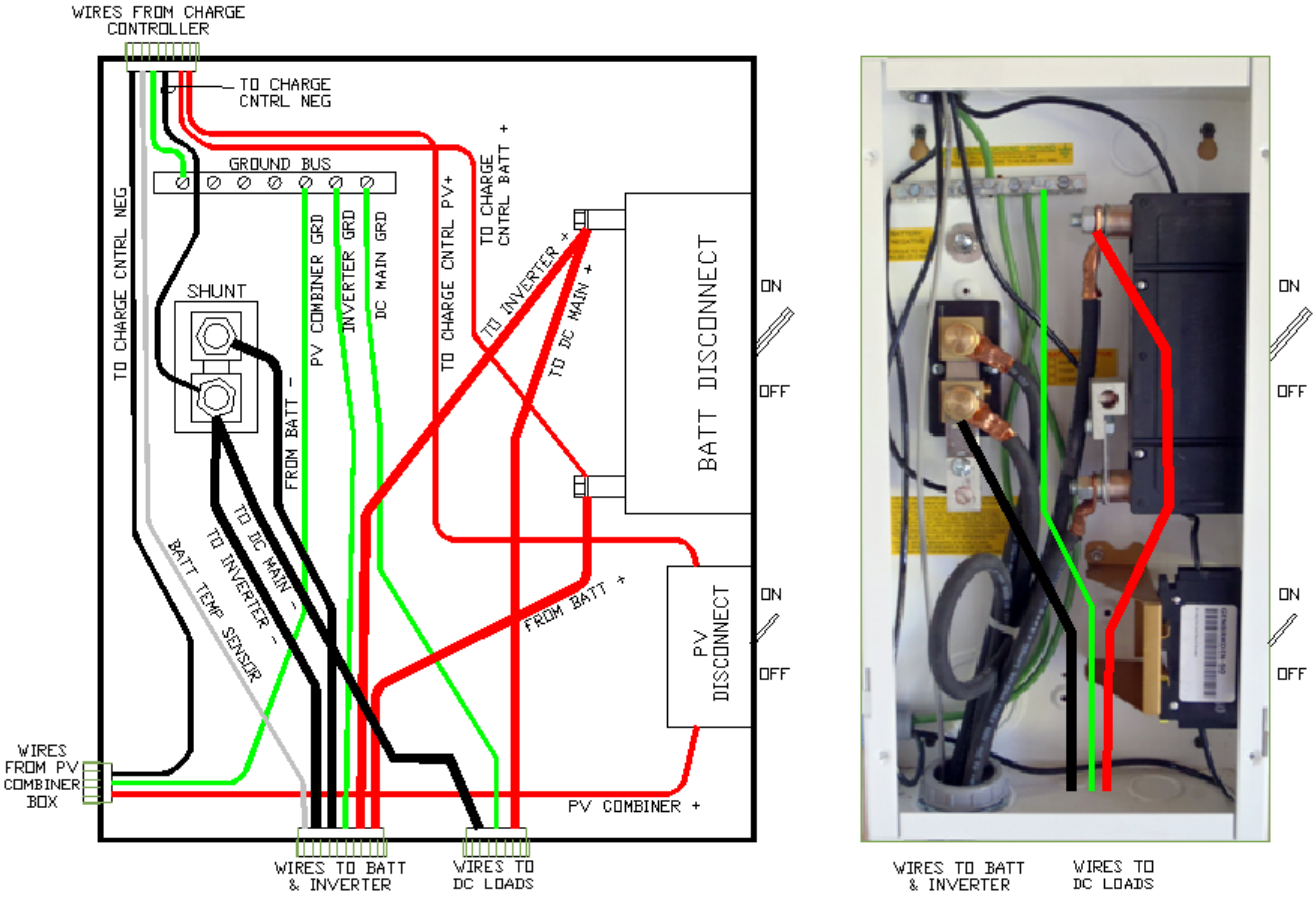
The breaker box will then be ready for the installation of the load AC circuit breakers with the proper size of wiring to each of the electrical loads.

ADDING A DC BREAKER BOX

Are you are planning on using any of the newer more efficient DC appliances? If so, to run some DC circuits in the building, use a second Circuit Breaker Box with the

appropriately sized DC circuit breakers for each of the loads that you want protected or you can use a DC fuse block. If you're using a DC Circuit Breaker Box, be sure to clearly label the box for **DC Circuits Only** and prominently label the specific voltage. (If you should only need one DC circuit, you can omit the second CB Box.) *Remember, AC and DC circuit breakers are not the same. Never mix voltages in a single box.*

Either way, to wire an Electrical Disconnect Box for the installation of a DC Circuit Breaker Box simply connect the positive wire to the output side of the Main Battery Disconnect breaker switch (where the connection for the cable running to the Inverter is located). This allows the Battery Disconnect Switch to also shut down the DC circuits (see diagram below).



Wiring diagram of the Electrical Disconnect Box for the installation of a DC Load or Circuit Breaker Box

> ***TIP**: If you will have multiple DC circuits and don't want to use a DC fuse block but prefer to use a DC circuit breaker load center, note that Square-D circuit breakers in their "QO" line are UL listed for 12 and 24-volt DC circuits or for 120/240 volt AC home or generator circuits. Remember to **always** use a separate box for DC and AC circuits. Never mix voltages in a single box.*

If you were to connect the DC circuit to the input side of the Main Battery Disconnect switch, the DC circuit will always remain hot anytime the batteries are connected regardless of the switch position (wiring diagram not shown). If you use this wiring option, just make sure you install a DC Disconnect for that circuit. You need to be able to shut off that circuit for repairs or emergencies.

THE GROUNDING ROD

The system ground wiring is useless without a good connection to a properly installed grounding rod. And the ground wire must be sized for the maximum amperage of the system from the solar panels all the way to the grounding rod. The rod needs to be placed in a location that will be protected from disturbances that could break the connection or the ground wire.

Grounding rod with the grounding wire securely fastened

To meet code, the ground rod must be 5/8 inch in diameter if not UL listed, at least 8-10 feet in length, and installed to a minimum depth of 8 feet. Copper ground rods are recommended due to their high conductivity and low corrosion factors. Always use a UL listed grounding rod (with the permanent certification marking visible at the top of the rod) to insure the rod will perform as required to protect your system.

Other grounding methods are acceptable if they meet the NEC code requirements but, obviously, the grounding rod is often used as it is easily installed and provides a safe ground. However, stainless and galvanized grounding rods are not recommended due to their limited lifespan because of corrosion issues.

SOME COMMON PROBLEMS

Some of the more common problems encountered with solar installations are listed below.

1) Solar panels and mounts are not properly grounded
2) Too many unnecessary roof penetrations
3) Roof penetrations are not properly sealed
4) Not using high-heat wire and insulation on roof mounts
5) Using undersized wiring which causes excessive DC voltage drops
6) Improperly using AC circuit breakers on DC circuits
7) Unsafe wiring practices
8) Equipment and components are improperly grounded
9) Improper use or no use of electrical conduit
10) Not testing the system circuitry and grounding as the installation progresses causing lengthy delays while troubleshooting

These problems are easily avoided by taking the time to do the job correctly the first time and remaining focused on the work currently being performed. Rushing a job is asking for problems and you only end up doing it twice. If you're unsure how to do something, find someone who knows. Electrical wiring is not something you want to learn by trial and error... especially when many of the components can be costly to replace. And you probably agree... *you* consider yourself irreplaceable!

SOLAR POWER INSTALLATION SUMMARY

In summary, we have just completed a solar power installation of a small system. Though it was a small project, it included all the components you will find in a typical off-grid solar powered structure, which makes it ideal for a course example. We discussed the basic safety issues that need to be practiced by everyone working with an electrical system.

We also discussed the materials and the tools you will need for the installation... from hand tools to meters to installation materials. Regardless of how prepared you think you are for the installation, you will probably end up making multiple runs to obtain additional tools or materials that you hadn't thought of or expected to encounter.

We then discussed the step by step installation of the solar panel rail mounts on a roof, mounting and grounding the solar panels to the rails, the wiring to the PV Combiner, the Surge Protector, the Electrical Disconnect Box, the Charge Controller, the Battery wiring, the Inverter, the Circuit Breaker Box, a DC Circuit Breaker Box, and how each is properly grounded.

Lights are on... the system works!

We also discussed some tips to keep in mind when installing the various components. And there are many others you can pick up simply by talking with different installers and watching other installations by experienced contractors.

While a solar PV system doesn't have to be installed in the exact sequence described, it does make it somewhat less likely that you will omit a component's installation or spend a lot of time troubleshooting. But you now know what to expect in an installation, what to look out for, and what you can expect to find behind all those component covers.

Text and pictures are a great start to learning anything but nothing beats first-hand experience. So... go build something!

P.S. – Feel free to send me any construction tips, comments, or suggestions to improve this course... or recommendations for future courses.

