How to Install...

A Pole-Mounted Solar-Electric Array: Part 1

Joe Schwartz

If you've decided that a pole-mounted solar-electric array is the best option for your site, here's all the info you need to secure it in the ground for the next 100 years or so.

While groundwork is arguably the least glamorous part of any construction project (it all just gets covered up anyway), it is in many ways the most important. So let's dig into the dirty work required to set a pole for a solar-electric array. In our next issue, we'll show you how to have some good, clean fun mounting and wiring the PVs.

1 Site the Array

PV modules are expensive. To maximize the energy produced by your investment and minimize system costs, always look for the sunniest location on your property to install your array. When PV modules are wired at high voltage (48 VDC nominal or more), pole mounts can be located a couple of hundred feet away from the batteries or inverter with minimal transmission losses and relatively small gauge wire.

The best tool for locating the sunniest spot for your panels is a Solar Pathfinder. It takes less than a minute to set up, and will show you when a particular location will be shade-free for every daylight hour, every day of the year. A good solar site should be unshaded from 9 AM to 3 PM, but a larger solar window is always better. Compromises may need to be made. If your site has morning shade but lots of afternoon sun, for example, the site will still be workable, but will likely require a larger array.

The photo at right shows the Pathfinder at the location of my arrays. Year-round, there is no shading between 9 AM and 5 PM. In the summertime, the solar window is even larger, with virtually no shading from 7 AM to 7 PM.

2 Dig the Hole

While working on roofs is never great fun, neither is digging holes. Pole mounts let you skip the roof work, but leave you doing dirt work instead. In some jurisdictions, the building department will require an engineer to specify foundation details that take into account maximum wind loads and soil types for your area. Pole mount manufacturers can also recommend the appropriate hole size for their racks if an engineer isn't required. See the table for one manufacturer's specs.

Because deep, narrow holes are difficult to dig by hand, and impossible to dig with a backhoe, a tractor-mounted auger is the best tool for the job. That said, augers don't work well in rocky soil, and may not be able to drill deep enough for taller poles. The type of ground you're working with will often dictate the actual dimensions of the pole's foundation, and the best way to get it dug. Wooden forms can be built if the hole ends up oversized, but I like to avoid this whenever possible, since it adds time and expense to the job.

At my place, the soil at the array's location consists of 3 feet (0.9 m) of loam and then bedrock. A 5-foot-deep (1.5 m) hole would be impossible to dig without a hydraulic rock hammer, so I expanded the size of the hole to 3 by 3 by 3 feet (0.9 x 0.9 x 0.9 m) deep, using the pole and hole sizing table as my guide. I had a friend with a backhoe come up when I was ready to dig the holes for the mounts. The backhoe made quick work of the holes—in twenty minutes it did what would have taken me two days to do with a shovel.

Pole & Hole Sizing for Top-of-Pole Mounts

Module Area (Sq. Ft.)	Sched. 40 Pipe Size (In.)	Depth In Ground (In.)	Height Above Ground (In.)	Hole Width (In.)
15	2.0	30–36	48–72	8–12
20	2.5	34–40	48–72	10–14
28	3.0	36–42	48–72	12–16
35	3.0	38–44	60–72	12–16
60	4.0	42–48	60–72	16–24
90	6.0	48–60	60–84	24–30
120	6.0	48–72	72–84	24–30
160	8.0	60–78	84–102	30–36
180	8.0	60–78	84–102	30–36
225	8.0	72–84	96–120	36
260	8.0	72–84	96–120	36

Courtesy of Direct Power & Water. Always consult your mount manufacturer for specifications for your site and mount.

3 Pipe Selection & Preparation

The diameter of the pole required for your installation will be specified by the pole mount manufacturer, as will the hole dimensions. Pipe sizes will range from 2 inches in diameter for small arrays, up to 8 inches for large arrays. Keep in mind that pipe sizes go by the inside diameter of the pipe. Make sure to double-check that the outside diameter of the pipe is correct for the pole mount you're purchasing.

Pole mounts are most often designed to rest on schedule 40 steel pipe, but large arrays or tall poles may require thicker walled, schedule 80 pipe. Consult your mount manufacturer for the right pipe for your array. The appropriate pipe is almost always available locally at wholesale plumbing warehouses or steel suppliers, and is typically sold in 21-foot (6.4 m) lengths. Usually, your supplier will cut the pipe to length for a nominal fee.

Aesthetic and practical considerations will affect pole height. In my case, I want the arrays fairly low so I can reach to brush snow off in the winter. Others choose a taller pole to allow people, animals, and lawnmowers to pass underneath unscathed, or to improve solar access.

If you require a taller pole than the standard specified height, you will need to have more pole in the ground. For each extra foot (30 cm) that you add above ground, you'll want approximately 6 more inches (15 cm) in the ground in concrete. If you have to go more than 2 or 3 feet (0.3–0.6 m) higher than what is shown in the table, a larger diameter pole may be necessary—consult your rack's manufacturer.

In windy conditions, a significant amount of stress is put on the pole's concrete foundation due to the surface area of the array. At a minimum, the pole should be drilled or cut to allow for the insertion of two rebar crosspieces in the concrete. Use 18-inch (0.46 m) pieces of 1/2-inch (13 mm) rebar running perpendicular to the pole (see photo on the next page). If the concrete mixture and curing process is less than perfect, some shrinking of the concrete can occur. The two crosspieces of rebar will keep the pole and the attached array from rotating in the hole during high winds.

Locate the holes for the two rebar crosspieces by measuring up from the base of the pole. For 1/2-inch (13 mm) rebar, I use a 5/8-inch (16 mm) drill bit and a high power AC drill to cut the holes. Run the drill at low speed, and use cutting oil to prolong the life of the bit and keep it running cool.

4 Position, Anchor & Plumb the Pipe

The 6- or 8-inch poles used for larger arrays are heavy, often weighing a couple of hundred pounds. When positioning the pole, it's good to have at least two people on site. Instead of just you and your back doing the job, enlist the help of a friend. If the hole has a narrow diameter, insert the rebar crosspieces before you position the pipe in the hole. There may not be sufficient clearance to do it once the pole is lowered into position.

After installing dozens of pole mounts, I've come up with a simple and inexpensive method to temporarily anchor the pole in a vertical position while I'm getting everything lined out for the concrete pour.

Run two, 8-foot (2.4 m) 2 by 4s flat along the ground on either side of the pole. Drill out the ends of each of the 8-footers using a 9/16-inch (14 mm) drill bit. Then cut four, 18-inch (46 cm) pieces of 1/2-inch (13 mm) rebar, and hammer the rebar through the drilled holes, securing the long 2 by 4s to the ground. Cut two shorter lengths of 2 by 4 (18 inches is usually perfect). Get the pole roughly vertical (plumb) and fasten the shorter 2 by 4s to the longer ones, snug against the other two sides of the pole to form a square hole with the pole in the middle. Use screws for easy removal of the lumber once the concrete has cured.

Plumb poles look good. Out-of-plumb ones don't. Once the pipe is anchored in place, use a 4-foot (1.2 m) carpenter's level to plumb up the pole in two directions. Place the level vertically on the south-facing side of the pole, plumb it up, and then check the east side of the pole. You'll need to check for plumb in each direction several times, since the pole will typically move a bit while you're making your adjustments.

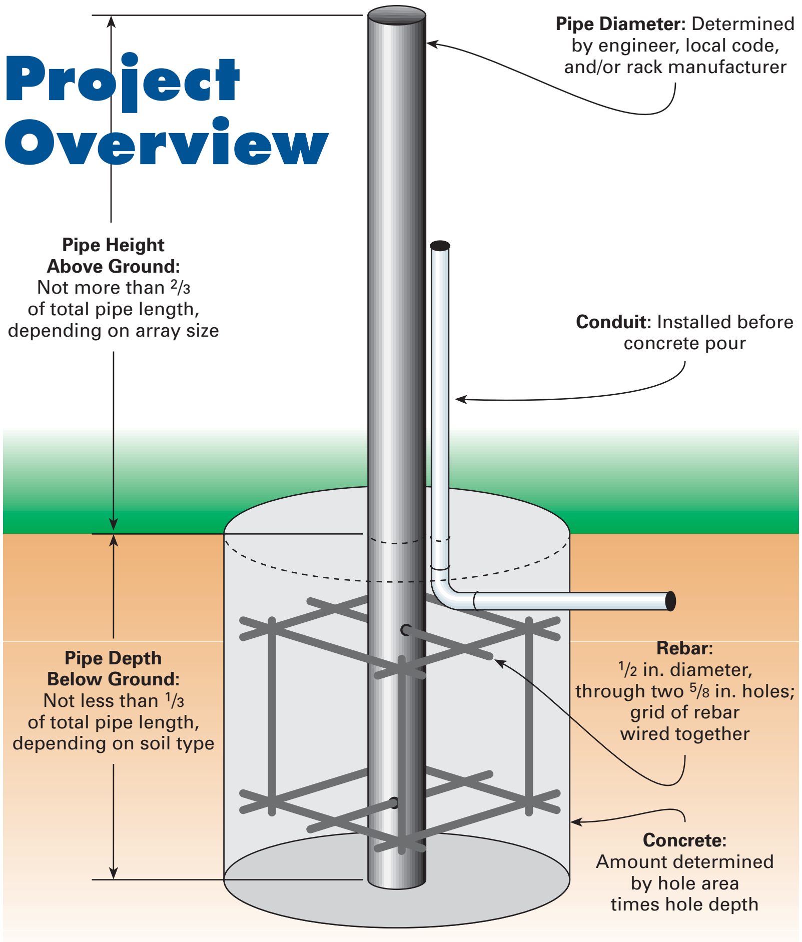
5 Install Rebar & Conduit

If your local building codes require engineering for the pole mount's foundation, the size and spacing of the rebar will be provided to you, and you just need to follow the engineer's specifications. At a minimum, always install rebar cross-pieces as described earlier. Use rebar tie-wire to hold the rebar in place while the concrete is being poured.

After the rebar is in place, drill a hole in the bracing and position the PVC conduit for the PV wire run before the concrete is poured. The conduit can be temporarily fastened to the pipe with the same type of tie-wire you used for the rebar. Choose the diameter and type of conduit based on *National Electrical Code* (*NEC*) specifications. The conduit will run down the pole to a 90-degree fitting and then out beyond the edge of where the concrete will be poured. Some installers use Unistrut to clamp the conduit to the pole once the concrete is cured. If you choose this approach, make sure to use spacer blocks or pieces of Unistrut to set the conduit at the correct distance from the pole.

In most locations, electrical inspectors require all aboveground PVC conduit runs to be schedule 80 PVC. This conduit has a thicker wall than the schedule 40 PVC that is typically used in trenches, and will better resist physical damage. Take a look at *NEC* sections 352.10(F) and 352.12(C) or section 352.2 in the *NEC Handbook* for more info on this requirement. Some installers prefer to use rigid metallic or EMT conduit for extra protection on exposed, outdoor conduit runs.

I'm installing data acquisition sensors on the PV arrays at my place to measure irradiance (the sun's intensity), wind speed, and ambient and PV module temperatures. This is why you can see a second, smaller, conduit run in the photos. Most systems will simply have a single conduit run coming down the pole.



6 Estimate the Amount of Concrete

The amount of concrete required to secure the pole for your PV array will vary depending on the size of the PV array, the soil type, the pole's height, local wind loads, and the dimensions of the finished hole. Deep, narrow holes will require less concrete than wider, shallower ones.

You can determine the amount of concrete required by calculating the volume of the hole. The volume will equal the surface area of the hole times the depth. For square holes, the equation is L x W x D (length x width x depth). For round holes, the equation is $\pi \times R^2 \times D$ (Pi x the radius squared x depth). Pi is a mathematical constant that always equals approximately 3.14. Finally, a cubic yard of concrete equals 27 cubic feet.

Let's run through the math required to calculate the amount of concrete required for two different hole sizes. The two holes my friend with the backhoe dug at my place are 3 feet by 3 feet across, and 3 feet deep. Each hole required one cubic yard of concrete (3 x 3 x 3 = 27 cubic feet or 1 cubic yard). If the holes had been round, and were 2 feet in diameter (1 foot; 0.3 m radius) and 5 feet deep, they would have only required 15.7 cubic feet of concrete ($\pi \times 1^2 \times 5 = 15.7$). To convert this to cubic yards, simply divide by 27 (15.7 ÷ 27 = 0.59 cubic yards).

7 Get the Concrete

There are a few different options for getting concrete for the pole's foundation. You can buy bags of ready-mix concrete and mix them on site. For larger holes, this can be both expensive and labor intensive. A 90-pound (41 kg) bag of ready-mix will make approximately 2/3 cubic foot of concrete. So a 3- by 3- by 3-foot hole would require about 40 bags of ready-mix (27 ÷ 0.66). That's a lot of concrete to mix in a wheelbarrow, but definitely doable. However, there are easier ways to go about getting the job done.

Many rental yards now have towable, 1-cubic-yard mixers. If you or a friend has a truck that's set up for towing, this is a great option. The mixer is filled at the rental yard with concrete and water. The mixing cylinder is trailer mounted and includes an engine that mixes the concrete while in transit, keeping it ready for the pour. This approach can be cost effective, and is definitely labor saving compared to purchasing, hauling, and hand mixing 40 bags of ready-mix.

Another option is to have a cement truck deliver and pour the concrete. While this is definitely the easiest way to go about it, it's usually going to be the most expensive. Many pole mounts only require a cubic yard of concrete or less. Typical commercial trucks are sized to haul 9 yards, and concrete companies will usually hit you with a short load charge if you need fewer than 3 yards delivered. In addition, if your site is a ways out of town, transport charges usually come into play. So unless you're installing multiple poles, or have the need for additional concrete, calling in a truck usually isn't your best bet.

My immediate needs for concrete included 2 cubic yards of concrete for the pole mounts (one yard for each hole), and 3 cubic yards for the slab floor of the power shed I'm building—5 yards total. Since my property is only 25 minutes out of town, simply calling in a truck made a lot of sense.

8 Pour the Concrete

Wooden forms are usually not needed when pouring a foundation for a pole mount. The sides of the hole will contain the concrete, keeping it where you want it. I like to pour the concrete to within an inch or so of the top of the hole, and then backfill over the top of the cured concrete with soil and some grass seed. To my eye, this looks the best.

If you want the concrete to be exposed, a simple form built out of 2 by 4 lumber placed at ground level over the hole, and secured with rebar, will allow you to pour and finish the top of the exposed foundation. You can also use a cardboard tube form (Sonotube) or thin plywood bent into a circle.

Immediately before you pour the concrete, grab a hose and wet down the bottom and sides of the hole. This will keep the soil from drawing moisture from the concrete as it cures. When pouring the concrete into the hole, make sure to direct the chute or shovel away from the pole to minimize the chance of knocking the pole out of plumb. Always make sure to double-check the pole for plumb immediately after the pour, since slight tweaking is often required.

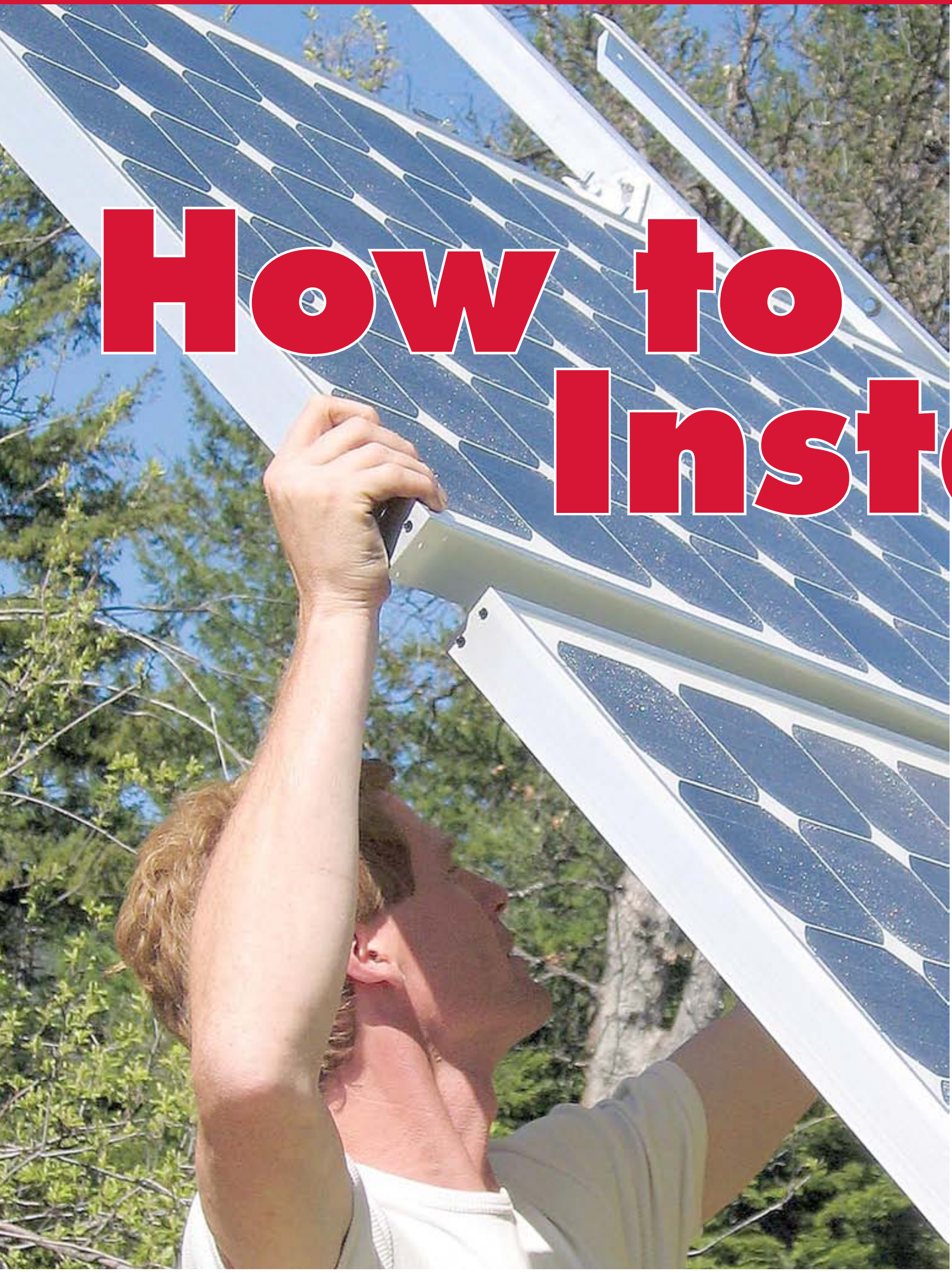
Make sure to give the concrete ample time to set up before you begin installing your PV array. The surface area of the installed array will act like a sail in windy conditions, and may move the pole out of plumb if the array is hastily installed before the concrete is sufficiently cured. Ideally, I like to wait five days before I begin installing the array. If you're working within a tight time frame, a day or two should be sufficient, depending on the ambient temperature during curing.

The completed pole—next issue, installing the solar-electric panels.

Finishing Touches

Finally, I like to paint the pole to prevent surface rust and keep it looking sharp for years to come. Talk with the folks at your local hardware store for info on prepping the pole for paint, and the best paint to use. Using galvanized pipe is another solution, costing less time, but more money.

In our next issue, I'll guide you through assembling the pole mounts, and installing and wiring the PV array and combiner boxes. Until then, get digging, or better yet, find a friend with a backhoe.



How to Install...

A Pole-Mounted Solar-Electric Array: Part 2

Joe Schwartz

Pole-mounted solar-electric (photovoltaic; PV) arrays are a great option for many sites. You don't need to worry about the orientation or angle of an existing roof, or about roof penetrations. Pole mounts allow easy, manual adjustment of the array's tilt angle, or you can choose automatic tracking mounts to optimize energy production. They provide great air circulation to keep PV temperature down and power output up during warm weather, and make clearing snow off the array a simple task in wintry climes.

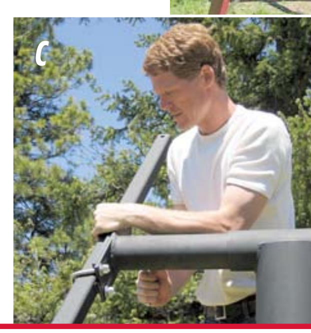
Last issue, I covered the groundwork—setting the pole. This time, I'll walk you through each step of the array assembly and wiring. Even if the equipment you use is different than mine, the information will be a useful installation guide for your own pole-mounted PV array.

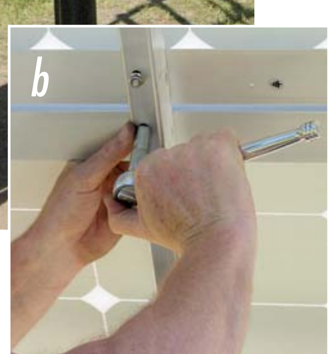
1 Assemble the Mount

Most pole mounts are designed and manufactured for specific PV modules. When you contact your mount supplier, they'll need to know the brand, model, and quantity of PV modules planned for your system. Each mount will come with step-by-step assembly instructions. Getting your mount assembled on the top of the pole is as easy as following the directions, but I have a couple of tips that will help simplify the job.

First, don't fully tighten the bolts that fasten the PV-mounting rails to the rest of the structure until all of the modules are in place. This will give you some wiggle room if any of the predrilled mounting holes in the rack are a little off. Don't forget to fully secure the rail hardware once the PVs are in place.

Second, pole mounts are designed to allow seasonal adjustment of the tilt angle of the array. While you're installing the array, it can be laid flat, at close to vertical, or anywhere in between. In general, I like to set the angle of the array at about 45 degrees. This limits the amount of uncomfortable overhead work. If the array is mounted on a tall pole, securing it in a horizontal position will make the whole array easier to reach.



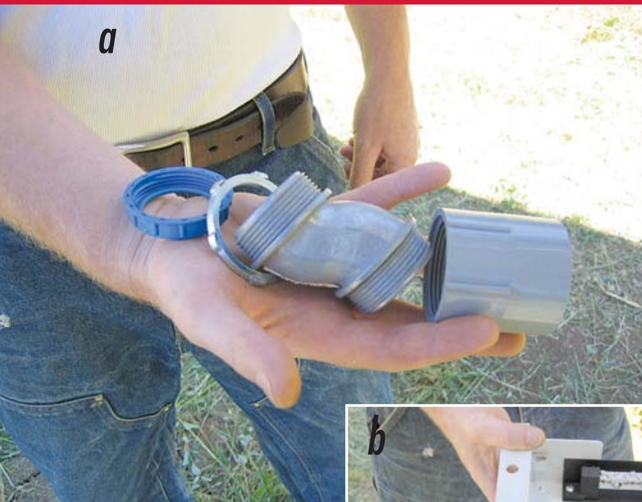


2 Mount the PVs

Once the rack is assembled, it's time to install the PVs. If you're assembling the array while it's fixed in a tilted position, install the bottom row of PVs first. Then you can rest the next row of modules on the first row while you're positioning them, which makes the job faster and easier.

The mounting hardware for the PVs will be included with the rack, not the modules. This hardware should be stainless steel to resist corrosion, and include either lock washers or lock nuts that will not loosen over time. It's easier to work with the mounting hardware if you insert the bolts through the module mounting holes from the inside of the PVs, and then through the rack. This gives you better clearance to get the washers and nuts in place.

An open-end wrench used in conjunction with a ratchet and socket (usually $^{7}/_{16}$ inch) will allow you to quickly fasten the PVs to the rack. If you have a big array, or several to install, a cordless drill fitted with a socket driver will definitely speed up the job. If you use this approach, make sure to set the driver's clutch to release before the hardware is overtightened. If you don't, you may snap off bolts.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3 Determine Combiner Box Conduit Fittings

The *National Electrical Code (NEC)* requires a dedicated breaker or fuse in line with each series string of PV modules (except with some high voltage inverters). To meet this code requirement, a combiner box is required in most pole-mounted array installations.

First, determine what conduit fittings you'll need to connect the combiner box to the conduit that runs up the pole. I typically run the conduit right against the pole. To make the transition from the conduit to the combiner box, you'll need a PVC female fitting, an offset, a nut, and a bushing.

Single-hole straps (clamps) are used to secure the conduit. Another channel and strapping system using Unistrut (not shown) is commonly used to secure the vertical length of conduit to the pole. This is a good approach, but requires a few more fittings.

4 Mount the Combiner Box


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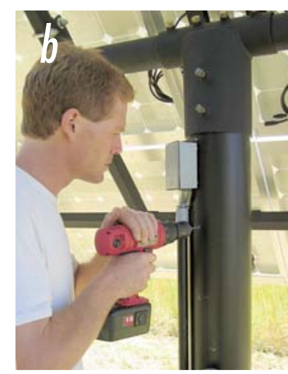
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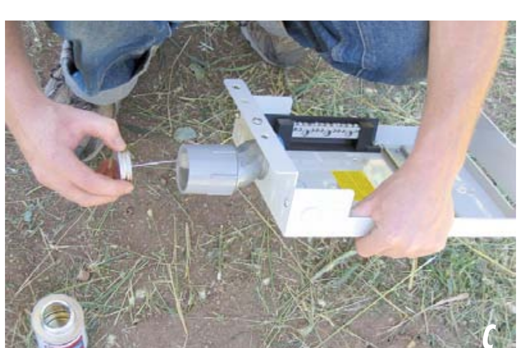
Attach the conduit fittings to the combiner box finger-tight, and position the assembly on the conduit (no glue yet). Grab a marker and a torpedo (short) level. Adjust the offset until the back of the combiner box rests evenly against the pole, and then level the box. Now that everything is in position, mark the location of the mounting holes on the pole itself.

Depending on the size of the pole and the combiner box you're using, the box's predrilled mounting holes may not be positioned where you need them. If this is the case, line it up where you want it, and mark the back of the combiner box to predrill custom mounting holes. Then mark the location of the new holes on the pole.

Use self-tapping screws to fasten the combiner box to the pole (I prefer square-drive screws). Even with self-tapping screws, pilot holes are necessary when mounting to steel pipe. Make sure to choose a drill bit that is slightly smaller than the screws you use. The curve of the pole will typically cause your pilot bit to drift off your mark, so use a center punch to make a starting point for the drill bit. This will ensure that everything lines up when you fasten the box to the pole.

Once your holes line up, apply PVC glue to the conduit, and slide the combiner box/fitting assembly into place. Wipe off any excess glue and drive the screws. I always neatly apply some high-quality 50-year silicone caulk over the screw heads, and seal any unused, predrilled mounting holes in the back of the box. Finally, use straps to secure the vertical conduit to the pole.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5 Install the Array Equipment-Ground Lugs

All PV arrays need to be properly grounded per the *NEC*. Pole-mounted PV array equipment-grounding systems have three main components—lugs that attach the ground wire to the PV module frames, the ground wire itself, and a ground rod driven into the earth at the base of the pole.

Lay-in lug kits, available from solar energy equipment resellers, are appropriate for long-lasting, corrosion-free connections between the ground wire and the module frame. Lay-in lugs are designed to accept wire from the side, so the hassle of feeding the ground wire through successive lugs is eliminated.

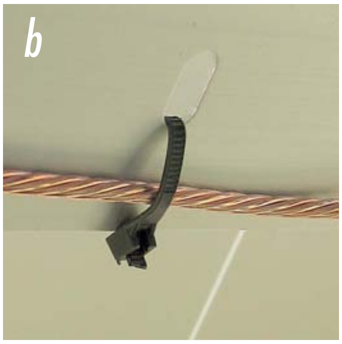
Lugs should be either bronze or stainless steel. They'll come with stainless mounting bolts or screws, and star washers that will cut through the anodizing on the module frame (ensuring a low-resistance connection). Low-cost aluminum lugs are not suitable, since the fastener will be exposed to weather in this application and corrosion will result.

Only the module grounding locations identified on the modules themselves should be used. Before you begin fastening the lugs to the module frames, plan the route the ground wire will run between each module, and then down to the combiner box. Use a cordless driver to fasten the lugs to the module frames.

6 Install the Array Equipment-Ground Wiring

Once the lugs are installed, it's time to run the ground wire from PV frame to PV frame, and then route it into the combiner box, where it will terminate at the box's equipment-ground lug. To ensure the lowest resistance electrical path, equipment-ground wire installed on PV arrays should be continuous.

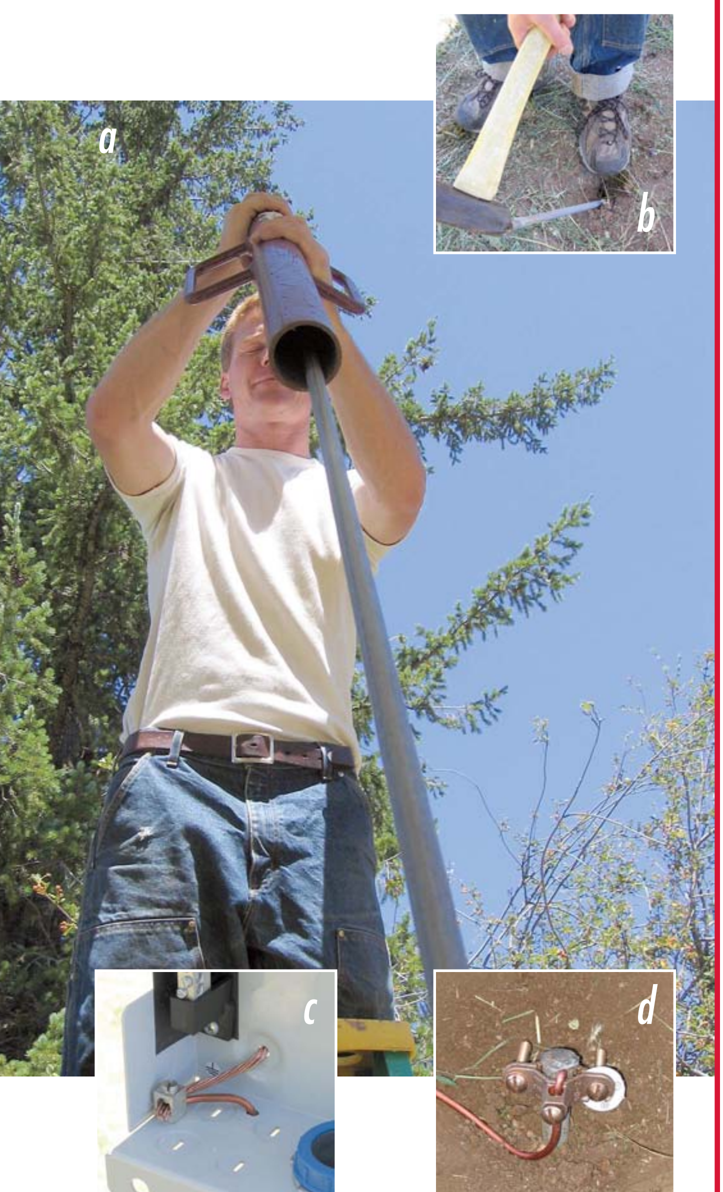
On the array, I always use #6 (13 mm^2) stranded, bare copper wire, which is more flexible than solid. Trying to bend #6 solid wire in the tight radiuses required when grounding module frames is not recommended. In some cases the *NEC* will allow smaller-gauge ground wire to be used, but I opt for #6 since it will better resist any physical damage.

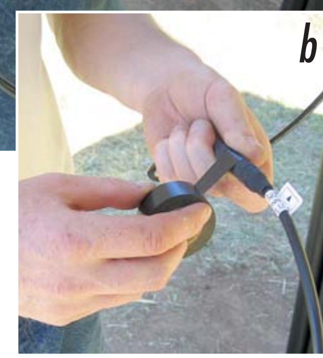


7 Install the Ground Rod & Wire

Next, pound a ground rod into the earth at the base of the pole, outside the edge of the concrete footing. Driving the ground rod at an angle can help you get it in all the way if bedrock is close to the surface.

Once the rod is driven, run #6 bare, solid, copper wire from the combiner box's ground lug, down along the vertical conduit, and then over to the ground rod. Where possible, I like to use a ground rod clamp approved for direct burial, completely bury the ground rod, and trench the ground wire in. This looks better, and won't trip people or animals if they pass by the base of the array.





8 Wire the PVs

When wiring the PVs, remember that they will generate electricity whenever the sun is shining, even in overcast conditions. So pay attention, and make sure you're qualified to get the job done right and safely. Some people even opt to cover the modules with an opaque material when wiring the array.

Almost all modern PV modules come with prewired, multicontact (MC) connectors. These connectors simply plug together, allowing fast installation and a low-resistance, weather-tight connection. MC connectors should be firmly pushed together and given about a quarter turn to make sure the seal is tight. Your system design will determine how many modules will be wired in series, and how many series strings your array will have. (See my article on wiring configurations for a PV array in *HP87*.)

Once the series strings are wired, the next step is to fully secure the wiring. All MC connectors should be either taped with high-quality electrical tape or sealed with heat-shrink tubing. While the connectors themselves are watertight, these methods will further weatherproof them, and provide some strain relief to keep them from being inadvertently disconnected. Finally, no PV wiring should be left hanging, since this looks sloppy and just invites trouble. Use UV-resistant (black) zip ties to secure the module wiring to the module frames or mount structure. Clips that attach to the module frame and hold the wires are available as well.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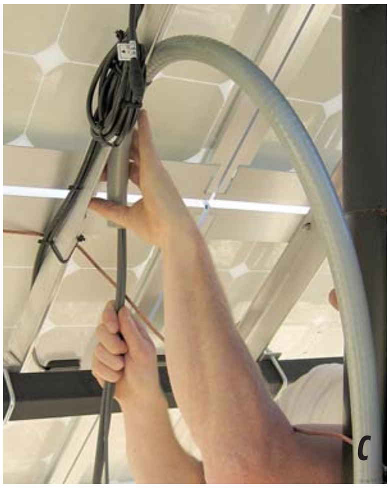
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9 Install the Home-Run Wiring

Your array will require an additional MC cable to run from each series string of PVs to the combiner box. Purchase extra lengths of pre-made, MC cable that have a female connector on one end and a male connector on the other. When cut in half, these cables will need to be long enough to reach from the PVs to the combiner box. This wire is referred to as a "home run."

The ends of the home-run wiring destined for the combiner box should be taped off and handled carefully to avoid shock hazard and electrical shorting. To keep polarity straight, positive leads should be taped with red electrical tape and negative leads with white.

While working with this wiring, the safest approach is to leave one of the home-run conductors of each series string open (disconnected) at the PV arrays until the home runs are in place and terminated in the combiner box.

I like to put the home-run wiring running down the pole and into the combiner box in nonmetallic, watertight, flexible conduit for extra physical protection. The PV end of the conduit will not have a fitting on it, so make sure to seal it with silicone caulk to keep water from running down the wiring and into the combiner box.

The flexible conduit can be secured to the pole using self-tapping screws with pilot holes, and heavy wall (HW) conduit straps. Finally, because pole mounts allow for seasonal adjustment for the tilt of the array, make sure to cut both the home-run wiring and flexible conduit to a length that will allow full adjustment of the array without placing any strain on the wiring.


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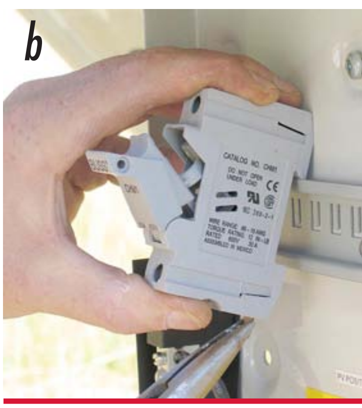
10 Wire the Array to the Combiner Box

Breakers should be in the off position (or fuses removed) during combiner box wiring. Positive PV array home runs will terminate at series breakers or fuses, and negative ones at the negative bus (combiner) bar. Use a torque wrench to fully tighten all electrical connections inside the combiner box to the manufacturer's specifications.

Once all the wiring in the combiner box is completed, double-check that the series breakers are in the off position, and then make the final connection in each series string's home-run wiring at the PV array. This strategy will ensure that you're not working with "hot" (energized) wiring during the installation. Use a digital multimeter to double-check that each series string's polarity is correct. The transmission wiring that runs between the array and the power room will also be terminated in the combiner box once it's pulled.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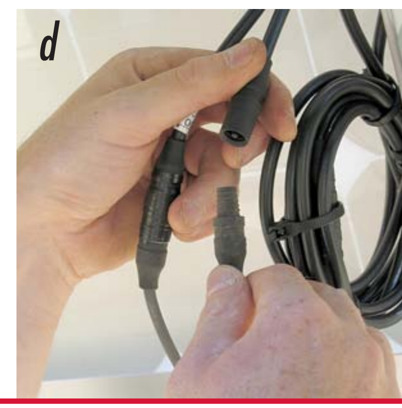
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Done Deal

Once the pole is set and the concrete is cured, assembling and wiring a pole-mounted solar-electric array can be done in a single day, or over a leisurely weekend. One person can easily get the job done, but it's nice to have a second set of hands when assembling the rack and mounting the PVs.

If you want a solar-electric array, and your site is suitable for a pole mount, definitely consider it. Pole mounts are one of the most fun—and most productive—things you can plant in your backyard.