Rooftop Grid-tied Solar Panels With Microinverters

by adaviel

This instructable describes the installation of a rooftop solar installation, from planning to full connected usage.

Glossary

- Solar panel - a commercially produced panel consisting of multiple silicon photovoltaic cells in series, mounted on glass
- Inverter - a solid-state electronic device that generates AC from a DC supply
- MPPT - Maximum Power Point Tracking, an algorithm to adjust the current drawn from a solar panel to maximize the power.
- Grid - the electricity distribution grid, operated by an electric utility
- Grid-tied - a system that is connected to the electricity grid and feeds power to it
- Microinverter - a device that combines an MPPT controller and grid-tied inverter, that takes DC power from a small number of panels and converts it to AC power at the same voltage, frequency and phase as the grid supply in order to obtain credit for power generated. As opposed to a string inverter, a larger inverter than takes power from a larger number of series-connected panels, or an off-grid inverter that will provide AC power in the absence of grid power.

Step 1: Planning

The first step is to find out whether you are allowed to connect a system to the grid, or to built a system at all.

Since you need to connect a grid-tied system to the electric grid, you need permission from the electric utility. You may also need permission from a planning authority. A typical prerequisite is that you have a smart meter - one that is capable of running backwards. So the first place to start is the website of your electric utility, to discover what the procedure is.

My utility does not allow householders to generate significantly more power on an annual basis than they use, so I had to document my expected usage from all loads (heating, cooling, electric vehicle charging, lighting etc.). They also require details of the grid-tie equipment (manufacturer and model numbers, with appropriate certification). So the steps were:

1. Check the utility requirements
2. Find a supplier
3. Design the overall system and pick a microinverter
4. Submit an application to the utility
5. Get approval from the utility to proceed
6. Obtain an electrical permit. Also a building permit if required.
7. Purchase the materials from the supplier
8. Install the system, without connecting it to the grid
9. Get an electrical inspection. A building inspection if required.
10. Submit a copy of the inspection report to the utility
11. Get permission to connect the system
12. Switch it on

Step 2: System Design

To state the obvious, a solar panel installation needs sunlight. Direct sunlight. You need locations where panels will have an unobstructed view of the sun for at least some of the day.There are various online calculators that will tell you how much sunlight a system will receive in different places in the world, based on past weather averages and on spherical geometry - geographic latitude and calculated sun positions.The one I use is PVWatts Calculator

That assumes your view of the sky is completely unobstructed by trees, other buildings, chimneys, mountains etc. If you do have obstructions, you will need to de-rate the power calculated and install more panels to meet your annual power target. Panels are very susceptible to even partial shading - they are constructed of a large number (maybe 60) of cells in series, and if just one is shaded its electrical resistance will rise and the entire panel will be essentially non-functional. So it's important not to have a panel partly shaded by something like a chimney or awning. A narrow shadow of something like a chimney bracket is not critical provided it only covers a small bit of any cells.

Roof Construction

Typically, the panels are mounted on metal rails, the rails are mounted on brackets, the brackets are fastened to the roof. There are different bracket designs for different roof materials. Since the panels have an expected lifetime of some 30 years, and represent considerable investment in time to install, it is prudent to install them on a roof with a commensurate lifetime, rather than one which will only last another 5 or 10 years. It is possible to remove and re-install panels, but you should consider replacing the roof first, for instance replace tar-paper or wooden shingles with metal or ceramic tile.

Electrical Connections

The panels that I used have a rated output of 300W each. The microinverters connect two panels and generate a maximum of 600W at 240V. They are equipped with industry-standard polarized connectors on the DC side, and a daisy-chained connector system on the AC side, so it's plug-and-play. A maximum of 7 inverters can be connected to one 20A circuit. So for every 14 panels, there needs to be a 20A breaker in an electrical panel with suitable wiring to a weatherproof box to interface to the daisy-chain. There also needs to be a separate grounding system, electrically connecting the panel frames, the rails, and the microinverters to the supply ground. Details will be given in the electrical code for your jurisdiction. Mine has an additional requirement that solar panels be connected at the opposite end of the breaker bus-bar from the supply.

Step 3: Safety

Local regulations may require the use of fall-arrest equipment when working on a roof.

Regardless of regulations, metal roofs are very slippery, particularly when sitting or kneeling, and I have some sections with a 1:1 slope. It's impossible to work without a harness. I have rock-climbing equipment including Jumar ascenders that let me stop at any place on the roof and place my full weight on the harness, with hands free. On my first house I used a belay device with a knot, but the Jumar was much easier. On the first roof, I set an eyebolt in the joist in a pony wall, and passed the rope across the ridge to work on the other side. On my second house, I tied the rope to the snow rail. Since I installed panels on both sides, I had two ropes, one in each direction.

Tools and other items can slide off a roof very easily. They might hit someone underneath, but apart from that it's just annoying having to retrieve them. Sometimes I secured tools with a lanyard, or stored them in a box that would not slide. Once you have some rails up, you can rest boxes against them.

Power cords and safety lines are a trip hazard. One time I stepped on a loose rope on the metal roof; it was like stepping on a bar of soap. I fell and hit my head; the harness stopped me sliding off the roof but my elbow hurt for months.

Solar panels generate voltage when in sunlight (somewhat obviously). However, the pre-attached connectors have shrouds so that there is little risk of touching the conductors. To stop a panel from being energized, you can cover it with a sheet of cardboard or rubber mat.

Step 4: Layout

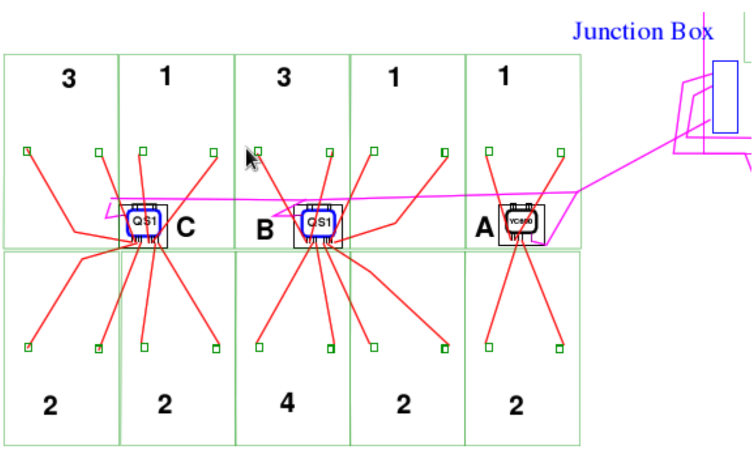
You need to decide how many panels are going go on what roof sections, which is going to affect how many microinverters are required, and what electrical connections are needed, as well as how many rails and brackets.

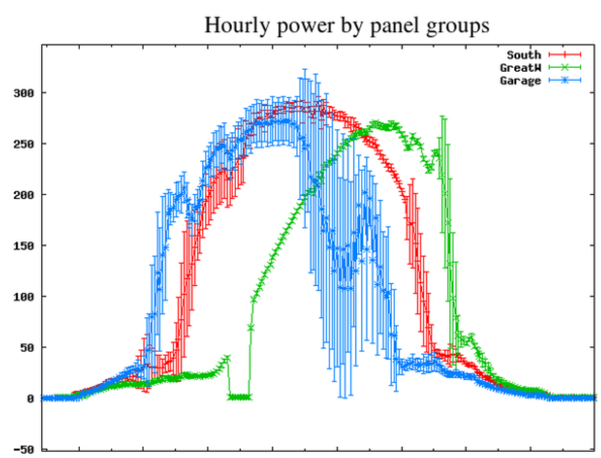
The rail system is designed to have panels fitted side-by-side, separated by a clamp. So the length of rail is the width of one panel plus the width of one clamp, multiplied by the number of panels, plus one more clamp width, plus some margin at the ends. Rails can be extended with a joining piece. You need some space around the edges to safely gain access to work - a couple of feet maybe. If there are vent pipes or chimneys you need to avoid those, leave a space in the grid for instance. Brackets are usually fitted to roof trusses, which are vertical. Rails are placed horizontally across the brackets, and panels vertically across two rails. This arrangement gives most flexibility in where panels may be positioned.

Roof orientation is not especially important, except that in the Northern hemisphere a North-facing roof will not see much sun. With grid-tie, it is the cumulative annual energy that is important, not the instantaneous power. If your roof faces east, you will get more power in the morning but less in the afternoon. If it has a steeper pitch, you will get more power in winter but less in summer. The dominant effect is that the panel produces little power if the sun drops below its horizon. I have panels facing east, south and west on pitches of 1:3 and 1:1, and they all generate power; see graph.

If you are working from architectural plans, do not forget to allow for foreshortening of the panels due to the pitch of the roof. My panels are 65 inches long on a 1:1 pitch roof, but on a floorplan they will appear only 46 inches long. The two PDF drawings show panels and rails on a floorplan, and panels at real aspect ratio on a distorted floorplan.

The panels come with a pair of pigtail wires with pre-assembled connectors. The microinverters also come with pairs of pigtails so that they just snap together. I have some inverters that take two panels, and some that take four. The inverters mount to the rails underneath the panels. Since the pigtail wires are only so long, the inverters have to be positioned appropriately else wire extensions must be used. I found it useful to place a group of panels face-down (on a firm flat surface so they won't be damaged) and mock up a connection to determine the best location. For the quad inverters, I could wire three panels directly and use one extension wire on the fourth. The connector spacing on the daisy-chain AC cable also comes into play, since each group of two or four panels must be connected with that. On one roof, I had to skip one panel on each pitch to avoid a vent, which left an odd number of panels on each pitch. One panel is connected across the ridge to an inverter on the other side.





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Step 5: Mounting Brackets

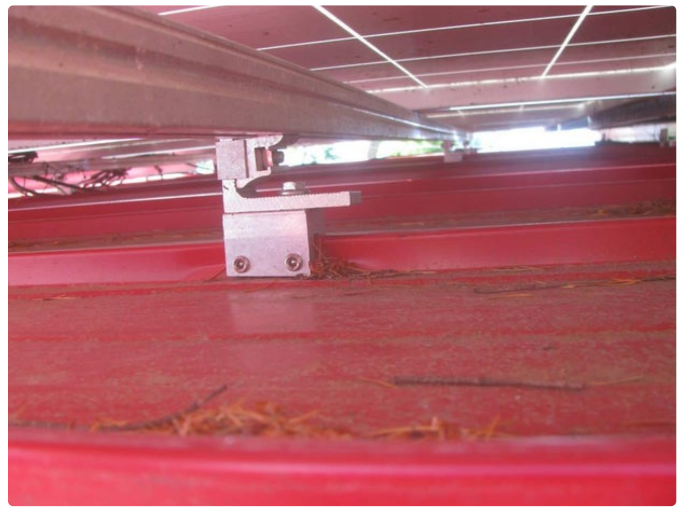
The mounting brackets hold the rails to the roof. There are different kinds of brackets intended for different types of roofing material. Usually, the bracket is secured to a roof truss with a bolt piercing the roof membrane. There are also brackets designed to clamp on to the seams of a metal roof.

My first house had a "duroid" tar/paper roof with composite shingles. The brackets are secured with lag bolts into the roof trusses, then covered with a metal shield which slides under the shingle to deflect rainwater. In order to locate the trusses, since I had access to the attic space, I drilled pilot holes either side of the truss from underneath, then drilled a hole from above between them to take the lag bolt. I then sealed the pilot holes, though they were protected by the shield.

For the second house, I had intended to use clamp-on brackets on the seams. The first brackets I tried, based on written specifications and pictures, did not fit the roofing material. The second brackets fit perfectly on a test piece of roofing, but not when the roof was actually nailed in place with the seams overlapped. I realized that the clamp depended on the seam compressing and snapping back into place when the clamp was hammered on, and with the mounting nails inserted, it could not move. I switched to a membrane-piercing type with a rubber gasket. On one roof I had access to the underneath, so I could locate the trusses and transfer measurements to the top. The brackets used a single lag bolt screwed into the truss. On other roofs I had no access to the underneath, so I used a different bracket designed to be secured onto plywood sheathing with four smaller lag bolts, shown in the photo. Again there is a rubber gasket, but I used sealant on the holes as well. I found it useful to make a jig to drill the four pilot holes in the metal roof for the lag bolts.

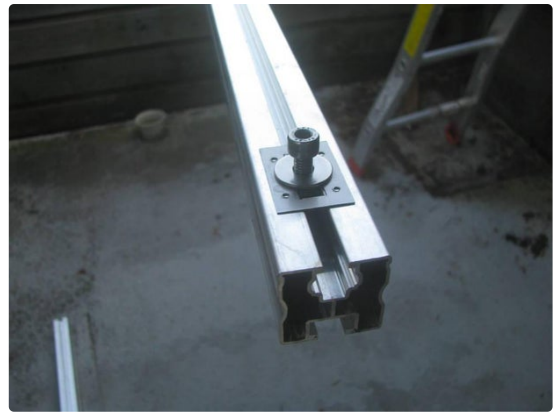
While it's possible to mount the panel clamps or the inverters on top of a roof clamp, it's much easier if you don't. So the bracket spacing should reflect that.




Step 6: Rails

The rails come next, secured to the mounting brackets. I had two different types of rail, probably two generations from the same manufacturer. These are aluminium extrusions with slots for captive stainless nuts and bolts. The earlier rail had a locating piece to centre the bolt in the rail, with bolts that had to be slid along the rail from one end. The later rails have cam bolts that can be inserted in a slot then twisted to bear on the rail before being tightened. The brackets have some adjustment for height so that the roof does not have to be perfectly even. All the parts are either aluminium or stainless steel, to prevent corrosion and rust staining. If you lose nuts or washers, replace with stainless. Make sure you fully understand how the brackets and rails are assembled and positioned before drilling holes in anything. When cutting rails, make sure there is sufficient extension beyond the panels to safely secure the outside clamps.



Step 7: Mounting and Wiring the Microinverters

Since the microinverters are mounted underneath the panels, they need to be fastened to the rails before the panels are placed. Using the previously worked-out layout, bolt the inverters to the rails with the supplied captive bolts. Mine had washers with oxide-piercing sharps, designed to make a good ground connection between the inverter body and the aluminium rails. There are similar sharps on the panel clamps, to make a connection to the panel frames. Since the inverter connectors are only waterproof when assembled, I placed plastic bags over the inverters in case of rain.

Connect the 240V daisy-chain cable to the inverters and secure with cable ties. Also run a grounding wire to the rails. My kit included grounding lugs with sharps for the purpose.

Step 8: Lifting and Positioning the Panels

Industry-standard panels are a convenient size for one person to lift and carry, but not up a ladder in one hand. For my first roof, I used G-clamps to hoist the panels with a rope. Later, I drilled a hole at one end of each panel frame and attached a temporary lifting bolt and lug, with a carabiner secured to a rope. I was able to lean a panel against the side of the house, then drop a rope down from the roof and secure it, then lift the panel straight up and lower it onto the rails.

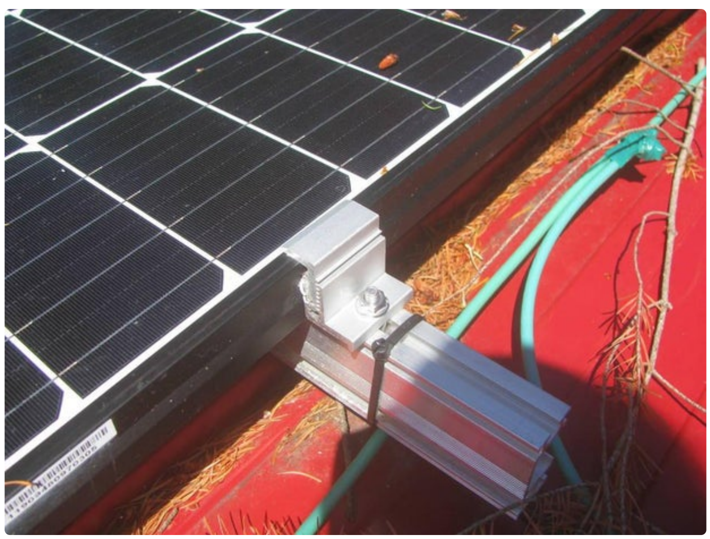
Once approximately in position, I moved the carabiner to a fixed rope on the roof to hold it. This rope was either secured to the safety rope at the roof apex, or secured separately to snow rails on the other side. Then I fitted the panel clamps. Since the clamps hold two panels, starting at one end of a rail I tightened the end clamps fully to hold the panel and fitted the mid clamps loosely. Then I moved the rope to the next panel, positioned that in turn, tightened the first mid clamps fully now holding two panels, added two more loose mid clamps, and so on. Connect the panels to the microinverters as you go.

Sometimes that requires moving and re-positioning panels and inverters. In some cases, I found it convenient to lay a sheet of plywood across a panel in order to lie on it to work on a panel further away. Half-inch ply should be rigid enough not to put pressure on the glass, and can often rest on the clamps and not touch the panel at all.

On the steep pitched roof, I used a pulley block at the apex, which made it easier to adjust the position of the panel. On the shallow pitches, the panels are more-or-less held by friction and the rope is just a precaution.

If you place the lower panels first, it's simple to slide the upper ones into place till they butt against the lower ones.

When wiring the microinverters, keep a note of which panels connect to which inputs of which microinverters - the serial numbers are required for monitoring.




Step 9: Wiring and Commissioning

I commissioned groups of panels using an extension cord, to make sure they were all operating properly. The older microinverters used a monitoring system with an ethernet connection, that allowed monitoring with a laptop. The newer ones use a different incompatible monitor using WiFi and a cellphone application. In both cases, it's possible to see the power produced by each panel.

The daisy-chain cables just plug in to the inverters, but the end of the chain must be wired to the house electrical system. Make sure you fully understand the connection - the inverter cables may not use the colour conventions of your jurisdiction. My older inverters had a 3-conductor cable for North American split-phase 240V, two live conductors and a neutral, with ground provided separately. My newer ones also had a 3-conductor cable, but with two live conductors and a ground. External ground is still required to the rails in either case. For commissioning, I temporarily connected a 3-conductor cable to a 240V outlet, changing the connection for the different inverters.

The inverters take some time to boot up and to characterize the AC supply in order to match it properly. If you don't see power coming from the panels as soon as you plug them in, wait a while.

My electrical code requires wire connections to be made in a waterproof electrical box. I have regular house wiring with 1-strand conductors coming into the box through the wall, and water-tight inlets for the multi-strand daisy-chain cable. In one place, I had to extend the daisy-chain cable under the panels with flexible cabtire, using crimp connectors and water-tight heatshrink insulation.

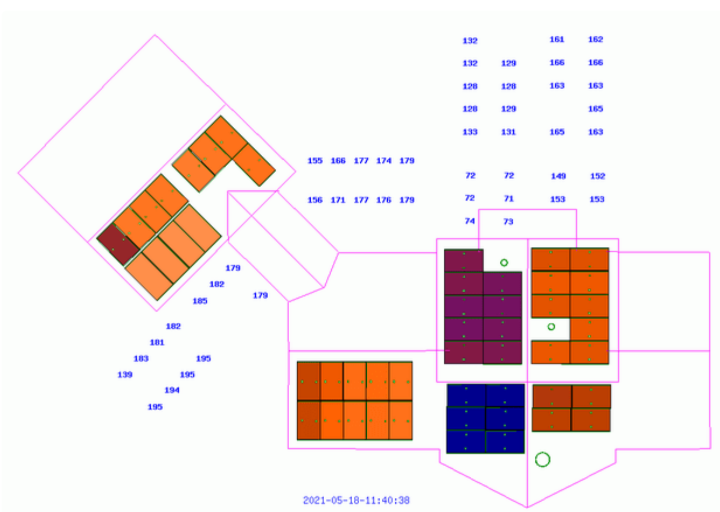
Each group of inverters goes to a separate electrical box and then via separate cables to separate ganged pairs of 20A breakers in the breaker panel. There are three boxes on one set of roofs (shown) and two on another.

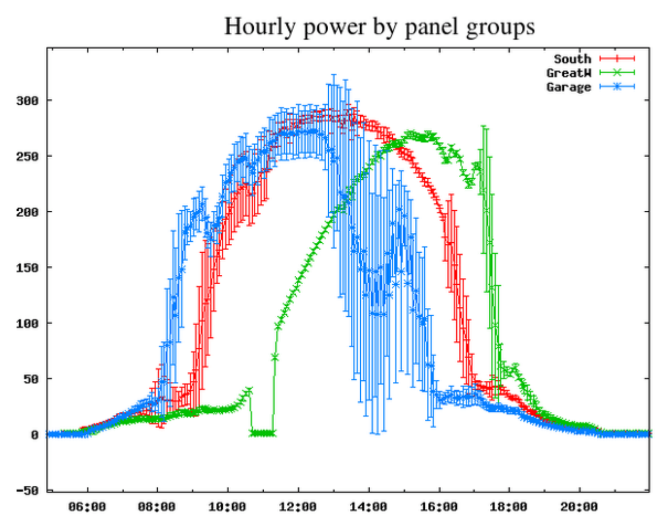
Step 10: Monitoring

The monitoring systems track the cumulative energy over time, per day, week or month, and also show instantaneous power for each panel. I wrote some software to collect the instantaneous power figures at regular intervals, easy enough on the old ethernet-connected monitor but somewhat complicated on the newer one.

The graphs show average panel power during a day from three different roof pitches, a shallow pitched garage facing southwest, a shallow pitch facing south, and a steep pitch facing west. The garage starts to get shaded by trees in the afternoon.

The graphic shows the power in false colour at one particular time (11:40 AM); the west-facing pitch (in blue) has not yet got much sun.





i'm not an expert, but if handling an energized solar panel is a safety hazard, why not just short the output until you're ready to connect it? (wire up a couple of spare connectors, for example.) it seems a lot easier than a cover, and it doesn't damage the cells.

Shorting the panel would dissipate all its power internally. It's probably safe to do that - they quote a short-circuit current - but I'm not certain. I mentioned it as a safety issue just in case someone might cut the cables and leave exposed ends. The only time I actually covered panels was when I found I'd lost my paper map, my computer drawing turned out to be incomplete, and I wanted to double-check which panel was on which inverter input.

great instructable, by the way!

Hi, good clear instructable.
Will those micro inverters/optimisers need cooling which they might not get in a plastic bag?

The plastic bag was temporary just while they were not yet connected, to stop any rain getting onto the connector pins

Nice Instructable, like many others I am stymied for grid connection as DIY won't be permitted.
I need to build a, sort of, Off Grid but on the grid system where I take solar during the day for aircon or water heating or whatever load I have during that time and then "Fail over" to the grid when solar is not available.
I look forward finding a safe and workable version of this, I may even try to design it myself but lots of research to do.
>>>>>>>>>>>>>>>>>> Loved this, wish I could do it. <<<<<<<<<<<<<<<<<<<

Hi
Perhaps you could do the install then have the work signed off by an electrician?

Excellent Instructable. I learnt a lot, thank you.

Perfect! That‘s what Instructables are all about:
You take a complex problem, break it down and explain the parts in an order that makes it easy to follow for even those, who have little or no previous experience.
I‘ve been planning to put solar on our roof for years and with your info, I can prove my wife, my plans are valid after all ;-)

You should teach. The way you presented everything, your students would love it and actually enjoy learning!

Many thanks for this tutorial....

One aspect you left out, Most counties require a building permit separate to an electrical permit / Inspection. Very well done Instructable :) Also note: We cant use Used panels for grid tie as they must be certified and used one's being sold are decommissioned. Buying used panels are fine for off grid.

Amazing instructable, well written and easily understood by someone who has a decent grasp on what needs to be done but doesn’t quite know some of the details. After reading this I’m even more confident in my abilities to build my own system on my home.

Great Instructable, I like that you included details from other systems / roof types.
I doubt I will ever invest in a system, but it was nice reading through the details. I am sure that many will benefit from this presentation.
Thanks so much for sharing,
Bob D