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Off-Grid Solar Systems: Understanding Components and Variables for Small Systems

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Off-grid solar systems are often considered on farms and small acreages in locations where power is difficult or expensive to run. These locations typically do not have huge power requirements; the landowners may want to light a barn, power a fence charger, or run a small motor or power tool nearby, for example. Off-grid solar systems can provide power without the expense of an electric service. Before purchasing an off-grid solar system, it is important to know what electrical devices the system will be used to operate and to understand the components that make up the solar panel system, including batteries, fuses, controllers, and inverters.

Figure 1. Solar panels mounted for demonstration.

Solar Panels

Solar panels convert sunlight into electricity (Figure 1). There are two common styles of solar panels: monocrystalline and polycrystalline, or multicrystalline. Monocrystalline panels tend to be more efficient at converting solar power to electricity and have a slightly longer lifespan, but they are usually more expensive. The selected panel type is a personal choice; however, for either style, it is important to review the specifications and choose the correct size. An off-grid solar system is sized based on the total power required to run all the components it will be used to operate (e.g., lights, a fence charger, a small motor, and a power tool) over a 24-hour period.

Understanding Wattage

Panels are typically rated at a given wattage based upon the maximum power the panel can convert. For example, a 250-watt (W) panel could produce 250 watts. It is important to note that panels rarely experience ideal conditions; however, this baseline provides an idea of how much power the panel can supply. Panels also typically have maximum voltage (V) and amperage (A) ratings; a nameplate showing the rated voltage, amperage, and wattage of a solar panel is shown in Figure 2. Based on Ohm's law, the wattage output from a solar panel is equal to the voltage multiplied by the amperage, or W=V*A.

Connecting Multiple Panels

Often multiple panels are connected to increase the power provided by an off-grid solar system. There are two ways to combine solar panels: in series or in parallel. In a series arrangement, the positive terminal of one solar panel connects to the negative terminal of another solar panel (Figure 3). This creates a circuit, or a single path through which a current can flow. If a single panel in the series connection were to fail, the entire circuit would stop working. When panels are connected in series, the voltage of each panel is added together to determine the total voltage, but the amperage stays the same. For example, an off-grid solar system designed to run on 24 volts with 12-volt panels would need two panels combined in series to provide the correct form of power to charge the batteries.

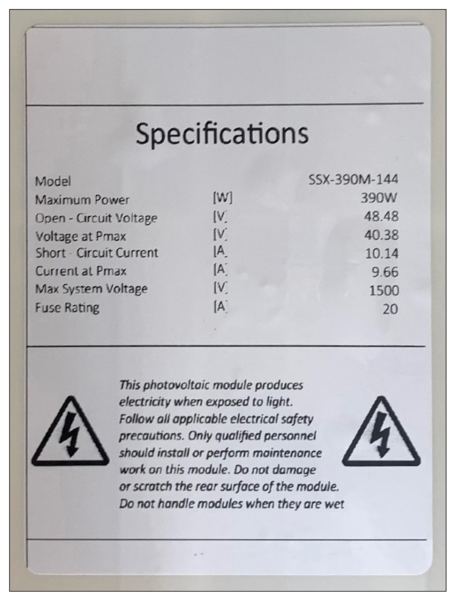

Figure 2. Nameplate on a solar panel. This panel is rated to provide up to 390 watts under ideal conditions with a maximum output voltage of approximately 48 volts and an expected output of 40.38 volts when providing peak power. Similarly, the maximum amperage output is just over 10 amps while the expected amperage output at peak power is 9.66 amps. When the amperage and voltage at peak power are multiplied, the resulting wattage is approximately the 390 W rated on the nameplate.

Figure 3. Two solar panels connected in series to ensure the correct output power, voltage, and amperage to match the charge controller and battery requirement.

A parallel arrangement is created by connecting the positive terminal of one panel to the positive terminal of another panel, as well as connecting the negative terminals of the two panels. When a parallel circuit is used, the current can travel multiple ways. When one panel in a parallel circuit is defective, the current will ignore the broken panel, and the other panel will still supply some power. When panels are connected in parallel, the amperage increases, but the voltage stays the same. For example, to create a 500-watt off-grid solar system that operates on 12 volts by using 250-watt panels with 12-volt outputs, two (or more) panels could be connected in parallel.

Batteries

For an off-grid solar system to be reliable, the power from the panels needs to be stored and released as needed. One or more batteries can provide a storage solution and ensure that the system will function on rainy days and even at night. The batteries must be sized adequately to store enough power for required operations during periods when sunlight is not available. Batteries are rated based on the number of ampere-hours supplied at a given voltage. To determine how many kilowatt-hours of electricity the batteries will supply, multiply the ampere-hours by the voltage of the battery and divide the result by 1,000. With batteries, the goal is always to have more storage capacity than the system is expected to pull, as excessive discharge from the batteries will shorten their lifespan. Batteries, like solar panels, can be connected in series (Figure 4) or parallel to match the energy profile that the inverter and charge controller expect. For example, two 6-volt, 100-ampere-hour batteries can be combined in series to produce a 12-volt, 100-ampere-hour battery system, or they could be combined in parallel to produce a 6-volt, 200-ampere-hour battery system.

Two styles of batteries are regularly sold for off-grid solar systems: sealed lead acid (also known as gel or AGM) and lithium ion. Sealed lead-acid batteries are less expensive and less energy dense (i.e., heavier). They also have a shorter lifespan and are susceptible to deterioration if the batteries are regularly discharged to less than 50 percent of total storage capacity. If the solar setup may regularly require more than 50 percent of the capacity of the batteries to be discharged, a lithium-ion setup is a better option.

Charge Controller

Solar panels create power based on how much sunlight they receive. However, that power only needs to enter the system if there is an energy demand causing the batteries to be discharged. A charge controller regulates how power flows between the panels and the batteries. Overcharging can permanently damage batteries. Also, the charge controller ensures power from the batteries does not backfeed to the panels when there is not a solar load creating power in the panels. For multiple panels connected in

Figure 4. Lead-acid batteries connected in series.

series, an appropriate charge controller should include the terminology "maximum power point tracking," or MPPT, to indicate how it manages the circuit from the panels (Figure 5). For panels set up in parallel, the right charge controller should include the terminology "pulse width modulation," or PWM, as it handles multiple circuits.

Inverter

Inverters convert the direct current (DC) power stored in the batteries to alternating current (AC), which is the type of power supplied by ordinary household outlets (Figure 6). The inverter needs to match the voltage level stored by the batteries and must provide slightly more wattage than the load power expected on the system.

Wiring

All the components in an off-grid solar system need to be connected for power to move between them. Wire is used to create these connections (Figure 7). It is important to size the wire correctly. Undersized wire will create voltage drop that will make the system less effective and may even create fire risk.

Figure 6. An inverter to change the DC power from the batteries to AC power, which can be used for tools and appliances that would typically plug into a wall outlet.

Figure 5. Charge controller for an off-grid solar system. "MPPT" indicates it is for a system with one circuit for the solar panel(s). The charge controller has wiring connections on the bottom of the unit; on the left are two connection points for the circuit with the panels, and two wires for the circuit to the batteries are connected in the center of the unit. The final two ports for wires on the right (not used in the picture) would power a small DC circuit.

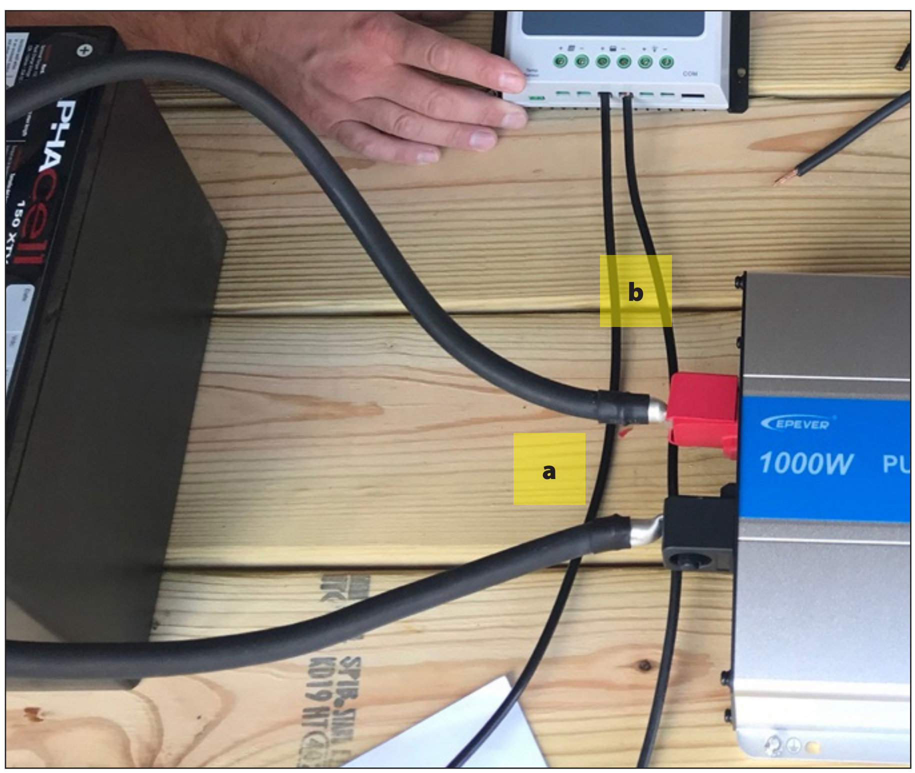

Figure 7. Larger battery-cable wiring (a) connects the batteries to the inverter, and smaller, 10-gauge wire (b) connects the charge controller to the batteries.

Breakers, Fuses, and Switches

It is important to protect all the components within the off-grid solar system. Breakers or fuses prevent power surges that can damage the components. Any fuses placed between the solar panels and the inverter must be specified for DC power (Figure 8). Also, it is a good idea to include breakers after the inverter (similar to the breakers used in a home) to protect the equipment powered by the off-grid solar system. These breakers not only protect the equipment but can also allow one circuit to be turned off without turning off the entire system.

Off-grid solar systems include many different parts, such as the panels, batteries, charge controller, inverter, wiring and safety components. In some cases, these components can be purchased as a kit or multiple components can be integrated with each other ("smart" batteries being one example), but understanding the role of these components and how they work together will help in creating an off-grid solar system that works well. Appropriate matching and sizing of these components is critical to creating a system that will function as expected.

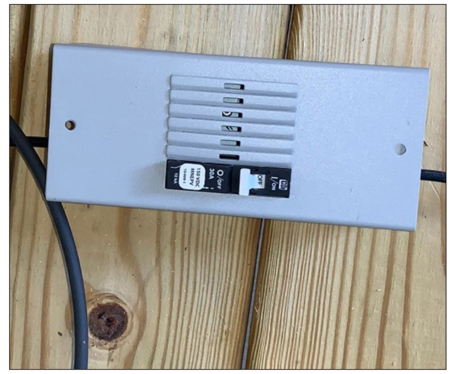

Figure 8. A DC fuse placed between the charge controller and the battery bank.

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