SOLAR NEXUS INTERNATIONAL

SHORTCUT TO FAILURE

Why Balance of System Components are Crucial to Solar Power System Performance

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Battery-based renewable energy (RE) systems consist of several main components that work together as a system. All systems, regardless of scale, need to be able to accomplish these three things:

1. Charge the batteries.
2. Store electricity in batteries.
3. Supply power to the electrical loads.

The primary components of a battery based RE system include charging sources (PV modules, wind or microhydro turbines), energy storage (batteries) and power electronics (DC charge and load controllers, AC inverters and chargers).

The vital balance of system (BOS) materials required for quality system integration can include wires, cables, fuses, circuit breakers, enclosures, wire terminals, strain relief fittings, conduit, raceways, mounting structures, battery boxes, metering and more.

How the various components of a system are integrated and connected can have major implications for how well the system will perform, how it will be maintained and operated, and how long it will last. The key to solar power system performance is the proper integration of components into a complete system.

Too often, high quality primary system components are poorly integrated and installed with substandard BOS materials. The problem is especially acute in developing world markets such as Sub-Saharan Africa. In these markets, major components are readily available from imported sources, but proper BOS materials are often not used, either because the proper materials are unavailable or too expensive locally, or simply due to ignorance and/or inexperience of the installers.

In most cases these are easily avoidable mistakes. Addressing this issue will be an important step towards improving the quality and longevity of systems and building a quality international off-grid solar electric industry for the future.

In my informal 2009 survey of off-grid solar electric systems in three African countries I found several common problems related to BOS materials in most of the systems I documented. These problems tended to include some or all of the following:

- Improper wire size, type and terminal use
- Lack of adequate fuses or circuit protection
- Lack of appropriate PV parallel combiner hardware
- Lack of adequate metering for systems
- Lack of earth grounding
- Lack of wire strain relief and excessive slack in wiring

Most household scale off-grid systems in Africa at this time are relatively small 12 volt systems. Small systems are simple to assemble and relatively safe because 12 volts doesn't present much shock or fire hazard relative to utility voltages. As systems increase in size and voltage the hazards present in the systems increase also. High power inverters carry high amounts of current, enough to seriously hurt someone or burn down a building. As the price of PV modules decreases and the industry matures, the scale of systems will increase.

Wire Size

Voltage drop is the reduction in voltage between a power source and a load caused by resistance in the wires conducting the power. Undersized wiring can cause substantial losses of power simply due to being too small in diameter and/or too long for the amount of current (Amperes) flowing over the distance required. This can be especially problematic for low-voltage DC circuits commonly used in off-grid PV systems.

For example, voltage drop on most household circuits in a 120V system isn't usually a major concern. The currents are relatively low—usually 20A or below—and the commonly available wire sizes are generally large enough to minimize resistance problems. When working with 12V systems, however, the amperage draw for any given load (or charging source) increases by a factor of 10. For example, a 200W 120V water pump draws about 1.6A of current, but an equivalent load at 12 volts draws 16A. If you use the same size and length wire in both systems, the voltage drop in the 12V system will be 10 times greater than in the 120V system. In this case, voltage drop becomes a significant consideration.

The loss of valuable solar charging power in PV source circuits due to voltage drop is unfortunately common in off-grid PV systems. Newer "Maximum Power Point Tracking" (MPPT) PV charge controllers can help reduce the effects of voltage drop by allowing the PV array to be wired at a higher voltage than the battery, but older "Pulse Width Modulated" (PWM) style controllers are still the most commonly used in small to medium sized systems. PWM controllers require that the PV array be configured into the same nominal voltage as the battery, which is generally 12 or 24 volts in systems with less than 500W of PV.

If the distance is greater than a few feet between the PV array and the battery, good system design would require using heavy gauge wire for that type of circuit. For example, a 400W rated, 12V PV array can be expected to produce around 25A of current under typical conditions. At 2% maximum voltage drop (the generally accepted standard for PV charging circuits) this circuit would require #6 wire (13mm^2) to go 12 feet (4 meters) and 2/0 gauge wire (67mm^2) to reach 60 feet (18M). That is significantly large wire, which would be both very expensive and hard to find in most developing world countries. As a result, many PV arrays have been installed with undersized wire, effectively choking out a significant amount of valuable PV charging power.

There are several solutions to the voltage drop problem. First, most stationary systems over about 400W of PV should be using 24 or 48 volt battery banks. Doubling the voltage reduces the amperage by half and increases the distance a given power load can travel on the same wire four times. Second, MPPT style PV charge controllers should be considered when PV to battery distances are great and/or when the choice is made to use 12V batteries with larger PV arrays. Finally, proper wire selection is essential. Generally the increased cost of heavier gauge wires for a PV charging circuit is justified by the improved efficiency and increased total energy delivered to the batteries over the lifetime of the system.

Wire Type

Many different types of wire are manufactured for the various segments of the electrical industry. Not all types of wire are appropriate for all applications. For example, most residential building wires are not rated for outdoor use and their insulated coverings will become brittle, crack and erode when exposed to prolonged UV exposure such as that found on rooftops near PV arrays.

The US National Electric Code (NEC) is very specific about what types of wires are suitable for different applications and what types of protection and coverings (such as conduit and raceways) need to be provided for any wire in any location. Generally these are good requirements that help to ensure that installed wiring will be safe and perform well over the lifetime of the installation.

All too often, however, the correct wire types are not used in developing world solar applications because either they are not available or deemed too expensive locally or due to the ignorance or inexperience of the installer. This presents several potential problems, including the failure of circuits due to the decay of the insulating covering, which can lead to faults such as short-circuits that could create fire and/or shock hazards, not to mention failure of the entire PV system.

Circuit Protection

Electric current flowing through wires can generate enough heat to melt through insulation and possibly start a fire. Accidental short circuits or ground faults in electrical equipment or wiring can increase the amount of current flowing in a circuit well beyond normal levels. Over-current protection such as fuses and circuit breakers will limit the amount of current capable of flowing through a circuit to the value of the fuse or breaker.

Storage batteries such as those used in off-grid PV systems can deliver thousands of amperes of current into an accidental short circuit. This can turn wires red hot almost instantly and easily start a fire. Because of this, the #1 safety rule of battery based electrical systems is: Any circuit attached to a battery must be protected with a fuse or circuit breaker! Furthermore, because DC arcs are harder to snuff than AC arcs, most AC rated fuses or circuit breakers will not provide adequate protection for DC circuits. Proper selection of DC rated fuses or circuit breakers is important element of safe system design.

Small systems can often get by with a catastrophic-overload fuse at the DC positive battery terminal. But DC rated circuit breakers are a better option than fuses because they also provide a convenient means of disconnect for system control, troubleshooting and maintenance. Also, a tripped circuit breaker can simply be reset once the problem that caused it to trip has been resolved. Fuses are one time only devices and must be replaced. In remote locations it can be very difficult if not impossible to find replacements and so blown fuses are sometimes bypassed or replaced with jumpers such as short pieces of wire or copper coins, which provide no overcurrent protection and leave the system vulnerable to damage.

Lugs and Terminals

The most common points of failure in solar electric systems (or any electrical system for that matter) is at the ends of wires, where a wire is connected to the next component in the circuit, be it a battery post, PV combiner, wire splice or other part. Loose and/or corroded connections at wire termination points create areas of higher resistance that over time can heat up and cause a short or fault.

Most failures at wire terminations can be avoided by simply using the appropriate terminals or connection hardware and properly torquing (tightening) mechanical connections. Unfortunately the proper parts are often not used, either because they are not available or deemed an unnecessary expense. A common African wiring technique is simply stripped wire ends twisted together and then covered with tape. Battery lugs are often neglected also, with wire ends simply twisted around battery posts or tightened between the post and a nut or washer. These types of poor connections are sources of additional resistance in circuits and likely points of future failure.

PV Combiners

A PV combiner is where multiple PV output circuits are combined in parallel and connected to a single pair of conductors to carry the current from the array to the charge controller and battery. When the array consists of a single module or one string of modules this connection is simply a few wire splices (hopefully with the correct terminals) but when multiple modules or strings are in parallel this is a special type of connection that requires proper termination hardware. Too often, from what I saw in Africa, the PV circuit combining is done with the 'twist and tape' method of wire connection. This is problematic for several reasons: the harsh environmental conditions on the roof are more likely to vibrate and wear the connection to the point of failure; the connections are not readily accessible; and partial or complete failure of that connection is likely to go unnoticed by the users of the system and may result in overly deep discharge of the battery.

The NEC requires that PV arrays with more than 2 strings or modules in parallel have overcurrent protection at the parallel combiner location. PV combiner boxes that meet this requirement are available but even unfused insulated bus bars or parallel combiner blocks would be preferable to the 'twist and tape' method for combining PV output circuits.

Metering

Adequate and understandable metering is an essential part of good system integration. At the very least the system users should be able to see a simple three-color (Green, Yellow and Red) battery charge indicator, and understand that they must reduce their electric usage when the batteries are depleted. Without proper meters and minimal education on how to understand them, systems will be abused and batteries will fail prematurely.

An analogous situation would be that of driving a car without a functional gas gauge. If you don't know how much gas you have and you don't know how much gas you've put into the tank, sooner or later you WILL run out of gas.

In an off-grid solar electric system 'running out of gas' means taking the batteries down to the Low Voltage Disconnect (LVD) setting of the inverter or DC load controller. In the absence of adequate metering this often becomes a regular method of system control: Run the loads until they shut off, then wait for the batteries to become (partially) recharged and the controller turns the loads back on, then repeat. If this type of system control method is continued over time the batteries are almost certain to fail prematurely.

Earth Grounding and Lightning Protection

The biggest reason for grounding ("earthing") small off-grid PV systems is to provide better protection against lightning strikes. PV modules high up on rooftops are attractive targets for lightning, particularly if they are not adequately grounded. And it does not take a direct hit by lighting to do damage; even nearby lightning strikes can damage sensitive electronics. Good grounding practice is to run a continuous copper conductor between all PV module frames, the rack and metallic components of the system and then connect that wire solidly to a buried ground rod, plate or pipe that is in direct contact with as much earth as possible. Additional lightning protection can be provided from SOV (Silicon Oxide Varistor) or similar type "lightning arrestors" that are designed to short out internally if voltage goes above a few hundred volts, as is the case with a lightning strike. In areas of high lightning activity, careful, thorough grounding is the first and most effective line of defense, and lightning arrestors can be cheap additional insurance.

Final Thoughts

Africa and other parts of the developing world represent huge potential markets for the off-grid solar electric industry. But as the industry in these markets grows, it will be important for the quality of the systems being installed to improve. The fastest way for quality to improve will be through the use of better balance of system components.

About the Author

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