APPLICATION NOTE

Lockout/tagout for solar power systems

As in all electrical systems, shock and electrocution pose serious risks in solar energy power systems. Likewise, solar installers and solar PV maintenance technicians must follow lockout/tagout (LOTO) procedure, wear personal protection equipment (PPE) and follow all protection guidelines.

PV systems always pose a shock hazard

The need to de-energize the system applies when installing, inspecting, or performing maintenance on photovoltaic (PV) systems, but de-energizing those systems can be a bit trickier than standard electrical systems. The energy from PV modules is "wild," meaning it varies with the sunlight and is not controlled by electronics. Even under cloudy conditions and at night there is the potential for shock hazard with a PV system.

Although PV modules can never be completely de-energized, the AC output of the inverter can be de-energized, and the DC voltage reduced to acceptable levels. The modules in a string can be manually disconnected to reduce the voltage to individual modules. Or you can use module-level power electronics, such as power optimizers and microinverters, which automatically reduce module voltage when the AC breaker is switched off.

To safeguard first responders, a disconnection mechanism is required to isolate a PV array from the rest of the building. The National Electrical Code (NEC) Article 690.12 "Rapid Shutdown" requires modules and exposed conductive parts within the PV array boundary to be reduced to 80 V within 30 seconds, and conductors outside the array boundary to be limited to 30 V within 30 seconds.

How to LOTO a PV system

While site specific, general shutdown procedures are the same for PV systems as for standard electrical systems:

1. Announce the shutdown and state the magnitude of the energy (i.e., voltage and current levels).
2. Use a clamp meter, such as the Fluke 393 FC CAT III 1500 V True-RMS Clamp Meter with iFlex to test voltage and continuity.
3. Open circuit breakers, fuses, and leads between modules.

4. Once you have verified there is no voltage in each component, apply the lock and tag to each component with the worker's name, date, energy sources, isolating devices, magnitude of stored energy, and work being performed.

For PV systems you need to control both the DC (before the inverter), and the AC (after the inverter) sides of the circuit. The steps below describe the process of LOTO procedures for systems that are grid-tied, in which the inverter senses the grid and shuts off when there is no grid voltage present. You should always follow all your organization's safety and maintenance procedures, as well as NEC regulations when working on PV systems.

DC-side LOTO

PV modules will always have voltage, so you need to LOTO the PV source circuit conductors, which run from the modules to the combiner box, to prevent the DC power from energizing the DC side of the inverter.

1. Disconnect fuses in the DC combiner box to remove parallel connections and isolate individual strings.
2. LOTO the output circuit from the combiner to the DC recombiner, which is found in large-scale PV systems between string combiner boxes and a central inverter.
3. LOTO source circuit leads, also known as home run wires, that run from the modules or battery bank to the combiner box. The leads are the positive and negative ends of a PV string, which is a group of modules connected in series. Use a plug lock or apply a tag without a lock if a lock on the leads is not feasible.

AC-side LOTO

On the AC side, incoming power from the grid will be present and precautions must be taken to isolate and deenergize the PV system.

1. Remove the fuses in the AC combiner, which connects multiple string inverters in large scale systems.
2. LOTO the AC recombiner output circuit between the AC combiner and the grid connection to ensure there is no voltage from the grid.
3. LOTO the low voltage (LV) side of the transformer. If the LV side is not de-energized, AC power may be present on the AC recombiner or central inverter.

Important considerations for individual systems

Even though design principles may be consistent from one PV system to the next, every site has its individual considerations. Here are some of the most important.

Conductor colors can be different

DC PV conductors not in conduit on the roofareoften black for positive and negative, since black wire is more sunlight resistant. AC wiring can be different colors depending on the voltage and number of phases. 120/240 volts (residential) has red and black ungrounded conductors. 120/208 three-phase has red, black, and blue ungrounded conductors and 277/480 three-phase for larger commercial wiring has orange, brown, and yellow ungrounded conductors. There are also other less common combinations. Neutral conductors (ungrounded conductors) are white or gray. Neutral conductors should have a voltage at about zero volts.

LOTO all disconnects

LOTO not only the PV circuit breaker in the main electrical panel but also all disconnects at the module, inverter, charge controller, and batteries. Note a battery bank with more than 24 two-volt cells in series must have a disconnection mechanism.

Understand module-level disconnect requirements

Module-level power electronics, such as microinverters, are becoming increasingly popular. DC voltages are often limited to 50 V DC or less with microinverters, compared to the 600 V DC limit in string inverters. As a result, the NEC permits certain connectors that comply with Section 690.33 of the NEC to be used as DC disconnects for microinverter DC circuits. Per Section 690.33(E)(1) states that connectors shall either "be rated for interrupting current without hazard to the operator" or "be a type that requires a tool to open and marked 'do not disconnect under load' or 'not for current interrupting'."

Different tests may require different energy states

In PV systems, inverters store energy in capacitors. It is important to discharge that energy before beginning work, because there still could be capacitance on the DC side. It can take a few minutes to ensure inverters are at a zero state of energy.

Some tests, such as determining PV string current or insulation resistance with a megohmmeter, require the system to be energized. In other instances, it is necessary to isolate and de-energize a specific component—such as an inverter or transformer—while leaving the rest of the system on.

Many new PV systems with battery storage are AC coupled, meaning the battery bank has its own multimode inverter with one AC circuit connected to stand-alone loads. This increases resiliency but also complexity in maintenance and LOTO. To fully deenergize the system, both the PV interactive inverter and battery multimode inverter need to be off.

Always follow your organization's procedures

The processes described in this article are intended to be used as an example of LOTO procedures for PV. Be sure to follow all or your organization's safety and maintenance procedures, as well as NEC regulations, when working on PV systems.

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