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Top 3 solar PV safety hazards and how to avoid them

Renewable energy (/en-us/learn/blog/renewable-energy)

Solar technicians know that turning the sun's radiation into electricity isn't magic. Solar energy safety takes specific expertise, exacting safety standards, and hard work.

Utility-scale solar installations use rapidly evolving technologies, from photovoltaic (PV) modules and inverters to battery storage and metering. In PV systems, current is "wild" and not limited by electronics. Solar panel safety precautions, control measures, and best practices are different from any other kind of energy generation. Your tools have to be designed to handle the job, because the stakes for solar safety are high.

These are three of the most common electrical hazards with PV systems that you can enounter, along with specific solar PV safety control measures you can take to reduce their risk.

1. Shock or electrocution from energized conductors

Just as with other electric power generation, PV systems present the risk of shock and electrocution when current takes an unintended path through a human body. Current as low as 75 milliamps (mA) across the heart is lethal. The human body has a resistance of about 600 ohms. Per Ohm's law, (https://www.fluke.com/en-us/learn/blog/electrical/what-is-ohms-law) voltage (V) equals current (I) times resistance (R), so $V = IR$.

To calculate the amount of current that would course through a person's body if exposed to 120 V, simply divide 120 V by 600 ohms (I = V/R), which totals 0.2 amps or 200 mA. That's more than 2.5 times the lethal limit of 75 mA, so protecting yourself and your workers against such an event is critical.

Electrical shocks are typically caused by a short circuit resulting from corroded cables and connections, loose wiring, and improper grounding. Key places to look for these conditions in a PV system include the combiner box, PV source and output circuit conductors, and the equipment grounding (https://www.fluke.com/en-us/learn/blog/grounding/why-ground) conductor. The grounding conductor bonds all metallic components together—and eventually to ground—through the grounding electrode conductor and grounding electrode.

Control measures: Rapid shutdown systems

Energy produced from PV string systems varies directly with the sun. To reduce shock hazard for technicians and first responders, we need a way to shut those strings off during a short circuit or power outage. The 2017 National Electrical Code (https://www.nfpa.org/electricalsolutions) (NEC), Section 690.12 requires the "rapid shutdown" of PV systems both inside and outside the PV array boundary. According to section 690.2 of that code, PV array boundary is a mechanically integrated assembly of modules or panels with a support structure and foundation, tracker, and other components, that form a DC or AC producing unit. This includes controlled conductors located inside the boundary or up to three feet from the point where they penetrate the surface of the building.

As of 2019, the NEC made these requirements more stringent by requiring:

- Modules and exposed conductive parts within the PV array boundary to be reduced to 80 V within 30 seconds.
- Conductors located outside the array boundary to be limited to 30 V within 30 seconds.

Rapid shutdown devices must be located either at the service disconnect or there must be a special rapid shutdown switch. There is an exception for systems that are controlled by module-level power electronics —such as micro-inverters and power optimizers—that reduce voltage. Arrays with no exposed conductive parts and located more than eight feet from exposed grounded conductive parts, are not required to comply.

In addition, many jurisdictions in the U.S. require that rooftop PV arrays have setbacks that allow firefighters to access the system. For instance, the California Residential Fire Code (https://www.dgs.ca.gov/BSC/Codes) requires PV modules be at least three feet from the ridge of the roof.

2. Arc faults that spark fires

As with any electrical system, fire is always a potential hazard. Perhaps one of the most common causes is electrical arc faults, (https://www.fluke.com/en-us/learn/blog/safety/understanding-arc-flash-boundary) which are high power discharges of electricity between two or more conductors. The heat caused by this discharge can cause the wire insulation to deteriorate and thus cause a spark or "arc" that causes a fire.

PV systems are subject to both series arc faults caused by a disruption in continuity of a conductor, or parallel arc faults caused by unintended current between two conductors, often due to a ground fault.

Control measures: Arc-fault circuit interrupters

An arc fault may lead to a short circuit or ground-fault, but it may not be strong enough to trigger a circuit breaker or a ground fault circuit interrupter (https://www.fluke.com/en-us/learn/blog/grounding/chasing-ghost-trips-in-gfci-protected-circuits) (GFCI). To protect against arc faults, you need to install an arc-fault circuit interrupter (AFCI) outlet or an AFCI circuit breaker. AFCIs detect low level hazardous arcing currents and shut off the circuit or outlet to reduce the chances of such an arc fault sparking an electrical fire.

The NEC Section 690.11 mandates that PV systems operating at 80 V DC or greater between any two conductors be protected by a listed PV AFCI or equivalent system component. The protection system needs to be able to detect arc faults resulting from a failure in the intended continuity of a conductor, connection module, or other component in the PV system DC circuits.

3. Arc flash leading to explosions

Large-scale PV arrays with medium and high levels of voltage are susceptible to arc flash. This is especially true when a technician is checking for faults in energized combiner boxes where PV source circuits are combined in parallel to increase current, and when checking medium-to-high voltage switchgear and transformers. An arc flash releases hot gases and concentrated radiant energy up to four times the temperature of the sun's surface—as high as 35,000° F (~19,500° C). It occurs when a large amount of energy is available to an arc fault, in both DC and AC conductors.

Arc flash is an issue for systems over 400 V so both residential inverters that typically have a maximum input voltage of 500 V and large-scale inverters that have a maximum of 1,500 V are at risk. Before the advent of large-scale solar energy systems, arc flash was solely considered an AC issue since DC voltage was limited to off-grid applications where batteries of less than 100 V were used. The National Fire Protection Association (https://www.nfpa.org/) (NFPA) Standard 70E requires an arc flash hazard risk analysis be conducted and Personal Protective Equipment (https://www.fluke.com/en-us/learn/blog/safety/avoid-the-shock-of-your-life) (PPE) used for DC systems over 100 V.

Control measures: AC and DC side mitigation

Arc flash mitigation in PV systems is divided by DC (before the inverter) and AC (after the inverter). DC-side mitigation for large solar arrays (100 kW +), is especially important at the combiner box where multiple strings of solar panels are combined in parallel to increase the current. To reduce the potential for arc flash, large-scale systems can use multiple string inverters that themselves can connect multiple strings in parallel, instead of using one or two large central inverters that require combiner boxes. AC-side mitigation includes arc resistant switchgear, which redirects arc flash energy through the top of the enclosure, away from personnel and equipment.

Depending on the task, basic PPE for solar PV technicians can include gloves, hard hat and ear protection, safety harness, arc-rated clothing, and a Fluke 87 V Industrial Multimeter.

Choose the correct solar testing equipment

Protecting your workers and your PV system from electrical hazards requires adherence to safe work practices and ensuring that your equipment is rated to withstand these potential hazards. (https://www.fluke.com/en-us/learn/blog/safety/safe-test-tools-real-world-use) That means multimeters, test leads, and fuses must all be rated for the application you are working on. Here are some basic guidelines:

- **CAT-appropriate equipment:** Choose a meter (https://www.fluke.com/en-us/products/electrical-testing/digital-multimeters) rated for the appropriate measurement category (CAT rating) and the voltage level of your application. Your multimeter must be able to withstand average voltage levels and high voltage spikes and transients that can deliver a shock or produce an arc flash. Overvoltage category III 1500 V systems are becoming the new normal in solar. The Fluke 393 FC True-RMS Solar Clamp Meter (https://www.fluke.com/en-us/product/electrical-testing/clamp-meters/393-fc) is the only CAT III 1500 V/CAT IV 600 V TRMS clamp meter that meets the insulation requirements for CAT III environments like solar installations. It also has Fluke Connect™ (https://www.fluke.com/en-us/products/fluke-software/connect) wireless capabilities, so you can monitor measurements from a safe distance on your smart phone.
- **High-altitude considerations:** CAT III and IV equipment must be used for PV systems at high altitudes because air becomes less insulating and less dense as you go up, which decreases its cooling ability. This means the breakdown voltage—the minimum voltage causing an insulator to become electrically conductive—decreases with altitude. For instance, for a 1-centimeter gap between conductors, the breakdown voltage would be 30kV at sea level, 1.2 kV at 50,000 feet, and 300 V at 150,000 feet.

- **High-quality test leads:** Select test leads (https://www.fluke.com/en-us/products/accessories/test-leads) that are CAT rated to match or exceed the CAT rating of the digital multimeter.
- **High-energy fuse replacements:** Always replace high-energy fuses with the same quality part and amperage rating. These fuses are designed to keep energy generated by an electrical short contained within the fuse enclosure. They are life savers and should never be replaced with cheaper generic fuses.
- **Probes and probe accessories:** Use retractable probes, probe tip covers, or probes with shorter tips to avoid accidentally touching metal to metal and causing a short circuit
- **Personal protective equipment:** Wear appropriate PPE, including arc-rated clothing, gloves, safety glasses or goggles, hearing protection, and leather footwear as required for the voltage you are working on. The 2018 NFPA Standard 70E Table 130.7(C)(15)(c) identifies a complete list of PPE categories and the appropriate arc rated clothing for each rating.

These are just the highlights of how to work more safely with PV systems. Be sure to follow all relevant safety standards and regulations, manufacturers' instructions, and your company's safety procedures when testing or servicing any electrical equipment.

About the expert

Michael Ginsberg is a solar expert, trainer for the U.S. Department of State, author and Doctor of Engineering Science candidate at Columbia University. He is also chief executive officer of Mastering Green, (https://www.mastering-green.com/) where he has trained nearly a thousand technicians world-wide in solar PV installation, maintenance, and operation.