The hidden hazards of ground faults in PV systems

Grounding (/en-us/learn/blog/grounding), Renewable energy (/en-us/learn/blog/renewable-energy)

DC ground faults are the most common type of fault in PV systems and half go undetected. A DC ground fault is the undesirable condition of current flowing through the equipment grounding conductor in the circuits carrying DC power (before the inverter). Ground faults can lead to significant safety issues, such as arc faults and, in the case of high voltage, arc flashes (https://www.fluke.com/en-us/learn/blog/safety/arc-flash-vs-arc-blast). In addition to a safety hazard, ground faults create a fire hazard as bare metal is heated by short-circuited current.

To better understand a DC ground fault, let's review some terminology and look inside a PV system.

Grounding (https://www.fluke.com/en-us/learn/blog/grounding/why-ground) terminology, as defined in the National Electrical Code, is:

- **Equipment Grounding Conductor (EGC)** = "The conductive path(s) that provides a ground-fault current path and connects normally non-current-carrying metal parts of equipment together and to the system grounded conductor or to the grounding electrode conductor, or both.
- **Grounding Electrode Conductor (GEC)** = "A conductor used to connect the system grounded conductor or the equipment to a grounding electrode or to a point on the grounding electrode system."
- **Grounded Conductor** = "A system or circuit conductor that is intentionally grounded."

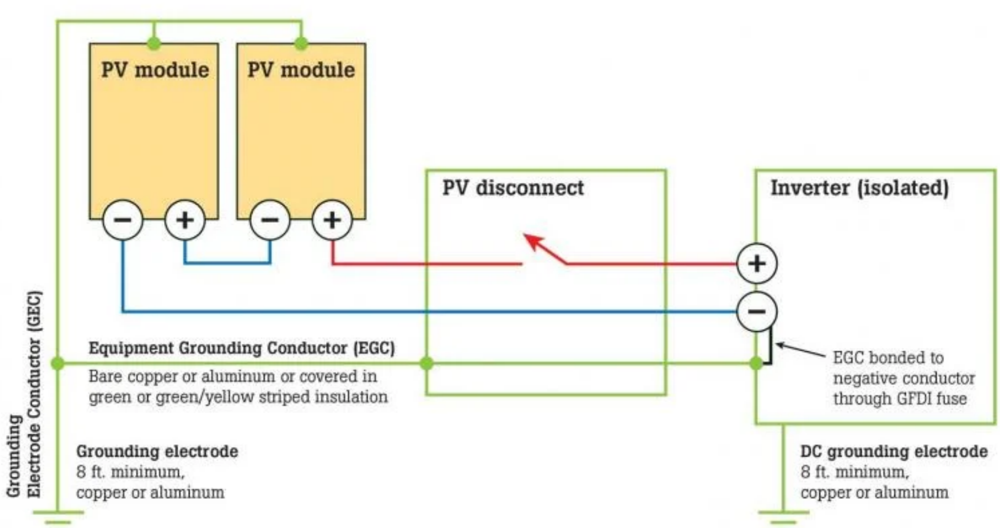

Figure 1: Negatively-Grounded PV System (DC Side)

The EGC is used to bond together all conductive parts (modules, racking) and provide a path to the GEC. The GEC connects the EGC, and thus the entire system, to the grounding electrode. The grounding electrode is a large metal rod driven into the earth at least 8 feet in depth. It is usually copper, aluminum, or copper-clad aluminum.

In a DC ground fault, current flows through the EGC or any piece of metal that is grounded due to unintended contact with the grounded conductor. This contact typically occurs due to damaged conductor insulation, improper installation, pinched wires, and water, which can create an electrical connection between the conductor and EGC.

Why are DC ground faults hazardous?

DC ground faults are particularly dangerous in large PV systems because they can go easily undetected. Ground fault protection (GFP) devices do not sense the small (< 1 amp) current leaking in a ground fault, hence why it is called a "blind spot."

In the event of a second fault with larger current in which the GFP would trip the circuit, the initial DC ground fault becomes a parallel path for massive current. This is precisely what happened in the 2009 Bakersfield, California fire (https://www.bakersfield.com/news/crime-shorts-arcing-power-line-caused-target-solar-panel-fire/article_440b1516-9a4b-5eaa-8bb9-53942f9d57b8.html) in a 383 kW PV array that led to a major fire - an initial 2.5-amp ground fault on a 12 AWG conductor became the path for a second 311-amp ground fault where an expansion joint separated on a large 500 MCM (7.7 AWG) output cable. While the GFP cleared the second ground fault, the high currents returned through the first undetected ground fault, quickly melting the insulation on the conductor and starting a fire.

How are DC ground faults detected, diagnosed and mitigated?

As mentioned, detection of a DC ground fault is difficult, particularly in large PV systems. This is because DC ground faults are often less than the minimum sensitivity of the GFP device. Techniques for detecting DC ground faults include insulation resistance monitoring and residual current detectors (RCDs). It is advisable to perform a grounding test using an insulation resistance monitor (https://www.fluke.com/en-us/product/electrical-testing/earth-ground/fluke-1623-2) every morning to measure the resistance to ground. This must be performed while the array is in open circuit condition. The test reveals two possibilities – the insulation resistance is above the minimum and the system can start, or the insulation resistance is below the minimum, which indicates damaged insulation and the potential for a ground fault. Also, RCDs can be placed on array conductors to measure abnormal current that would indicate a ground fault.

Diagnostic techniques

Even when the ground fault detection interrupter (GFDI) in the inverter successfully trips the circuit it can be difficult to locate the source of a ground fault. First, technicians should check if the GFDI is blown through a continuity test. A continuity test is performed by placing the leads of a multimeter (https://www.fluke.com/en-us/product/electrical-testing/digital-multimeters/fluke-117) on the metal ends of a fuse and turning the dial to resistance. If the resistance is high the fuse is blown and must be replaced.

Next, technicians should perform an insulation resistance test (https://www.fluke.com/en-us/product/electrical-testing/insulation-testers/fluke-1550c-kit) on the conductors using an insulation tester. In this test a voltage is applied on the conductors, generating a current on the wire that is measured (and compared against a baseline for insulation in good condition) to determine the state of the insulation resistance.

In practice, identifying the source of a ground fault can be challenging since a ground fault can occur between the grounded conductor and the EGC or a metallic component at any point in the circuit. To determine the source of a ground fault:

1. Ensure the inverter is isolated from the array by removing the positive and negative conductors;
2. Close the DC disconnect to put a live voltage on the conductors;
3. Measure the voltage between the positive and negative conductors to determine the open circuit voltage of the array; and
4. Measure positive to ground and negative to ground.

If there is no ground fault there should be 0 volts to ground from either conductor. If voltage to ground exists from either conductor, check each connection point (DC disconnect, combiner box) all the way back to the array. Once the fault is discovered, replace the wire(s), and keep a record of tests and replacements.

What is the future of DC ground fault prevention in PV systems?

DC ground faults can be prevented using transformer-less (non-isolated) inverters, which) have sensitive electronics that can sense a fault as low as 300 mA and 2) do not have a grounded conductor, thus reducing the possibility of unintended current to ground. Instead of inverting the DC to AC through electromagnetic induction, transformer-less inverters employ electronics for inversion and are not electrically-isolated by an iron core. Unlike practically-grounded inverters with transformers with GFP fuses, they can sense small ground faults and effectively trip the circuit. Another increasingly-prevalent strategy is the use of module level power electronics (MLPEs), which can shut off the power from an individual module.

Successful prevention, detection and diagnosis of DC ground faults is part of a larger commissioning plan for PV systems, which will be the subject of the next article in this series.

About the expert

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