FLASH— KABOOM!

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It was a dark and stormy day many years ago. As I sat in my office overlooking the grounds of the United States Naval Academy, I could see lightning striking frequently throughout the area. Peals of thunder sounding shortly after the flashes indicated that the strikes were nearby. Suddenly the telephone rang; it was my wife. She said that the PV inverter was on fire and that the lights were out in our two-bedroom townhouse.

She told me that she had been sitting in the living room talking quietly with a friend when—Kabam!, lightning stuck in back of the house and the inverter appeared to be on fire. The noise and the fire had certainly unnerved them both. I asked if the fire was still going or if there was any need to call the fire department. She said that the ball of fire around the inverter lasted only a few seconds, but seemed like an eternity, and that there appeared to be no damage to the room. I asked if there was much smoke. She said that there was no smoke, but that there was a very pungent smell in the room for several minutes and the power seemed to be off on the circuits that were fed by the inverter.

I immediately went home to survey the damage. The inverter was indeed dead. After reviewing the details of the event and discussing them with my wife, I came to the following conclusions.

Analysis

Lightning had struck near or on the PV modules mounted on the fence in the small back yard. A surge of ball lightning had entered the house and settled on the inverter, an event that did the internal electronic components no good at all. The pungent smell was from ozone created by the ball lightning. Why did this happen and could it have been prevented?

The frame grounding for the modules was accomplished by using the bare grounding conductor in a number 10-2 with ground sheathed UF cable that was used to carry current from the modules to the power center. This equipment grounding conductor was connected to the grounding hole on each of the module frames and was then connected to the power center in a corner of the living room. From that location, a number 2/0 AWG grounding electrode cable was run back outside the house to a ground rod in the back yard—all according to the 1984 National Electrical Code (NEC). In this tiny townhouse, there was no garage or spare room to mount the power center, the inverter, or the batteries in any other location than in a corner of the living room. The batteries were in an outside-vented container and therefore they were protected from the fireball on the nearby inverter.

The nearby or possibly direct lightning strike had induced a large surge current into the equipment grounding conductors from the modules to the power center. The surge currents may have also been induced into the positive and negative current-carrying conductors, but there was no damage in the power center to indicate that this had occurred. Since the module frames were not otherwise grounded, the surge of current, and the ball lightning, traveled down the conductors from the PV modules into the house and then finally back out of the house to the ground rod and earth. The case of the 2500-watt inverter represented a large grounded surface and for unknown reasons, the ball lightning evidenced itself by settling on the inverter for a few seconds.

Solutions

The NEC provides little guidance in this area with only a brief mention of lightning arrestors in Article 280. See recent articles in Home Power Magazine and Access for other sources of information on surge arrestors.

Better grounding is the first solution that should be addressed in areas where lightning is common. PV modules are usually mounted high, in open areas to prevent shading from nearby objects. They resemble lightning rods and should be treated as such. Section 250-57 (b) Exception 2 of the NEC allows the equipment grounding conductor on DC circuits to be run separately from the current-carrying conductors. This was the first step that I took to protect my PV system, my family, and my home from lightning strikes.

I drove three 8-foot ground rods directly under the PV modules. The frame of each PV module was connected by a number 6 AWG bare copper conductor directly to the nearest ground rod with appropriate clamps on each end. Each of these new ground rods was connected (bonded) to the original main ground rod with a number 2 AWG bare copper wire buried two feet in the ground. The equipment grounding conductor in the UF cable was disconnected at both ends. These changes allowed any direct lightning hits or induced currents in the PV module frames to be directly shunted to the earth. By disconnecting the equipment grounding conductor in the UF cable, surges previously traveling along it could no longer be induced into the adjacent current-carrying conductors. The NEC requires that the ground rods be bonded and this bonding forms a far more effective grounding system than a single rod. The rods should be at least six feet apart to meet the requirements of Section 250-84 of the NEC.

The next action that I took was to minimize the potential for damage that might occur if surge currents were induced on the positive and negative current-carrying conductors from the modules to the power center.

Near the modules, I mounted a 4" x 4" x 8"'/ metal enclosure (NEMA 3R junction box). In this enclosure, I mounted a listed, heavy-duty terminal strip (power distribution block) with three sets of feed-through compression terminals. The positive, and negative conductors from the PV modules, and a grounded conductor (to the ground rod) were connected to these three terminals. The case of the enclosure was connected to the number 6 AWG bare copper conductor going to the ground rod. Between each pair of these terminals (positive-to-negative, positive-to-ground, and negative-to-ground), I connected a metal oxide varistor (MOV) rated at twice the open-circuit voltage of my PV array. MOVs are usually protected with a fuse because they eventually fail in a short-circuit mode and then burn, but these were mounted in a metal box outdoors so the inevitable damage would be safely contained. These MOVs were later replaced with silicon oxide varistors (SOV) which, while taking up more space, do not fail in a short-circuit mode and can handle far greater surges.

I also connected pieces of number 10 AWG solid bare wire between these pairs of terminals. The wires were cut in the middle and the cut ends positioned as closely as possible without touching. These cut wires create spark gaps that provide a place for surge currents to jump to ground before they can harm other parts of the system. A surge suppression device at this location will protect the modules to some extent from induced surges and limit the magnitude of the surge currents reaching the power center.

At the location where the module conductors entered the house, a second enclosure was mounted containing the same components as the one at the modules. Surge suppression at this point should keep surges out of the house and is a requirement in the NEC that applies to telephone, cable TV, and antenna conductors. Since PV arrays are mounted in similar locations and are exposed to similar hazards, the conductors from the arrays should have surge suppression at the entrance to the building. All grounds for all conductors entering a building (PV, ac power, telephone, ham radio, TV, etc.) should be tied to the same grounding system.

As a final protection at the power center, I installed SOV surge suppressors on each circuit going to the PV array. These SOVs were connected between positive, negative, and ground conductors. Unfused MOVs should never be used inside a building where there is danger of fire.

The main grounding lug in the power center was connected to the nearest ground rod with a number 2/0 AWG conductor. The 1996 NEC requires only a number 6 AWG conductor for most installations. In the power center, the negative conductor of this 24-volt system was connected to the grounding system as the single-point DC ground for the system. Note that even though the DC conductor is grounded, it still receives the same surge protection as the ungrounded positive conductor. This is because there is considerable inductance in this grounded lead which is subject to induced surges.

Even now, when I am at home and the storms are coming (usually at night), I open the PV subarray circuit breakers and the main PV disconnect circuit breaker to provide even more isolation from unwanted electrical surges and even fire balls.

Additional Measures

Lightning rods can be placed behind the north sides of the PV array, but a professional lightning system installer should be consulted. Tall poles with a grounded conductor strung between them have been placed to either side of the array. The shadow caused by the wire on the PV array must be small enough to not cause significant loss of power. Above-ground conductors from the array can be installed in grounded metallic conduit. Commercial surge suppressors used by the TELCOM and TV broadcast industries could be used. PV conductors may be wound around a 1” x 12” steel pipe to form an inductance that may reduce the magnitude of the surges. In very bad conditions, some sort of plug and socket arrangement might be used to physically disconnect and separate the PV conductors from the building.

Summary

Little can be done to protect the PV system from a direct lightning strike that gets past modest amounts of surge protection. Dealing with nearby surges is a case of paying more money and installing more surge suppression to increase levels of protection.

Questions or Comments?
If you have questions about the NEC or the implementation of PV systems following the requirements of the NEC, feel free to call, fax, or write me at the location below. Sandia National Laboratories sponsors my activities in this area as a support function to the PV Industry.

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MOV Surge Arrestors are available from Digi-Key Corporation, 701 Brooks Ave. South, Thief River Falls, MN 56701-0677 • 800-344-4539 • http://www.digikey.com

SOV Surge Arrestors are available from Delta Lightning Arrestors, Inc. PO Box 1084, Big Spring, TX 79721 • 800-351-1464