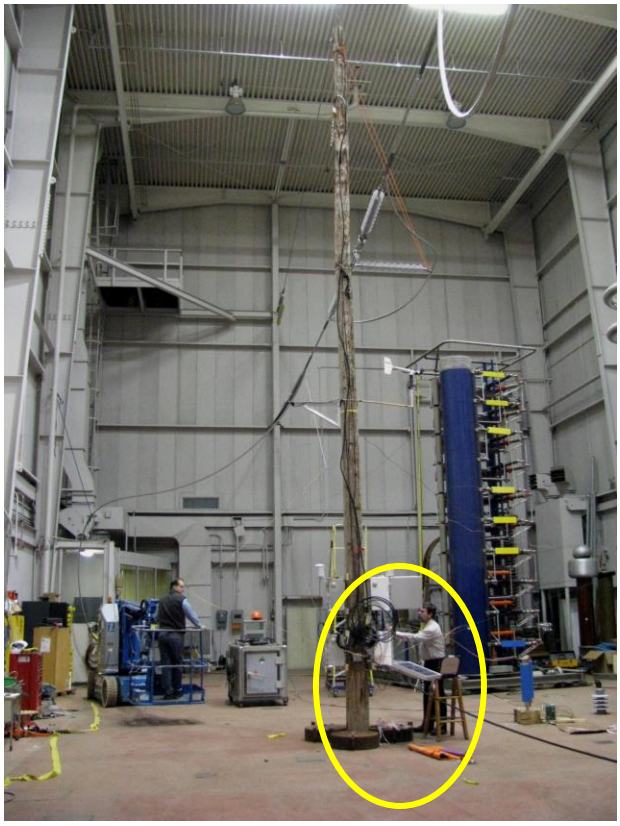
APP NOTE: Surge Protection and Lightning in PV installations

HISTORY:

There has been a great deal written about surge protection and lightning over many years. It is difficult to know what to believe or how to apply the advice in practical methods which make a meaningful difference for PV installations. We hope this App Note will provide some clarity to this complex subject for our PV Installer customers.

At Apollo Solar we had an opportunity to dig into this subject beyond where most companies will ever go. We were hired to redesign the front end of a PV powered system that lives on electric utility towers just below 360kV transmission lines. The systems take both direct and in-direct lightning strikes on a regular basis. The photos below show a piece of our equipment undergoing man–made lightning strikes at the Kinectrics lab in Toronto. The results of the testing proved that we improved the survivability of the equipment by 1600%. Apollo developed circuits to protect the sensitive front ends of the equipment such that all of the 5 systems that were tested ran perfectly after taking over 100 strikes up to 25kA each with a 4uS rise time. The lab said that these were equivalent to real world strike of 35kW with the 8uS rise and 20uS fall time.



Keith from Apollo Solar setting up the test

Our equipment taking 25kA strikes

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OVERVIEW:

From the work we did on that job and from research we have done before and since, we have come up with the following basic understandings:

1. There is no such thing as Protection against Lightning. Mother Nature, God, or the laws of physics (depending on your belief system) can create more voltage and more current than any man can reasonably insulate against.

2. The proper term for the devices we deal with is "Surge Protection" and even that has to be tightly qualified.

3. There are no experts who know everything about this subject. (See point 1)

4. A good ground is hard to find and is essential for any surge protection.

5. The cost of really good surge protection including the design, multiple devices and the installation labor for a good ground system can easily cost more than the equipment it is supposed to protect. Of course when lives are at stake, the cost equation is irrelevant.

6. Reasonable surge protection is affordable, but knowing where to spend the money is not simple. We hope to help.

BASIC THEORY MADE PRACTICAL:

One should read the general literature on the subject. Instead of cutting and pasting paragraphs of the original work done by others, we prefer to give them the credit. Apollo did the work of weeding through countless documents until we found some good ones written by honest researchers who seem to know what they are talking about. The best overall set of documents was done by DEHN in Germany. http://www.dehn-usa.com/dehn-Lightning-Protection-Guide-pubcid4.html It covers the grounding very well. The Littlefuse company addresses the circuit design and components used for surge protection better than most. See AN9769 - An Overview of Electromagnetic and Lightning Induced Voltage Transients.

Here are some general guidelines purposely oversimplified:

1. **GOOD GROUNDS** -- The quality of the connection to earth ground is the single most important issue. The resistance from the ground system to the earth must be very low. At 10 ohms a medium size strike of 30kA will lift the wires that you thought were ground up to 300,000 volts. You will need many ground rods and if the soil is dry and/or sandy, extreme measures will be required to get a reasonably low resistance. Much is written on this subject.

2. **EQUAL POTENTIAL GROUNDS** -- Equal Potential Grounding is an important rule. Even if your equipment ground is elevated in voltage during a surge event, we want ALL our equipment grounds to be elevated the same amount. The differential is the killer. This means a single "star point" ground in your equipment with the best earth connection you have connected to that same star point.

3. **GROUND WIRING** -- All grounds must be short, thick and straight. Any coil in a ground wire makes an inductance which prohibits the fast surge from going to ground. All connections must be free of resistance. They are called "ground bonds" not ground connectors or ground tie points.

4. **THE PV ARRAY WILL GET STRUCK** -- Since a PV array makes a good target for lightning, it is important to add whatever surge protection you can afford to the wires coming from the array before the wires get to a building or equipment. This usually means putting devices in the combiner boxes and grounding those devices directly.

5. **THE WIRING TO THE EQUIPMENT IS VULNERABLE** -- Depending on the length of the home runs from the combiner boxes to the Charge Controllers or Inverters, various amounts of protection must be added. If the home runs are outside, bury them several feet down and bury a good ground wire 1 foot on top of the home runs.

6. **THE EQUIPMENT** -- The first piece of equipment that the home run sees is at the greatest risk. A second set of surge protection devices should be mounted directly on the incoming wires from the PV array or combiner boxes.

7. **RISE TIME OF THE SURGE** -- The literature cited above will show drawings of the 8/20uS spike. This is a typical, albeit small, surge that we are trying to keep out of the front ends of our charge controllers and inverters. It is defined as 8us rise time from 10% to 90% followed by 20uS fall time from that 90% peak down to 50% of the peak voltage. The tail can be very long after the 50% point and it not defined. The important issue is the rise time. Whatever components are used in the Surge Protection Devices, they must turn on fast enough to stay ahead and short that fast rising spike to ground. Remember that the components have no advanced warning. When the spike hits them, it says: "Jump", and the components have to ask "how high and how fast" on the way up. Unless effectively shorted to ground, the spike will continue past your surge protection device at the speed of light.

8. **CHOICE OF SURGE PROTECTION COMPONENTS** -- This is were Apollo Solar has done our own research and experiments. The choices are MOVs (Metal Oxide Varistors), TVSs (Transient Voltage Suppressors), and GDTs (Gas Discharge Tubes). We won't go into the history of now obsolete components. MOVs are the clear choice today because of their speed and ability to take multiple hits. Their weakness is that the clamping voltage is not accurate. TVSs will not take the amount of energy that the MOVs take, but their clamping voltage is more accurate. The down side is that they are not as fast as MOVs. GDTs can be accurate, but their parameters change with the number of hits and they are slightly slower than MOVs. The biggest drawback with GDTs is that once they start to conduct, their conduction voltage drops very low. That effectively rules them out from being used across the PV inputs.

9. **HYBRID SURGE PROTECTION** -- One solution which can work well for PV applications is a hybrid combination of the above devices. The key parameter is clamping speed. An old trick that we re-discovered is to slow down the

incoming surge so the devices can deal with it. Specifically, good MOVs are used as the first component between both the + and the – PV inputs to ground. Then a small inductor in series with the input is used to slow down what is left of the spike so a pair of TVS with slightly lower clamping voltage can finish the job. We have also used GDTs effectively, but not on the PV input wires.

10. **THE DEVIL IS IN THE DETAILS** -- There is a long list of other issues which can circumvent the best grounding and surge protection devices. For example:
    - A surge can easily be induced from the incoming wires into other wires in the system. Using a common wire raceway for PV input and other wires should be avoided.
    - After all the effort to shunt the surge to ground, it must be clear that all that energy has to go someplace. It has a nasty habit of coming back elsewhere in the system because the ground has been elevated by the surge that you forced to go there.
    - The surge is going to get in somehow. Not only the PV input wires, but all the AC lines, data lines and even occasionally the battery wires may need surge protection devices and they are all different because of the operating voltage.
    - To take surge protection to the next level, requires years of study and decades of experience.

LOOK AT THE PV INSTALLATION FROM THE LIGHTNING'S POINT OF VIEW

Below are some photos of installations using Apollo Solar equipment. From the perspective of a lightning bolt in the clouds, can you imagine a more tempting target? And what is your assessment of the quality of the grounding in such dry soil?

I hope this helped.
John Pfeifer, CEO
Apollo Solar, Inc.