

Protecting Electrical PV Systems from the Effects of Lightning



Introduction

By their very nature, photovoltaic (PV) arrays are generally constructed in large, open, and unobstructed locations. If lightning occurrences are present in those locations, the system may be highly susceptible to a lightning strike.

Direct discharges to the PV array, nearby strikes to earth, and cloud to cloud discharges may have damaging effects on the PV system and its components. The most noticeable effects from discharges are catastrophic damage with visible carbonization of system components. Less noticeable are the effects on the electrical system caused by the long term exposure to repeated high transient voltages. These transients may cause premature component failure, resulting in substantial repair and/or replacement costs, as well as lost generation revenue. While solar systems will always remain in highly exposed environments, they can be designed to be safe from the effects of lightning.

Lightning protection systems (LPS) provide a protective zone to assure against direct strikes to PV systems by utilizing basic principles of air terminals, down conductors, equipotential bonding, separation distances and a low-impedance grounding electrode system. Single air terminals offer a cone of protection based on the height of the air terminal. Using a rolling-sphere model for lightning protection, several air-terminals create zones of protection. Equipment below the arc between the tips of the air-terminals is considered to be protected.

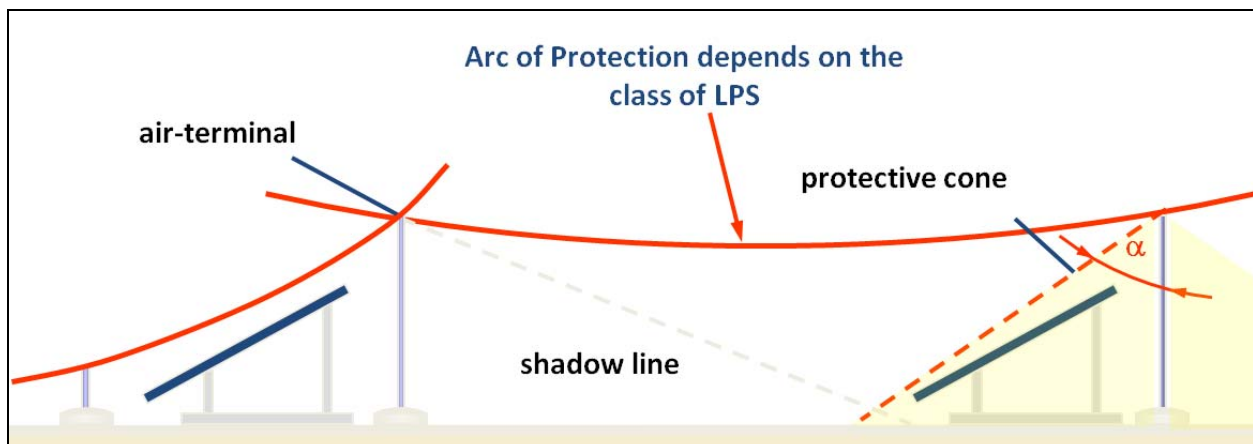


Figure 1. Criteria for Designing Lightning Protection Systems for PV Installations

The decision to employ an LPS is generally driven by the economics of the project and usually depends on the cost to replace damaged equipment and the geographic location of the installation.

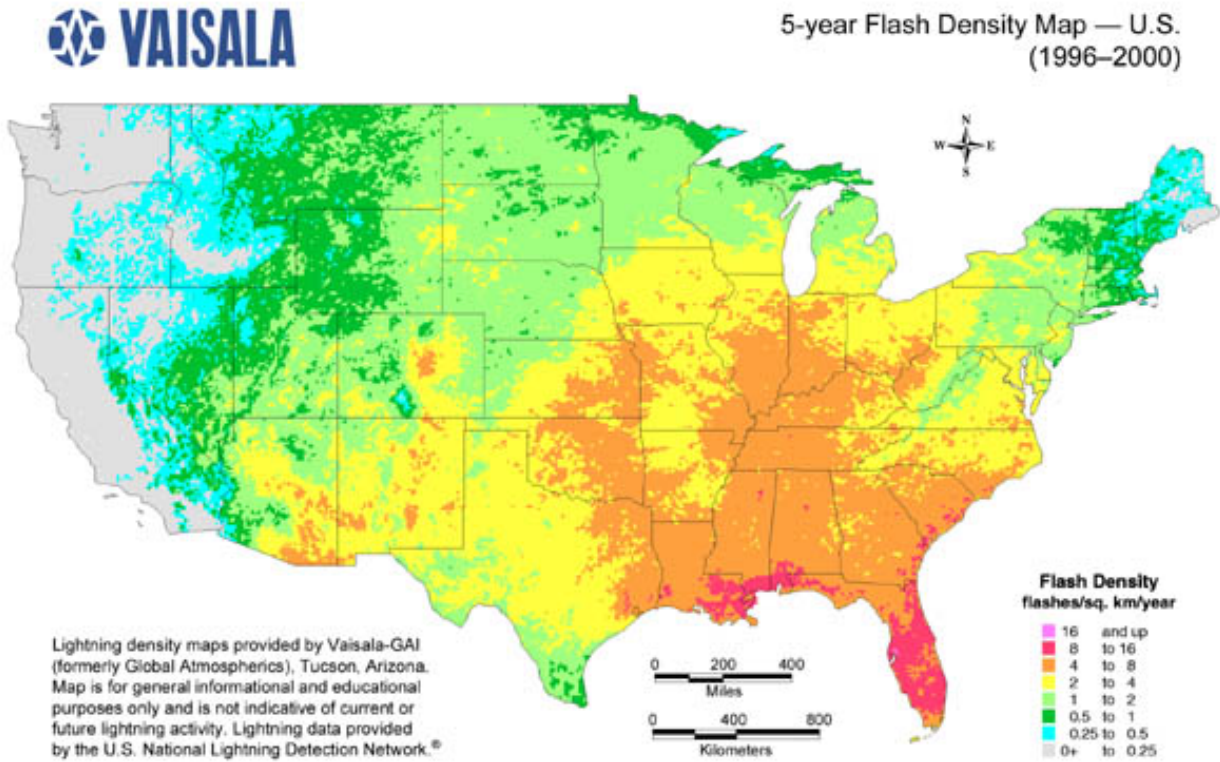


Figure 2. Lightning Flash Density in the U.S.

Surge Protective Devices (SPDs) may be used as a secondary measure of protection when installed in conjunction with a LPS. SPDs may also be used as a primary measure of protection if the cost of installing an air termination system cannot be economically justified. SPDs installed at key locations will protect major components such as inverters, arrays, equipment in combiner boxes, measurement and control equipment, instrumentation systems, and communications systems from being affected by lightning induced current surges. These devices have an added benefit of protecting against utility-generated transients. Surge protection should be applied to both the AC and DC sides of the inverter, as well as on applicable control and communication circuits.

The strategic placement of SPDs helps to prevent lightning induced damage by either shorting or clamping the voltage, thereby minimizing the transient voltage that would otherwise be present at the equipment terminals.

SPDs are connected between the energized conductor and ground. They must be installed as close to the terminals of the equipment as reasonably possible using the shortest and straightest routed conductors of sufficient cross sectional area. NEC 2011 Article 285 requires that SPD conductors in wiring systems 1 kV or less “shall not be any longer than necessary and shall avoid any unnecessary bends (NEC 285.12)” and must be no smaller than 14 AWG copper or 12 AWG aluminum (NEC 285.26). If this design criterion is not implemented, the result will be higher than necessary voltage drops in the SPD circuit during the discharge and will expose the protected equipment to higher transient voltages than necessary.

DC Side Surge Protection

Direct strikes to nearby grounded structures (including the LPS), as well as inter- and intra- cloud flashes of magnitudes in excess of 100 kA, cause magnetic fields to induce transient currents into PV system wire loops. These transient voltages will appear at equipment terminals and cause insulation and dielectric failures of key components, such as inverters, combiner boxes, PV modules (including bypass and blocking diodes) and other electrical and electronic equipment used for controls, instrumentation and communications.

Induced and partial lightning currents could appear as transient voltages at equipment terminals, but may be mitigated placing SPDs at these locations.

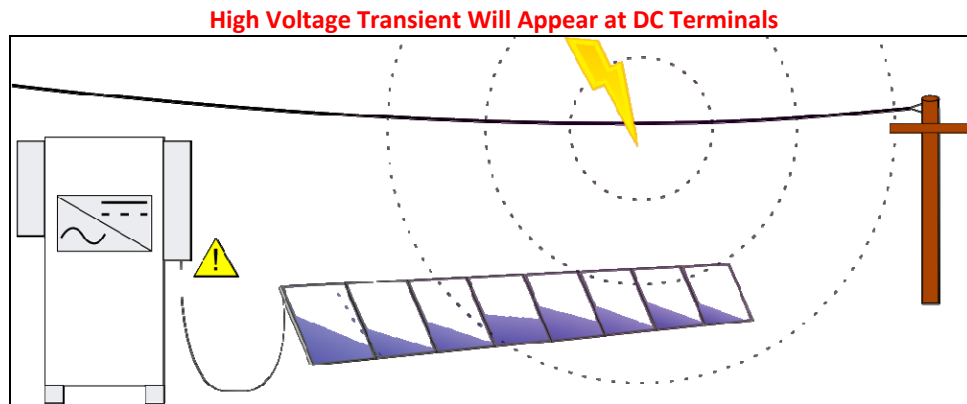


Figure 3. Influence of the Magnetic Field from a Lightning Induced Transient

A commonly used SPD configuration on large utility PV systems operating at 600 VDC is connecting Metal Oxide Varistor (MOV) modules in a Y configuration. Each leg of the Y contains a MOV module, connected to each pole and to ground. In this configuration, each SPD module is rated for half the system voltage, so if there is a pole to ground fault, each component is protected to its nominal rating by two elements in series.

Consideration must also be given to the ability of the SPD to disconnect itself from the DC source should it fail. The integral disconnect must be rated for interrupting a potential DC arc at the operating voltage. A standard AC SPD is not suitable for this application. The SPD applied to the PV DC system must be UL certified to the latest standard 14449 3rd edition and compliant to the associated supplement (Certificate Requirement Decision (CRD)) specifically applicable to PV systems.

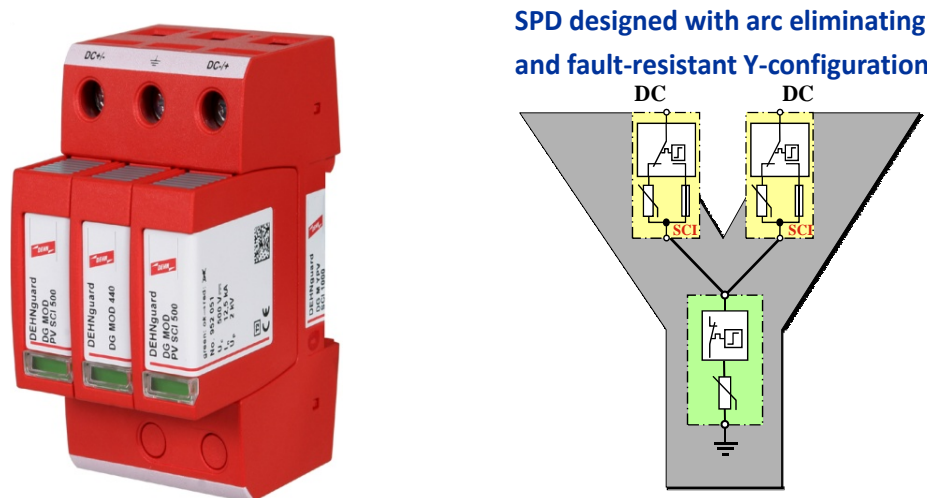


Figure 4. DC Surge Protection Device

One method to overcome the issue of extinguishing the DC fault arc is to place a parallel fused by-pass circuit around the MOV. Should the thermal disconnect operate, an arc will appear across its opening contacts. However, that arc current would be redirected to the parallel path containing a fuse, where the arc would be extinguished and the fuse would operate, interrupting the fault current.

The circuit below in figure 5 represents a negatively grounded PV system in which the negative conductor is bonded to the DC equipment ground through the Ground Fault Detection and Interruption (GFDI) fuse. The SPD between this grounded conductor and the DC equipment ground only becomes active once the GFDI fuse is blown.

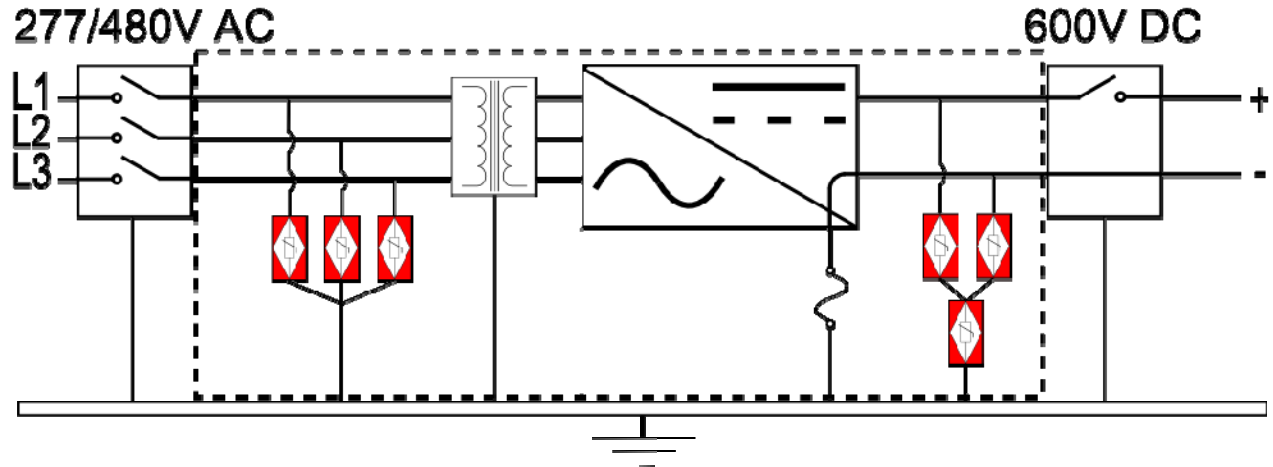


Figure 5. Typical SPD application for PV Inverters

The circuit also depicts the appropriate AC surge protection scheme for the output of an inverter that employs an isolation transformer. If a transformerless inverter is utilized, an additional SPD may be needed due to the DC offset involved.

AC Side Surge Protection

Direct lightning strikes to the utility service entrance or a nearby ground will cause a local Ground Potential Rise (GPR) with regard to distant ground references. Conductors spanning long distances in the system will expose equipment to significant voltages. Surge protection should be placed at the service entrance to primarily protect the utility side of the inverter from damaging transients. The transients seen at this location are of a higher magnitude and duration (10/350 μ sec versus 8/20 μ sec), and therefore must be managed by surge protection with appropriately high discharge current ratings. Spark Gap technology has the ability to discharge the full magnitude of “Lightning Currents” by providing equipotential bonding during the occurrence of a lightning transient. A coordinated MOV has the ability to clamp the residual voltage to an acceptable level for the equipment it is to protect.

In addition to the effects of GPR, the AC side of the inverter may also be affected by induced lightning transients and utility switching transients that will appear at the service entrance, such as voltage tap changing or capacitor bank switching actions.

	Type	Impulse current capability	Let Through Voltage	TOV Withstand Capability	Follow current	Power Dissipation
Voltage Switching	Spark Gaps (SG)	~ 10 -50 kA (10/350 us)	high (*)	high	yes (*)	low
	Gas Discharge Tubes (GDT)	< 5 kA (10/350 us)	high	high	yes	low
Voltage Limiting	Metal Oxide Varistor (MOV)	some 10 kA (8/20 us)	medium	low	no	high
	Silicon Avalanche Diodes (SAD)	some 100 A (8/20 us)	low	low	no	high

(*) but can be limited

Figure 6. Technologies Used for SPDs

SPD selection criteria are as follows:

- Ability of the devices to change states quickly enough for the brief time the transient is present
- Ability to discharge the magnitude of the transient current that is associated with the transient voltage without failing
- Minimizing the voltage drop across the SPD circuit to protect the equipment it is connected to
- No interference with the normal operation of that circuit

The SPD must also have an integral, self-protecting device that will disconnect itself from the circuit should a failure of the SPD occur. Since the SPD is placed in the circuit in a parallel configuration to ground, a failure of the device causing its disconnection will not be readily noticed. To make this disconnection apparent, many SPDs will display a “flag” indicating the status. An enhanced added feature to indicate the status of the SPDs is an integral auxiliary set of contacts that will change state upon the operation of the disconnect switch. This open auxiliary contact may be read out to provide a maintenance alarm for the installer by means of an advanced data monitoring system. A further enhancement is the easy removal and replacement of the failed SPD module without the use of tools or without de-energizing the circuit by utilizing a removable “touch safe” module.

Non-Power System Surge Protection

Just as power system equipment and components are susceptible to the effects of lightning, so is the equipment associated with measurement and control, instrumentation, SCADA and communication systems.

When selecting SPDs for these circuits, consideration must be given to the ability of these SPDs to discharge the transient currents without failure, and provide an adequate voltage protection level. In order to avoid interference with the system’s function, these SPDs should have specify unique characteristics including series impedance, line-to-line and ground capacitance, frequency bandwidth, etc. Signal level SPDs are on the market for twisted pair communication, CAT 6 Ethernet or coaxial RF cable.

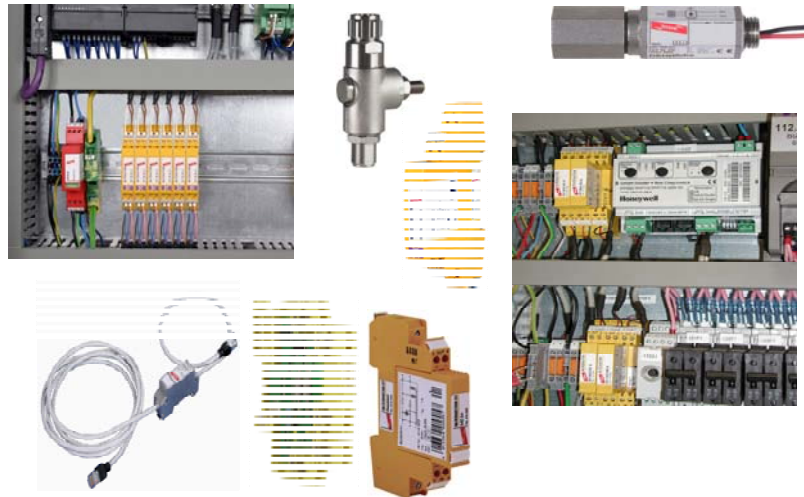


Figure 7. SPDs for Non-Power Applications

Conclusion

Despite the high lightning risk that PV systems are exposed to, they may be protected by the appropriate application of Surge Protection Devices and a Lighting Protection System. One must give thoughtful and careful consideration to the following:

- Proper equipotential bonding of all grounded members
- Proper grounding electrode system
- Strategic placement of the SPDs in the system, including integration into combiner boxes and inverters
- The connection quality from the system to the SPDs
- Adequacy of discharge rating of the SPD
- Voltage protection level of the SPD
- Suitability of the SPD for the system it is applied to, i.e. DC versus AC
- Consideration of failure mode of SPDs and status indication
- Local and remote status indication, and ease of replacing devices
- Suitability of SPDs on systems so as not to affect normal system function, specifically on non-power systems

Authors:

Michael Zuercher-Martinson
Solectria Renewables, LLC

Robert Schlesinger, P.E.
DEHN Inc.