FS Series PV Modules
Reverse Current Overload

Purpose

The purpose of this document is:

- to describe the system conditions that can cause reverse current overload (RCOL) and the behavior of FS modules in this condition;
- to provide information on mitigating the potential causes of RCOL; and
- to provide information on protection of photovoltaic (PV) modules in the event of reverse current flow.

Definitions

1. **Reverse Current Overload:** A condition where an electrical current in excess of the rated maximum overcurrent protection value flows through a PV module in the direction opposite to the direction of current flow in normal operation. A table of these values is below.

   Table 1: Rated Maximum Overcurrent Protection

Module Type	Rated Maximum Overcurrent Protection
Series 2	2.0A
Series 3	3.5A
Series 3 Black	3.5A
Series 3 Black Plus	4.0A
Series 4, 4A, 4V2, 4AV2,4V3 and 4AV3	4.0A
Series 6, 6A	6.0A

2. **Positive Voltage Bias:** A differential electrical potential between two terminals of a device that is in the same polarity as the bias during normal operation.

3. **Open Circuit Voltage:** The difference of electrical potential between positive and negative terminal of the PV module or string of modules when no external load is connected.

4. **Array:** An electrically connected collection of PV modules

5. **Grounded Conductor:** The wire(s) or electrical bus in a PV system electrically connected to an earth ground with an electrical potential of zero with respect to an earth ground.

6. **PV Source Circuit:** Electrical circuits between modules and from modules to the common connection point(s) of the DC system.

7. **Ground Fault**: Accidental electrical grounding of a PV system component intended to operate at an electrical potential with respect to that of the earth (module, conductor, etc.).

8. **Ground Fault Detector Interrupter**: A safety device for a PV array which, in the event that the array becomes shorted to ground, disconnects the PV system from ground.

Background Information

When a PV array is exposed to light, PV modules within the array normally operate at a voltage between zero and the module's rated Open Circuit Voltage ($\mathbf{V}_{oc}$). When the modules are generating electrical power, the conventional flow of current through the module moves from the negative to the positive terminal. If an abnormal condition develops within the array and positive voltage bias significantly in excess of the rated $\mathbf{V}_{oc}$ is applied to a PV module (or series of modules), and if sufficient current is present, current will flow though the module in a reverse direction (positive to negative). Under this scenario, instead of generating electrical power, a PV module behaves as a load and attempts to dissipate electrical power mainly in the form of heat. When this power dissipation exceeds the level that can be tolerated by the module (as defined by module safety tests), the module experiences a condition known as a Reverse Current Overload (RCOL).

There may be a risk of RCOL if a single PV module is exposed to positive voltage biases in excess of ~1.4 times its labeled $\mathbf{V}_{oc}$. An RCOL condition can cause the PV module to dissipate electrical power which can result in module overheating and eventually failure. A string of PV modules may also be affected in a similar manner if the string is positive biased in excess of 1.4 times the sum of the $\mathbf{V}_{oc}$ ratings of the PV modules in the affected string. For example, a series of four PV modules may experience RCOL if a positive voltage bias is generated by several parallel strings of six modules.

Operating a PV module in a sustained RCOL condition is likely to result in module failure. Several factors influence the likelihood of module failure. These are the magnitude of the reverse current, the duration of the RCOL event, ambient conditions, system design, etc.

International PV module standards (IEC 61730, UL 1703, and EN 50380) include required testing which establishes the reverse current tolerance characteristic for PV modules under the defined test conditions of these standards. According to UL 1703, PV modules must be labeled with the 'maximum series fuse rating' required to protect the module from failure as defined in the testing protocol for this standard. According to IEC 61730, information on the module's 'maximum overcurrent protection rating' must be included in the module's documentation. According to EN 50380, information on the module's 'limiting reverse current rating' must be included in the module's datasheet. These values are listed below.

Table 2: Rated Maximum Overcurrent Protection by Standard

Module Type	UL 1703	IEC 61730	EN 50380
Series 2	2.0A	2.0A	2.0A
Series 3	3.5A	3.5A	3.5A
Series 3 Black	3.5A	3.5A	3.5A
Series 3 Black Plus	4.0A	4.0A	4.0A
Series 4, 4A, 4V2, 4AV2, 4V3, 4AV3	4.0A	4.0A	4.0A
Series 6, 6A	6.0A	6.0A	6.0A

Effects of Reverse Current Overload on First Solar Modules

When reverse current flows into a module, instead of producing electricity the module acts as load and it will attempt to dissipate the energy flowing into it. When the reverse current passing through the module exceeds its maximum reverse current rating as shown in Table 1, RCOL occurs. When RCOL occurs, the module may experience high surface temperatures, and could crack, smoke, arc, or ignite itself or surrounding materials, depending on the length and severity of the RCOL condition.

Please refer to the FS Series PV Module User Guide(s) for further information on the proper operating conditions for FS Series modules and for specific warning and caution information related to the installation and use of FS Series modules.

Conditions which can Cause Reverse Current Overload in First Solar Modules

The conditions which are necessary to trigger RCOL in FS modules do not occur in the typical operating modes of a properly installed PV system. The specific conditions which could potentially result in RCOL occurrence are:

Voltage Imbalance

1. In order for RCOL to occur in a string, the effective open circuit voltage of the string needs to be less than 70% of the open circuit voltage of the rest of the strings in the array.
2. A string that has effective open circuit voltage that is less than 70% of the open circuit voltage of the rest of the strings in the array can be created by the formation of an *effective short*

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string that contains the electrical equivalent of 70% of the modules in the rest of the strings in the array (assuming all modules have nominally equal voltage). Some examples of effective short strings include 4 or fewer modules for arrays designed with 6 modules per string; 7 modules or fewer for arrays designed with 10 modules per string; and 10 modules or fewer for arrays designed with 15 modules per string.

There are multiple ways in which *effective short strings* can be created:

a. Ground fault of module lead wire or module in a string shorting the modules between the location of the ground fault and the ground, creating an *effective short string*

    i. Grounded PV System: A single ground fault inside a string

    ii. Ungrounded PV System: A single ground fault inside a string AND another ground fault that is simultaneously present at any point in the array

b. Installation error which results in the existence of one or more *effective short string(s)* in the array

c. The existence of multiple shorted modules (module fault) inside an otherwise properly installed single string

Grid Fault and Inverter Failure

In addition, RCOL could be created in an array where all the strings are substantially of the same voltage through a voltage/current surge from the inverter due to grid fault and failure of the inverter to protect the array from this event, biasing the whole array to an extreme voltage which is larger than the inherent V_{OC} of the array.

It should be noted that shading of some of the PV modules in a string can result in very small reverse currents, but these reverse currents will not exceed the PV modules' limiting reverse current specifications. Module shading does not lead to a RCOL condition.

Mitigation Approaches

PV systems should be designed to prevent the conditions that trigger module RCOL. The system designer should ensure that modules are not subjected to reverse currents in excess of the module rating. Modules damaged as a result of reverse currents in excess of the module rating are not covered under the First Solar Module Warranty. Module warranty eligibility is not affected by the presence, absence, or type of reverse current protection used in a system design.

Please refer to the FS Series PV Module User Guide(s) for further information on the proper operating conditions for FS Series modules and for specific warning and caution information related to the installation and use of FS Series modules.

The use of Ground Fault Detector Interrupter (GFDI) devices or other advanced fault monitoring techniques can significantly reduce the likelihood of sustained ground faults. By ensuring the ground current cannot exceed the maximum overcurrent rating of the module, the likelihood of RCOL will be reduced dramatically. If a GFDI limits the ground current to remain below maximum overcurrent rating of the module, the likelihood and severity of RCOL events will be low and will not increase with additional strings connected to a single fuse.

FS modules must be installed to ensure an equal number of modules per string in the same PV Source Circuit. Failure to do so may result in voltage imbalance, which in turn could trigger reverse current flow within the PV array.

Properly selected and installed string fuses or blocking diodes can increase protection against RCOL. For example, a system which incorporates a single fuse per string of modules, where the fuse is no larger than the modules' maximum series fuse rating, typically provides adequate module protection against RCOL.

The system designer is responsible for complying with all applicable laws and codes related to the system designer's installation. Application of First Solar modules in different geographical locations requires that the system designer understand the local regulatory requirements which may apply to a particular installation site. It is strongly recommended that the system designer consult with the local electrical code officials well in advance of the installation.