UL 3741 Compliance – SolarEdge's DC Optimization Architecture – Application Note

Revision History

Version 1.3, February 2024: Edited text

Contents

Overview

This Application Note discusses how SolarEdge's Power Optimizers and inverters compare to other UL 3741-compliant solutions, and how different models of Power Optimizers comply with UL 3741 and National Electrical Code (NEC) requirements. It explains how each version of NEC applies to installations using SolarEdge Power Optimizers.

Rapid shutdown requirements for rooftop solar systems have seen multiple iterations and revisions in the NEC code and UL safety standard. SolarEdge has been a leader in integrated rapid shutdown solutions, as the capability has been inherent in its module-level architecture. While compliance strategies have changed, SolarEdge remains a dominant and consistent solution provider for rooftop solar applications that must meet the latest NEC requirements for rapid shutdown.

Rapid shutdown requirements were first introduced in NEC 2014 and subsequent versions of the NEC have been revised and updated as the hazards of rooftop solar systems were further identified. SolarEdge has maintained compliance continuity throughout these code cycles with product updates and innovations, from parallel inputs and series input to UL 3741 certification for 2:1 Power Optimizer applications. SolarEdge commercial Power Optimizers comply with all versions of NEC 690.12 Rapid Shutdown of PV Systems on buildings.

Brief history

NEC 2014 690.12 requires that conductors outside the array boundary of 10 feet must be below 30V within 10 seconds of initiating rapid shutdown. The conductors inside the array boundary do not have a specified voltage limit and are not controlled. SolarEdge inverter and Power

Optimizer combinations are listed and labeled to UL 1741 as PV Rapid Shutdown Systems and control the voltage outside the array boundary.
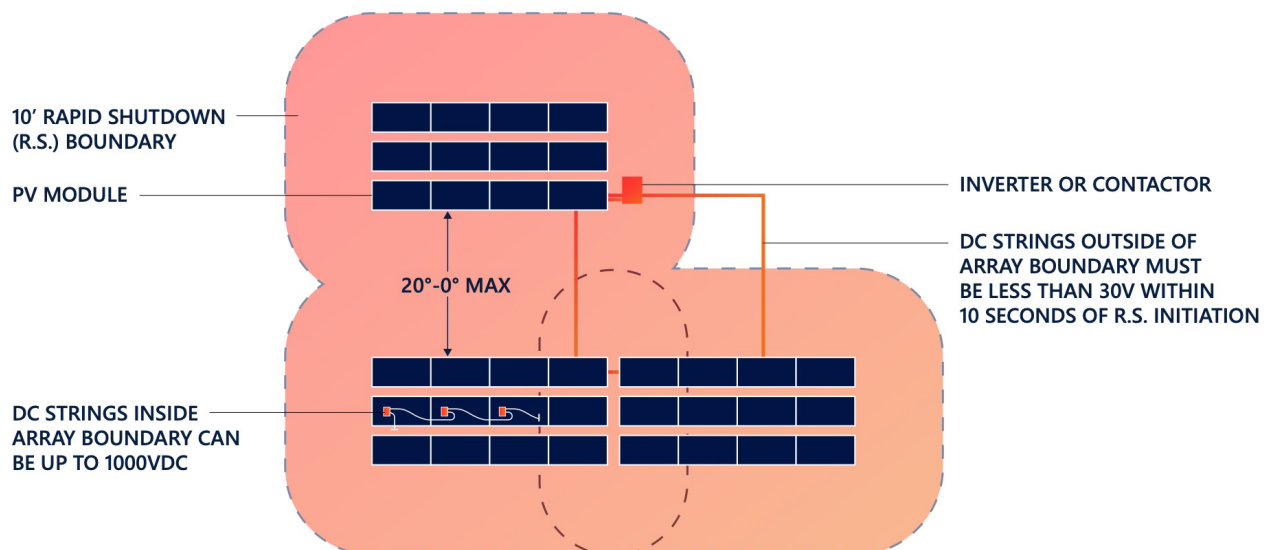
NEC 2017 690.12 revised the array boundary to be 1 foot from the array in all directions and included the conductors **inside** the array boundary as controlled conductors. Controlled conductors **outside** the array boundary of 1 foot must comply with 690.12(B)(1) which requires conductors to be limited to no more than 30V within 30 seconds of rapid shutdown initiation. Controlled conductors **inside** the array boundary of 1 foot shall comply with 690.12(B)(2) which requires conductors to be limited to no more than 80V within 30 seconds of rapid shutdown initiation.

NEC 2020 690.12 was only slightly revised in this code cycle. The most significant change is the clarification of what NEC 2017 refers to as a "listed or field labeled rapid shutdown PV array", 690.12(B)(2)(1) Informational Note. NEC 2020 now refers to this as a "PV Hazard Control System" (PVHCS) and specifically refers to a new UL standard, UL 3741.
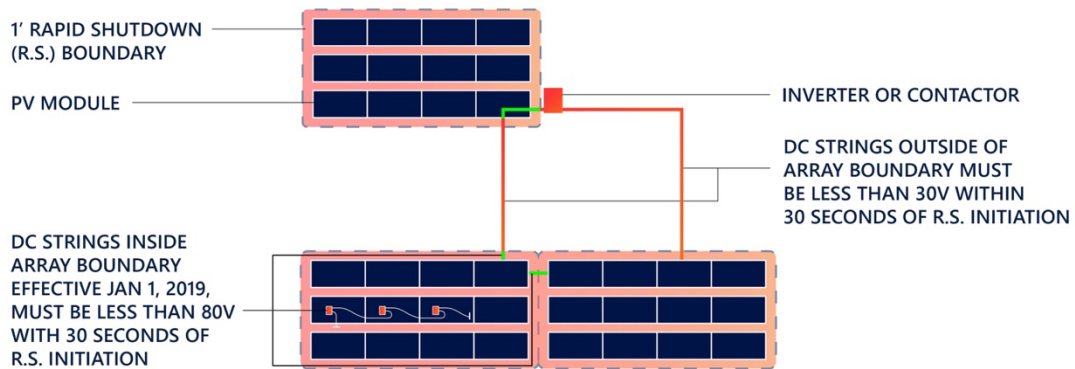
NEC 2023 690.12 remains largely unchanged in this code cycle. References to "shock hazard" are inserted in the rapid shutdown language and the allowance for Building Integrated Photovoltaic (BIPV) systems has been removed.

The illustrations below highlight the rooftop safety requirements with each NEC iteration.

NEC 2014

10' RAPID SHUTDOWN (R.S.) BOUNDARY

PV MODULE

20°-0° MAX

DC STRINGS INSIDE ARRAY BOUNDARY CAN BE UP TO 1000VDC

INVERTER OR CONTACTOR

DC STRINGS OUTSIDE OF ARRAY BOUNDARY MUST BE LESS THAN 30V WITHIN 10 SECONDS OF R.S. INITIATION

NEC 2017

1' RAPID SHUTDOWN (R.S.) BOUNDARY

PV MODULE

INVERTER OR CONTACTOR

DC STRINGS OUTSIDE OF ARRAY BOUNDARY MUST BE LESS THAN 30V WITHIN 30 SECONDS OF R.S. INITIATION

DC STRINGS INSIDE ARRAY BOUNDARY EFFECTIVE JAN 1, 2019, MUST BE LESS THAN 80V WITH 30 SECONDS OF R.S. INITIATION

Rapid Shutdown Code – Part 2 (Effective beginning January 1, 2019)

NEC 2020 & 2023

1' RAPID SHUTDOWN (R.S.) BOUNDARY

PV MODULE

INVERTER WITHIN 1' OF ARRAY IS CONSIDERED PART OF THE ARRAY

DC STRINGS OUTSIDE OF ARRAY BOUNDARY MUST BE LESS THAN 30V WITHIN 30 SECONDS OF R.S. INITIATION

DC STRINGS INSIDE THE ARRAY BOUNDARY CAN BE UP TO 1000VDC IF LISTED TO UL 3741

UL 3741

A new standard, UL 3741, was introduced in late 2020 which set testing requirements for a device or system to be listed as a PV Hazard Control (PVHC). SolarEdge Power Optimizers are inherently compliant with these requirements because of our proprietary SafeDC™ technology. SolarEdge was one of the first systems to receive the UL 3741 listing.

Since then, other manufacturers have introduced equipment listed to UL 3741. These systems maintain 1000VDC in the array by depending on mechanical separation to achieve compliance. The SolarEdge solution is safer and more reliable as it immediately reduces the presence of high voltage DC power on the roof.

As displayed in the illustration below, the SolarEdge solution breaks up the array into 2-module segments where the maximum voltage present, upon initiation of rapid shutdown, is limited to

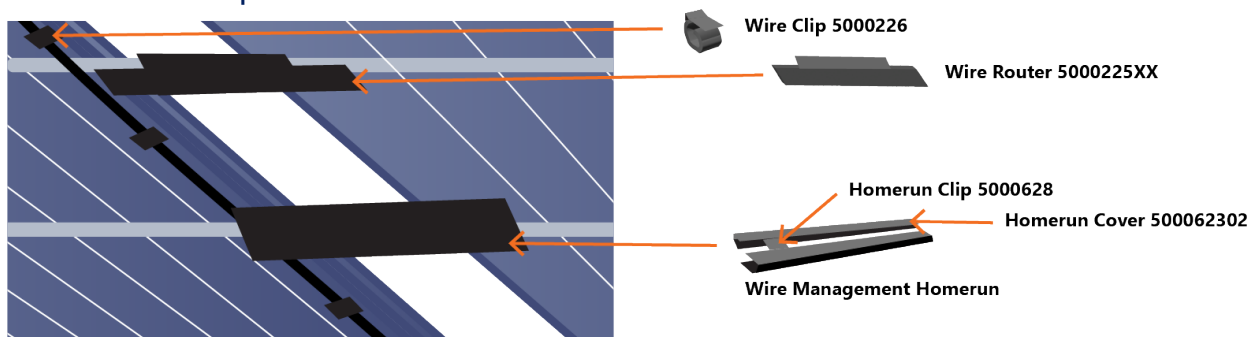125VDC maximum. Other solutions operate at hazardous voltage levels.

Voltage segmentation

2 Module Segment

125Vdc vs 1000Vdc

**1Vdc per optimizer. vs 1000Vdc
Up to 30 Vdc per
string.**
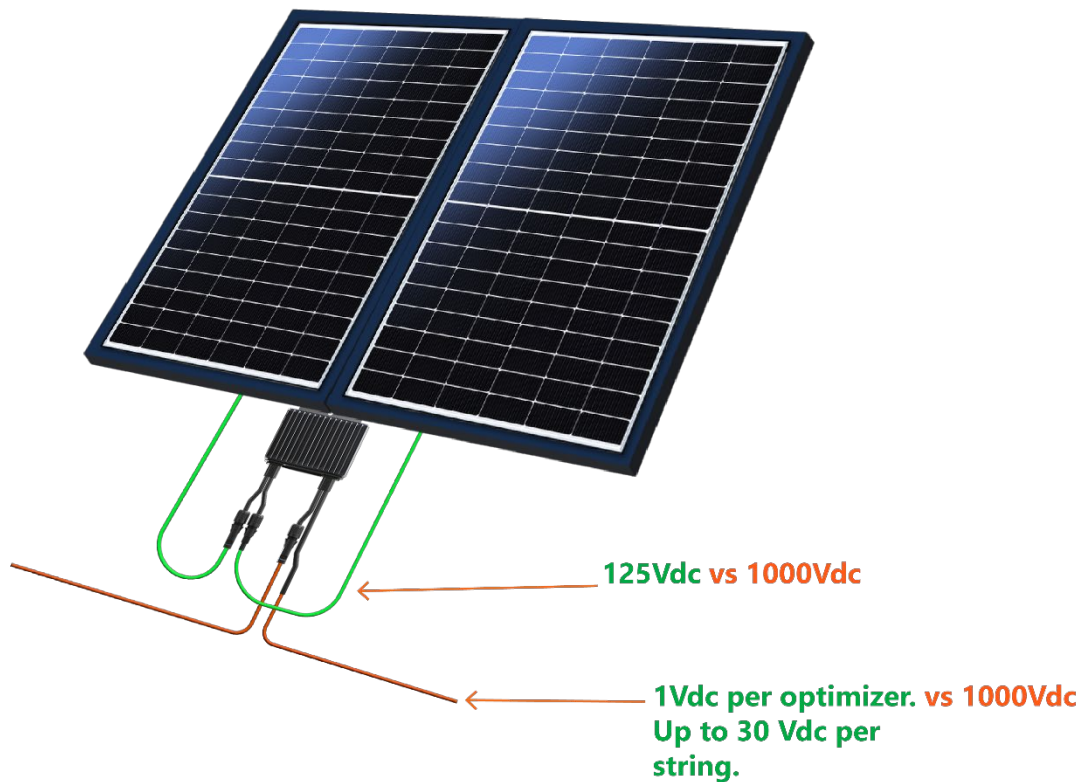
Other solutions also require extra accessories that mechanically separate and protect the high voltage conductors from damage, as shown below.

Mechanical separation

Wire Clip 5000226

Wire Router 5000225XX

Homerun Clip 5000628

Homerun Cover 500062302

Wire Management Homerun

How do different SolarEdge Power Optimizers comply?

SolarEdge commercial Power Optimizers and inverters have been tested and certified in compliance with UL 3741 as PV hazard control systems as well as UL 1741 PV Rapid Shutdown Systems. Power Optimizers can connect two modules in series (for series connected Power

Optimizers) or two modules in parallel (each module connected separately) if the total voltage does not exceed the rated input voltage of the Power Optimizer.

P960

The SolarEdge P960 Power Optimizer has two module inputs. Each input is rated for a maximum voltage of 60VDC. This meets the requirement of 690.12(B)(2)(2) of not having more than 80VDC present on controlled conductors inside the array boundary.

P1101

The SolarEdge P1101 Power Optimizer has one module input and is certified to the UL 3741 standard. It is rated for a maximum input voltage of 125VDC. This Power Optimizer, when paired with SolarEdge inverters, has been evaluated as a PV Hazard Control System (PVHCS) and is evaluated as a Hazard Level 1 (the lowest) in the UL standard. This meets the requirement of 690.12(B)(2)(1).

S1201

The SolarEdge S1201 Power Optimizer has one module input and is certified to the UL 3741 standard. The input is rated for a maximum voltage of 125VDC. This Power Optimizer, when paired with SolarEdge inverters, has been evaluated as a PV Hazard Control System (PVHCS) and is evaluated at Hazard Level 1 (the lowest) in the UL standard. This meets the requirement of 690.12(B)(2)(1). In addition, this Power Optimizer features a new safety innovation called Sense Connect. This hardware update includes the ability to measure the temperature of the output circuit connector on each Power Optimizer deployed in a rooftop photovoltaic system.

UL 3741 hazard levels and equipment requirements

The table below lists the hazard levels present at different voltage levels according to the UL 3741 standard using the worst-case firefighter interaction with PV array equipment where a sharp tool could be employed to cut through the PV module, wires, junction box, Power Optimizer, etc.

SolarEdge Power Optimizers are at the lowest level, Hazard Level 0-1 due to controlled voltage on the input and output. All other solutions without MLPE are <u>above</u> a Hazard Level 3 (the highest) since they do not control voltage within the array.

Calculated Voltages

Injury	Array Voltage DC
Tingling	0-14
Contraction	15-165
Seizures, Spasms	166-300
Cardiac Problems (serious life or injury probable)	>300
Possible Death	600
Possible Death	1000

SolarEdge is here

UL 3741 Table 8 Description of Hazard Levels

Hazard Level (HL) Description (DC Current Limits for Adult Women derived from 1.33 times the IEC 60479-1 Figure 22 table values that include children)

Hazard Level	Range mA	Description
0	0 – 2.67	Perception with slight pricking sensation. No risk of shock or reaction (Similar to IEC 60479-1 DC-1 modified for adult females.)
1	> 2.67 – 40	Muscle Contraction. Insignificant threat to life or injury. May result in a reaction response. (Similar to IEC 60479-1 DC-2 modified for adult females.)
2	> 40 – 100	Strong Involuntary Muscle Reaction. (Similar to IEC 60479-1 DC-3 modified for adult females.)
3	> 100	For the purpose of this standard, this is the maximum allowed exposure current. This 100mA value was chosen to provide a safety factor and is 66% of the fibrillation threshold (Catastrophic – serious life or injury probable (Similar to IEC 60479-1 DC-4 modified for adult females) calculated at 5% of the adult women population.
	~ 270	
	~ 460	

New products have recently been released that carry the UL 3741 certification. However, these solutions still have high-voltage DC power present on the roof (up to 10kW @ 1000VDC). Although the UL 3741 standard specifically evaluates the risk to firefighters with full PPE that are working on a roof with a solar array, the risk to untrained personnel, HVAC maintenance workers, O&M providers, and others is still present.

The safest solution

The safest approach to reducing the risks associated with rooftop solar systems is to reduce the hazard. Reducing the voltage to an acceptable level protects ALL personnel that may be working on the roof. SolarEdge inverters and Power Optimizers do this by limiting the input voltage of each Power Optimizer to 125VDC maximum and limiting the output voltage of each Power Optimizer to 1VDC (SafeDC). Other solutions without voltage control leave the array components at 1000Vdc often with little or no additional guards or barriers between the

conductors and personnel.

The SolarEdge UL 3741 certified PV Hazard Control System and the new Sense Connect feature built into each Power Optimizer provide the safest possible solution to meet rapid shutdown requirements.

Conclusion

In conclusion, per UL 3741, article 7.1, as SolarEdge inverters and Power Optimizers have been tested and certified as a PV Hazard Control System with voltage control (Hazard Level 1), no other components are necessary to meet the rapid shutdown requirements in NEC, as displayed in the table below. Racking and string inverter solutions are above Hazard Level 3 and require additional protection and installation methods/products such as wire guards, special racking, wire management, and PV rapid shutdown equipment and systems for conductors outside the array boundary. The following table describes the hazard reduction for UL3741:

Hazard reduction description

FO	Hazard Level 0	Hazard Level 1	Hazard Level 2	Hazard Level 3
Frequent FO = (6)	No Action Required	No Action Required	Action Required	Action Required
Probable FO = (5)	No Action Required	No Action Required	Action Required	Action Required
Occasional FO = (4)	No Action Required	No Action Required	Action May Be Required	Action Required

Frequency of Occurence: FO = (Pf + Pe)