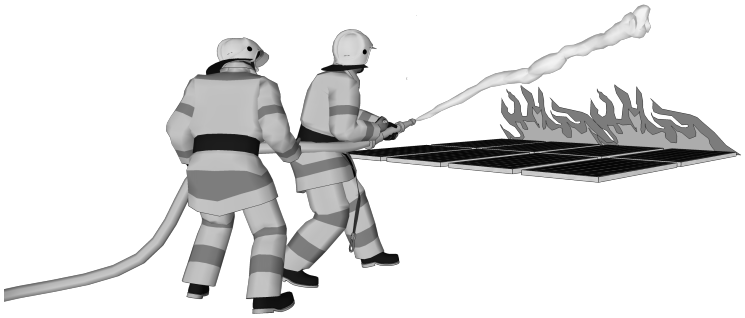
NEC 690.12 Rapid Shutdown Primer

Introduction



The 2014 edition of the National Electrical Code[1] (NEC) was the first to introduce a mandatory requirement called Rapid Shutdown, intended as an aid to firefighters by reducing the risk of shock hazard when fighting fires. This new requirement applies to PV systems on buildings in the US and is contained in Section 690.12 of the 2014 and later editions of the NEC. At a high level the requirement is that controlled conductors must be at safe voltage levels quickly after initiation of Rapid Shutdown. Controlled conductors were defined in the 2014 edition as any conductor more than 10 feet from the PV array. Since then the requirements have evolved further in the 2017 edition.

This article is not intended to be academically thorough or rigorous – some excellent articles are listed at the end for those that need depth. This is a general overview focused on 3-phase commercial inverter installations.

Summary of Requirements

A brief overview of how the Rapid Shutdown requirements have evolved is given in Table 1.

690.12 Rapid Shutdown evolution	No requirement	<30V beyond 10' of the array boundary within 10s[i]	<30V beyond 1' of the array boundary within 30s	80V max within array boundary
NEC 2011 and prior	✔			
NEC 2014		✔		
NEC 2017			✔	
NEC 2017 after 1st Jan, 2019				✔

Table 1: Overview of Rapid Shutdown requirements

[i] Since increased to 30s – see later in this document

2014 NEC Requirements

The following is taken from the Bill Brooks article listed at the end[2], and gives the exact wording of the Rapid Shutdown requirement in the 2014 code, as follows:

"690.12 Rapid Shutdown of PV Systems on Buildings
PV system circuits installed on or in buildings shall include a rapid shutdown function that controls specific conductors in accordance with 690.12(1) through (5) as follows.

(1) Requirements for controlled conductors shall apply only to PV system conductors of more than 1.5 m (5 ft) in length inside a building, or more than 3 m (10 ft) from a PV array.
(2) Controlled conductors shall be limited to not more than 30 volts and 240 volt-amperes within 10 seconds of rapid-shutdown initiation.
(3) Voltage and power shall be measured between any two conductors and between any conductor and ground.
(4) The rapid-shutdown initiation methods shall be labeled in accordance with 690.56(B).
(5) Equipment that performs the rapid shutdown shall be listed and identified."

Since this language was introduced, a TIA (Tentative Interim Amendment) has been issued that relaxes the allowed time limit from 10s to 30s[3,4] with an effective date of 24th August, 2016.

Discussion

Opening the AC disconnect serving a utility-interactive inverter causes the inverter to shut down (UL1741 anti-islanding requirements mandate this for utility-interactive inverters in the US). However, this doesn't ensure that all conductors on the DC side between the inverter and the PV array will become de-energized – the PV modules will still be producing a voltage any time there is sufficient irradiance. Common practice for central and string inverter installations has been to mount the inverters on a wall or down on the ground, and to install long runs of wire up to the PV array. The Rapid Shutdown requirement complicates this – shutting the inverter off down on the ground doesn't de-energize the DC wires running up to the roof. An obvious next step is to put remote-controlled or auto-sensing DC disconnects within 10 feet of the array, and such products are available for sale. Unfortunately there are several problems with this approach. Firstly it adds extra cost, install time, complexity and points of failure. Secondly, when the DC side of some inverters goes open-circuit, capacitors inside the inverter keep the voltage high for up to 5 minutes (a maximum time allowed by UL1741.) This is far longer than the allowed time required by the original language of the 2014 NEC. For the reasons mentioned above it is increasingly common to mount inverters on the roof, within the defined boundary of the array. Doing this means that one throw of the AC disconnect shuts the inverters down, and any high DC voltages are within the boundary of the array, where they are allowed. An overview of different approaches to complying with the 2014 requirements is shown in Figure 1.

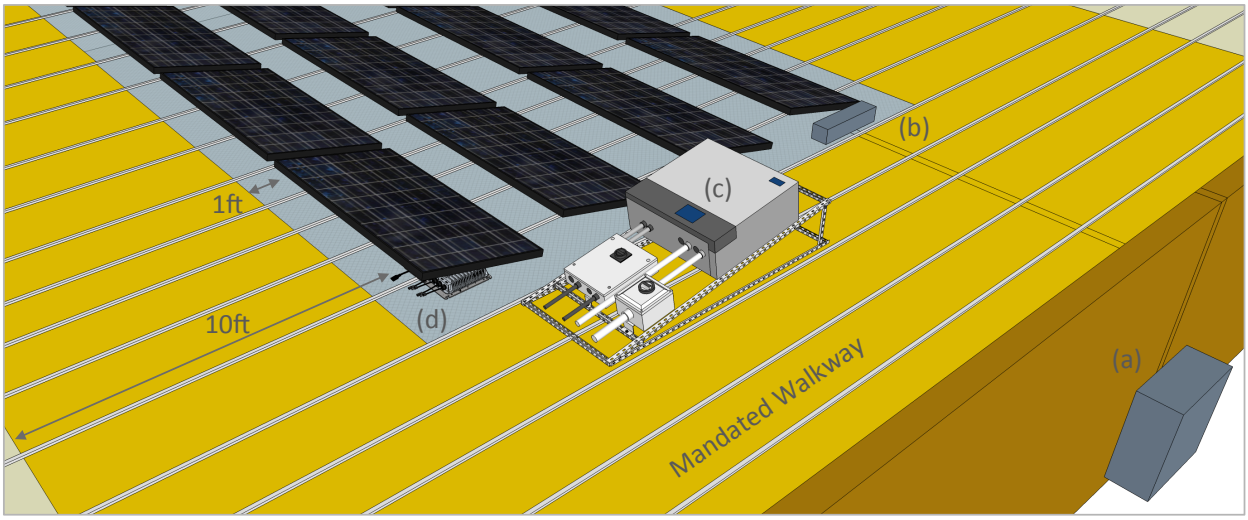


Figure 1: Different approaches to complying with the Rapid Shutdown requirement. (a) Central and wall-mounted string inverters often add an intelligent (i.e. expensive) DC disconnect switch (b) that senses when the inverter has shut down and disconnects the array. Alternatively (c) has the string inverter mounted within 10 feet of the array on a cradle. (d) The HiQ TrueString inverter tucks naturally under the array and easily fulfills the 10' and 1' requirements for Rapid Shutdown

2017 NEC Requirements

The section dealing with Rapid Shutdown has been significantly expanded in the 2017 edition[5]. Again, Bill Brooks provides a good summary, listed at the end of this paper[6]. Of the many updates made, the following are notable in the context of 3-phase inverters:

- The array boundary now has a 1' perimeter from the edge of the PV modules instead of 10'.
- Equipment must be specifically certified for Rapid Shutdown use.
- There are three ways that an array can be compliant:
    - The specific component parts together are listed as an assembly to comply.
    - The array has no exposed metal, and is more than 8' away from any grounded metal
    - Within the array boundaries there is no conductor with a voltage higher than 80V when Rapid Shutdown is initiated. This differs significantly from the NEC 2014 requirement, as DC conductors could still be at up to 1,000V inside the boundary after shutdown is initiated.

These rules require equipment that complies, which consequently means that methods must be developed for certifying the equipment. For this reason, the implementation is phased – while the '1' rule' is in immediate effect for states that have adopted the 2017 NEC, the rules restricting the voltage to 80V inside the footprint of the array are not due to come into effect until 1st January, 2019.

There are many other requirements, including the labeling and accessibility of shutdown switches etc. – refer to the 2017 NEC for more details.

References

1. "NFPA 70®: National Electrical Code® (NEC®), 2014 Edition", by National Fire Protection Association
2. Article in SolarPro magazine by Bill Brooks, January 2015: "Rapid Shutdown for PV Systems: Understanding NEC 690.12" http://solarprofessional.com/articles/design-installation/rapid-shutdown-for-pv-systems?v=disable_pagination
3. TIA 14-10, effective date August 24th, 2016. http://www.nfpa.org/assets/files/AboutTheCodes/70/TIA_70_14_10.pdf
4. http://ecmweb.com/news/nfpa-issues-three-tias-related-2014-nec
5. "NFPA 70®: National Electrical Code® (NEC®), 2017 Edition", by National Fire Protection Association
6. Presentation to AEE Dealer Conference by Bill Brooks: http://aeesolar.com/wp-content/uploads/2017/01/2017DC-Rapid-Shutdown-2017-NEC.pdf

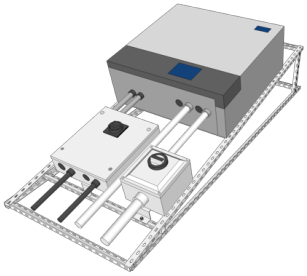
Appendix: HiQ Solar's TrueString Inverters and the Push for Array Mounting

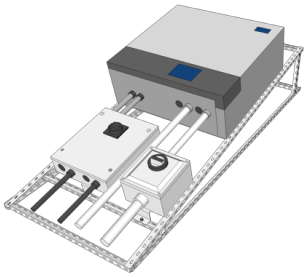
When it comes to array mounting, not all inverters are created equal. If you're a manufacturer of central inverters you are quietly crying at this point, and a maker of micro inverters cheering loudly. However, micro inverters are usually too expensive for commercial rooftops, and central inverters are being used less and less in favor of 3-phase string inverters. So the problem faced by many installers is that they want to use 3-phase string inverters, but somehow have to comply with the Rapid Shutdown requirement.

Most 3-phase string inverters were designed to be mounted vertically on a wall in a sheltered environment. Usually they cannot lie flat on their backs. They also frequently have LCD screens giving system information, and these are known to need frequent replacement when used in direct sunlight and harsh environments. However, it's not usually practical to build a suitable wall to mount these inverters on, which is why attempts are being made to mount them on angled cradles such as is illustrated in the picture at the start of this discussion. It's obvious that this is no one's idea of a perfect solution.

Cradle Compromises or Purpose-Designed Solution

The HiQ Solar TrueString inverters were designed from the outset to be array-mounted. Below is a quick comparison of our approach with the large 3-phase string inverters that are increasingly common.

		3-phase String on a Cradle 	**HiQ TrueString mounted under the array** 
1.	Satisfies 2014 NEC 690.12 Rapid Shutdown 10' rule?	When installed correctly and within 10 feet of the array, yes	When installed correctly and within 10 feet of the array, yes
2.	Satisfies 2017 NEC 690.12 Rapid Shutdown 1' rule?	Possible, but awkward - not designed for this	When installed correctly and within 1 foot of the array, yes
3.	Ease of designing with	Requires extra wide walkways or takes up space in mandated walkways	Sits under the array, but easy to access unlike micro inverters
4.	Ease of installation	Typically weigh more than 150 lb., hard to lift, requires more than one person. Requires extra effort and cost to buy and assemble the cradle	Weighs 24 lb. Easy to lift, easy to install, easy to carry spares. Easy to install by one person. Connector-based electrical connections.

		3-phase String on a Cradle	HiQ TrueString mounted under the array
			
5.	Reliability	LCDs, fans etc. require maintenance and regular replacement. Often these inverters use electrolytic capacitors. Sits in full sun. Not being used as originally intended	NEMA6, no electrolytics, no display, no fans. Maintenance-free. Robust, single circuit board, automotive grade components. Being used as intended
6.	Ease of replacement later	150 lb.+, hard to get replacement units onto a roof later, requires several people in the crew to do so	Tuck one under your arm, climb a ladder. Unclick the connectors, click in the new one. Easy
7.	Other	Usually strings are paralleled, making poor granularity of monitoring, fault-finding and arc detection	Each string has separate MPPT, monitoring. Single string arc detection, placed next to the modules, makes arc detection reliability better, and reduces occurrence of false-positives

Summary

HiQ's TrueString inverters were designed to be mounted in many locations, including under the PV array, and naturally comply with the requirements of 690.12 of the NEC. The HiQ solution also provides additional benefits of reduced cost, easier installation and maintenance.