Communication Signal for Rapid Shutdown
SunSpec Interoperability Specification

Abstract
This document defines a multi-vendor, multi-device (e.g. inverter, module, string combiner) communication interoperability specification to support NEC 2014, NEC 2017 and UL 1741 module-level rapid shutdown requirements. The intended audience for this document includes hardware and software designers as well as implementers of communication systems.
License Agreement and Copyright Notice

THIS DOCUMENT AND THE INFORMATION CONTAINED HEREIN IS PROVIDED ON AN "AS IS" BASIS AND THE SUNSPEC ALLIANCE DISCLAIMS ALL WARRANTIES, EXPRESS OR IMPLIED, INCLUDING BUT NOT LIMITED TO ANY WARRANTY THAT THE USE OF THE INFORMATION HEREIN WILL NOT INFRINGE ANY OWNERSHIP RIGHTS OR ANY IMPLIED WARRANTIES OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE.

THIS DOCUMENT MAY BE USED, COPIED, AND FURNISHED TO OTHERS, WITHOUT RESTRICTIONS OF ANY KIND, PROVIDED THAT THIS DOCUMENT ITSELF MAY NOT BE MODIFIED IN ANY WAY, EXCEPT AS NEEDED BY THE SUNSPEC TECHNICAL COMMITTEE AND AS GOVERNED BY THE SUNSPEC IPR POLICY. THE COMPLETE POLICY OF THE SUNSPEC ALLIANCE CAN BE FOUND AT WWW.SUNSPEC.ORG.

Attribution

This specification was developed by the SunSpec Alliance Communication Signal for Rapid Shutdown Workgroup. This workgroup includes the following individuals and companies:

Sauro Macerini, Giovanni Manchia, Ronnie Pettersson, Robert White, Mirco Mirra, Enrico Pietrantonzi (ABB); Andrew Misenheimer (Alevo Inc.); Devin Cao, Daniel Richardson (Canadian Solar); Anton Fischer (Celestica); Peter Chung, Nick Lee (Delta Products Corp.); John Berdner (Enphase); Martin Beran, Christian Fasthuber, Brian Lydic, Christoph Wolf (Fronius); Bernie Grant, Terence Parker (Ginlong-Solis); Ben Castillo, Bill Reaugh (KACO new energy); Seth Kahn, Charles Razzell, Ryan Ricchiuti (Maxim Integrated); Thierry Arnaud, Ali Julazadeh (Mersen); Ryan Stankevitz (Midnite Solar); Andrew Ahmad, Anand Janaswamy (OneRoof Energy); Brian Foley, Philip Undercuffler, Mara White (OutBack Power); Lotte Ehlers, Wolfgang Hoëft (Phoenix Contact); Larry Sherwood (Sherwood Associates); Markus Hopf, Hannes Knopf, Michael Viotto (SMA Solar Technology); Alex Mayer, Sandeep Narla, Jake West (SolarCity); Magnus Asbo, Yaron Binder, Jason Bobruk, Yoni Ziv (SolarEdge); Steve Robbins (Sunfield Semiconductor); Jonathan Ehmann, Kelly Mekechuk (SunPower); Tom Tansy (SunSpec Alliance); Amneh Akour, Dick Hester, Il Han Kim, Nat Natarajan, Tim Pauletti (Texas Instruments); Gal Bauer, Vered Sharon, Bijay Shrestha, Danny Eizips (Tigo Energy); Chris Flueckiger, Tim Zgonena (UL); Ward Bower (Ward Bower Innovations); Emily Hwang, Aegir Jonsson (Yaskawa Solectria Solar); Ralf Schulze (Yingli).

Contact Information

SunSpec Alliance
4030 Moorpark Avenue, Suite 109
San Jose, CA 95117
info@sunspec.org
## Revision History

<table>
<thead>
<tr>
<th>Revision</th>
<th>Date</th>
<th>Reason</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>09-02-2015</td>
<td>First Draft in SunSpec Template</td>
</tr>
<tr>
<td>2</td>
<td>09-09-2015</td>
<td>General requirements revised per discussion at 9/9/15 Work Group meeting.</td>
</tr>
<tr>
<td>3</td>
<td>10-07-2015</td>
<td>Section 3.1 Power Line Communication Requirements added,</td>
</tr>
<tr>
<td>4</td>
<td>10-15-2015</td>
<td>Changes added from 10/14/15 meeting</td>
</tr>
<tr>
<td>5</td>
<td>10-28-2015</td>
<td>Revision to Section 3.1.2, notes from 10/28/15 meeting</td>
</tr>
<tr>
<td>6</td>
<td>11-04-2015</td>
<td>Add Wireless Protocol</td>
</tr>
<tr>
<td>10</td>
<td>11-25-15</td>
<td>Add all changes discussed at meetings through November 25. Add revised Wireless Section 6</td>
</tr>
<tr>
<td>11</td>
<td>12-16-15</td>
<td>Add revised Wireless Proposal.</td>
</tr>
<tr>
<td>12</td>
<td>1-18-16</td>
<td>Changes defined frequencies, add Section 5.4.2 on Continuous Phase, make editorial changes throughout the document.</td>
</tr>
<tr>
<td>13</td>
<td>2-26-16</td>
<td>Incorporates edited copy throughout document and removed the wireless section to a separate document.</td>
</tr>
<tr>
<td>14</td>
<td>3-02-16</td>
<td>Incorporates edits from March 2, 2016 meeting</td>
</tr>
<tr>
<td>15</td>
<td>3-09-16</td>
<td>Incorporates edits from March 9, 2016 meeting</td>
</tr>
<tr>
<td>16</td>
<td>3-16-16</td>
<td>Incorporates edits from March 16, 2016 meeting</td>
</tr>
<tr>
<td>17</td>
<td>4-11-16</td>
<td>Incorporates edits from March 31, 2016 meeting and add Definition table and description of optional requirements.</td>
</tr>
<tr>
<td>18</td>
<td>5-18-16</td>
<td>Incorporated edits from May 18, 2016 meeting.</td>
</tr>
<tr>
<td>19</td>
<td>5-27-16</td>
<td>Incorporates changes inferred from the output of the Amplitude/EMC subgroup chaired by Michael Viotto</td>
</tr>
<tr>
<td>20</td>
<td>6-01-2016</td>
<td>Updated Table 1 Mode Transition Parameters to incorporate input.</td>
</tr>
<tr>
<td>21</td>
<td>6-28-2016</td>
<td>Updated formatting and layout, removed test plan outline.</td>
</tr>
<tr>
<td>22</td>
<td>8-30-2016</td>
<td>(1) Updates to incorporate 3-on, 13-off duty</td>
</tr>
<tr>
<td>Date</td>
<td>23</td>
<td>9-07-2016</td>
</tr>
<tr>
<td>----------</td>
<td>----------</td>
<td>-----------</td>
</tr>
<tr>
<td>Date</td>
<td>24</td>
<td>9-16-2016</td>
</tr>
</tbody>
</table>
| Date     | 25       | 9-21-2016 | • Changed terminology of master/slave to transmitter/receiver  
• Added Figure 1  
• Added Figure 5  
• Added footnote 5 to Table 5  
• Added Appendix D |
| Date     | 26       | 10-3-16   | • Added revised Figure 1  
• Added changes from 9/28/16 meeting  
• Added revisions to Table 6 |
| Date     | 27       | 10-20-16  | • Final copy editing                                                                 |
| Date     | 28       | 10-28-16  | • Changes discussed at 10/26/16 Working Group meeting added                                    |
| Date     | 29       | 4-13-17   | • Revise Footnote 5 to Table 6  
• Table 6 – revise $T_s$ |
| Date     | 30       | 4-26-17   | • Change to timing requirements in Section 4.4  
• Values changes in Figure 5 and Table 5  
• Table 4 revised to agree with Table 4. |
| Date     | 32       | 6-7-17    | • Cleaned up numbering of requirements                                                            |
|     |     | • Edits to Section 4.3  
|     |     | • Edits to Table 1 and footnotes to Table 1  
|     |     | • Revised Requirement 5.2.6  
|     |     | • Revised Table 6 for Proprietary Use and Reserved signals; added footnotes 2-4  
|     |     | • Edited total of Appendix C  
|     |     | • Corrected values in Appendix D  
| 33  | 06-14-17 | • Editorial revisions to Requirements 5.1.1 and 5.2.4 and Footnote 2 for Table 6.  |
About the SunSpec Alliance

The SunSpec Alliance is a trade alliance of developers, manufacturers, operators and service providers, pursuing open information standards for the Distributed Energy industry. SunSpec Alliance standards address operational aspects of PV, storage and Distributed Energy power plants on the smart grid—including residential, commercial, and utility-scale systems—thus reducing cost, promoting innovation, and accelerating industry growth.

Global leaders from Asia, Europe, and North America are members of the SunSpec Alliance. Membership is open to corporations, non-profits, and individuals. For more information about the SunSpec Alliance, or to download SunSpec specifications at no charge, please visit www.sunspec.org.

About the SunSpec Specification Process

SunSpec Alliance specifications are developed by SunSpec member companies seeking to establish industry standards for mutual benefit. Any SunSpec Alliance member can propose a technical work item. Given sufficient interest and time to participate, and barring significant objections, a workgroup is formed. Workgroups meet regularly to advance the agenda of the team.

The output of a workgroup is a SunSpec interoperability specification. SunSpec interoperability specifications are considered to be normative, meaning that there is a matter of conformance required to support interoperability. The revision and associated process of managing these documents is tightly controlled. Other SunSpec documents are informative, and provide recommendations regarding best practices, but are not a matter of conformance. Informative documents can be revised more freely and frequently to improve the quality and quantity of information provided.

SunSpec interoperability specifications follow this lifecycle pattern of DRAFT, TEST, APPROVED and SUPERSEDED.

For more information or to download a SunSpec Alliance specification, go to http://sunspec.org/about-sunspec-specifications/.
# Contents

1 Overview .......................................................................................................................... 10

2 Specification Objectives .................................................................................................. 10

3 General Requirements ...................................................................................................... 10
   3.1 System Configuration ................................................................................................. 11
   3.2 Operational Considerations ....................................................................................... 12
   3.3 Safety Considerations ............................................................................................... 13

4 Modes of Operation ........................................................................................................... 13
   4.1 Active Mode ............................................................................................................... 13
   4.2 Shutdown Mode ........................................................................................................... 13
   4.3 Standby Power For Electronics .................................................................................. 14
   4.4 Mode Transitions ....................................................................................................... 14
   4.5 Mode Transition Parameters ..................................................................................... 15

5 Power Line Communication (PLC) Requirements ............................................................. 16
   5.1 Transmitter Requirements ......................................................................................... 16
   5.2 Receiver Requirements ............................................................................................. 19
   5.3 PLC Protocol Requirements ...................................................................................... 21

6 Test Plan Specification .................................................................................................... 23

7 Appendix A: References .................................................................................................. 24

8 Appendix B: Spread Frequency Shift Keying (S-FSK) Principle ........................................ 24

9 Appendix C: Low Power Standby ................................................................................... 25

10 Appendix D: PV System Configuration Limits for the provided Power Line
    Communication Values .................................................................................................... 25

11 Appendix E: Adoption of 2017 NEC ............................................................................. 24
Tables

Table 1 Mode Transition Parameters........................................................................................................... 15
Table 2 Out-of-Band Spectral Mask Parameters........................................................................................... 18
Table 3 In-Band Spectral Mask Parameters.................................................................................................. 18
Table 4 Rejection Ratio Values..................................................................................................................... 20
Table 5 In-Band Rejection Values................................................................................................................ 21
Table 6 Power Line Communication Values................................................................................................ 23

Figures

Figure 1: Rapid Shutdown System................................................................................................................... 11
Figure 2 Out-of-Band Spectral Mask Graphic................................................................................................. 18
Figure 3 In-Band Spectral Mask Graphic....................................................................................................... 19
Figure 4 Rejection Ratio Graph..................................................................................................................... 20
Figure 5 In-Band Rejection Graphic............................................................................................................ 21
Figure 6 FSK on Frequency Domain............................................................................................................ 24
## Definitions

<table>
<thead>
<tr>
<th>Term</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Components</td>
<td>Equipment intended to be used in a PV Rapid Shutdown System to initiate, disconnect, isolate or attenuate the controlled conductors of a PV system. (UL 1741, Section 2.49D). UL 1741 refers to components as PV Rapid Shutdown Equipment (PVRSE).</td>
</tr>
<tr>
<td>Initiation Device</td>
<td>A manual or automatic switching device, input port or signal that will result in the activation of the Rapid Shutdown System function(s). An initiation device is intended to meet the function of the initiation methods mentioned in Section 690.12 of the National Electrical Code (UL 1741, Section 2.49B). The Initiation Device is the same as the Initiator.</td>
</tr>
<tr>
<td>PV Power Source</td>
<td>A dc array or aggregate of arrays that generates dc power. (see NEC, Section 690.2)</td>
</tr>
<tr>
<td>Receiver</td>
<td>The equipment that is responsible for accepting the communication signal sent by a Transmitter and is capable of initiating a state change of PV power source components based on the signal received. (see Section 3.1 of this document)</td>
</tr>
<tr>
<td>System</td>
<td>System made up of components intended to disconnect, isolate or attenuate the controlled conductors of a PV system. (see UL 1741, Section 2.49E)</td>
</tr>
<tr>
<td>Rapid Shutdown System</td>
<td>Collection of Components and Communication Protocols that are used to fulfill rapid shutdown requirements as defined by NEC 2014 or NEC 2017. Components of a rapid shutdown communication system are Initiator(s), Transmitter(s), and Receiver(s).</td>
</tr>
<tr>
<td>Transmitter</td>
<td>The equipment that is responsible for sending a communication signal that reflects the current state of the Initiation Device. (see Section 3.1 of this document)</td>
</tr>
</tbody>
</table>
1 Overview

The National Electrical Code (NEC) applies to the construction of PV systems installed on buildings and does not apply to ground-mount PV systems. The 2014 version of the NEC (2014 NEC) includes a requirement for rapid shutdown of controlled conductors outside the PV array boundary. The 2017 version of the NEC (2017 NEC) includes a requirement for module-level shutdown. The module-level shutdown requirement is anticipated to become effective January 1, 2019 rather than January 1, 2017 for the rest of the code.

UL 1741 is concurrently being revised to include requirements for PV Rapid Shutdown Equipment (PVRSE) and PV Rapid Shutdown Systems (PVRSS). The current revision of the UL 1741 standard requires PVRSE and PVRSS be designed to meet 2014 NEC requirements. A future revision will include the requirement for PVRSE and PVRSS to meet the 2017 NEC.

To meet the requirements of the 2017 NEC and UL 1741, it is advantageous for modules, inverters, charge controllers, and other equipment to communicate with each other. Furthermore, it is desirable to have a single communication protocol to provide interoperability between the different components from different manufacturers that are required to participate in a Rapid Shutdown System. This specification describes a Rapid Shutdown System communication protocol.

It is possible to achieve NEC compliance without a Rapid Shutdown System communication protocol. This specification does not apply in that case.

2 Specification Objectives

The objectives of this specification are:

- Identify the communication requirements specified or implied by NEC 2014, NEC 2017 and UL 1741 that pertain to module-level rapid shutdown.
- Describe a communication framework that is open, flexible, scalable, and available royalty-free to manufacturers of power electronics, PV modules, inverters, and PV balance-of-system components that addresses module-level rapid shutdown requirements.
- Define parameters and operating ranges associated the communication framework to support module-level rapid shutdown such that disparate components can be evaluated for conformance to this specification and multi-vendor interoperability can be achieved.

This document is offered at no cost from SunSpec.org and is part of a library of royalty-free SunSpec Alliance interoperability specifications.

3 General Requirements

These general requirements apply to PV system components and communication networks supporting the Rapid Shutdown System communication capabilities defined in relevant NEC and UL standards.
This SunSpec Communication Signal for Rapid Shutdown Specification defines how to propagate the operational state of the entire PV system to the individual power production components comprising the PV system. The document also describes requirements and constraints associated with power line communication networks that are used to support this application.

3.1 System Configuration

A Rapid Shutdown System is a collection of Components and Communication Protocols that are used to fulfill rapid shutdown requirements as defined by NEC 2014 or NEC 2017. Components of a rapid shutdown communication system are Initiator(s), Transmitter(s), and Receiver(s).

The SunSpec Communication Signal for Rapid Shutdown Specification is designed to support rapid shutdown requirements of any PV system governed by NEC 2014, NEC 2017, or applicable UL standard(s), irrespective of system configuration. Issues that commonly affect application protocol performance, such as cross-talk from other protocols, noise, and line impedance, must be accounted for.

*All initiators defined in NEC 2017, art. 690.12 (C) ‘Initiation Device’ are permitted

Figure 1: Rapid Shutdown System
Initiator
An Initiator is the equipment that is responsible for initiating the rapid shutdown mechanism in the System.
The term Initiator, in this context, is defined in the 2017 NEC.

3.1.1 Requirement: A System must have one or more Initiator(s).

Transmitter
A Transmitter is the equipment that is responsible for sending a communication signal that reflects the current state of the Initiator. The portion of the PV system controlled by a single Transmitter is referred to as a Sub-system. The minimum and maximum size of a Sub-system supported by a single Transmitter is manufacturer-dependent and must be specified by the manufacturer.

3.1.2 Requirement: A System must have at least one Transmitter.

3.1.3 Requirement: A Sub-system must have only one Transmitter.

3.1.4 Requirement: A Transmitter must comply with the minimum output voltage and minimum output source impedance specified in Table 1 Mode Transition Parameters.

Receiver
A Receiver is the equipment that is responsible for accepting the communication signal sent by a Transmitter and is capable of initiating a state change of PV power source components based on the signal received.

3.1.5 Requirement: A Sub-system must have at least one Receiver.

Transmitter/Receiver Interactions
Transmitter/Receiver interactions are at the heart of Communication Signal for Rapid Shutdown operation. By optimizing for efficiency and simplicity, low-cost and reliable system solutions are possible.

3.1.6 Requirement: A Transmitter must transmit a permission to operate signal to Receivers when the Initiator indicates rapid shutdown is not active.

3.1.7 Requirement: A Transmitter must stop transmitting a permission to operate signal to Receivers when the Initiator indicates rapid shutdown is active.

3.1.8 Requirement: A Receiver must be able to receive a permission to operate signal and initiate the ability of the associated power-producing equipment to produce power.

3.1.9 Requirement: A Receiver must detect the absence of a permission to operate signal and initiate the shutdown of power production by associated power producing equipment.

3.2 Operational Considerations
Operational simplicity is a key goal of the Communication Signal for Rapid Shutdown Specification. Complexity or unnecessary human interaction is to be avoided if possible.
3.2.1 Requirement: Rapid Shutdown Systems must provide a mechanism to bring the PV system(s) back online after a rapid shutdown event.

Local regulations may add requirements for start-up activation.

3.3 Safety Considerations

Mandatory features of the Communication Signal for Rapid Shutdown Specification represent minimum functionality required to achieve NEC 2014 or NEC 2017 safety standards.

3.3.1 Requirement: Communication Signal for Rapid Shutdown Systems must support shut down in a manner that meets the function safety requirements of UL 1741.

3.3.2 Requirement: Communication Signal for Rapid Shutdown System must energize the PV system only when Initiator mechanism is set to “permission to operate” position.

3.3.3 Requirement: Communication Signal for Rapid Shutdown Systems must conform to applicable UL standard(s).

4 Modes of Operation

Two modes of operation are defined for a Rapid Shutdown System: Active Mode and Shutdown Mode. Active Mode is characterized by the typical state of a PV system, generating power unimpeded by the Rapid Shutdown System. For this condition to persist, the Initiator must be set to the “on” state. If the Initiator is set to “off” state, the respective Transmitter (including all Sub-systems) must enter the Shutdown Mode. Transitioning from Active Mode to Shutdown Mode must comply with overall timing constraints as set forth in NEC 2017. There are no timing constraints when transitioning from Shutdown Mode to Active Mode.

4.1 Active Mode

No specifications or restrictions are placed on PV generators during the Active (power producing) Mode. The Rapid Shutdown System must continuously monitor the Initiator for a change in operating state.

4.2 Shutdown Mode

NEC 2017 specifications require the illuminated PV generators and complete PV system to be de-energized to a maximum when in the Shutdown Mode. Instead of completely zeroing output power capability, the receiver must provide a non-zero output voltage and current within the range offered as allowable by NEC 2017. Please see Appendix C: Standby for additional information about the advantages of this approach.
4.3 Standby Signal/Standby Power

When in shutdown mode, the receiver shall provide a standby signal to indicate the presence of irradiance. Furthermore, it is possible for Receiver(s) to provide enough standby power to supply both the standby signal and the “permission to operate” circuitry (e.g. the Transmitter or signal generator and a circuit which measures and signals the Shutdown operation) from the illuminated PV generator. This prevents a deadlock with purely PV powered systems. With this feature no AC supply is needed to power up the system.

4.3.1 Requirement: The output power of the PV system in Shutdown Mode must stay below the maximum voltage specifications stated per NEC 2017.

4.3.2 Requirement: The minimum current available in the shutdown state must be sufficient to guarantee operation of equipment monitoring the state of the modules as specified in Table 1 Mode Transition Parameters.

4.3.3 Requirement: When in the Shutdown state, each PV generator must provide output voltage $V_{OFF}$, with minimum current $I_{OFF}$ as defined in Table 1 Mode Transition Parameters.

4.3.4 Option (Standby Power): When in the Shutdown state, each PV generator must provide output voltage $V_{OFF}$, with minimum current $I_{OFFHI}$.

When offering power to the Transmitter is desirable, higher current capability is required. Standby Power (4.3.4) is an option and not a requirement but may be implemented and validated for conformance to this specification.

4.4 Mode Transitions

NEC 2014 and NEC 2017 allow for 30 seconds from the initiation event until the system must be fully settled in the de-energized Shutdown Mode. In order to facilitate interoperability, it is important that the total time to de-energize is equitably allocated to the constituent steps of the de-energization process.

A typical de-energization process (mode transition) can be considered as the following sequence of events.

- TT1: Initiator signals Shutdown Mode to Transmitter
- TT2: Transmitter ceases to send permission to operate signal to Receiver(s)
- TT3: Receivers de-energize all PV Power Sources
- TT4: Inverter stored charge is eliminated

The timing requirements for this sequence of events are indicated in Table 1 Mode Transition Parameters.

There is a single requirement placed on the system with respect to a mode transition from Shutdown Mode to Active Mode.

- TR1: Time for Receivers to enable PV power generation after compliant KeepAlive signaling commences at the output of the Transmitter.
4.5 Mode Transition Parameters

The following values and parameter ranges are Requirements of the Mode Transition attributes of this specification.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Mode Specification</th>
<th>Min.</th>
<th>Max.</th>
<th>Unit</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{OFF}$</td>
<td>PV Power Source voltage in Shutdown</td>
<td>0.6</td>
<td>NA</td>
<td>V</td>
<td>Accommodates % or fixed methods</td>
</tr>
<tr>
<td>$I_{OFF}$</td>
<td>Output current for $V_{OFF}$ tolerance window</td>
<td>10</td>
<td>NA</td>
<td>mA</td>
<td>Requirement</td>
</tr>
<tr>
<td>$I_{OFFHI}$</td>
<td>Output current for $V_{OFF}$ tolerance window for high power option</td>
<td>400</td>
<td>NA</td>
<td>mA</td>
<td>Option</td>
</tr>
<tr>
<td>TT1</td>
<td>Time for Initiator to relay to Transmitter</td>
<td>NA</td>
<td>2</td>
<td>s</td>
<td></td>
</tr>
<tr>
<td>TT2</td>
<td>Time for Transmitter to stop permission to operate signal</td>
<td>NA</td>
<td>2</td>
<td>s</td>
<td></td>
</tr>
<tr>
<td>TT3</td>
<td>Time for Receiver to de-energize PV Power Sources</td>
<td>NA</td>
<td>13</td>
<td>s</td>
<td></td>
</tr>
<tr>
<td>TT4</td>
<td>Time for Inverter stored charge to be eliminated</td>
<td>NA</td>
<td>13</td>
<td>s</td>
<td></td>
</tr>
<tr>
<td>TT5</td>
<td>Total time to complete TT1+TT2+TT3+TT4</td>
<td>NA</td>
<td>30</td>
<td>s</td>
<td></td>
</tr>
<tr>
<td>TR1</td>
<td>Time for Receivers to enable PV power generation after compliant KeepAlive signaling commences at the output of the Transmitter.</td>
<td>NA</td>
<td>20</td>
<td>s</td>
<td>Under all expected operating conditions.</td>
</tr>
</tbody>
</table>

Table 1 Mode Transition Parameters

(V$_{OFF}$)

According to NEC 2017 the generator voltage in shutdown mode shall not exceed 30 V. This requirement limits the maximum number of modules that can be connected in series in dependence on $V_{OFF}$. The smaller $V_{OFF}$, the more modules can be put into one string. In contrast, a higher $V_{OFF}$ is more useful for installation and maintenance of the system. For example, with the maximum $V_{OFF}$ of 1 V, strings with 30 modules are possible, allowing for a wide range of systems.

In addition to choosing a fixed voltage for this parameter, the wide range allows a relative value which depends on the actual open circuit voltage of the switched off module. This gives information on the available PV voltage, which can help during installation and operation. As an example for a typical 60 cell PV module the value for $V_{OFF}$ can be chosen as 2% of the actual voltage of the PV module. This would result in a $V_{OFF}$ of 0.8V at an actual 40 V open circuit voltage of the PV module. The manufacturer of the module should provide information about the implementation (fixed or relative) and the value of $V_{OFF}$ in the product data sheet.

(I$_{OFFHI}$)

According to NEC 2014 and UL 1741, the generator current in shutdown mode shall not exceed 8 A (240VA). This requirement limits the maximum number of strings that can be connected in parallel in dependence on this parameter. The smaller $I_{OFFHI}$ the more strings can be implemented in parallel. In contrast, a higher $I_{OFFHI}$ is more useful for powering...
auxiliary circuitry to prevent the dead lock situation described in Section 4.3. For example, with a $I_{OFFH}$ of 0.8 A, PV generators with 10 strings in parallel are allowed. The choice of a larger $I_{OFFH}$ can be beneficial for the overall system (e.g., less requirement on the auxiliary circuit, better startup of the system at low generator voltage). The value for $I_{OFFH}$ can be chosen by the designer of the PV module and is dependent on the anticipated use of the PV module. A PV module which is targeted at off grid systems could have a higher $I_{OFFH}$ because the system start up on PV power only has a high value in this application which can justify the additional effort in the module integrated electronics with a higher $I_{OFFH}$. The manufacturer of the module should give information about the value of $I_{OFFH}$ in the data sheet.

**Total Time**

The total time for shutdown is 30 seconds per the 2014 and 2017 NEC.

## 5 Power Line Communication (PLC) Requirements

A Transmitter communicates with all Receivers in the Sub-system over Power Line Communications. The Transmitter continuously transmits a “permission to operate” bit sequence to indicate PV Power Sources have permission to operate in the Active Mode. If the Transmitter ceases to transmit the permission to operate sequence then the Sub-system enters the Shutdown Mode. Other bit sequences are defined and reserved for future use.

### 5.1 Transmitter Requirements

The Transmitter broadcasts a permission to operate signal using a Spread Frequency Shift Keying (S-FSK) modulation. The Transmitter must provide the Receiver(s) with signals at satisfactory level for demodulation. It must develop sufficient power on a given load impedance and must have a well-defined output impedance.
5.1.1 Requirement: Transmitter(s) must continuously send a cyclical code sequence, which includes ‘permission to operate’ when an Initiator indicates rapid shutdown is not active, corresponding to the code sequences defined in Table 6.

5.1.2 Requirement: Transmitter(s) must have an output impedance in the range specified for \( Z_{\text{OUT}} \) in the transmission frequency band \( F_M \) to \( F_S \).

5.1.3 Requirement: Transmitter(s) must provide an open circuit output voltage in the range specified for \( V_{\text{TX}} \).

5.1.4 Requirement: Transmitter(s) must transmit permission to operate signal using a mark and space tone frequency of \( F_M \) and \( F_S \) respectively.

5.1.5 Requirement: Transmitter(s) must maintain the transmission of a mark or a space tone for \( T_S \) duration.

5.1.6 Requirement: Transmitter(s) must transmit ‘permission to operate’ signals according to a fixed duty cycle defined by an integer number of consecutive transmitted code words followed by an integer number of zero-energy code words.

5.1.7 Requirement: Transmitter(s) must maintain phase coherency when transitioning between mark and space tones.

5.1.8 Requirement: Transmitter(s) must maintain SFSK tone frequencies (\( F_M \) and \( F_S \)) and effective bit rate (\( R_S \)) to within a \( \pm 100\text{ppm} \) tolerance when in operation inclusive of allowances for temperature and aging.

5.1.9 Requirement: Transmitter(s) must ensure that the SFSK tone frequencies and the effective bit rate remain proportional to each other for variations within their permitted tolerances.

Transmitter Out-of-Band Emission Requirements

The Transmitter(s) must not generate spurious out-of-band signals that could interfere with other communication systems or with PV system components like MPP tracker or AFCI.

5.1.10 Requirement: the Out-of-Band spurious frequency components must not exceed the levels defined in Table 2 and depicted in Figure 2.
To ensure easy separation of the carriers in the demodulator, the in-band spectrum of the two FSK carriers must be limited.

5.1.11 Requirement: In-Band frequency components must not exceed the levels defined in Table 3 and depicted in Figure 3.

The frequency and amplitude values are relative to the actual frequency and power of each of the two FSK carriers.

<table>
<thead>
<tr>
<th>In-Band Spectral Mask</th>
<th>-50 &lt; F ≤ -9</th>
<th>-9 &lt; F ≤ -5</th>
<th>-5 &lt; F ≤ 5</th>
<th>5 &lt; F ≤ 9</th>
<th>9 &lt; F ≤ 50</th>
</tr>
</thead>
<tbody>
<tr>
<td>F-Fc [kHz]</td>
<td>-30</td>
<td>-20</td>
<td>0</td>
<td>-20</td>
<td>-30</td>
</tr>
<tr>
<td>P [dBc]</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3 In-Band Spectral Mask Parameters
5.2 Receiver Requirements

The Receiver(s) must be able to handle a large range of input signal amplitude. Maximum amplitude is received with maximum TX power and minimum PV string attenuation, and conversely, minimum signal is received with minimum TX power and maximum PV string attenuation.

5.2.1 Requirement: Receiver(s) must decode the FSK signals at $F_M$ and $F_S$ as sent by the Transmitter.

5.2.2 Requirement: Receiver(s) must indicate the presence of permission to operate signals without gaps or interruptions over at least a one (1) hour observation period in the presence of an SunSpec-compliant SFSK signal having a compliant duty cycle and an amplitude in the range $V_{RXSENSE} \text{ mV} - V_{RXMAX} \text{ mV}$ r.m.s.

5.2.3 Requirement: Receiver(s) must meet the requirements of this specification when tested with SunSpec-compliant signals that are subject to any allowable frequency/timing offset within the tolerances specified in Table 6.

5.2.4 Requirement: Receiver(s) must indicate the absence of permission to operate signals in response to any SunSpec compliant code other than the designated code sequences, which state a permission to operate code specified in Table 6.

5.2.5 Requirement: Receiver(s) must have pass-through impedance with absolute value in the range specified for $Z_{RXS}$ and $Z_{RXM}$ at $F_S$ and $F_M$ frequencies respectively.

5.2.6 Requirement: Receiver(s) must indicate the absence of permission to operate signals without any false alarms over at least one hundred (100) hours observation period in the presence of a standardized noise and interference test signal as specified in the SunSpec Rapid Shutdown Compatibility Test Plan.
Informative Note: Manufacturers are advised that Keep Alive code word consistency checking should be implemented so as to guarantee a rate of false alarms of less than one per hundred hours of continuous operation. Methods to achieve this include, but are not limited to, checking the bit pattern match of two or more successive code word triplets \(W_1W_2W_1\) and checking the time interval between them is within acceptable tolerances. Due to practical concerns, compliance testing may use shorter observation intervals than the above-specified formal requirement.

Receiver Out-of-Band Rejection Specifications

The receiver must not be perturbed by signals outside the receive band.

5.2.7 Requirement: Receiver must tolerate the presence of out-of-band signals having rejection ratio values as defined in Table 4 Rejection Ratio Values and depicted in Figure 4 Rejection Ratio Graph, for a sensitivity reduction of no more than 3dB.

<table>
<thead>
<tr>
<th>Frequency (KHz)</th>
<th>0 ≤ F ≤ 30</th>
<th>30 ≤ F ≤ 72</th>
<th>72 &lt; F ≤ 120</th>
<th>120 &lt; F ≤ 155</th>
<th>155 &lt; F ≤ 200</th>
<th>200 &lt; F ≤ 300</th>
<th>300 &lt; F ≤ 1000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rejection (dB)</td>
<td>-50</td>
<td>-40</td>
<td>-20</td>
<td>0</td>
<td>-20</td>
<td>-30</td>
<td>-40</td>
</tr>
</tbody>
</table>

Table 4 Rejection Ratio Values

![Graph of rejection ratio values](image)

Figure 4 Rejection Ratio Graph

Receiver In-Band Rejection Specifications

The receiver must be able to separate the two carrier frequencies of the FSK modulated RF signal.

5.2.8 Requirement: Receiver must reject in-band signals by values defined in Table 5 In-Band Rejection Values and depicted in Figure 5 In-Band Rejection Graphic.
Rx In-Band Rejection

<table>
<thead>
<tr>
<th>F-Fc [kHz]</th>
<th>-50 &lt; F ≤ -9</th>
<th>-9 &lt; F ≤ -3</th>
<th>-3 &lt; F ≤ 3</th>
<th>3 &lt; F ≤ 9</th>
<th>9 &lt; F ≤ 50</th>
</tr>
</thead>
<tbody>
<tr>
<td>RR [dB]</td>
<td>-20</td>
<td>-20</td>
<td>0</td>
<td>-20</td>
<td>-20</td>
</tr>
</tbody>
</table>

Table 5 In-Band Rejection Values

Figure 5: In-Band Rejection Graphic

### 5.3 PLC Protocol Requirements

![Diagram of PLC Protocol]

**Figure 5: Keep Alive Duty Cycle Timing Diagram**

The following values and parameter ranges are Requirements of the Power Line Communication attributes of this specification.
<table>
<thead>
<tr>
<th>Symbol</th>
<th>Transmitter Specification</th>
<th>Min.</th>
<th>Nom.</th>
<th>Max.</th>
<th>Unit</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>$W_1$</td>
<td>Logic 1 Code Word</td>
<td>${-1, -1, -1, +1, +1, -1, +1, -1, +1}$</td>
<td></td>
<td></td>
<td></td>
<td>kHz</td>
</tr>
<tr>
<td>$W_0$</td>
<td>Logic 0 Code Word</td>
<td>${+1, +1, +1, -1, -1, -1, +1, +1, -1, -1, -1}$</td>
<td></td>
<td></td>
<td></td>
<td>kHz</td>
</tr>
<tr>
<td>$Z$</td>
<td>Zero Energy Word</td>
<td>${0, 0, 0, 0, 0, 0, 0, 0}$</td>
<td></td>
<td></td>
<td></td>
<td>Hz</td>
</tr>
<tr>
<td></td>
<td>Cyclical Transmission</td>
<td>${A, B, C, Z, Z, Z, Z, Z, Z, Z, Z}$</td>
<td></td>
<td></td>
<td></td>
<td>kHz</td>
</tr>
<tr>
<td></td>
<td>Permission To Operate Code</td>
<td>$A\ B\ C = W_1\ W_1\ W_1$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Accelerated Shutdown</td>
<td>$A\ B\ C = W_0\ W_0\ W_0$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Proprietary Use 1</td>
<td>$A\ B\ C = W_1\ W_0\ W_1$</td>
<td></td>
<td></td>
<td></td>
<td>kHz</td>
</tr>
<tr>
<td></td>
<td>Includes permission to operate</td>
<td>$A\ B\ C = W_0\ W_0\ W_0$</td>
<td></td>
<td></td>
<td></td>
<td>kHz</td>
</tr>
<tr>
<td></td>
<td>Proprietary Use 2</td>
<td>$A\ B\ C = W_0\ W_1\ W_0$</td>
<td></td>
<td></td>
<td></td>
<td>kHz</td>
</tr>
<tr>
<td></td>
<td>Without permission to operate</td>
<td>$A\ B\ C = W_0\ W_0\ W_1$</td>
<td></td>
<td></td>
<td></td>
<td>kHz</td>
</tr>
<tr>
<td></td>
<td>Reserved</td>
<td>$A\ B\ C = W_0\ W_1\ W_0$</td>
<td></td>
<td></td>
<td></td>
<td>kHz</td>
</tr>
<tr>
<td></td>
<td>Includes permission to operate</td>
<td>$A\ B\ C = W_0\ W_0\ W_0$</td>
<td></td>
<td></td>
<td></td>
<td>kHz</td>
</tr>
<tr>
<td></td>
<td>Reserved</td>
<td>$A\ B\ C = W_0\ W_1\ W_1$</td>
<td></td>
<td></td>
<td></td>
<td>kHz</td>
</tr>
<tr>
<td></td>
<td>Without permission to operate</td>
<td>$A\ B\ C = W_0\ W_0\ W_1$</td>
<td></td>
<td></td>
<td></td>
<td>kHz</td>
</tr>
<tr>
<td></td>
<td>Reserved</td>
<td>$A\ B\ C = W_0\ W_1\ W_0$</td>
<td></td>
<td></td>
<td></td>
<td>kHz</td>
</tr>
<tr>
<td></td>
<td>Without permission to operate</td>
<td>$A\ B\ C = W_0\ W_0\ W_1$</td>
<td></td>
<td></td>
<td></td>
<td>kHz</td>
</tr>
<tr>
<td>$F_M$</td>
<td>Mark Frequency</td>
<td>131.236875</td>
<td>131.25</td>
<td>131.263125</td>
<td>kHz</td>
<td>$6.25kHz \times 21$</td>
</tr>
<tr>
<td>$F_S$</td>
<td>Space Frequency</td>
<td>143.735625</td>
<td>143.75</td>
<td>143.764375</td>
<td>kHz</td>
<td>$6.25kHz \times 23$</td>
</tr>
<tr>
<td>$T_S$</td>
<td>Average Bit Period</td>
<td>5.119488</td>
<td>5.12</td>
<td>5.120512</td>
<td>ms</td>
<td>(Time to complete one full duty cycle)/219</td>
</tr>
<tr>
<td>$T_T$</td>
<td>Transmission Period</td>
<td>168.943104</td>
<td>168.96</td>
<td>168.976896</td>
<td>ms</td>
<td>3 Words</td>
</tr>
<tr>
<td>$T_Q$</td>
<td>Quiet Period</td>
<td>901.029888</td>
<td>901.12</td>
<td>901.210112</td>
<td>ms</td>
<td>16 Words</td>
</tr>
<tr>
<td>$T_C$</td>
<td>Cycle Period</td>
<td>1069.972992</td>
<td>1070.08</td>
<td>1070.187008</td>
<td>ms</td>
<td>19 Words</td>
</tr>
<tr>
<td>$Z_{TX}$</td>
<td>Transmitter Output Impedance</td>
<td>0.05</td>
<td>1.5</td>
<td></td>
<td>Ω</td>
<td></td>
</tr>
<tr>
<td>VTX</td>
<td>Transmitter Output Voltage into &gt;100 kΩ</td>
<td>0.9</td>
<td>1.0</td>
<td>1.1</td>
<td>V r.m.s.</td>
<td></td>
</tr>
<tr>
<td>---------------------</td>
<td>----------------------------------------</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>----------</td>
<td></td>
</tr>
<tr>
<td>VRXMAX</td>
<td>Receiver Input Voltage Max</td>
<td>142</td>
<td></td>
<td></td>
<td>mV r.m.s.</td>
<td></td>
</tr>
<tr>
<td>VRXSENSE</td>
<td>Receiver Input Voltage Minimum Sensitivity</td>
<td></td>
<td>1.20</td>
<td></td>
<td>mV r.m.s.</td>
<td>118:1 dynamic range</td>
</tr>
<tr>
<td>ZRXS</td>
<td>Receiver Line Impedance @ FS</td>
<td>0.7</td>
<td></td>
<td>1.5</td>
<td>Ω</td>
<td></td>
</tr>
<tr>
<td>ZRXM</td>
<td>Receiver Line Impedance @ FM</td>
<td>0.7</td>
<td></td>
<td>1.5</td>
<td>Ω</td>
<td></td>
</tr>
<tr>
<td>P_FALSE</td>
<td>Probability of false detection</td>
<td></td>
<td></td>
<td></td>
<td>Per SunSpec testing</td>
<td></td>
</tr>
</tbody>
</table>

Table 6 Power Line Communication Values

Table Footnotes:

1. Sequences shall be transmitted in left-to-right order \{b1, b2, b3...\} means bit 1 followed by bit 2, followed by bit 3 etc.
2. Code words are transmitted continuously in a repetitive, cyclical fashion with no extraneous signaling bits nor additional time delay inserted between them.
3. Code sequences without permission to operate can be sent during a Rapid shutdown initiation while code sequences with permission to operate shall only be sent when an initiator indicates rapid shutdown is not active. If there is no functional indication to use any other code sequence with permission to operate, the code sequence A B C = W1 W1 W1 must be used.
4. Reserved code sequences are for future use by this standard.
5. Receiving a code sequence without permission to operate is not an accelerated shutdown and should be treated like there was no permission to operate signal received.
6. All frequencies and durations are subject to ±100 ppm tolerances on their nominal values at the transmitter.
7. Receivers shall perform within SunSpec specification limits for any long-term frequency deviations at the transmitter that lie within the allowable ±100 ppm tolerance.
8. Receivers may assume that transmitted bit rate and Mark/Space tone frequencies are correlated (i.e., derived from the same original clock source).
9. The receiver line impedance for the mark and space frequency is defined at the input terminals of the device, without the attached wiring under all operating conditions of the device. The specified sensitivity refers to this specified receiver line impedance.

6 Test Plan Specification

The test plan specification is a separate SunSpec document: Communication Signal for Rapid Shutdown Test Specification.
7 Appendix A: References

2014 National Electrical Code, National Fire Protection Association (section 690.12 includes Rapid Shutdown requirements)

2017 National Electrical Code, National Fire Protection Association (section 690.12 includes Rapid Shutdown requirements)

Underwriters Laboratories Standard 1741, Standard for Inverters, Converters, Controllers and Interconnection System Equipment for Use with Distributed Energy Resources (draft sections on Rapid Shutdown Equipment and Rapid Shutdown Systems)

8 Appendix B: Spread Frequency Shift Keying (S-FSK) Principle

S-FSK is a modulation and demodulation technique combining some of the advantages of a classical spread spectrum system, i.e., immunity against narrowband interferences with the advantages of a classical FSK system, low-complexity, and well-investigated implementations.

The transmitter assigns the space frequency $f_S$ to “data 0” and the mark frequency $f_M$ to “data 1”. The difference between S-FSK and the classical FSK lies in the fact that $f_S$ and $f_M$ are placed far from each other (spreading). By placing $f_S$ far from $f_M$, their transmission quality becomes independent, i.e., each frequency will have its own attenuation factor and local narrow-band noise spectrum.

The receiver performs conventional FSK demodulation at the two possible frequencies (the half-channels) resulting in two demodulated signals $d_S$ and $d_M$. If the average reception quality of the two half-channels is similar, then the decision unit decides on the higher of the two demodulated channels (“data 0” if $d_S > d_M$, “data 1” if $d_S < d_M$). If, however, the average reception quality of one half-channel is significantly better than the quality of the other half-channel, then the decision unit compares the demodulated signal of the better channel with a threshold $T$, thus ignoring the worse channel.

![Figure 6 FSK on Frequency Domain](image)

Figure 6 FSK on Frequency Domain
9 Appendix C: Standby Signal

When in shutdown mode, the Receiver(s) providing a low voltage, low current standby signal offer the following advantages:

**Reduced power consumption during the night**

The presence of the standby signal of the Receivers indicates the presence of daylight. It allows to turn-off the permission to operate signal of the Transmitter overnight and reduces thereby the power consumption of the system.

**Ease of installation**

The installer can verify the correct polarity, the count of modules per string, the string associated wires etc. without a special tool to inject the permission to operate signal. He has the additional benefit of working on safe voltage levels and limited power.

10 Appendix D: PV System Configuration Limits for the provided Power Line Communication Values

The provided Power Line Communication Values out of this Specification are based on the following PV System Configuration Limits:

- 6 to 30 modules with Receivers in series
- 1 to 10 strings in parallel per Transmitter
- Minimum wire impedance of 6.4 Ohm @ mark frequency (including module wiring; equates to 7.8 µH)
- Maximum wire impedance of 234 Ohm @ space frequency (including module wiring; equates to 259 µH)