APPROVED

Version 35

August 27, 2019

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.

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Attribution

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

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Revision History

Revision	Date	Reason
1	09-02-2015	First Draft in SunSpec Template
2	09-09-2015	General requirements revised per discussion at 9/9/15 Work Group meeting.
3	10-7-2015	Section 3.1 Power Line Communication Requirements added,
4	10-15-2015	Changes added from 10/14/15 meeting
5	10-28-2015	Revision to Section 3.1.2, notes from 10/28/15 meeting
6	11-4-2015	Add Wireless Protocol
10	11-25-15	Add all changes discussed at meetings through November 25. Add revised Wireless Section 6
11	12-16-15	Add revised Wireless Proposal.
12	1-18-16	Changes defined frequencies, add Section 5.4.2 on Continuous Phase, make editorial changes throughout the document.
13	2-26-16	Incorporates edited copy throughout document and removed the wireless section to a separate document.
14	3-2-16	Incorporates edits from March 2, 2016 meeting
15	3-9-16	Incorporates edits from March 9, 2016 meeting
16	3-16-16	Incorporates edits from March 16, 2016 meeting
17	4-11-16	Incorporates edits from March 31, 2016 meeting and add Definition table and description of optional requirements.
18	5-18-16	Incorporated edits from May 18, 2016 meeting.
19	5-27-16	Incorporates changes inferred from the output of the Amplitude/EMC subgroup chaired by Michael Viotto
20	6-1-2016	Updated Table 1 Mode Transition Parameters to incorporate input.

21	6-28-2016	Updated formatting and layout, removed test plan outline.
22	8-30-2016	(1) Updates to incorporate 3-on, 13-off duty cycle for AFD. (2) Included ±100ppm frequency tolerance allowance at the transmitter. (3) Required that receivers must tolerate ±100ppm frequency tolerance at the transmitter (4) Improved sensitivity requirement and reduced minimum receiver impedance per Amplitude Subgroup recommendations. (5) Stipulated MSB-first bit ordering in Table 5 footnote. (6) Defined an optional code to mean accelerated shutdown. Neither Transmitters nor Receivers are required to implement this.
23	9-07-2016	Replace Barker-13 word with Barker-11 word. Keep timing approximately constant by increasing number Zero codewords to 16. Resultant duty cycle is 3-on, 16-off.
24	9-16-2016	Adjust input impedance Z_rx after updated tolerance analysis.
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
26	10-3-16	• Added revised Figure 1 • Added changes from 9/28/16 meeting • Added revisions to Table 6
27	10-20-16	• Final copy editing
28	10-28-16	• Changes discussed at 10/26/16 Working Group meeting added
29	4-13-17	• Revise Footnote 5 to Table 6 • Table 6 – revise T_S
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.
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.
34	08-21-17	• Made formatting changes • Updated status to APPROVED
35	06-25-19	• Incorporated changes to sections 4.2 and 4.3 to address applications of the receiver in devices that are not PV modules • Referenced to UL 3741 in Appendix A • Set document status to TEST
36	08-27-2019	• Accepted changes from v35 • Set document status to APPROVED

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Definitions

Term	Meaning
Components	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).
Communication Protocol	Formal descriptions of digital message formats and rules.
Initiation Device	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.
PV Power Source	A dc array or aggregate of arrays that generates dc power. (see NEC, Section 690.2)
Receiver	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)
System	System made up of components intended to disconnect, isolate or attenuate the controlled conductors of a PV system. (see UL 1741, Section 2.49E)
Rapid Shutdown System	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).
Transmitter	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)

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.

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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.

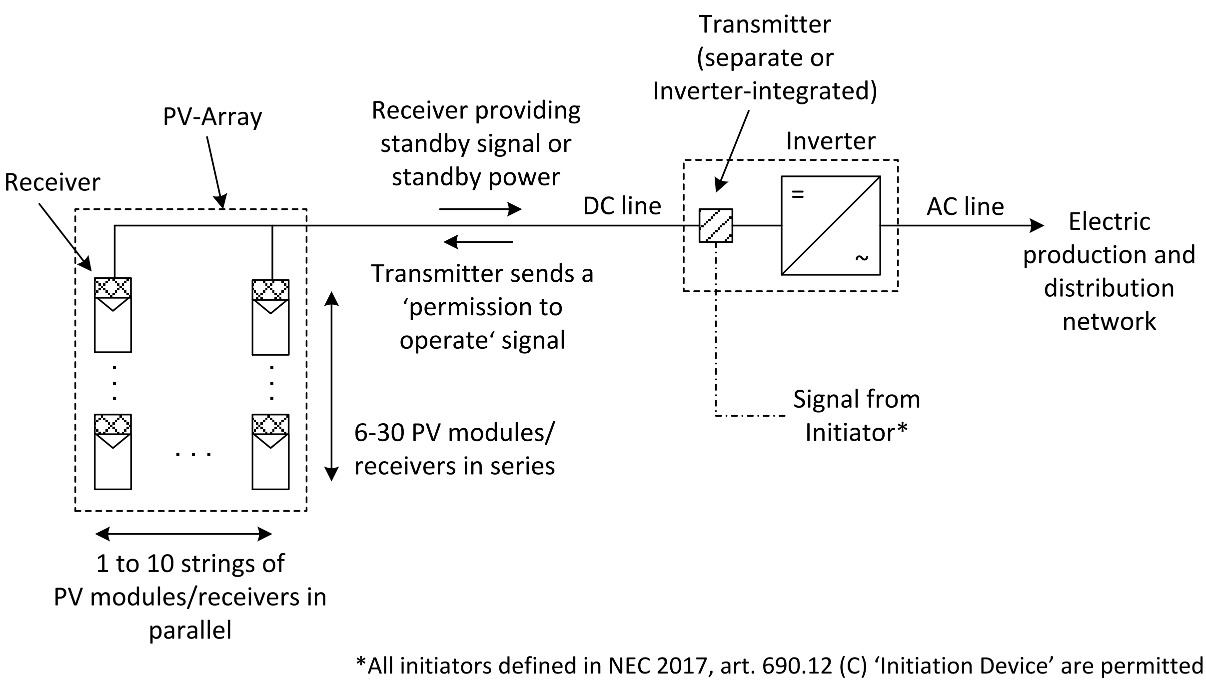

Figure 1: Rapid Shutdown System

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 system to be in a controlled state when in the Shutdown Mode.

4.2.1 Requirement: The output power of the PV system in Shutdown Mode must be controlled in accordance with NEC 2017.

4.3 Standby Signal/Standby Power

When in shutdown mode, the receiver shall provide a standby signal to indicate the presence of irradiance. The standby signal shall be a non-zero output voltage and current within the range allowed by NEC Article 690.12 (B)(2). Please see Appendix C: Standby for additional information about the advantages of this approach.

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 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.

4.3.2 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.

4.3.3 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 (4.3.3) is an option and not a requirement but may be implemented and validated for conformance to this specification. String or sub-string level disconnecting devices in systems compliant with UL 3741 and that do not control all modules in a string are exempt from the requirements of Section 4.3.

Note: UL 3741 provides for alternative methods of achieving rapid shutdown beyond the use of devices that control every module in a string. Where PV strings in Shutdown Mode consist of PV modules not bypassed by receiver devices, the voltage on those modules remain un-controlled, and therefore it is not practical for the sub-string devices to attempt to provide a shutdown state voltage or current.

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.

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

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_{OFFHI} of 0.8 A, PV generators with 10 strings in parallel are allowed. The choice of a larger I_{OFFHI} 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_{OFFHI} 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_{OFFHI} 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_{OFFHI}. The manufacturer of the module should give information about the value of I_{OFFHI} 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_{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_{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 ±100ppm 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.

Out-of-Band Spectral Mask								
				F_M – 11.25	F_M – 11.25	min(F_S + 11.25, 150)	min(F_S + 11.25, 150)	
F [kHz]	0	72	72	120	120	150	150	1000
P [dBm]	-60	-60	-40	-40	0	0	-40	-40

Table 2 Out-of-Band Spectral Mask Parameters

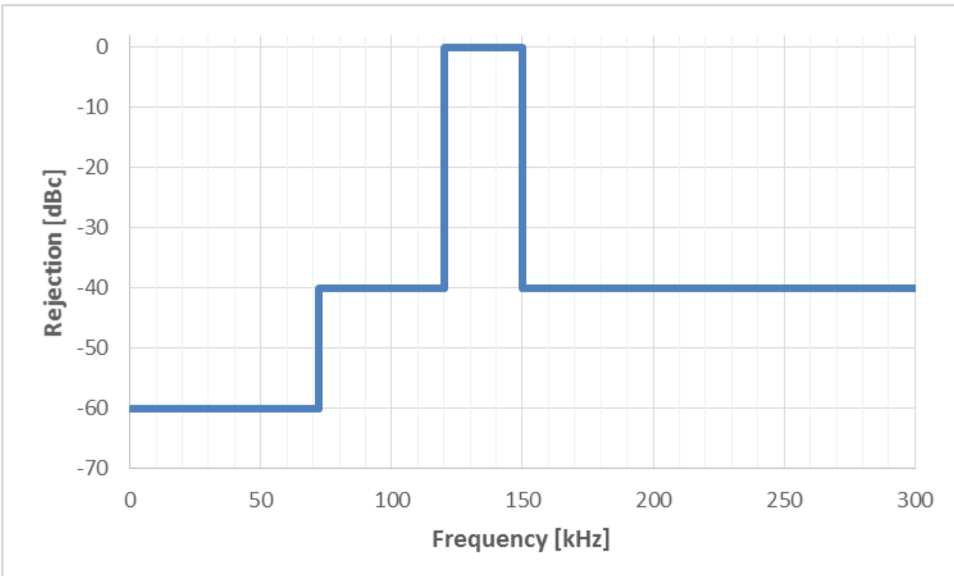

Figure 2 Out-of-Band Spectral Mask Graphic

Transmitter In-Band Emission Requirements

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.

In-Band Spectral Mask					
F-Fc [kHz]	-50 < F ≤ -9	-9 < F ≤ -5	-5 < F ≤ 5	5 < F ≤ 9	9 < F ≤ 50
P [dBc]	-30	-20	0	-20	-30

Table 3 In-Band Spectral Mask Parameters

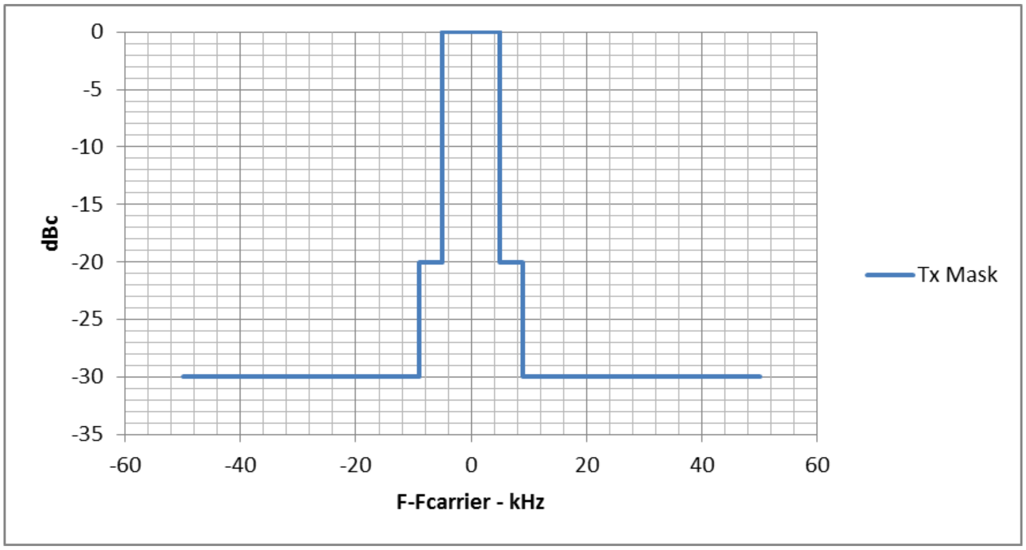

Figure 3 In-Band Spectral Mask Graphic

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 $V_{RXSENSE}$ mV – V_{RXMAX} 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 ($W_1W_1W_1$) 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.**

Frequency (KHz)	0 < F ≤ 30	30 < F ≤ 72	72 < F ≤ 120	120 < F ≤ 155	155 < F ≤ 200	200 < F ≤ 300	300 < F ≤ 1000
Rejection (dB)	-50	-40	-20	0	-20	-30	-40

Table 4 Rejection Ratio Values

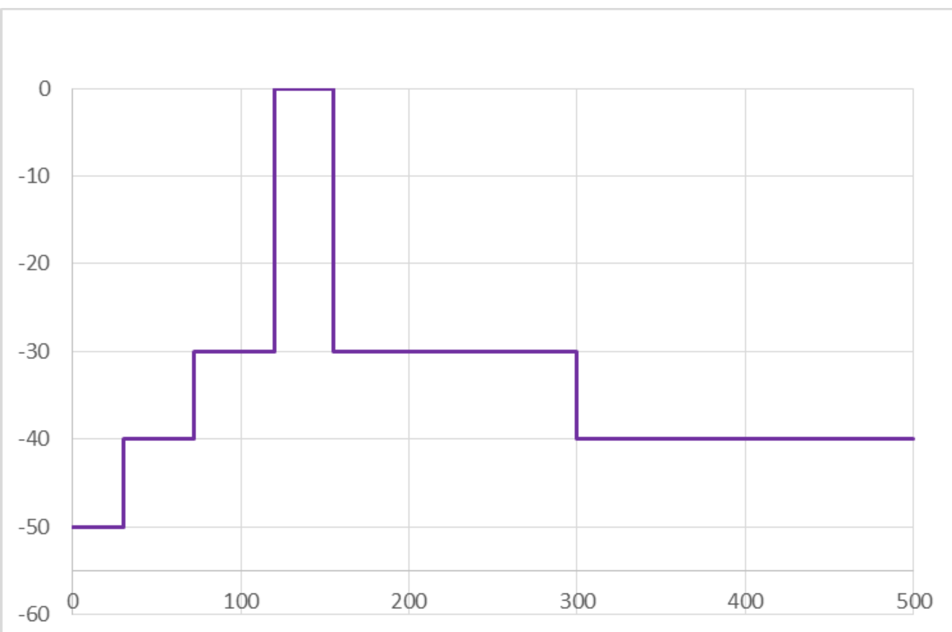

Figure 4 Rejection Ratio Graph

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					
F-Fc [kHz]	-50 < F ≤ -9	-9 < F ≤ -3	-3 < F ≤ 3	3 < F ≤ 9	9 < F ≤ 50
RR [dB]	-20	-20	0	-20	-20

Table 5 In-Band Rejection Values

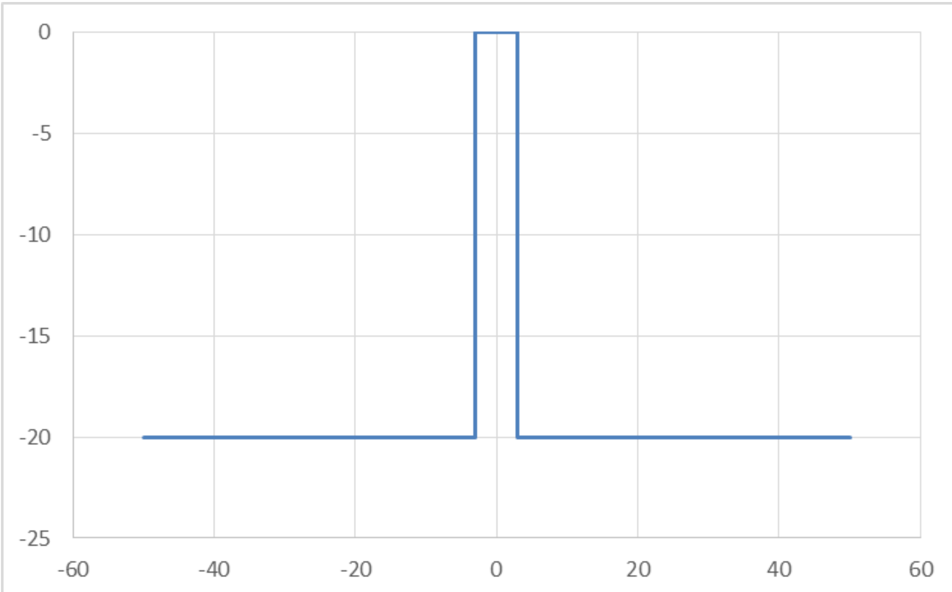

Figure 5 In-Band Rejection Graphic

5.3 PLC Protocol Requirements

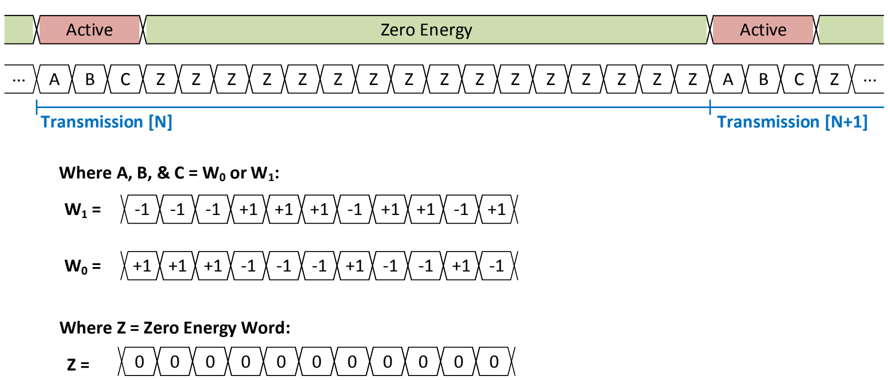

Figure 5: Keep Alive Duty Cycle Timing Diagram

The following values and parameter ranges are **Requirements of the Power Line Communication** attributes of this specification.

Symbol	Transmitter Specification	Min.	Nom.	Max.	Unit	Remark
W_1	Logic 1 Code Word	{{-1, -1, -1, +1, +1, +1, -1, +1, +1, -1, +1}				+1 = mark, -1=space
W_0	Logic 0 Code Word	{+1, +1, +1, -1, -1, -1, +1, -1, -1, +1, -1}				+1 = mark, -1=space
Z	Zero Energy Word	{0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0}				0 = zero energy
	Cyclical Transmission	{A, B, C, Z, Z, Z, Z, Z, Z, Z, Z, Z, Z, Z, Z, Z, Z, Z, Z}				A,B,C are W_0 or W_1 Z=zero energy word
	Permission To Operate Code	A B C = W_1 W_1 W_1				Mandatory
	Accelerated Shutdown	A B C = W_0 W_0 W_0				Optional
	Proprietary Use 1 Includes permission to operate	A B C = W_1 W_0 W_1				Optional
	Proprietary Use 2 Without permission to operate	A B C = W_0 W_1 W_0				Optional
	Reserved Includes permission to operate	ABC = W_1 W_1 W_0				Do not use
	Reserved Without permission to operate	ABC = W_0 W_0 W_1				Do not use
	Reserved Without permission to operate	ABC = W_0 W_1 W_1				Do not use
	Reserved Without permission to operate	ABC = W_1 W_0 W_0				Do not use
F_M	Mark Frequency	131.236875	131.25	131.263125	kHz	6.25kHz × 21
F_S	Space Frequency	143.735625	143.75	143.764375	kHz	6.25kHz × 23
T_S	Average Bit Period	5.119488	5.12	5.120512	ms	(Time to complete one full duty cycle)/219
T_T	Transmission Period	168.943104	168.96	168.976896	ms	3 Words
T_Q	Quiet Period	901.029888	901.12	901.210112	ms	16 Words
T_C	Cycle Period	1069.972992	1070.08	1070.187008	ms	19 Words
Z_{TX}	Transmitter Output Impedance	0.05		1.5	Ω	

V_{TX}	Transmitter Output Voltage into >100 kΩ	0.9	1.0	1.1	V r.m.s.	
V_{RXMAX}	Receiver Input Voltage Max	142			mV r.m.s.	
$V_{RXSENSE}$	Receiver Input Voltage Minimum Sensitivity			1.20	mV r.m.s.	118:1 dynamic range
Z_{RXS}	Receiver Line Impedance @ F_S	0.7		1.5	Ω	
Z_{RXM}	Receiver Line Impedance @ F_M	0.7		1.5	Ω	
P_{FALSE}	Probability of false detection					Per SunSpec testing

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 = W_1 W_1 W_1 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)

Underwriters Laboratories Standard 3741, Standard for Safety Photovoltaic Hazard Control (draft sections on 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.

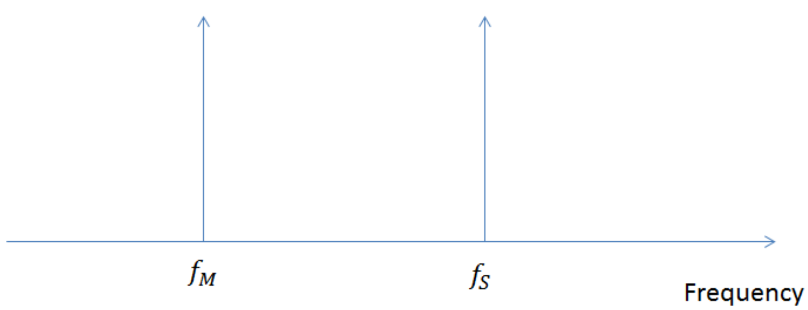

Figure 6 **FSK on Frequency Domain**

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)

