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Power line communication for DC shutdown equipment - Communication signal, physical layer

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CONTENTS

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Power line communication for DC shutdown equipment - Communication signal, physical layer

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The text of this International Standard is based on the following documents:

Draft	Report on voting
82/2189/FDIS	82/2593/RVD

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this International Standard is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

– reconfirmed,
– withdrawn, or
– revised.

INTRODUCTION

This document defines the communication requirements for reducing the output voltage of the DC cables that leave a PV array. This output voltage reduction function can support emergency responders during firefighting operations. For this function, communication is necessary from the inverter / initiator to the PV-modules. Today there are many ways to accomplish this communication task and it is possible to use either wired or wireless solutions. With wireless solutions issues with range and/or communication robustness may occur. Although robustness can be tackled with protocols and modulation schemes, it is sometimes hard to get the necessary range due to physical limitations and normative regulations. With wired communication the need of an additional wire which has to be installed along with the DC power cabling is often a problem. A solution for this is to use power line communication so that the DC power and the information signal are on the same cable and therefore installation requirements and costs are low because the necessity of laying an extra communication cable is eliminated. This document has been developed to set rules for such a power line communication.

1 Scope

This document applies to photovoltaic (PV) system components and communication networks supporting the communication of the DC shutdown equipment using power line communication.

This document defines how to propagate the operational state of the entire PV system (normal / shutdown) 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.

NOTE 1 It is possible to have systems communicating in different ways to the method covered in this document. E.g., in systems where all components of the PLC communication are from the same manufacturer. For those systems this document does not apply.

NOTE 2 Not included in the scope of this document are requirements for DC shutdown initiator mechanism, disconnection and de-energization.

NOTE 3 This document does not address whether DC shutdown is required or not.

NOTE 4 EMC requirements are not included in this document.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC TS 61836, *Solar photovoltaic energy systems - Terms, definitions and symbols*

IEC 62548:2016, *Photovoltaic (PV) arrays - Design requirements*

CISPR 11:2015, *Industrial, scientific and medical equipment - Radio-frequency disturbance characteristics - Limits and methods of measurement*
CISPR 11:2015/AMD1:2016
CISPR 11:2015/AMD2:2019

3 Terms, definitions and abbreviated terms

For the purposes of this document, the terms and definitions given in IEC TS 61836 and the following apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

– IEC Electropedia: available at https://www.electropedia.org/
– ISO Online browsing platform: available at https://www.iso.org/obp

3.1 Terms and definitions

3.1.1
components
equipment intended to be used in a DC shutdown system to initiate, disconnect or isolate the controlled conductors of a PV system

3.1.2
communication protocol
formal descriptions of digital message formats and rules

3.1.3
initiation device
initiator
manual or automatic switching device, input port or signal that will result in the activation of the shutdown system function(s)

3.1.4
PV power source
DC array or aggregate of arrays that generates DC power

3.1.5
receiver
equipment responsible for accepting the communication signal sent by a transmitter and capable of initiating a state change of PV power source components based on the signal received (see 5.2)

3.1.6
shutdown function
function that reduces the output voltage of the DC cables leaving a PV array in a certain amount of time

3.1.7
DC shutdown system
components and communication protocols that are used to perform shutdown function. Components of a shutdown communication system are initiator(s), transmitter(s), and receiver(s)

3.1.8
transmitter
equipment responsible for sending a communication signal that reflects the current state of the initiation device (see 5.2)

3.1.9
barker code
finite sequence of digital values with ideal autocorrelation property used for synchronization in digital communication

3.1.10
spread frequency shift keying
S-FSK
frequency modulation scheme which uses discrete frequency changes of a carrier signal to transmit digital information

Note 1 to entry: The main benefit compared to normal frequency shift keying is that the carrier frequencies are separated by at least 10 kHz and the receiver only needs one carrier to decode the complete message.

3.2 Abbreviated terms

AFD	Arc Fault Detector
AFPE	Arc Fault Protection Equipment
MLE	Module Level Electronics
MLPE	Module Level Power Electronics
MLSD	Module Level Shutdown Device
NRZ	Non-Return to Zero
PLC	Power line Communication
PPM	Parts per Million
PS	Power Supply
PV	Photovoltaic
RCMU	Residual Current Monitoring Unit
RMS	Root Mean Square
SD	Shutdown Device
S-FSK	Spread Frequency Shift Keying
SS	Shutdown System

4 Power line communication systems

4.1 General history of PLC

Since the beginning of the electrification of households and the industry there has also been the need for data communication, so power line communication has an over hundred-year history. It started with ripple control with frequencies ≤ 2 kHz back in the early 1900s to switch streetlights on and off and is nowadays capable of Gbit/s transmissions with cheap plug-in adapters that use frequencies from 2 MHz up to 300 MHz for in-home use.

As the calculation power of microprocessors or microcontrollers now reaches levels which were unimaginable at the beginning of the computer era, we can now have a myriad of carriers each with different complex modulation schemes and error correcting codes so we can reach the goal of a transmission system that operates nearly at the Shannon limit (the theoretical maximum rate of error free data that can be transferred over a given noisy transmission channel) with very high data rates or very robust data transmission.

4.2 PLC operational considerations

Interoperability and safety are the main goals of this document, but also unnecessary human interaction or complexity is to be avoided if possible.

For this reason, a very common, robust and easy modulation technique, spread frequency shift keying (S-FSK) is used. Additionally, Barker codes ensure robustness against noise and false signal detection.

5 DC shutdown system configuration

5.1 General

A DC shutdown system comprises components and communication protocols to perform shutdown function. See Figure 1. The switches shown in the diagram are just an example of how the modules can be disconnected.

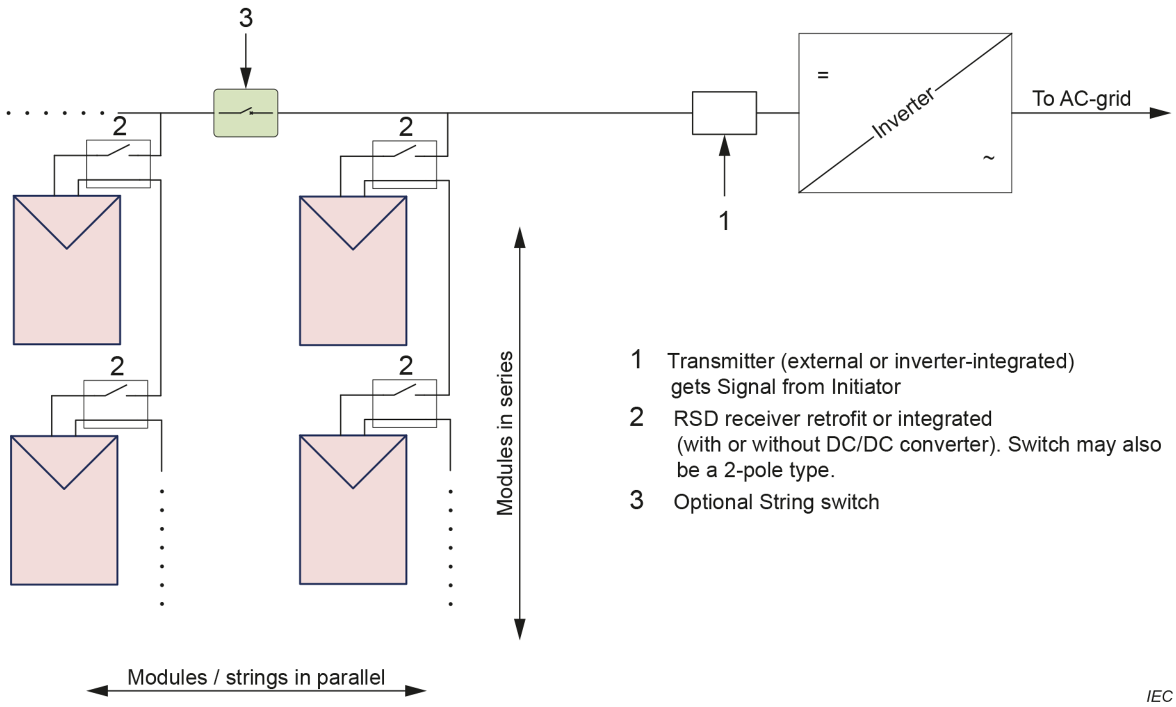


Figure 1 – Example of DC shutdown system

5.2 System setup

A system shall have at least one initiator and one transmitter and several receivers for the shutdown signal. The receivers can also incorporate a transmitter for sending status information back to the inverter / shutdown transmitter. See Annex D for the system boundaries that are the basis for all the parameter values in this document.

5.3 Operational considerations

Shutdown systems shall provide a mechanism to bring the PV system(s) back online after a shutdown event.

6 Operating modes

6.1 General

Two modes of operation are defined for a shutdown system: active mode and shutdown mode.

6.2 Active mode

In active mode the system generates power and operates unimpeded by the shutdown system. This mode is active as long as the initiator is set to “on”. The system shall monitor the Initiator for a change in operating state. It is activated by periodically sending a ‘permission to operate’ (keep alive) signal.

6.3 Shutdown mode

As the initiator is set to “off” the system shall change into the shutdown mode in a certain amount of time as specified in Table 1. In shutdown mode the system needs to limit the power and voltage of the DC system. The change from shutdown mode to active mode shall be done in a certain amount of time specified as T_{Start} in Table 1.

6.4 Standby signal

When in shutdown mode each PV-module receiver can output a standby-signal. If a standby signal is used it shall be a low voltage, low current signal as defined in Annex A.

6.5 Mode transitions

As the PV system has to be de-energized in a certain period of time, e.g. 30 s, each subsystem has to get a share of the total time to facilitate the process steps needed to do this.

A typical process can be considered as the following sequence of events:

– T_1: Initiator signals shutdown mode to shutdown transmitter.

– T_2: Shutdown transmitter stops sending the periodical permission to operate signal.

– T_3: Receiver / MLE disconnects / de-energizes all PV power sources.

– T_4: Stored energy from equipment connected to the DC-lines (e.g., an inverter) is reduced so a safe voltage level (V_{Off}) is reached.

The timing requirements can be found in Table 1 and are depicted in Figure 2 and Figure 3.

Table 1 – Timing requirements for mode transitions

Symbol	Mode specification	Max.	Unit
T_1	Time for initiator to relay to transmitter	2	s
T_2	Time for transmitter to stop sending permission to operate signal	2	s
T_3	Time for receiver to switch off / de-energize PV power sources	13	s
T_4	Time for stored energy to be reduced	13	s
T_T	Total time $T_1 + T_2 + T_3 + T_4$	30	s
T_{Start}	Time for the MLE to switch on PV power sources	20	s

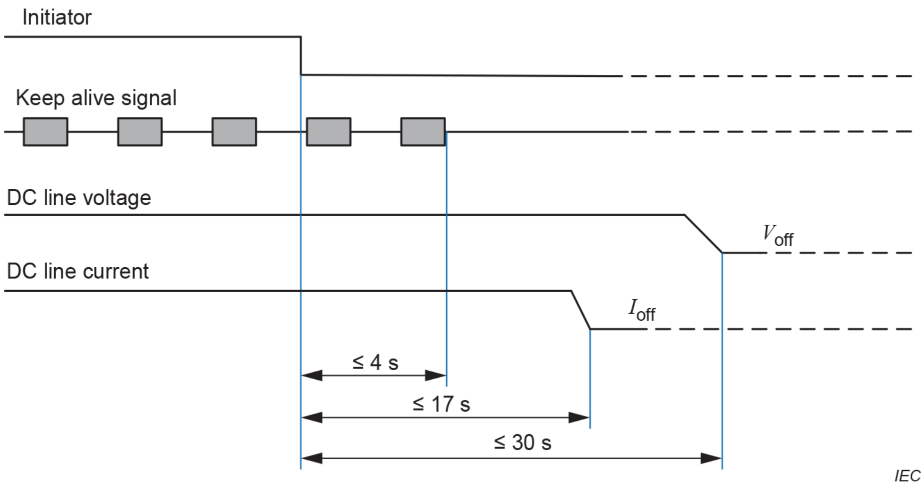


Figure 2 – Stop process timing

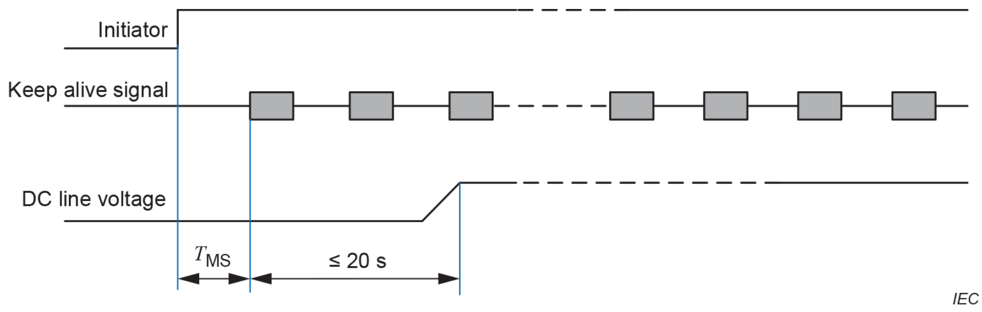


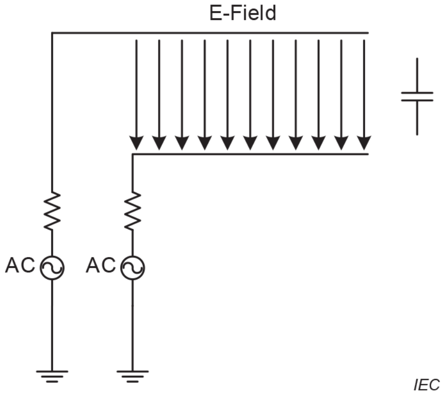
Figure 3 – Start process timing

The time from the Initiator sending permission to operate to the transmitter sending the first keep alive signal (T_{MS}) depends on the manufacturers implementation and shall be stated in the product manual.

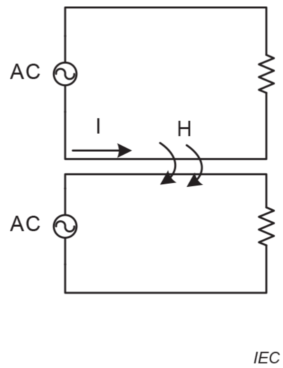
7 Power line communication requirements

7.1 Crosstalk

A big challenge in many communication systems, especially with PLC is crosstalk. Crosstalk means that a (PLC-)signal on one line/wire is influencing a signal/channel on another line/wire to which it is not galvanically connected. Crosstalk is usually caused by unwanted capacitive and/or inductive coupling and can lead to deteriorated signal reception or to unwanted behaviour due to misinterpreted signals. In a PV system it is very common that the DC wires of the modules are put together in conduits. If there are DC wires from different inverters put together in one conduit the wires will run in parallel, so crosstalk is inevitable. If a communication system uses broadcast messages (unaddressed messages) then even receivers that are not directly connected with the transmitter can receive the broadcasted message. See Figure 4.



Capacitive coupling



Inductive coupling

Figure 4 – Capacitive and inductive coupling

7.2 Crosstalk mitigation

7.2.1 General

There are two ways of coping with crosstalk. Physically, by preventing signal coupling through shielding and/or better wiring practices or logically by implementing suitable protocols. A combination of both can be useful.

7.2.2 Physical crosstalk mitigation

It is important that the wiring in the system is done according to applicable safety standards. By following the rules of IEC 62548:2016, 7.4.3 and the points listed below, the system will be more robust against overvoltage from indirect lightning, will have lower EMI radiation and have less crosstalk.

- The DC+ and DC- cables from one string shall be put together as close as possible. This reduces the loop area and therefore minimizes the unwanted radiation of signals. See Figure 5.
- Cables going from the inverter to the PV modules shall be placed in a metal conduit that is connected to earth.
- Cables from different inverters shall be bundled in different conduits.
- Avoid wire loops.

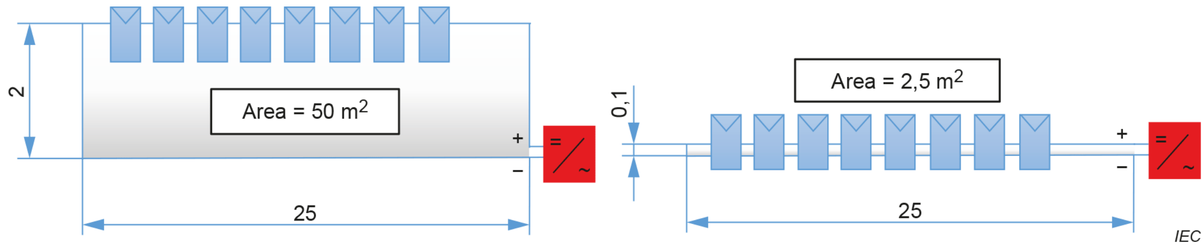


Figure 5 – Example of string cabling

See Annex E for more examples.

7.3 Physical layer aspects

The transmitter uses the DC power lines to transmit a signal to the receivers of the (sub)system. The transmitter continuously sends a “permission to operate” (“keep alive”) signal if the initiator is set to “permission to operate”. As long as the receivers get this signal, they are allowed to put power on the DC lines. When the transmitter ceases to send this “permission to operate” signal, the receivers shall enter shutdown mode. The frequencies for this signal were selected with the following constraints:

- Shall be derivable from a standard quartz frequency (e.g., 16 MHz).
- The two tones shall be at least 10 kHz apart from each other (minimum spreading so a disturbance of both tones from one interference source is unlikely).
- Shall be below 150 kHz for CISPR 11 compliance. It is important to note that the receiver bandwidth at 150 kHz is 9 kHz and the filter has a roll-off so it is necessary that the chosen frequencies are below 140 kHz so they do not fall into the detection bandwidth of the EMI-receiver.
- The arc fault detection shall not be impaired by permanent transmission and the frequencies below 100 kHz shall be available for arc detection.

The base frequency is 6 250 Hz and the two tones are basically 19 and 21 times the base frequency as can be seen in Table 6.

7.4 Transmitter

7.4.1 General

The transmitter broadcasts a permission to operate signal using S-FSK modulation. The transmitter shall have a well-defined output impedance and shall be capable of driving low impedance loads, see Table 6.