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TECHNICAL SPECIFICATION

colour inside

Explosive atmospheres –
Part 39: Intrinsically safe systems with electronically controlled spark duration limitation

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EXPLOSIVE ATMOSPHERES –

Part 39: Intrinsically safe systems with electronically controlled spark duration limitation

FOREWORD

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Technical specifications are subject to review within three years of publication to decide whether they can be transformed into International Standards.

IEC TS 60079-39, which is a technical specification, has been prepared by subcommittee 31G: Intrinsically safe apparatus, of IEC technical committee 31: Equipment for explosive atmospheres.

The text of this technical specification is based on the following documents:

Enquiry draft	Report on voting
31G/236A/DTS	31G/242/RVC

Full information on the voting for the approval of this technical specification can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts in the IEC 60079 series, published under the general title *Explosive atmospheres*, can be found on the IEC website.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- transformed into an International standard,
- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

A bilingual version of this publication may be issued at a later date.

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INTRODUCTION

This part of IEC 60079, which is a Technical Specification, is being issued as a "prospective standard for provisional application" in the field of *Explosive Atmospheres – Intrinsically safe systems with electronically controlled spark duration limitation* because there is an urgent need for guidance on how standards in this field should be used to meet an identified need.

Intrinsically safe systems with electronically controlled spark duration can provide more power available in intrinsically safe circuits while maintaining the level of protection "ib" or "ic". In addition to limiting the voltage and current (similar to conventional intrinsically safe circuits), the duration of the spark is limited, which also restricts the amount of energy available for ignition.

The general requirements for the installation of IS equipment are applicable to Power-i circuits.

This new technology allows an expansion in the field of industrial applications using the type of protection Intrinsic Safety 'i.

This technology, however, requires a new and more extensive approach of the type of protection Intrinsic Safety "i".

EXPLOSIVE ATMOSPHERES –

Part 39: Intrinsically safe systems with electronically controlled spark duration limitation

1 Scope

This Technical Specification specifies the construction, testing, installation and maintenance of Power-i apparatus and systems which utilise electronically controlled spark duration limitation to maintain an adequate level of intrinsic safety.

This Technical Specification contains requirements for intrinsically safe apparatus and wiring intended for use in explosive atmospheres and for associated apparatus intended for connection to intrinsically safe circuits entering such atmospheres.

This Technical Specification excludes the level of protection “ia” and the use of software-controlled circuits.

This Technical Specification applies to electrical equipment utilising voltages not higher than 40 V d.c. and a safety factor 1,5 for Groups IIB, IIA, I and III. It is also applicable to Group IIC “ic” apparatus with a safety factor 1,0. Group IIC “ib” apparatus with a safety factor 1,5 are restricted to voltages up to 32 V d.c.

This type of protection is applicable to electrical equipment in which the electrical circuits themselves are incapable of causing an explosion of the surrounding explosive atmospheres.

This Technical Specification is applicable to intrinsically safe apparatus and systems which utilise electronically controlled spark duration limitation with the aim of providing more electrical power while maintaining an adequate level of safety.

This Technical Specification is also applicable to electrical equipment or parts of electrical equipment located outside hazardous areas or protected by another type of protection listed in the IEC 60079 series, where the intrinsic safety of the electrical circuits in explosive atmospheres depends on the design and construction of such electrical equipment or parts of such electrical equipment. The electrical circuits located in the hazardous area are evaluated for use in such locations by applying this Technical Specification.

This Technical Specification supplements and modifies the requirements of IEC 60079-0, IEC 60079-11, IEC 60079-14, IEC 60079-17 and IEC 60079-25.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60079-0, *Explosive atmospheres – Part 0: Equipment – General requirements*

IEC 60079-11, *Explosive atmospheres – Part 11: Equipment protection by intrinsic safety "i"*

IEC 60079-14, *Explosive atmospheres – Part 14: Electrical installations design, selection and erection*

IEC 60079-25, *Explosive atmospheres – Part 25: Intrinsically safe electrical systems*

3 Definitions

For the purpose of this document, the terms and definitions given in IEC 60079-0 and IEC 60079-11, as well as the following apply.

3.1
Power-i
intrinsically safe concept where the level of protection is provided by voltage and current limitation and additional electronically controlled spark duration limitation

Note 1 to entry: Power-i contains Power-i devices and Power-i wiring.

Note 2 to entry: Power-i encompasses electric circuits which in the Power-i mode operate with voltage and current values which can exceed the values defined in IEC 60079-11.

3.2
Power-i device
Power-i source, Power-i field device(s) and (if applicable) Power-i terminator

3.3
Power-i terminator
unit to prevent reflections of voltage and current waves at the end of the Power-i wiring

Note 1 to entry: The Power-i terminator is only relevant where data transmission uses the Power-i wiring.

3.4
Power-i source
power supply for Power-i devices providing shutdown of power in case of faults

Note 1 to entry: Operating in two modes: Power-i mode and shutdown mode.

3.5
Power-i field device
device that is connected to one Power-i source via Power-i wiring

Note 1 to entry: Power-i field devices can have additional connections to other devices (e.g. loads).

3.6
Power-i mode
operating mode of the Power-i source delivering the rated Power-i output power

Note 1 to entry: In this mode the values of permitted voltage and current can exceed the values of curves and tables stated in IEC 60079-11.

3.7
shutdown mode
operating mode of the Power-i source after a spark event has been detected

3.8
spark pulse
information resulting from a spark event in the Power-i system

Note 1 to entry: A distinction is made between the make spark pulse and the break spark pulse.

3.9
Power-i response time

3.9.1
$t_{resp\text{-}source}$
maximum delay time between the detection of the spark pulse and reaching the shutdown mode (only relevant for the Power-i source)

3.9.2
$t_{resp\text{-}trunk}$
propagation time of the trunk cable used (only relevant for Power-i wiring)

3.9.3
$t_{resp\text{-}system}$
time between the occurrence of a spark and the reduction of the spark power to safe operation in the shutdown mode in a Power-i system

3.10
assessment factor AF
factor of attenuation or sensitivity of Power-i devices and Power-i wiring

Note 1 to entry: The assessment factor has to be distinguished between:

– Assessment factor for Power-i field devices, for the Power-i terminator and for Power-i wiring: In these cases the assessment factor is a parameter for the attenuation of a spark pulse.
– Assessment factor for the Power-i source: In this case the assessment factor is a parameter defining the sensitivity for the detection of a spark pulse.

Note 2 to entry: The assessment factor should be expressed in logarithmic units.

4 Power-i architecture

In a Power-i system only one active Power-i source shall be connected via Power-i wiring to supply one or several Power-i field devices. The simplest structure consists of one active Power-i source, Power-i wiring and one Power-i field device (see Figure 1).

The use of redundant power supplies which present one effective source of power is permitted.

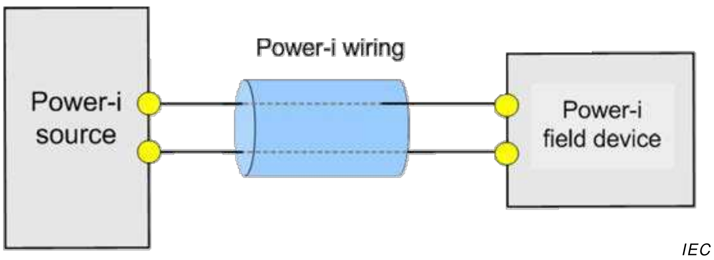

Figure 1 – The simplest Power-i architecture

A Power-i system may be extended to a complex system as shown in Figure 2.

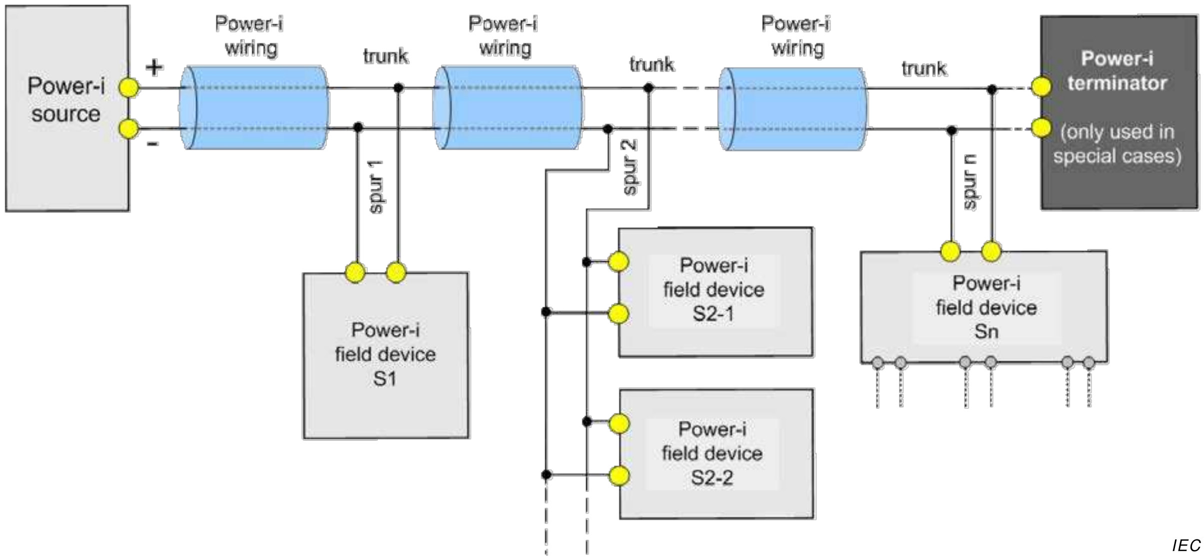

Figure 2 – Example of complex Power-i concept architecture

NOTE The Power-i field device Sn is identical to Power-i field device S1, S2-1 or S2-2 in terms of the connection to Power-i wiring but is shown with additional output/input terminals. These terminals are subject to requirements of a type of protection prescribed by the IEC 60079 series suitable for the applications.

5 Requirements for Power-i devices

5.1 General

Power-i has to be considered as a system. Therefore the following requirements for all Power-i devices apply:

a) The detection of the spark pulse shall not be invalidated during static or transient conditions (e.g. soft start) – neither by the Power-i wiring nor by the Power-i devices; therefore Power-i requires the consideration of the whole system.

b) All Power-i devices and the Power-i wiring shall be assessed and tested in accordance with Annex A.

c) All Power-i devices shall be classified in accordance with 5.7.

d) Power-i devices shall meet the requirements of IEC 60079-0, IEC 60079-11 and IEC 60079-25 as applicable in addition to other IEC 60079 standards (e.g. IEC 60079-7, IEC 60079-18 if applicable).

e) The application of these requirements shall additionally take into account any effect in timing and sensitivity of the safety function of the Power-i devices due to temperature effects and component tolerance.

f) Faults determined to be the most onerous (e.g. for timing, sensitivity etc.) for the safety function of Power-i devices shall be applied to equipment for all tests required by this Technical Specification.

5.2 Power-i source

There shall be only one active Power-i source per Power-i system. The Power-i source shall be placed at one end of the Power-i wiring (trunk).

A Power-i source shall detect make-sparks (sparks occurring when short-circuiting an electrical circuit causing a current change $+\frac{di}{dt}$) and break-sparks (sparks occurring when opening an electrical circuit causing a current change $-\frac{di}{dt}$) and it shall provide a fast shutdown of the output power when a spark pulse occurs. Figure 3 shows the core elements of a Power-i source with an upstream safety-relevant voltage and a current limitation unit.

In all modes of operation where the intrinsically safe values based on conventional power limitation according to IEC 60079-11 and IEC 60079-25 are exceeded, the detection of current changes $\pm \frac{di}{dt}$ shall not be invalidated. This includes the transition phase from the safe mode to the Power-i mode.

NOTE A current change $\frac{di}{dt}$ might be suppressed in the constant current mode; therefore a spark cannot be detected in this mode.

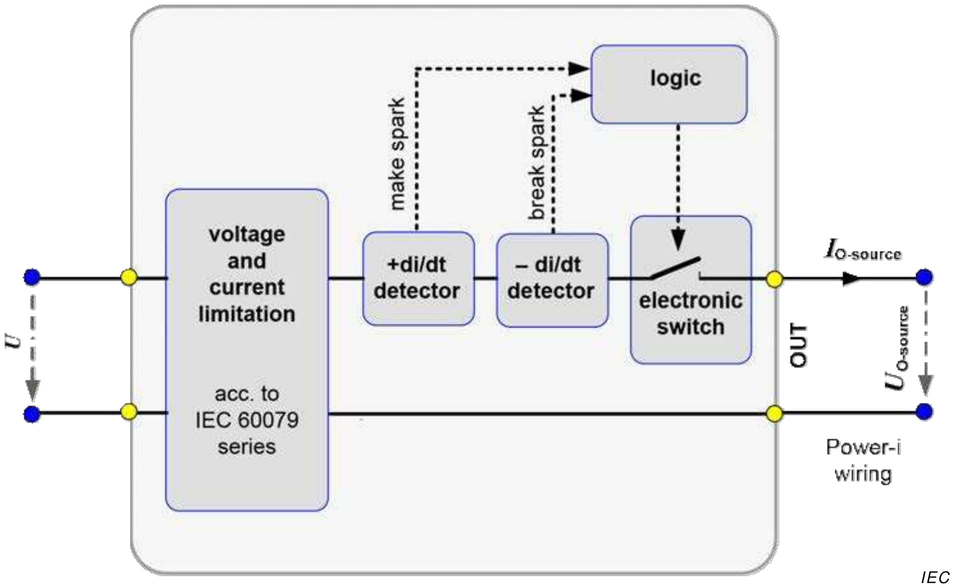

Figure 3 – Elements of a Power-i source with voltage and current limitation

The Power-i source shall conform to the following safety-relevant requirements:

a) The Power-i source output current $I_{O\text{-source}}$ and output voltage $U_{O\text{-source}}$ limited by the voltage and current limitation shall meet the requirements of Table 1 and Table 2.

b) The Power-i source shall be capable of detecting dynamic changes of the output current I_O $\frac{di}{dt}$ as defined in A.3.2. The source shall react with a subsequent transition from Power-i mode to shutdown mode.

c) In the shutdown mode the value of the output current $I_{shutdown}$ may be zero but shall not exceed 50 % of the permissible current $I_{O\text{-IEC}}$ based on IEC 60079-11 or IEC 60079-25 with the applicable safety factor for the appropriate Power-i voltage class; in this case the following equation applies.

$$I_{\text{shutdown}} = I_{\text{O-source}} \leq 0{,}5 I_{\text{O-IEC}} .$$

d) Within 20 µs of the spark disturbance information arriving at the Power-i source, the output current of the Power-i source shall be equal to or less than 75% of the $I_{O\text{-IEC}}$ -value within the first 20 µs of the transition to shutdown mode a transient output current $I_{shutdown\text{-}20\mu s}$ of 75 % of the $I_{O\text{-IEC}}$ value is allowed (see Figure A.5); in this case the following equation applies:

$$I_{\text{shutdown}-20\mu\text{s}} = I_{\text{O-source}} \leq 0{,}75 I_{\text{O-IEC}} .$$

e) The transient output voltage overshoot $U_{overshoot\text{-}40\mu s}$ during shutdown mode shall not exceed the rated output voltage $U_{O\text{-source}}$ by more than 6 V for a maximum duration of 40 µs. In this case the following equation applies:

$$U_{\text{overshoot}-40\mu\text{s}} \leq U_{\text{O-source}} + 6V .$$

f) The Power-i source shall meet the requirements of the test procedures of A.3.2.

g) The following components of the Power-i source (see Figure 3) are safety relevant and shall meet the requirements of 5.1 a) and d) for the respective type of protection:

- output voltage limitation $U_{\text{O-source}}$ and output current limitation $I_{\text{O-source}}$;
- $+\frac{di}{dt}$ detector and $-\frac{di}{dt}$ detector;
- logic and
- electronic switch.

h) The output circuit of a Power-i source shall be isolated from earth. The requirements for the isolation shall be taken from IEC 60079-11.

5.3 Power-i field device

Power-i field devices consist of a decoupling device and the actual load. Power-i field devices shall decouple the load from the Power-i wiring.

The design of a Power-i field device shall ensure the detection of a spark pulse in accordance with this Technical Specification.

Power-i field devices shall meet the following safety-relevant requirements:

a) They shall ensure that both, make-sparks and break-sparks, are not attenuated in any way that the detection by the Power-i source is invalidated.

b) Under normal or fault conditions as specified in IEC 60079-11 the power-i field device shall remain passive, that is the terminals shall not be a source of energy to the system except for a leakage current not greater than 50 μA.

The consideration of Li and Ci for Power-i field devices based on IEC 60079-11 is not required. This is taken into account in the test procedures described in A.3.3.

c) They shall have an appropriate type of protection in accordance with IEC 60079-0 for the respective explosive atmosphere in which they are used.

d) They shall have safety-relevant parameters determined in accordance with A.3.3.

NOTE Due to parallel connection with Power-i wiring, the Power-i response time for field devices is negligible.

e) All components determinant for both the assessment factor $AF_{\text{field device}}$ and the result of the transition pulse test (A.3.3.4) shall meet the requirements of 5.1 a).

f) The input circuit of a Power-i field device shall be isolated from earth. The requirements for the isolation from earth shall be taken from IEC 60079-11.

As an example the Power-i field device shown in Figure 4 conforms to the requirements mentioned above and can be used for a wide field of applications. The field device in Figure 4 consists of a decoupling device in combination with an arbitrary load.

The basic structure of the Power-i field device depicted in Figure 4 shows the elements necessary to ensure that both make and break sparks are not attenuated in such a way that the detection by the Power-i source is invalidated.

In Figure 4 inductance L, capacitance C, all diodes and the V-limitation unit are safety relevant and shall meet the requirements of 5.1 for the appropriate type of protection.

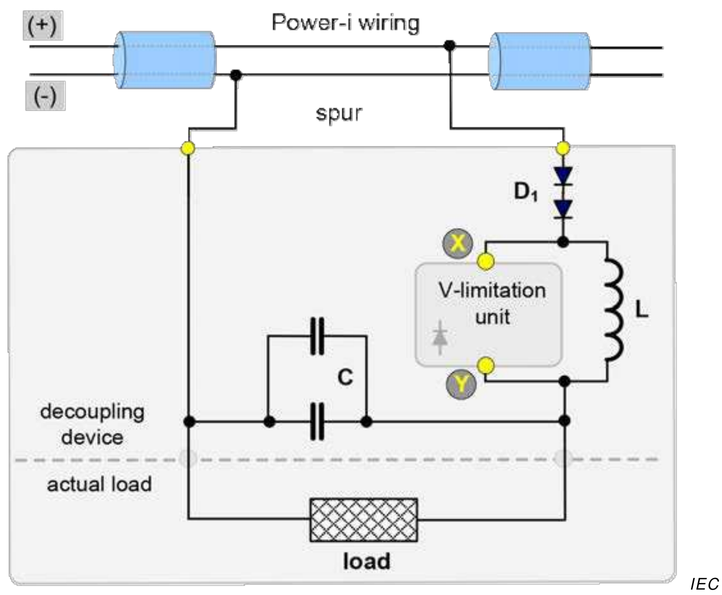

Figure 4 – Example of a universal Power-i field device (basic structure)

The V-limitation unit shall limit the positive voltage (plus (+) at point Y and minus (-) at point X) measured from Y to X to a value of 5 V ± 1 V and shall meet the requirements in accordance with A.3.3.4.

Practical examples of Figure 4 are shown in C.3.

5.4 Power-i wiring

The Power-i wiring shall meet the following requirements:

a) The transmission of a spark pulse shall not be impaired in a way that prevents the detection of a relevant make or break spark pulse;

b) All Power-i wiring (Power-i trunk cable including all spur cables) shall meet the specific requirements given in IEC 60079-11, IEC 60079-14 and IEC 60079-25;

c) Multi-core (multi-circuit) cable type C as defined in IEC 60079-25 shall be excluded for Power-i wiring;

d) The system response time $t_{\text{resp-system}}$ depends decisively on the length and propagation delay of the Power-i trunk cable used; the requirements of Table 3 shall apply;

NOTE The cable parameters and the cable length are safety-relevant and determine the maximum response time or the Power-i trunk (see A.3.4).

e) The maximum length of each spur is limited to 15 m. The maximum total length of all spurs in the whole Power-i system is 50 m;

f) If the Power-i trunk cable length is less than 40 m, the value of response time of this cable is considered to be 0,5 µs (see A.3.4.2);

in this case the spur length of each spur is limited to 10 m and the total length of all spurs in the whole Power-i system is 20 m;

g) The calculation basis for characteristic cable impedance Z_W in this Technical Specification is Z_W = 100 Ω; the permitted range of characteristic cable impedance Z_W for Power-i wiring is 80 Ω ≤ Z_W ≤ 120 Ω; the specified values for the characteristic cable impedance refer to a measuring frequency of 100 kHz ± 20 %.

Section g) does not apply for f);

h) The wiring shall meet the requirements of 6 and A.3.4;

i) The use of a screen for Power-i wiring is not essential for safety; if a screen is used it may be earthed as long as it is isolated from the Power-i circuit in accordance with the cable dielectric strength requirements of IEC 60079-25;

j) The Power-i wiring shall be isolated from earth. The requirements for the isolation from earth shall be in accordance with the cable dielectric strength requirements of IEC 60079-25.

5.5 Power-i terminator

Where used, a Power-i terminator shall meet the following requirements:

a) It shall have safety-relevant parameters determined according to A.3.5.

b) All components of the Power-i terminator to prevent feeding back of the current from the Power-i terminator into the Power-i wiring and all components determinant for the assessment factor $AF_{\text{terminator}}$ (see A.3.5.3) are safety relevant and shall meet the requirements of 5.1 a).

c) It shall have a type of protection in accordance with IEC 60079-0 for use in the appropriate explosive atmosphere.

d) The input circuit of a Power-i terminator shall be isolated from earth. The requirements for the isolation from earth shall be taken from IEC 60079-11.

NOTE 1 The Power-i terminator ensures an ac-matching to the characteristic impedance of the connected trunk and is only necessary in case of data transmission as for example in fieldbus systems.

NOTE 2 Due to parallel connection with Power-i wiring, the Power-i response time for terminators is negligible.

An example of a Power-i terminator is shown in Figure C.5.

5.6 Test instruments for Power-i loop check

Intrinsically safe test instruments in accordance with IEC 60079-11 may be connected directly to Power-i wiring without further verification of the Power-i system if the following requirements are observed:

a) the effective inductance L_i of 5 μH is not exceeded (L_i < 5 μH);

b) the effective input capacitance C_i of 1 nF is not exceeded, additionally the input resistance R_s shall not be less than 10 kΩ ($R_S \geq$ 10 kΩ);

c) the test instrument shall have input parameters U_i and I_i not less than the voltage and current class of the Power-i circuit;

d) the test instrument shall not be a source of energy to the system except for a leakage current not greater than 50 μA.

Alternatively where test instruments complying with the requirements for Power-i field devices are used, they shall be included in the verification of a Power-i system according to 6.2.

NOTE These requirements do not apply to test instruments used by the manufacturer during production, test, repair or overhaul.

5.7 Power-i application classes

Each Power-i device shall be classified into Power-i application classes according to Table 1 and Table 2.

Table 1 – Definition of Power-i voltage classes

maximum output voltage $U_{\text{O-source}}$	Power-i voltage class
24 V	24V
32 V	32V
40 V	40V

Table 2 – Definition of Power-i current classes

maximum output current $I_{\text{O-Source}}$	Power-i current class
0,5 A	0A5
1,0 A	1A0
1,5 A	1A5
2,0 A	2A0
2,5 A	2A5

The voltage and current values of Table 1 and Table 2 shall not be exceeded taking into account the applicable faults according to IEC 60079-11.

Power-i field devices and Power-i terminators provided with a safety-relevant internal current limitation can be assigned to Power-i current class 2A5.

With the internal current limitation it is not necessary that the Power-i source limits the current to prevent overload of the Power-i field device or Power-i terminator and so it may be connected even to a Power-i source of current class 2A5.

6 System requirements

6.1 Selection of the permissible Power- i current class of the Power-i source

The maximum permissible Power-i current class given in 5.7 depends on the selected Power-i voltage class and on the Power-i system response time $t_{\text{resp-system}}$ taking into account the Group and safety factor required for the specific application.

Table 3 shows the permitted combinations for Groups I, II and III with the safety factors SF 1,0 and SF 1,5 depending on the respective level of protection.

Table 3 – Permitted combinations of Power-i application classes for Power-i sources as a function of the system response time for all Groups (n.a. = not allowed)

Group + safety factor SF	voltage class	permitted maximum Power-i current class of Power-i sources						
		system response time $t_{resp\text{-}system}$						
		1 µs	2 µs	4 µs	6 µs	8 µs	10 µs	12 µs
IIC "ib" SF 1,5	24 V	2A0	1A5	1A0	1A0	0A5	0A5	n.a.
	32 V	2A0	1A5	1A0	0A5	0A5	n.a.	n.a.
IIC "ic" SF 1,0	24 V	2A5	2A5	2A0	1A5	1A0	0A5	0A5
	32 V	2A5	2A0	1A5	1A0	0A5	0A5	n.a.
	40 V	2A5	1A5	1A0	1A0	0A5	n.a.	n.a.
IIB "ib" SF 1,5	24 V	2A5	2A5	2A0	1A5	1A0	1A0	0A5
	32 V	2A5	2A5	1A5	1A0	1A0	0A5	0A5
	40 V	2A5	2A0	1A5	1A0	0A5	0A5	0A5
IIB "ic" SF 1,0 and IIA, I and III SF 1,0 and 1,5	24 V	2A5	2A5	2A0	1A5	1A0	1A0	0A5
	32 V	2A5	2A5	2A0	1A5	1A0	1A0	0A5
	40 V	2A5	2A0	1A5	1A0	1A0	0A5	0A5

NOTE 1 The allowed current classes in Table 3 are based on a maximum possible voltage increase of 1 V/µs for a spark event.

NOTE 2 Example: The selected Power-i voltage class is 32 V and the selected system response time is 2 µs:

IIC SF=1,5: maximum permitted Power-i current class for the Power-i source is 1A5 (in addition 1A0 and 0A5 are permitted);

IIB SF=1,5: maximum permitted Power-i current class for the Power-i source is 2A5; (in addition 2A0, 1A5, 1A0 and 0A5 are permitted);

NOTE 3 The permitted values for Groups IIA, I and III are the same as allowed for Group IIB ic.

Practical examples of applications of Table 3 are shown in Annex D.

The assessment procedures specified in Annex A have been defined and optimized specifically for the parameters in Table 3 and the above-mentioned requirements. The interconnection conditions for various Power-i devices allow interoperability and plug-and-play applications.

NOTE 4 Parameters beyond the ranges of Table 1, Table 2 or Table 3 require special considerations and are not covered by this Technical Specification.

6.2 Verification of a Power-i system

The interconnection of all Power-i devices and the Power-i wiring used in a Power-i system shall fully meet the following requirements:

NOTE For Power-i devices the information necessary for this verification is stated in the documentation and on in the marking of each Power-i device.

a) The Power-i voltage class of Power-i field devices and Power-i terminators shall be higher than or equal to the Power-i voltage class of the Power-i source.

b) The Power-i current class of all Power-i field devices and the Power-i terminators shall match the current class of the Power-i source according to Table 4.

Table 4 – Power-i current classes of Power-i field devices or Power-i terminators matching the current class of the Power-i source

Power-i current class of Power-i source	allowed Power-i current classes for Power-i field devices and Power-i terminators
0A5	0A5 / 1A0 / 1A5 / 2A0/ 2A5
1A0	1A0 / 1A5 / 2A0/ 2A5
1A5	1A5 / 2A0/ 2A5
2A0	2A0 / 2A5
2A5	2A5

c) The Power-i system response time tresp-system shall not exceed the value given in Table 3 for the Power-i voltage and current class of the Power-i source used, taking into account the Group and the safety factor of the specific application.

Determine the Power-i system response time $t_{\text{resp-system}}$ in accordance with A.3.4.

The following applies:

$$t_{\text{resp-system}} = t_{\text{resp-source}} + 2t_{\text{resp-trunk}} \; .$$

d) The sum of the assessment factors (AF) of all Power-i field devices, Power-i wiring and Power-i terminators in a Power-i system shall not exceed the assessment factor of the Power-i source used. The assessment factors are determined in accordance with A.3.

The following applies:

$$AF_{\text{source}} \geq (AF_{\text{terminator}} + AF_{\text{power-i-trunk}} + AF_{\text{field-device-1}} + AF_{\text{field-device-2}} + \ldots) \; .$$

Figure 5 illustrates the assessment process of a Power-i system. Practical examples are shown in Annex D.

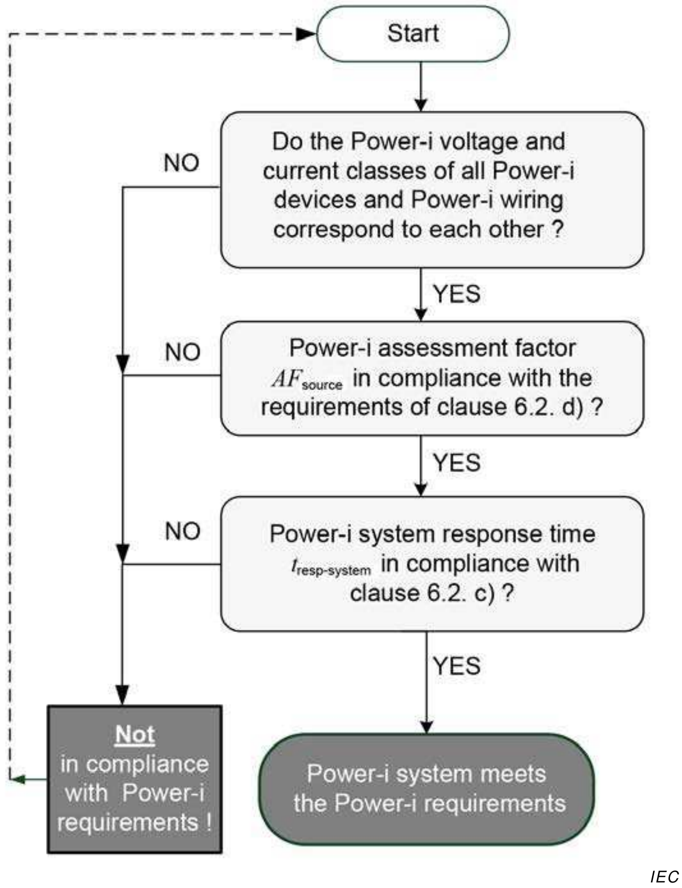

Figure 5 – Basic assessment procedure for a Power-i system

7 Assessment and testing

7.1 Procedure to define safety-relevant parameters

The safety-relevant parameters of Power-i devices and Power-i wiring shall be determined and verified in accordance with the following Power-i test procedures. Detailed information is given in Annex A.

a) Determine the safety-relevant maximum electrical values (voltage U and current I) as a basis for the classification into the Power-i voltage and current classes in accordance with clause 5.7.

b) Determine the response time of the Power-i source $t_{resp\text{-}source}$ (see A.3.2.2) and the response time of of the Power-i trunk $t_{resp\text{-}trunk}$ (see A.3.4.2).

c) Determine the Power-i-specific assessment factors (AF) of the Power-i source, the Power-i field device(s) and – if applicable – the Power-i terminator applying the test methods specified in A.3.2.3, A.3.3.3 and A.3.5.3.

NOTE 1 To assess the safety of a Power-i system, the sum of the assessment factors AF of all Power-i devices including Power-i wiring contained in the system is relevant.

d) Power-i field devices and Power-i sources shall meet the requirements of the transition-pulse test specified in A.3.2.5 and A.3.3.4.

NOTE 2 This test is necessary to ensure intrinsically safe transition behaviour (test of the spark pulse characteristic).

e) Power-i sources shall meet the requirements of the routine test for assessment factors in accordance with A.3.2.4.

Table 5 shows in detail the relevant Power-i test procedures (a) to (e) for each Power-i device and for Power-i wiring.

Table 5 – Relevance for Power-i test procedures

Power-i test procedures	Power-i source	Power-i field device	Power-i terminator	Power-i wiring
(a) safety-relevant electrical parameter	type test A.3.2.1	type test A.3.3.1	type test A.3.5.1	see A.3.4.1
(b) maximum response time tresp	type test A.3.2.2	not relevant	not relevant	relevant A.3.4.2
(c) assessment factor AF	type test A.3.2.3	type test A.3.3.3	type test A.3.5.3	relevant A.3.4.3
(d) transition-pulse test	type test A.3.2.5	type test A.3.3.4	not relevant	not relevant
(e) assessment – factor test	routine test A.3.2.4	not relevant	not relevant	not relevant

NOTE 3 The testing methods specified in Annex A are based on the application of defined test pulses. Thereby the alteration of the test pulse by the Power-i devices including Power-i wiring will be analyzed. This enables the interoperability and the plug-and-play function of different Power-i devices from different manufacturers.

7.2 Type test

Type tests shall be performed according to Table 5.

7.3 Routine test

Routine tests shall be conducted on each Power-i source to verify the assessment factor AF_{source} (see Table 5).

8 Marking of Power-i devices

8.1 General

Except where modified by this section, each apparatus shall be marked in accordance with IEC 60079-0 and IEC 60079-11 and additionally with the word “Power-i” followed by an indication of its function, i.e. “source”, “field device” or “terminator”.

Where apparatus is dual marked so that it can be used in both a Power-i system and a conventional intrinsically safe system, care shall be taken to differentiate between the Power-i marking and the marking for the conventional intrinsically safe system.

For Power-i sources, output parameters U_o, I_o, C_o, L_o, P_o and L_o/R_o need not be marked. For Power-i field devices and Power-i terminators, input and internal parameters U_i, I_i, C_i, L_i, P_i and L_i/R_i need not be marked. Instead of these parameters the following specifications shall be used: Power-i voltage and current classes, the specified Power-i assessment factor AF and, if applicable, the specified Power-i response time t_{resp}.

8.2 Examples of marking

The following are examples of marking.

a) Power supply

Power-i source

John Delon Ltd., SW99 2AJ UK, Type ACD-XX1

–5 °C ≤ T_a ≤ +50 °C
PTB-Nr 13C 98765
Serial No. 012345
[Ex ib Gb] IIC
IN: U_m = 250 V
OUT: 32V1A0
t_{resp} = 1,2 µs AF = 12

b) Power supply
Power-i source
Max Denver Ltd., SW99 2AJ UK, Type BCD-YY1
–10 °C ≤ T_a ≤ +50 °C
PTB-Nr 13C 98722
Serial No. 012333
Ex eb mb [ib] IIC T4 Gb
IN: U_m = 250 V
OUT: 32V2A0
t_{resp} = 0,7 µs AF = 10

c) Field device
Power-i field device
Peter Pan plc., GL99 1JA UK, Type ZZS-222A
BAS 13 C 151860
Serial No. 812369
Ex ib mb IIC T4 Gb
IN: 32V1A5
AF = 3,1

d) Field device
Power-i field device
Hans Müller GmbH, 38116 Braunschweig, D, Type 1AZS-33A
BAS 02 A 1234
Serial No. 220367
Ex ib IIB T4 Gb
IN: 40V1A5
AF = 2,8

9 Instructions

Instructions required in Documentation of IEC 60079-11 shall additionally contain the type of device with power-i parameters:

- Power-i source: OUT, t_{resp} and AF;
- Power-i field device and Power-i terminator: IN and AF;

For Power-i sources, output parameters U_o, I_o, C_o, L_o, P_o and L_o/R_o need not be mentioned. For Power-i field devices and Power-i terminators, input and internal parameters U_i, I_i, C_i, L_i, P_i and L_i/R_i need not be mentioned.

Annex A
(normative)

Assessment of Power-i safety parameters

A.1 General

The determination and verification of the safety-relevant parameters for Power-i devices and Power-i wiring are based on the Power-i specific test procedures as described in 7.1 and in this Annex. The necessary assessment and test procedures are shown in Table 5.

A.2 Power-i specific test equipment

A.2.1 Power-i universal test equipment

Figure A.1 shows the schematic diagram of the Power-i universal test equipment used to determine the Power-i specific parameter and to confirm the Power-i specific behaviour.

Components of the Power-i universal test equipment (Figure A.1)

- Pulse generator

  Adjustable single shot pulse generator which generates two different types of reference rectangular pulses with rise and fall times less than 0,2 µs;

  a) reference rectangular pulse for break sparks $\Rightarrow -\frac{di}{dt}$:

     a single shot positive rectangular pulse with an amplitude of $U_{\text{puls-ref}}$ =+10 V ± 5 %; the absolute value of the amplitude can be adjusted to lower values and has a defined reference pulse duration of $t_{\text{pulse-generator}}$ = 20 µs ± 5 %;

  b) reference rectangular pulse for make sparks $\Rightarrow +\frac{di}{dt}$:

     analogous to the positive rectangular reference pulse, a negative rectangular pulse $U_{\text{puls-ref}}$ = -10 V ± 5 % with the same pulse characteristics as in a) is generated.

- Toggle switch S1

  Used to toggle between the operation modes “response time” (position B) and “assessment factor” (position A:

  Switch – Position A: Assessment factor AF mode;

  Switch – Position B: Response-time mode.

  NOTE Toggle switch S1 position A simulates a fault in the parallel path of the cable. In position A, the test apparatus attenuates the applied pulse generating the lowest pulse amplitude.

- Variable resistance R_{variable}

  Ohmic resistance which is adjusted to a value which is the quotient of U_o and I_o derived from Annex A of IEC 60079-11.

- Coupling module

  Simple equivalent circuitry to simulate the line impedance with a defined characteristic impedance Z_W:

$$Z_W = \sqrt{\frac{L'}{C'}} = \sqrt{\frac{660\mu H}{66nF}} = 100\Omega$$

- Low pass filter

  Simple low pass RC filter.

- Switch S2

Used for switching to the pulse amplitude measurement mode (S2 position “OFF”).

- DC decoupler

  Used for DC decoupling of the Power-i universal test equipment.

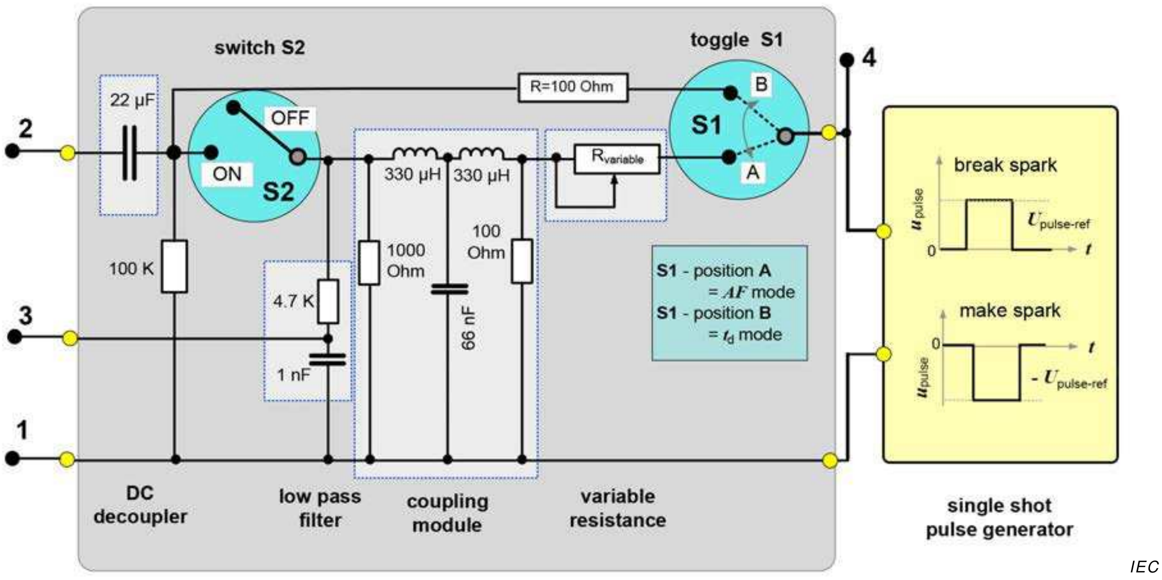

Figure A.1 – Basic principle of the Power-i universal test equipment

Figure A.2 shows the low pass output signal U_{LPF} of Figure A.1 between the connecting points 3 and 1 with toggle S1 in position A and switch S2 in position ON and the Power-i device connected between the connecting points 2 and 1.

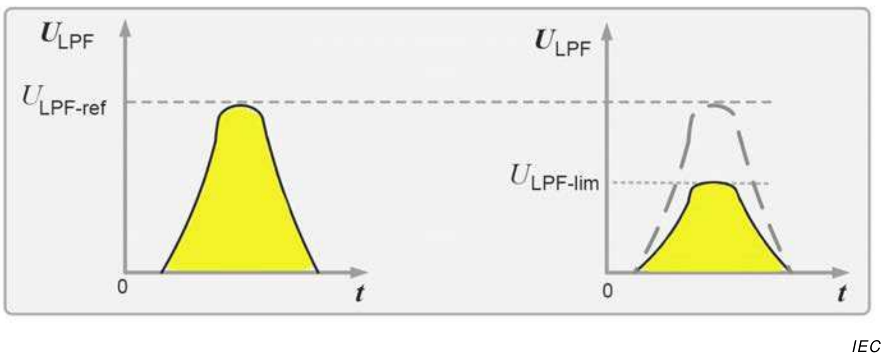

Figure A.2 – Pulse output between terminals 3 and 1 of Figure A.1

NOTE The pulse with reduced amplitude is resulting from reducing the amplitude of the single shot pulse generator in order to determine the assessment factor AF of Power-i devices (see Figure A.6 and Figure A.10).

A.2.2 Power-i dummy load

The Power-i dummy load shall ensure defined starting behaviour (soft start) realizing a slow current rise. This enables the source to operate in Power-i mode.

The dummy load shall cause minimum impairment of the test pulse of the universal test equipment (see Figure A.1).

The principle of a Power-i dummy load is shown in Figure A.3. It consists of a soft start unit in combination with a gyrator to meet the aforementioned requirements. An example is shown in C.4.

The assessment factor of the Power-i dummy load is measured in accordance with A.3.3.3. In this case the Power-i field device shown in Figure A.10 is replaced with the Power-i dummy load. To accomplish a high assessment factor of the Power-i source it is advisable to use a dummy load with a low assessment factor. A practical example with a low assessment factor is shown in Figure C.4.

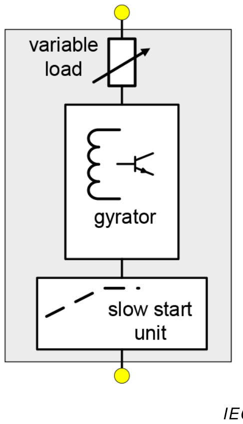

Figure A.3 – Basic principle of a Power-i dummy load

A.3 Determination of the safety-relevant parameters for Power-i devices and Power-i wiring

A.3.1 General

This section is based on the Power-i specific testing procedures described in 7.1.

A digital storage oscilloscope is necessary to measure the response time and the assessment factor. The minimum cut-off frequency of the digital storage oscilloscope shall not be lower than 50 MHz.

A.3.2 Safety-relevant parameters for the Power-i source

A.3.2.1 Determination of the safety-relevant maximum values for Power-i sources

The output values of the Power-i source $U_{\text{O-source}}$ and $I_{\text{O-source}}$ shall not exceed the values defined for the voltage and current classes in Table 1 and Table 2 in order to assign the application classes of the Power-i source under the conditions given in IEC 60079-11 for U_o and I_o.

A.3.2.2 Determination of the response time $t_{\text{resp-source}}$ for Power-i sources

The determination of the response time of the Power-i source $t_{\text{resp-source}}$ is performed with the test equipment as shown in Figure A.4. The time $t_{\text{resp-source}}$ is determined with a defined test pulse initiated by the Power-i universal test equipment (including the single shot pulse generator) in accordance with Figure A.1 resulting in shutdown mode according to 5.2. This test shall be performed with toggle S1 in position B and switch S2 in position “OFF”, (see Figure A.1). The test shall be performed with an adjustable Power-i dummy load (see A.2.2). This load consists of a combination of a Power-i field device with a load adjusted to achieve maximum output power.

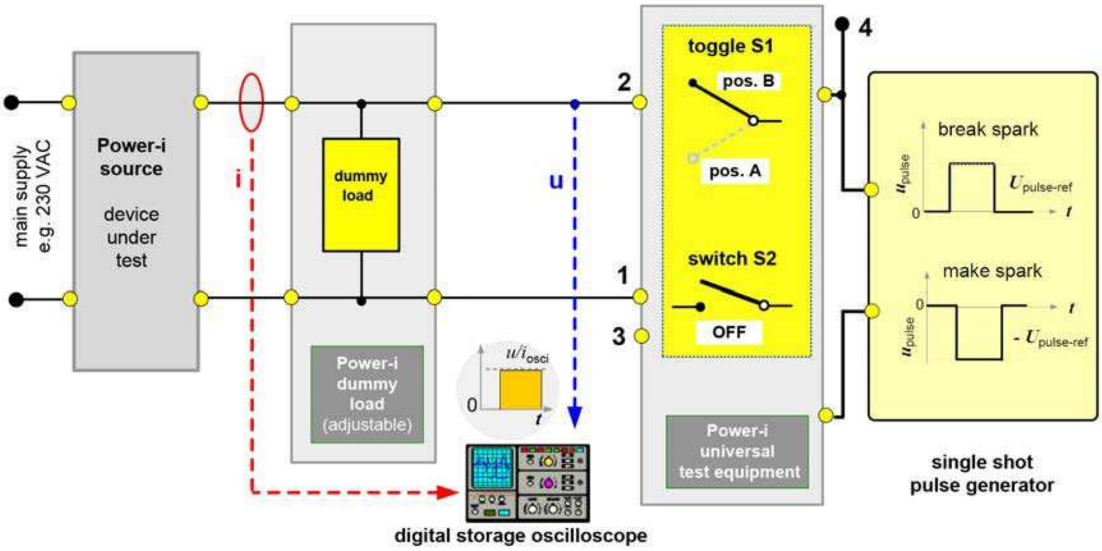

Figure A.4 – Basic principle of the equipment for the determination of the response time $t_{\text{resp-source}}$

A shut down is achieved when the conditions described in 5.2 b), d) e) are fulfilled.

NOTE More information is given in B.2. In Figure B.4 the value of I_{shutdown} is based on the value of the resistance R_{start}.

Figure A.5 shows an example of determining the response time $t_{\text{resp-source}}$ of a Power-i source (24 V, IIC, SF 1,5).

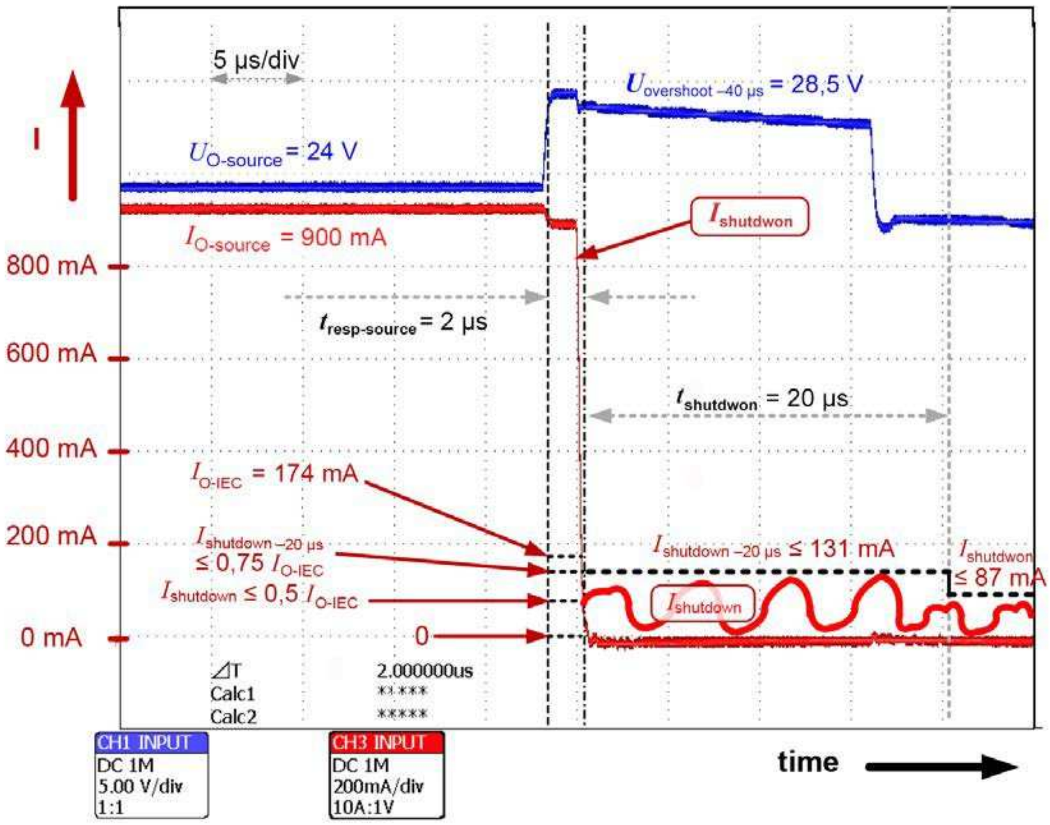

Figure A.5 – Example of an oscillogram to determine the response time $t_{resp\text{-}source}$

A.3.2.3 Determination of the assessment factor AF_{source} for the Power-i source

The determination of the assessment factor AF is performed with test equipment as shown in Figure A.6. This test shall be performed for specified load conditions with an adjustable Power-i dummy load (see A.2.2) in accordance with Figure A.6. The test shall be performed with toggle S1 in position A at the Power-i universal test equipment (see Figure A.1).

NOTE The different load conditions can only be performed using loads with Power-i specific start-up or switch-on behaviour.

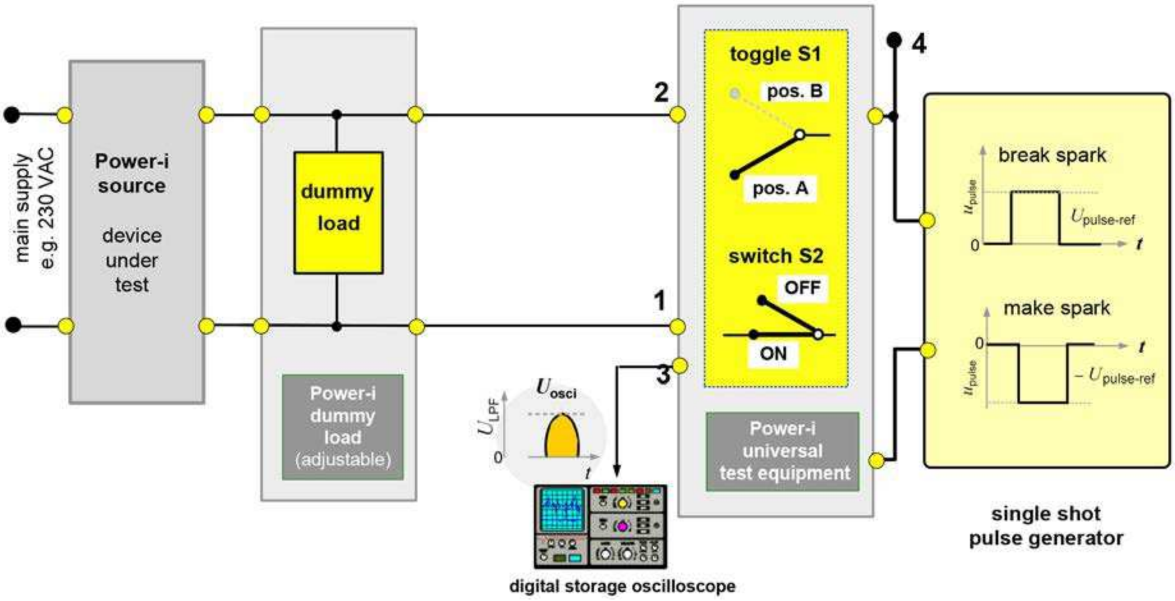

Figure A.6 – Test equipment for the determination of the assessment factor AF_{source} (basic principle)

Components of the test equipment Power-i source – AF_{source}

- Power-i universal test equipment with S1 in switch position A (see Figure A.1) including the single shot pulse generator;
- adjustable Power-i dummy load:

  is used to prove safe shutdown in defined load ranges;

  These are specified as follows:

  1) full output power; $I_{\text{O-source-max}}$
  2) three quarters of full power; ¾ $I_{\text{O-source-max}}$
  3) half output power; ½ $I_{\text{O-source-max}}$
  4) one quarter of full output power; ¼ $I_{\text{O-source-max}}$

Procedure to determine the assessment factor of a Power-i source

a) Set up the test arrangement as shown in Figure A.6.

b) R_{variable} from Figure A.1 shall be adjusted in accordance with IEC 60079-11; e.g. a given voltage of U = 24 V leads to a permissible current of I = 174 mA resulting in a resistance of R = 138 Ω; this value shall be adjusted for R_{variable}.

c) Adjust the Power-i dummy load to obtain the maximum output power from the Power-i source (maximum output current $I_{\text{O-source}}$).

d) Adjust the reference rectangular pulse for break sparks of the single shot pulse generator of the Power-i universal test equipment (see Figure A.6) on terminal 4 to the following parameters

$$U_{\text{puls-ref}} = 10V \pm 5\% \quad \text{and} \quad t_{\text{puls-ref}} = 20\mu s \pm 1\mu s \,.$$

e) Switch S2 to position "OFF": release a single shot pulse of the pulse generator and measure the peak level of the reference pulse at the low pass filter output $U_{\text{LPF-ref}}$ (see Figure A.2) on output terminal 3 of the universal test equipment; this is used to determine the reference value $U_{\text{LPF-ref}}$ for the assessment factor evaluation of the Power- source.;

f) Switch S2 to position “ON”: progressively reduce the amplitude of the rectangular pulse U_{puls} < 10 V until the Power-i source no longer responds with a shut down; the shutdown behaviour shall be checked with this pulse; a shut down is achieved when the conditions apply according to 5.2.

g) Switch S2 to position “OFF”: determine the peak level of the reduced pulse $U_{LPF-lim}$ according to f) at the low pass filter output in Figure A.6 output terminal 3 by means of an oscilloscope.

h) The assessment factor AF_{source} is obtained as follows (see Figure A.2):

$$AF_{source} = 20\lg\left(\frac{U_{LPF-ref}}{U_{LPF-lim}}\right)$$

i) Repeat the test steps d) to h) for dummy loads with ¼ , ½ and ¾ $I_{O-source-max}$.

j) Repeat the test steps e) to i) with the reference rectangular pulse for make sparks using the Power-i universal test equipment in accordance with Figure A.1 and Figure A.6.

k) The lowest assessment factor of all tests determined shall be used as the rated assessment factor AF_{source}.

A.3.2.4 Routine test for assessment factor of Power-i source

This test is only relevant for the routine test in accordance with 7.3 and is performed with test equipment as shown in Figure A.7.

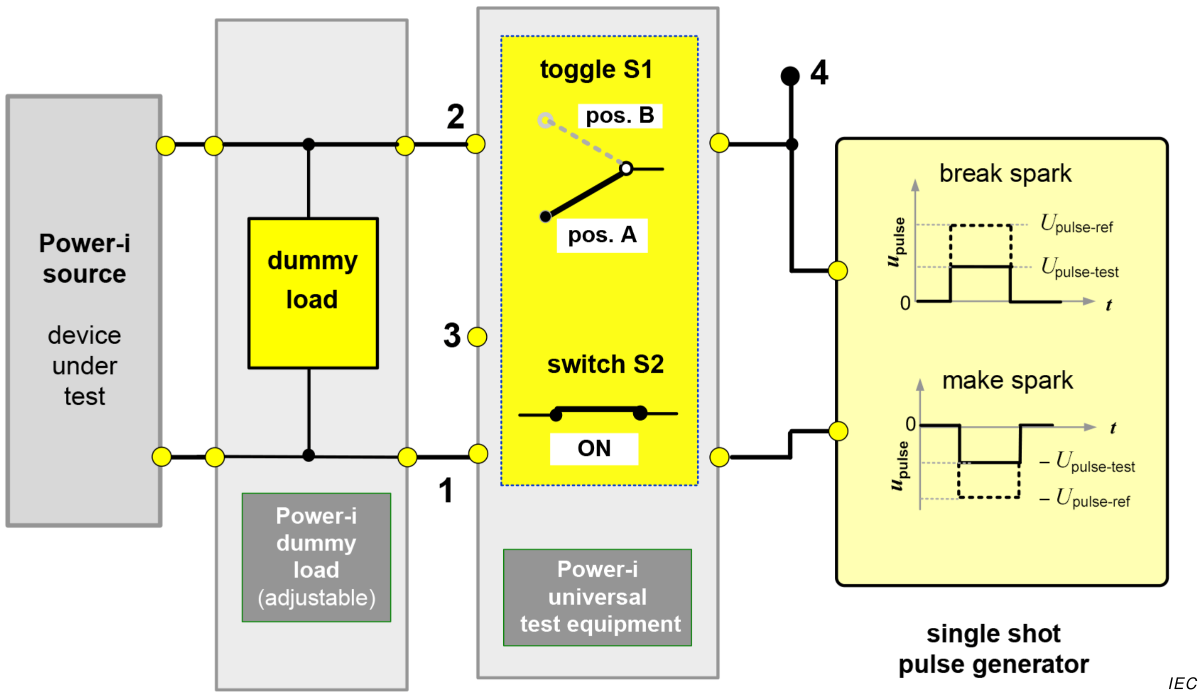

Figure A.7 – Test equipment for the assessment factor test for Power-i source

Procedure of assessment factor test

a) Set up the test arrangement as shown in Figure A.7.

b) $R_{variable}$ of the Power-i universal test equipment (see Figure A.1) shall be in accordance with IEC 60079-11

(E.g. U = 24 V ⇒ I = 174 mA ⇒ $R_{variable}$ = 138 Ω).

c) The Power-i dummy load (see A.2.2) shall be adjusted to load the Power-i source with the maximum rated output current.

d) The pulse amplitude $U_{\text{puls-test}}$ of the single shot pulse generator in Figure A.7 on terminal 4 shall be adjusted in accordance with the following equation:

$$U_{\text{puls-ref}} = 10V \pm 5\% \quad \text{and} \quad U_{\text{puls-test}} = U_{\text{pulse-ref}} * 10^{-\frac{AF}{20}} = 10V * 10^{-\frac{AF}{20}}$$

and $t_{\text{puls-ref}} = 20\mu s \pm 1\mu s$.

AF is the rated assessment factor AF_{source} of the Power-i source under test, as defined in A.3.2.3 i);

An example of this procedure is shown in Figure A.8 for a break spark. The given value for the assessment factor in this oscillogram is AF = 8,29. Using the equation in d) this results in a calculated value for the test pulse amplitude of $U_{\text{puls-test}}$ = 3,85 V. This pulse amplitude shall lead to a shutdown of the Power-i source according to 5.2.

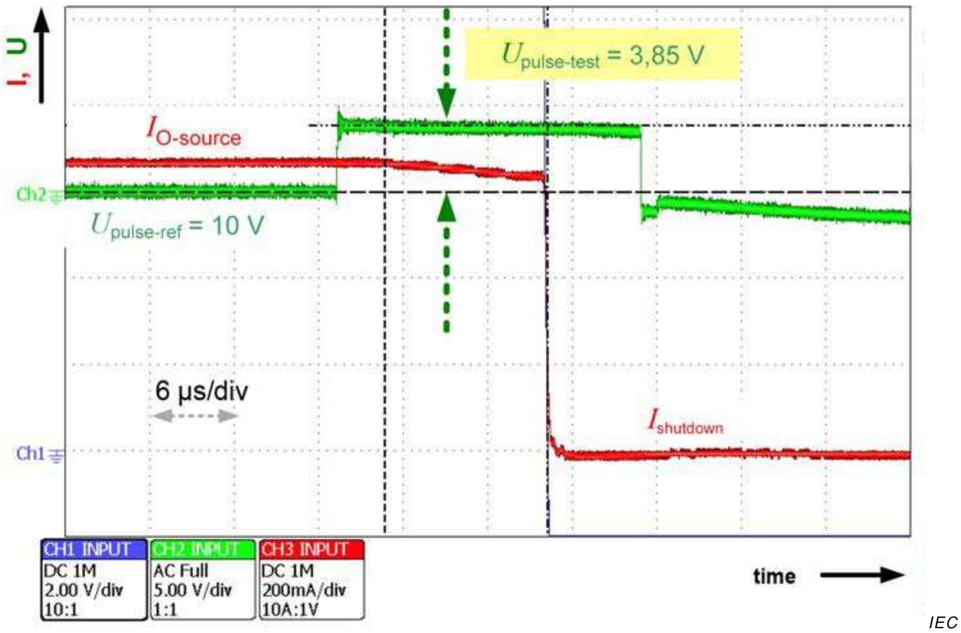

Figure A.8 – Example of an oscillogram from a test of a Power-i source with an assessment factor AF = 8,29 for a break spark

e) A single shot break pulse with the pulse amplitude in accordance with d) shall result in a shutdown of the Power-i source according to 5.2.

f) The same applies for a single shot make pulse.

g) The test is passed when the conditions in e) and f) are fulfilled.

A.3.2.5 Transition pulse test for Power-i source

Figure A.9 shows the equipment setup required to perform the transition pulse test for the simplest kind of a Power-i source as shown in Figure 3.

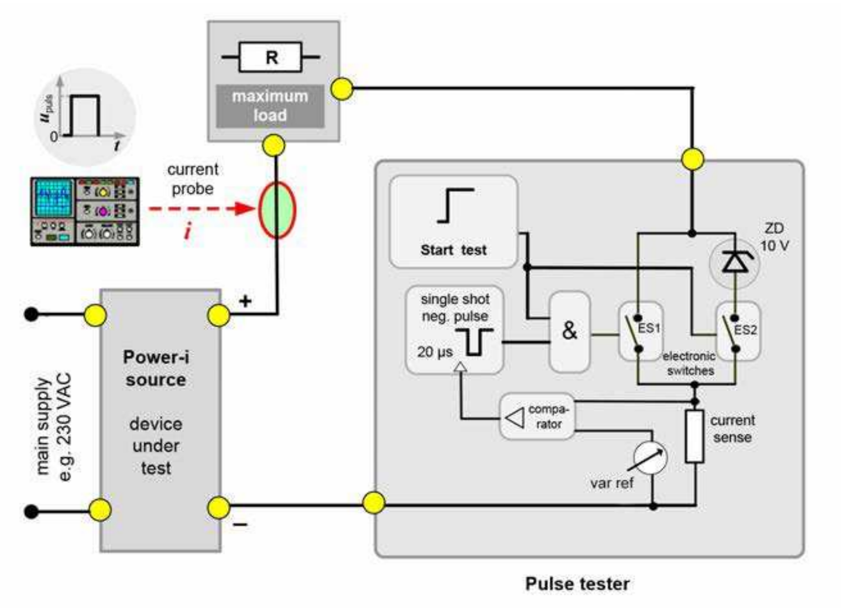

Figure A.9 – Test equipment for transition pulse test of a Power-i source

The test setup consists of the following components:

- Power-i source (device under test);
- maximum load (based on the markingof the Power-i source);
- digital storage oscilloscope;
- pulse tester with the components:
  - start button;
  - electronic switches: ES1 and ES2 simulating connection / disconnection of the maximum load;
  - current sense and variable reference element to adjust comparator threshold $U_{\text{var ref}}$;
  - negative pulse single shot: gets triggered by the comparator when current through current sense exceeds the threshold value.

Procedure to perform the transition pulse test for a Power-i source:

a) Set up the test arrangement as shown in Figure A.9.

NOTE 1 positive pulse from the start button results in closing ES1 and ES2; this leads to a connection of the maximum load to the Power-i source and a subsequent current drop down to shutdown of the Power-i source.

NOTE 2 Due to the slow start-up characteristics of the power-i source after the current drop down to shutdown, an increasing current flows through the current sense.

NOTE 3 if the voltage across the current sense exceeds the primarily adjusted reference voltage $U_{\text{Var ref}}$, the comparator triggers the single shot negative pulse.

This leads to a switch off of ES1 and a 10 V pulse in the system.

b) The reference voltage $U_{\text{var ref}}$ in Figure A.9 shall be adjusted to allow a triggering of the voltage comparator at current values of 25 %, 50 %, 75 % and 100 % of the maximum output current $I_{\text{O-source}}$.

c) Press the start button and verify that this leads to a shutdown of the Power-i source according to 5.2 b). This is to be verified by checking the current drop down to shutdown with the oscilloscope.

A.3.3 Safety-relevant parameters for the Power-i field devices

A.3.3.1 Determination of the safety-relevant maximum values for Power-i field devices

The maximum safety-relevant parameters shall meet the requirements of IEC 60079-11 and IEC 60079-25 and shall be classified in accordance with 5.7.

A.3.3.2 Determination of the response time $t_{\text{resp-field-device}}$ for Power-i field devices

Determination of the response time $t_{\text{resp-field-device}}$ for Power-i field devices is not necessary (see 5.3)

A.3.3.3 Determination of the assessment factor $AF_{\text{field device}}$ for Power-i field devices

Figure A.10 shows the test equipment setup required to determine the assessment factor. This test shall be performed for maximum load conditions of the Power-i field device.

Components of the test equipment in Figure A.10:

- Power-i universal test equipment (see Figure A.1);
- voltage source: generates the specified maximum voltage for the field device;
- coupling module: consists of an inductor to ensure ac decoupling of the voltage source in combination with a parallel 100 Ω resistor;
- switch S3: is used to connect the field device to the measurement setup;
- Power-i field device with maximum load conditions;
- digital storage oscilloscope.

Procedure to determine the assessment factor of a Power-i field device:

a) Set up the test arrangement as shown in Figure A.10.

b) Set up universal test equipment as shown in Figure A.1:
   - switch S2 to position “ON” and toggle switch S1 to position A;
   - adjust the break spark pulse peak value of the single shot pulse generator to +10 V ±5 % on terminal 4 of Figure A.10.

c) Set up test equipment as shown in Figure A.10:
   - switch S3 to position “OFF”: voltage source adjusted to the safety-related maximum value;
   - switch S3 to position “OFF”: measure the pulse peak value $U_{\text{LPF-ref}}$ (see Figure A.2) with the oscilloscope at output 3 of the universal test equipment (see Figure A.1);
   - switch S3 to position “ON”: measure the pulse peak value $U_{\text{LPF-lim}}$ (see Figure A.2) with the oscilloscope at output 3 of the universal test equipment (see Figure A.1);

d) The assessment factor $AF_{\text{field device}}$ is obtained as follows:

$$AF_{field-device} = 20\lg\left(\frac{1{,}25U_{LPF-ref}}{U_{LPF-\lim}}\right).$$

NOTE The factor 1,25 includes a defined additional attenuation of 25 %. A higher assessment factor $AF_{\text{field-device}}$ means higher safety due to an artificial (intended) impairment.

e) Repeat the steps b) to d) with the reference rectangular pulse of the single shot pulse generator for make sparks -10 V ± 5 % on terminal 4 of Figure A.10.

f) The highest determined assessment factor shall be used as the rated assessment factor for the Power-i field device (marking).

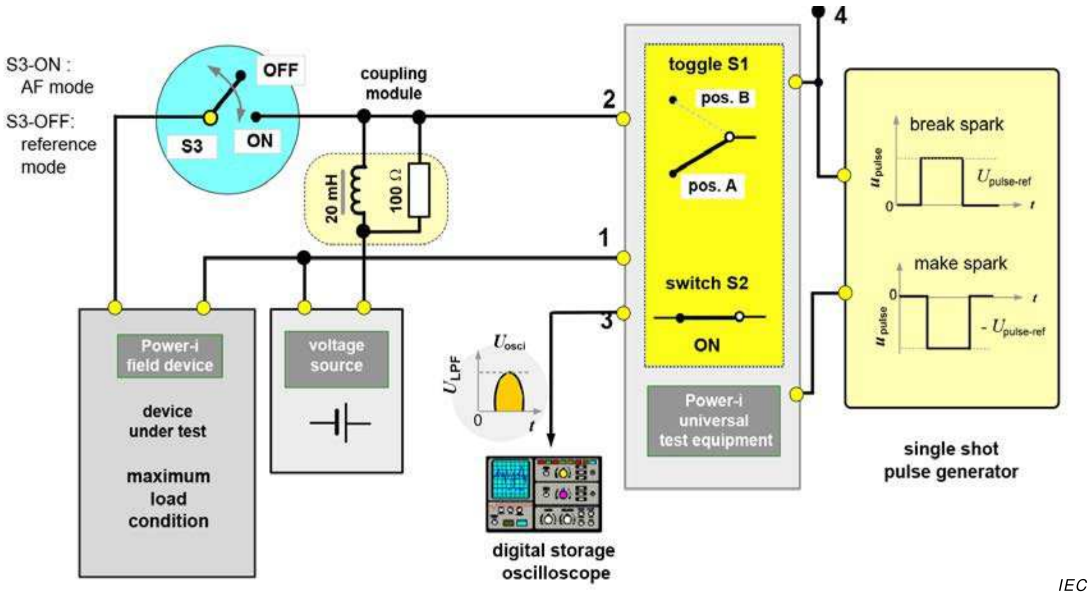

Figure A.10 – Test equipment for the determination of the assessment factor $AF_{\text{field device}}$ for Power-i field devices (basic principle)

A.3.3.4 Transition pulse test for Power-i field devices

Figure A.11 shows the equipment setup required to perform the transition pulse test.

This test equipment consists of the following components:

- Power-i field device under maximum load conditions;
- commercially available voltage source;
- coupling module;
- digital storage oscilloscope;
- pulse tester for field devices with the components (see also Figure A.9):
  - start button;
  - electronic switches: ES1 and ES2 simulating connection/disconnection of the Power-i field device to the voltage source;
  - variable reference element to adjust comparator threshold and current sense;
  - single shot/negative pulse: gets triggered by the comparator when current through current sense exceeds the threshold value.

Procedure to perform the transition pulse test:

a) set up the test arrangement as shown in Figure A.11.

NOTE 1 a positive pulse from the start test unit results in closing ES1 and ES2; this leads to a connection of the power-i field device to the voltage source;

NOTE 2 Due to the slow start up characteristics of the power-i field device an increasing current flows through the current sense.

NOTE 3 if the voltage across the current sense exceeds the primarily adjusted reference voltage of the comparator, the single shot negative pulse is triggered. This result is the switching off of ES1 thus generating a 10 V pulse across the terminals of the pulse tester;

b) Adjust the reference voltage $U_{\text{var ref}}$ in Figure A.11 to allow a triggering of the voltage comparator at current values of 25 %, 50 %, 75 % and 100 % of the maximum current.

c) Measure the voltage pulse U_{pulse} (see Figure A.11) resulting from the switching action across the coupling module with the oscilloscope for the different current values as described in b).

   The resulting U_{pulse} level shall be above the level of the envelope curve as shown in Figure A.12 within the shown time window. Alternatively the voltage-time area of the resulting pulse shall be above ±64 μVs within the shown time window of 20 μs.

   NOTE 4 This applies especially to field devices with active decoupling components.

Power-i field devices containing an internal current limitation unit (see 5.7) shall be tested with the internal current limitation working, i.e. the nominal internal/external load shall be shorted.

The test procedures a) to c) shall be performed with the variable reference of the pulse tester adjusted to trigger the comparator at a current value which matches the limit value of the internal safety-related current limitation.

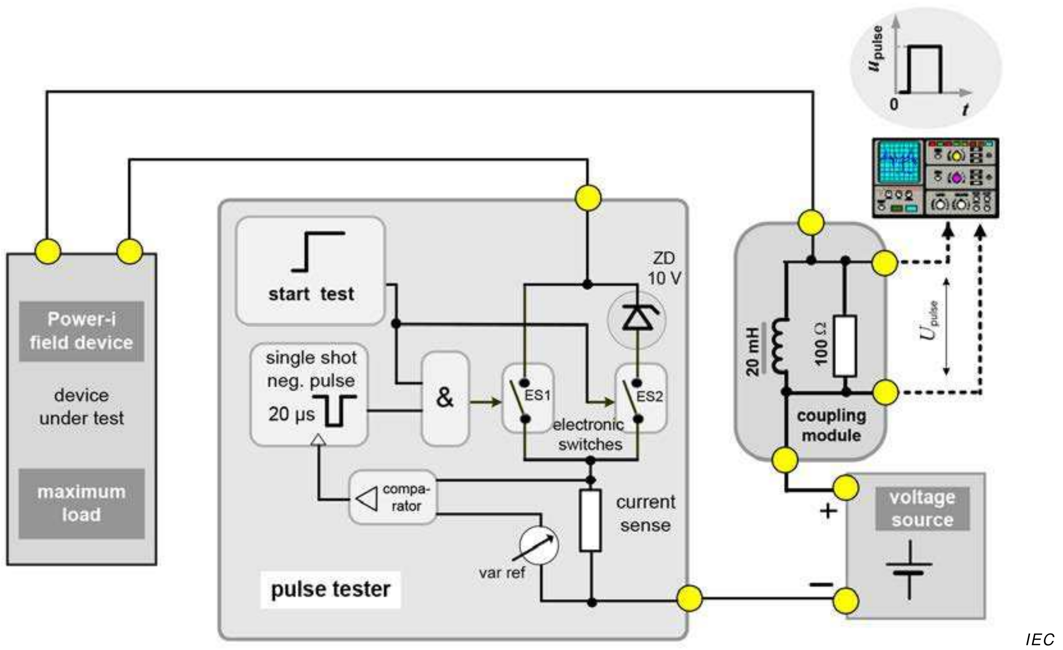

Figure A.11 – Test equipment for the transition pulse test of Power-i field devices

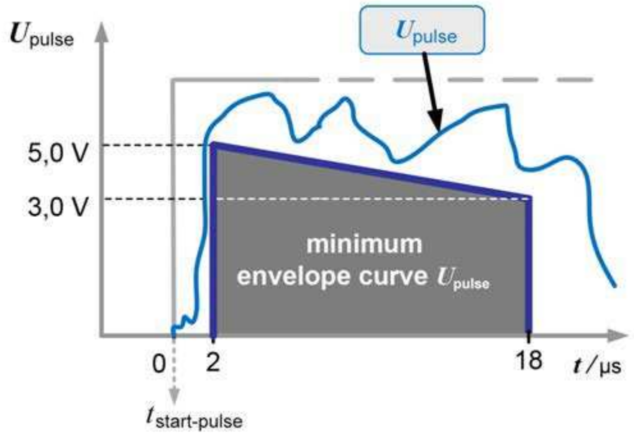

Figure A.12 – Evaluation parameter of test pulse U_{pulse} for transition pulse test

A.3.4 Safety-relevant parameters for Power-i wiring

A.3.4.1 Determination of the safety-relevant maximum values for Power-i wiring

Cable used for Power-i wiring shall comply with IEC 60079-11, IEC 60079-25 and IEC 60079-14.

A.3.4.2 Determination of the response time $t_{resp\text{-}trunk}$ for the Power-i trunk

The response time $t_{resp\text{-}trunk}$ shall be regarded as one way propagation time in the Power-i trunk cable. If the trunk cable length is less than 40 m the response time $t_{resp\text{-}trunk}$ is defined to be 0,5 µs. For all other cases two different methods of assessment can be used:

Calculate $t_{resp\text{-}trunk}$

This method is based on using the most unfavourable values of the cable parameter L' and C'. The parameters L' and C' are units per length of the trunk cable and shall be known, the value of $t'_{resp\text{-}trunk}$ is a time unit per length. The following applies:

(l_{cable} is the length of the considered cable e.g. in m)

$$t'_{resp-trunk} = \sqrt{L'C'} \quad \text{and} \quad t_{resp-trunk} = t'_{resp-trunk} * l_{cable}$$

NOTE 1 Typical values for $t'_{resp\text{-}trunk}$ are 5... 7 ns/m.

Practical measurement of $t_{resp\text{-}trunk}$

Figure A.13 shows an example of a test equipment setup required to measure the response time of the cable.

NOTE 2 The minimum cable length of 100 m is advisable to reach a sufficient precision.

Procedure to determine the response time $t_{resp\text{-}trunk}$:

a) Set up the test arrangement as shown in Figure A.13.

NOTE 3 Most generators possess an internal resistance R of 50 Ω, therefore, it is recommended to reduce the value of the external resistance R in order to match the cable resistance of 100 Ω.

b) Generate a positive pulse of 200 ns duration by the pulse generator.

c) Observe the signal at point B with an oscilloscope.

d) Measure the delay time t_{delay} between the positive rising edge of the initial pulse and the negative falling edge of the reflected pulse.

e) Calculate the response time per length $t'_{resp\text{-}trunk}$ from the following equation: (l_{cable} = length of the considered cable):

$$t'_{resp-trunk} = \frac{t_{delay}}{2l_{cable}} \text{ and } t_{resp-trunk} = t'_{resp-trunk} * l_{cable} .$$

f) If necessary calculate the characteristic impedance Z_W from the following equation:

$$Z_W = \frac{100\Omega * U_B}{U_A - U_B} .$$

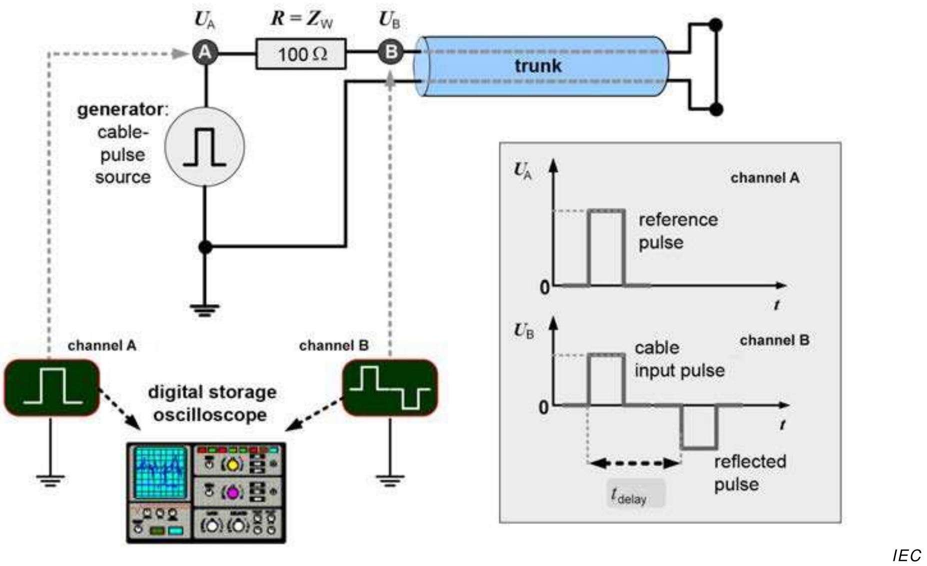

Figure A.13 – Test equipment for the determination of the response time of the Power-i trunk $\mathbf{t}_{resp\text{-}trunk}$ (basic principle)

A.3.4.3 Determination of the assessment factor AF_{trunk} for the Power-i trunk

The assessment factor of the Power-i trunk cable AF_{trunk} used shall be specified in accordance with the following formula:

$$AF_{trunk} = 4.34 \frac{R}{Z_W} \text{ and } R = R' * l_{cable}$$

The parameter R is the ohmic resistance (loop resistance with the unit Ω) of the used cable and shall be known, the parameter R' is the ohmic resistance per length.

The characteristic impedance Z_W can be determined by the following equation:

$$Z_W = \sqrt{L'/C'}$$

To determine the value of the characteristic impedance Z_W it is also possible to use the test setup for practical measurement of the response time $t_{resp\text{-}trunk}$ in accordance to A.3.4.2 f) by using the test equipment of Figure A.13.

NOTE 1 The loop resistance R can be easily measured with an ohmmeter.

NOTE 2 Example: R'= 25 Ω/1000 m, L'= 666 µH/1000 m and C'= 66 nF/1000 m ⇒ Z_W=100 Ω ⇒ AF_{trunk}=1,1;

A.3.5 Safety-relevant parameters for the Power-i terminator

A.3.5.1 Determination of the safety-relevant maximum values for Power-i terminators

The maximum safety-relevant parameters shall meet the requirements in accordance with IEC 60079-11 and IEC 60079-25 and shall be classified in accordance with clause 5.7.

A.3.5.2 Determination of the response time $\boldsymbol{t}_{resp\text{-}terminator}$ for Power-i terminators

Determination of the response time $t_{resp\text{-}terminator}$ for Power-i terminators is not necessary (see 5.5)

A.3.5.3 Determination of the assessment factor $\boldsymbol{AF}_{terminator}$ for Power-i terminators

The determination of $AF_{terminator}$ is based on the procedure to determine the assessment factor for Power-i field devices as described in A.3.3.3 with the following changes:

- replace the Power-i field device (device under test) in Figure A.10 with the Power-i terminator;
- follow the procedure described in A.3.3.3 to measure the assessment factor $AF_{termination\text{-}unit}$;
- the highest determined assessment factor shall be used as the rated assessment factor for the Power-i terminator.

Annex B
(informative)

Explanation and details of the Power-i basic concept

B.1 Physical basics of an ignition

By testing the ignitibility of sparks of intrinsically safe equipment the aim is to distinguish between inductive, capacitive, mixed and resistive circuits on one hand and various output characteristics of the power-source on the other. Of particular relevance are the spark parameters spark voltage U_s, spark current I_s and spark duration time t_s. This allows the determination of the spark-power P_s and the spark energy W_s. Based on these parameters in most cases it is possible to assess the spark energy released by the circuit.

The general precondition for an ignition is the necessity to exceed a defined ignition temperature in an initial volume of the gas/air mixture. For this, the reaching of a certain energy density in this initial volume is necessary. As the energy density derives from the power consumption within a certain spark duration time, it can be deduced that the factor "time" is of fundamental importance during an ignition. By influencing the factor "time" in a well-aimed manner, the ignition behavior can be strongly influenced – that means significantly higher intrinsically safe approved values can be reached. The present standard IEC 60079-11:2011 does not account for this circumstance.

“Power-i” considers this circumstance and takes the factor “time” into account because it is based on dynamic recognition and reaction to safety-critical conditions.

For optimization, however, a safety-related assessment of the three essential components of the overall system – Power-i source + Power-i wiring + Power-i field devices (including load) – is required.

To understand the operating principle of “Power-i” it is helpful to have a look at the typical trace of a break spark given by the spark test apparatus according to IEC 60079-11. Figure B.1 shows an example of a break spark supplied by a source with resistive limiting. Every break spark is characterized by an initial step with a voltage rise of about 10 V in combination with a current drop. The end of the spark is characterized by the maximum output voltage of the power supply.

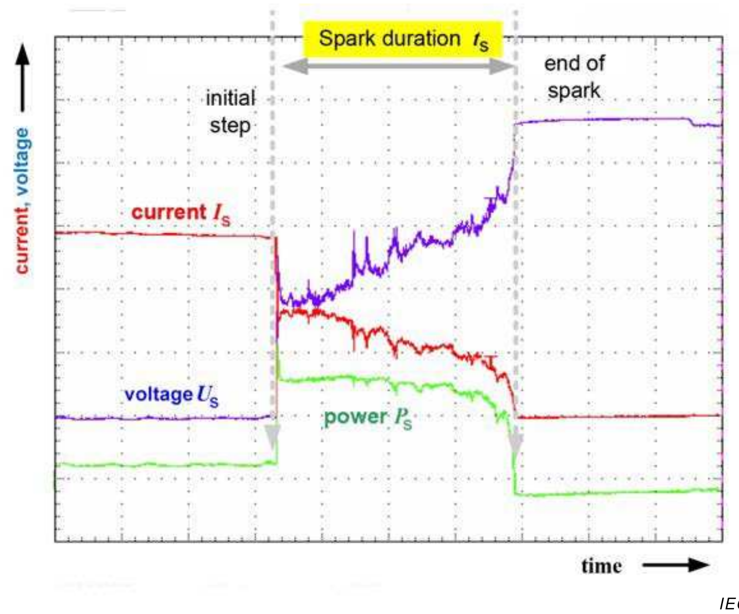

Figure B.1 – Example of a typical trace of a break spark supplied with a linearly limited source

This type of spark is characterised by a very variable spark duration – usually between 20 μs and 2 ms (for equipment group IIC). The varying spark duration leads to an undefined energy input into the spark and the hazardous mixture. In conventional intrinsic safety the input spark power is therefore limited to low values where thermal loss exceeds the energy input. Therefore the temperature of the gas surrounding the arc temperature cannot reach the ignition threshold value. This means that the available power for functional requirements is also limited.

Power-i does not rely on power limitation, but rather on time limitation. This means that more power is available for functional requirements. Time limitation of the spark ensures that the temperature of the gas mixture cannot reach the ignition threshold (see Figure B.2).

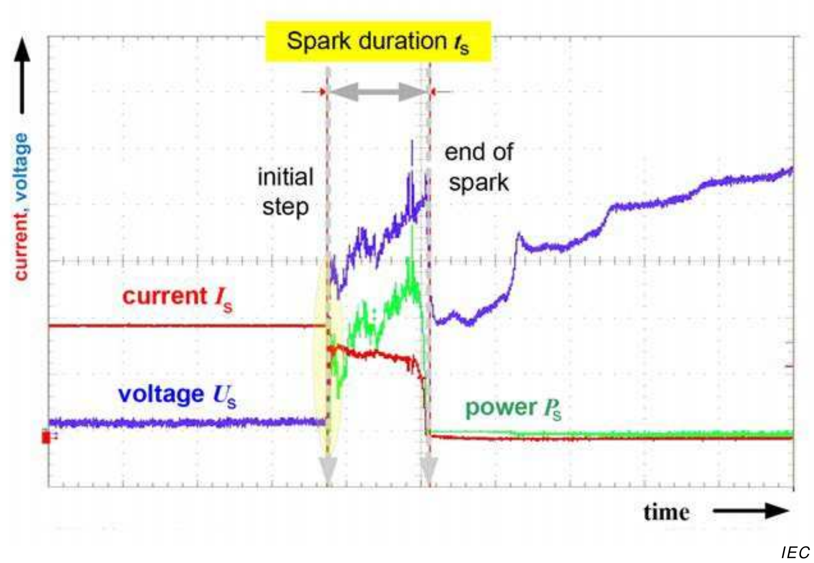

Figure B.2 – Example of a typical trace of a break spark limited by a Power-i source

When using Power-i devices the initial step in Figure B.2 is identical to that shown in Figure B.1. The fundamental difference is that Power-i is based on the defined limitation of the spark duration. The spark duration depends primarily on the maximum system response time of the whole Power-i system. This time is mainly dependent on the cable/trunk used (cable propagation time) and the response time of the Power-i source (hardware shutdown time of the source). Typical values for a cable/trunk with a length of 1 000 m are e.g. 10 µs to 15 µs and for a Power-i source e.g. 1 µs. Therefore the maximum spark energy can be calculated relatively exactly.

B.2 Output characteristics of a Power-i source

In Power-i two modes of operation are implemented: The shutdown mode and the Power-i mode. In the shutdown mode the complete system is situated in the intrinsically safe area in accordance with IEC 60079-11 or IEC 60079-25. The Power-i mode is the normal operation mode.

Power-i is based on a targeted influence on the source of any kind of spark formation, whereby a return to normal operation (Power-i mode) is not possible before the critical state (spark) has ended. When using Power-i, the whole system consisting of the source, field devices, the wiring and the terminator are to be assessed as an entity under safety-relevant aspects.

Two functional transition modes from shutdown mode to the Power-i mode are possible:

a) Continuous return mode: The Power-i source returns slowly to the Power-i mode. The $\frac{di}{dt}$ current rise time shall be low enough to avoid triggering the Power-i source to shutdown mode. The intention of this mode is to power simple applications as there are solenoid values, heating elements etc.

b) Voltage threshold return mode: For the transition from shutdown mode to Power-i mode a defined threshold voltage U_{thres} shall be exceeded, to ensure that a transition to Power-i mode is impossible in case of low resistance or short circuit situations. Power-i field devices in compliance with this mode will remain in high resistance state until transition to Power-i mode is completed (see Figure B.3)

Figure B.4 shows a hardware example to ensure this behaviour. The intention of this mode is to supply power to more complex applications (e.g. fieldbus devices).

For both functional transition modes the following applies: If an illegitimate current change is detected during return to Power-i mode – the Power-i source immediately falls back to shutdown mode.

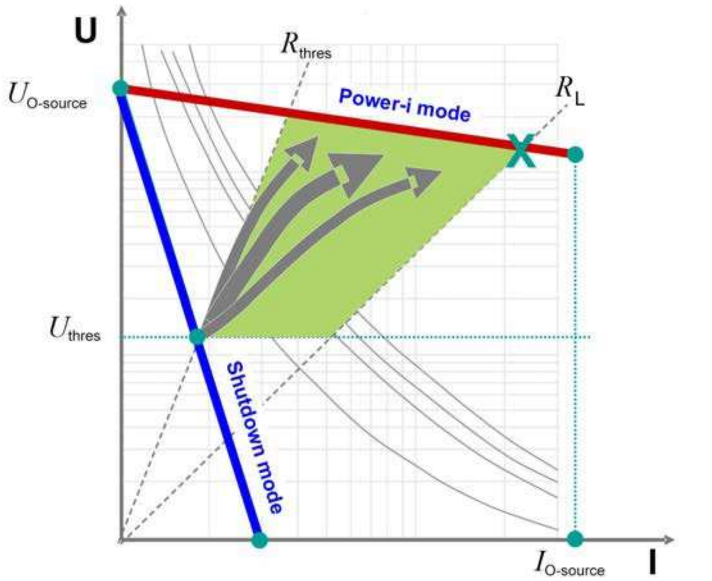

Figure B.3 – Example of output set of characteristic curves of a Power-i source during load connection

The set of characteristic curves as shown in Figure B.3 consists of two different ranges – the shutdown range and the Power-i range. The shutdown range is the intrinsically safe area below values in accordance with the IEC 60079-11 or IEC 60079-25. This is the starting and the return range. The Power-i range is the normal or working range based on a hardware concept according to Figure B.4.

a) Shutdown mode: (see Figure B.5 – electronic switch S1 of Figure B.4 is open). This curve is completely situated in the intrinsically safe area in accordance with IEC 60079-11. The intrinsically safe (residual) output current in combination with the load resistance therefore determines the voltage at the output clamps of the Power-i source. As soon as the specified threshold value U_{thres} (see Figure B.3 – U_{thres} and R_{thres}) is exceeded, the transition into the range of the Power-i characteristic starts.

b) Power-i mode: (see Figure B.5 – electronic switch S1 of Figure B.4 is closed). The Power-i mode is the operating range which permits the maximum output power.

c) If a current change $\frac{di}{dt}$ is detected which is above the minimum triggering value for the dynamic shutdown it quickly leads to a return to shutdown mode (electronic switch S1 in Figure B.4 is open).

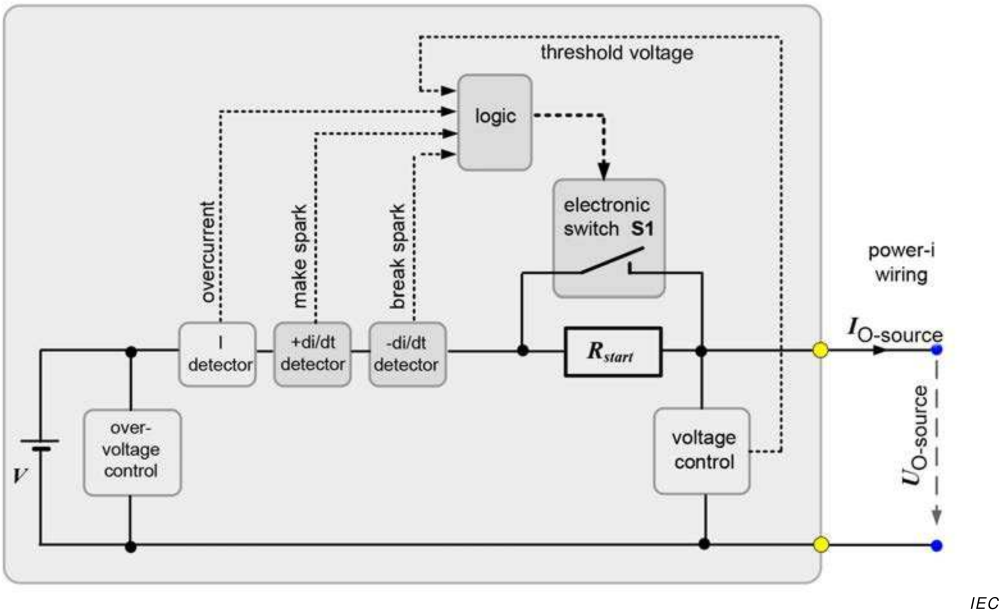

Figure B.4 – Basic principle of a Power-i power source for the voltage threshold return mode

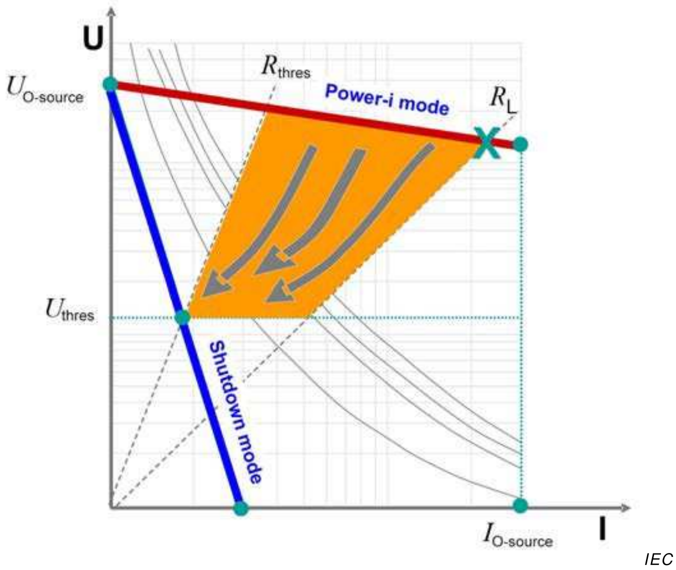

Figure B.5 – Example of output set of characteristic curves of a Power-i source in the case of a failure

The transition of shutdown mode to Power-i mode (starting) can take place slowly – it is not safety relevant – i.e. in the ms range. The safety-relevant transition from the Power-i mode to the shutdown mode is preferably as short as possible (in the range of a few μs).

B.3 Measurement and scientific results as basis for Power- i minimum ignition values

B.3.1 Test setups for the determination of the ignition probability

To find the worst case ignition values for Table 3 tests have been performed with setups for break and for make sparks as shown in and Figure B.7.

Components of the test setups (see Figure B.6 and Figure B.7):

- Power-i source: device under test;
- STA: Spark test apparatus according to IEC 60079-11;
- Current detector: ensure contact counts only at specified current;
  - – Decoupling unit: necessary to ensure functionally and safety of the Power-i system;
  - – Adjustable load: determine the specified current for measurement;
  - – Digital counter: to count valid contacts.

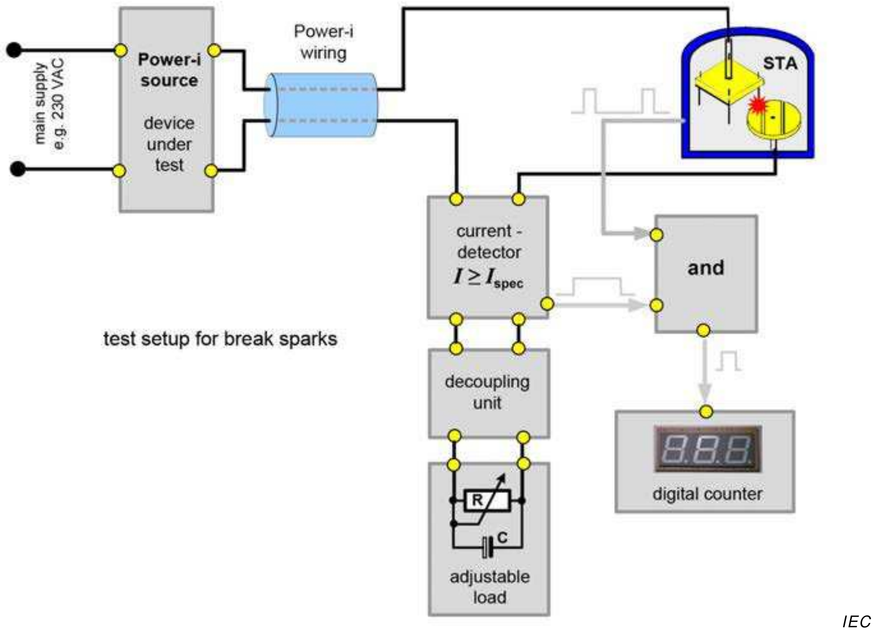

Figure B.6 – Test setup with STA for break sparks

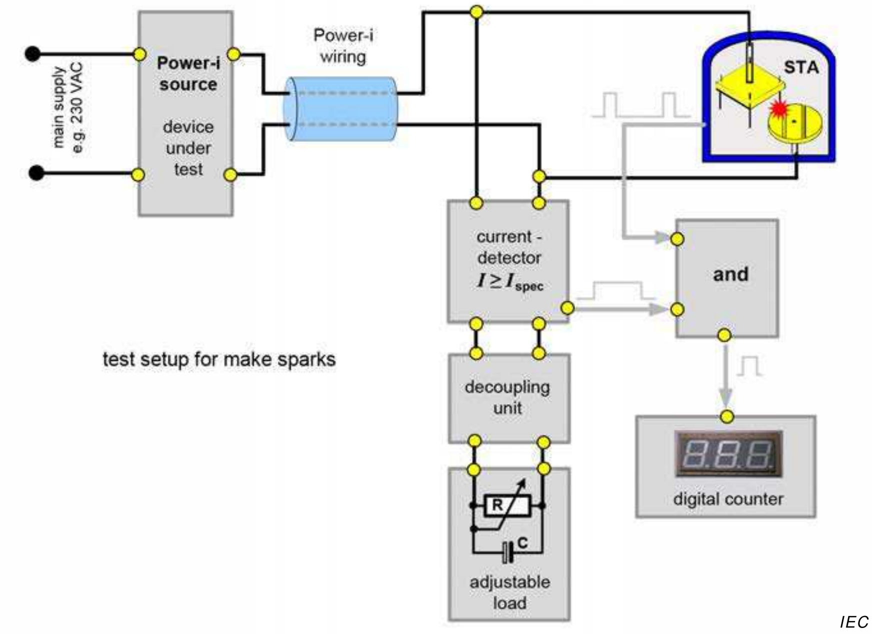

Figure B.7 – Test setup with STA for make sparks

With these test setups an ignition probability of 10^{-3} or lower has been achieved, i.e. in average one ignition in 1 000 contacts is allowed.

Procedure to determine the ignition limiting values:

The determination of the ignition probability for Power-i was performed in compliance with the evaluation of the ignition tables and curves in IEC 60079-11 Annex A. These values are based on the above mentioned ignition probability of 10^{-3} or lower. Due to the characteristic of the Power-i system it is necessary to ensure that the system is in specified Power-i mode during the make/break contact of the STA. The detector is used to monitor the system state. Therefore the digital counter only counts valid contacts during Power-i mode. The tests shall be performed with the STA in two different positions – as shown in and Figure B.7. The test results are to be found in Figure B.8, Figure B.9 and Figure B.10. The marked values in the measured curves are based on at least 15 ignitions.

All tests had been performed with equipment group IIC for safety factor 1,5 – by using an Oxygen enriched mixture, i.e. 30 % hydrogen, 53 % Air and 17 % oxygen (in accordance with IEC 60079-11).

The resulting ignition values in Table 3 are based on the following assumption:

Figure B.11 shows the dependence of the minimum ignition energy in relation to the used hydrogen – air ratio of the gas mixture. The minimum ignition energy is approximately 17 µJ at 21 % hydrogen in air. The used oxygen enriched mixture for safety factor SF 1,5 for Group IIC has a minimum ignition energy of approximately 10 µJ. The safety factor SF 1,0 for IIC and the safety factor SF 1,5 mixtures for equipment group IIB and IIA are based on hydrogen air mixtures in accordance with IEC 60079-11.

B.3.2 Result of the spark ignition tests and their implementation in Table 3

All measured curves in, Figure B.9 and Figure B.10 have been performed with Oxygen enriched mixture for equipment group IIC by using the IEC 60079-11 Spark Test Apparatus.

All curves in, Figure B.9 and Figure B.10 with the name " ***Table 3" are for reference. Here only the marked points correspond to valid current classes in Table 3.

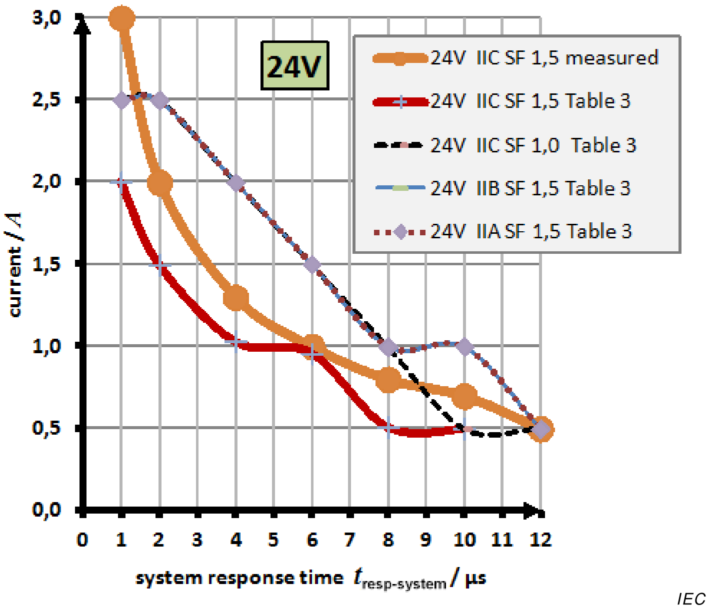

Figure B.8 – Power-i ignition values for voltage class 24V (24 VDC)

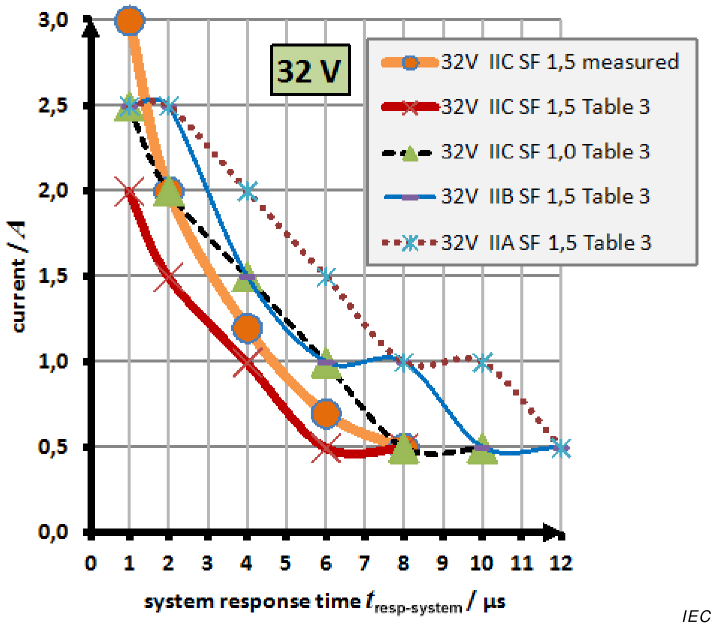

Figure B.9 – Power-i ignition values for voltage class 32V (32 VDC)

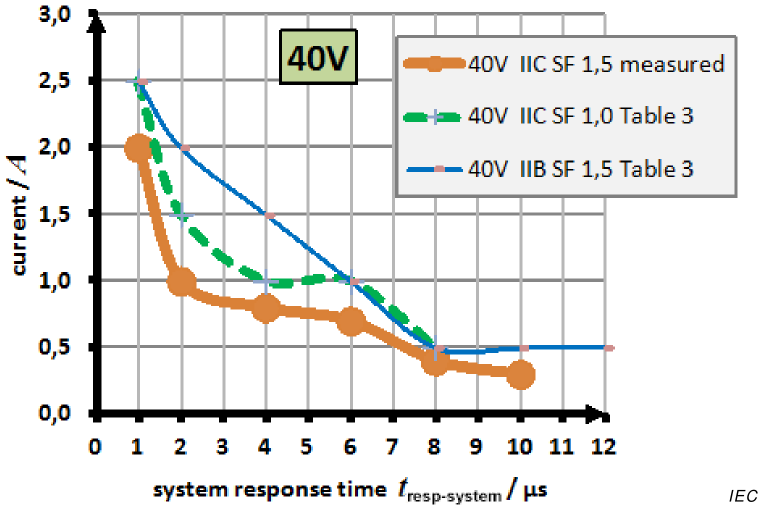

Figure B.10 – Power-i ignition values for voltage class 40V (40 VDC)

NOTE In Figure B.10 the curve “40V IIC SF 1,5 measured” is the basis for the curves “ 40V IIC SF 1,0 Table 3” and “40V IIB SF1,5 Table 3”.

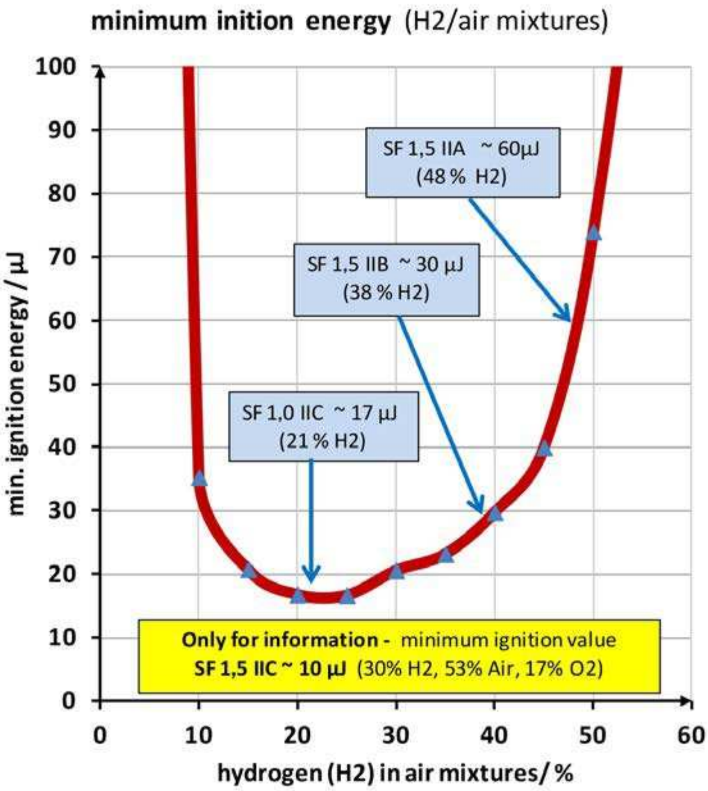

Figure B.11 – Ignition energy in relation to the used hydrogen percentage in the gas mixtures

Annex C
(informative)

Examples of Power-i devices and systems

C.1 Power-i application for a solenoid valve

Figure C.1 shows a Power-i system optimized for simple solenoid valves with the following boundary conditions for Group IIC, Power-i level of protection “ib” and safety factor SF 1,5:

20 V d.c. $\leq U \leq$ 30 V d.c., $P <$ 15 W, maximum trunk length = 400 m

This corresponds to the maximum Power-i application class: 32V2A0;

An example of this specific application is shown in Figure C.1. The solenoid in Figure C.1 is used as decoupling inductance. The parallel capacitance C depends on the inductance L and the static current of the solenoid valve. The following requirements should be met:

$$L \geq 10mH \text{ , } C \geq 500nF \text{ et } R_3 = \frac{5V * R_2}{(U_{\text{O-source}} - 5V)} \geq 1000\Omega$$

Inductance L, capacitance C, resistances R_2 and R_3 and all diodes are safety relevant in accordance with IEC 60079-11. Furthermore the following applies (for the time constant):

$$\frac{L}{R} \geq 10 R_2 C$$

This application of the solenoid valve field device requires an explosion protected design (e.g. encapsulation according to Ex “m”).

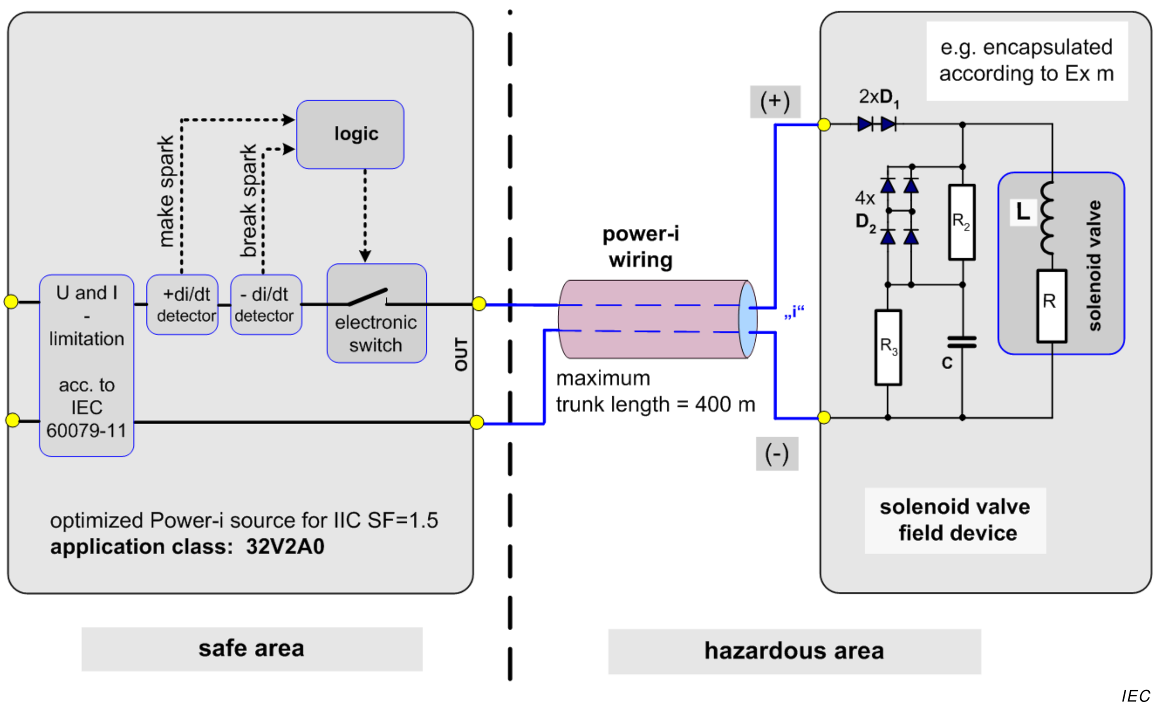

Figure C.1 – Simple solenoid valve Power-i application (example)

NOTE Other parameters for U, I, P or trunk lengths are also possible – but for this case additional safety-relevant considerations are necessary.

C.2 Example of a generally designed Power-i source

Figure B.4 shows one example of a generally designed Power-i source. This Power-i source is performed as a combination of functionally and safety-relevant components. This Power-i source is in compliance with the following important functional requirements:

- Preventing return from shutdown mode to Power-i mode as long as a threshold voltage U_{thres} of 15 V is not exceeded;

  (Other values from 10 V up to 2/3 of the supply voltage are also possible.)

  NOTE It is necessary to ensure that only a value of resistance above a minimum resistance connected to the output of the Power-i source leads to a transition from shutdown mode to Power-i mode. Otherwise a transition to Power-i mode would be possible with a low resistance connected (e.g. contact resistance).

- The transition from the shutdown mode to the Power-i mode requires defined start behaviour (soft start) of the Power-i source.

C.3 Example of a Power-i field device

Figure C.2 shows an example of a generally styled Power-i field device. The internal soft start shown in Figure C.2 is only necessary for functional reasons. If the current limiter is relevant for the classification in a Power-i current class (see clause 5.7) it is to be considered as safety relevant.

NOTE 1 Soft start is safety relevant for temperature classification.

Capacitance C in Figure C.2 is relevant to generate a detectable $\frac{di}{dt}$ pulse for any type of load (arbitrary load) connected (e.g. high inductances). The capacitance C should have a minimum value of 500 nF. Inductance L determines the assessment factor value of the Power-i field device. A higher value of L results in a lower assessment factor.

The Power-i field device shown Figure C.2 ensures that any make or break spark in the Power-i wiring will cause a spark pulse with a sufficient amplitude to trigger a shutdown reaction of the Power-i source (for level of protection "ib").

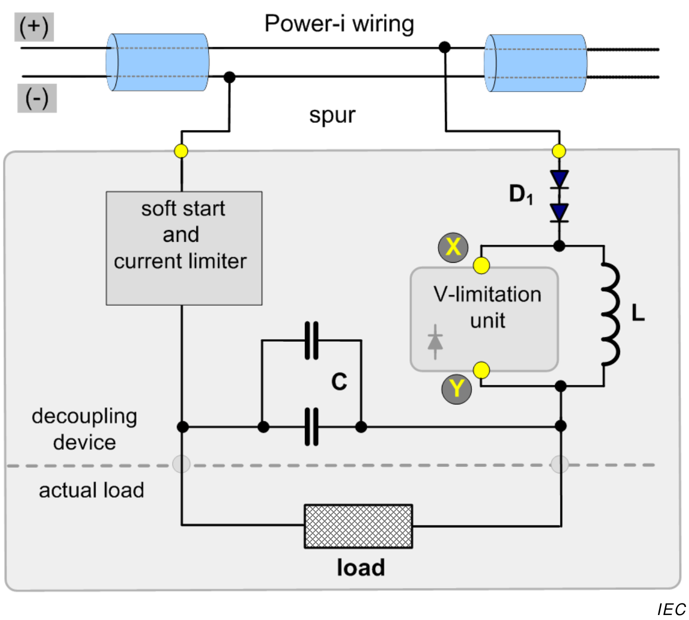

Figure C.2 – Example of a generally styled Power-i field device

A practical example of the V-limitation unit for level of protection “ib” is shown in Figure C.3.

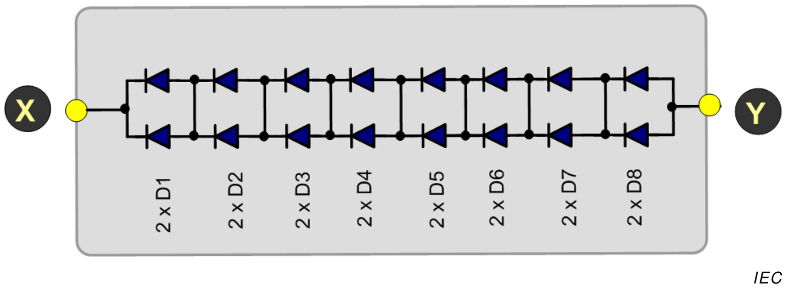

Figure C.3 – Example of a V-limitation unit (level of protection “ib”)

NOTE 2 In case of a short circuit of one diode, the voltage across the V-limitation unit decreases by 0,7 V.

C.4 Example of a Power-i dummy load

Figure C.4 shows a detailed circuit of a Power-i dummy load as an example.

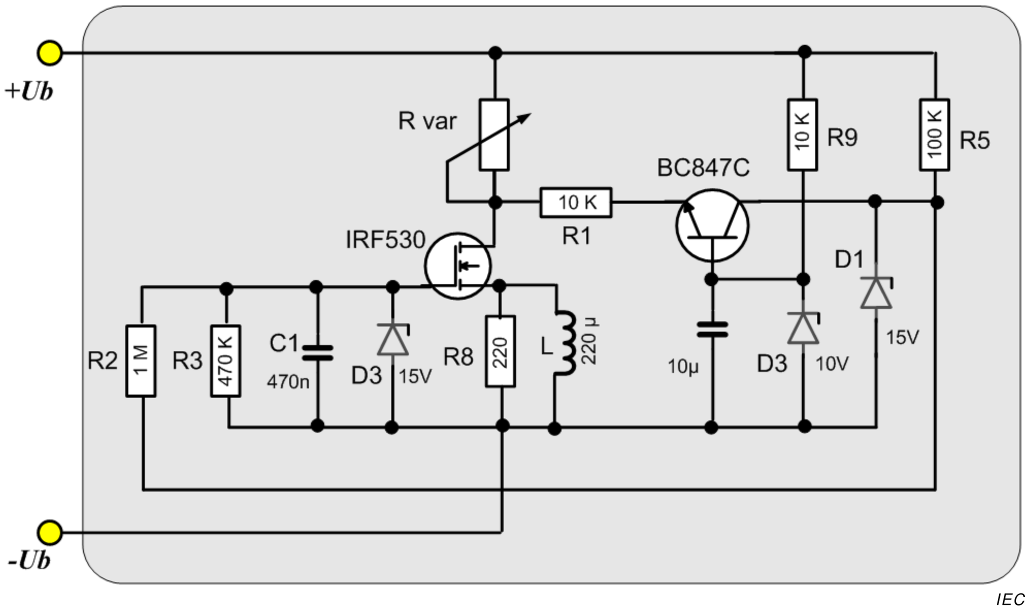

Figure C.4 – Example of a Power-i dummy load

C.5 Example of a Power-i terminator

An example of a Power-i terminator for the level of protection “ib” is shown in Figure C.5:

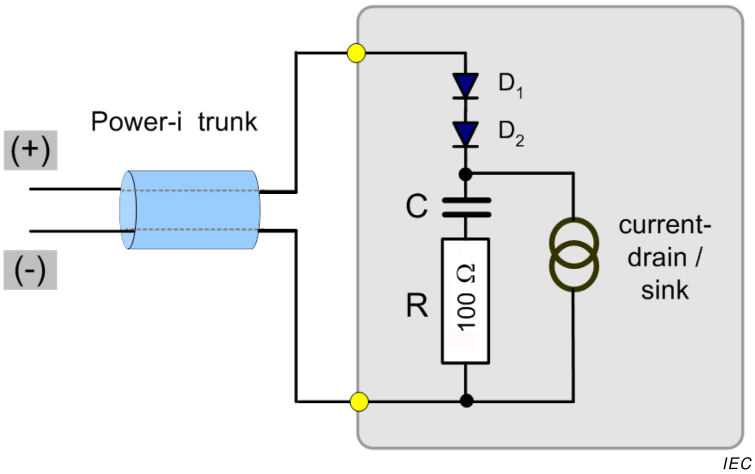

Figure C.5 – Example of a Power-i terminator

In Figure C.5 only the diodes D1 and D2 are safety relevant.

NOTE The current drain is necessary to generate a bias current for data transmission purposes only.

Annex D
(informative)

Example of interconnection of Power-i devices including Power-i wiring to a Power-i system

D.1 Specific aim and given values

Determination of the maximum numbers of Power-i field devices on a given (predefined) Power-i trunk.

The given equipment group is IIC with a safety factor SF = 1,5 and the given Power-i voltage class is 32 V.

The following Power-i field devices and the following Power-i terminator are available:

- Power-i field devices type 1: 32V2A0, $AF_{\text{field device-1}}$ = 1,5 or
- Power-i field devices type 2: 32V2A0, $AF_{\text{field device-2}}$ = 2,1;
- Power-i terminator: 40V2A0, $AF_{\text{terminator}}$ = 5,0.

The following Power-i wiring application is given:

cable length l_{cable} = 700 m $t_{\text{resp-trunk}}$ = 3,2 µs AF_{trunk} = 1,1.

D.2 Solution example

Step 1: Which kind of Power-i source is applicable? (see Clause 6)

Each Power-i source which meets the requirements according to the application classes given in Table 3 is applicable.

permitted application classes: 32V0A5

preselected Power-i source: 32V0A5, $t_{\text{resp-source}}$ = 1 µs, AF_{source} = 12;

Step 2: Verify the Power-i system response time $t_{\text{resp-system}}$ (see 6.2c)

$t_{\text{resp-system}} = 1\ \mu s + (2{*}3{,}2\ \mu s) = 7{,}4\ \mu s \leq 8\ \mu s$

The preselected Power-i source is in accordance with Table 3 and is suitable for this application.

NOTE 2 If the value of the response time of the selected Power-i source $t_{\text{resp-source}}$ exceeds 1,6 µs this Power-i source is unsuitable for this application.

Step 3: Determination of the maximum number of field devices to the Power-i trunk in accordance with Clause 6.

$$AF_{\text{source}} \geq AF_{\text{terminator}} + AF_{\text{trunk}} + \sum_{1}^{n} AF_{\text{field-device}}$$

without Power-i terminator:

$$12 \geq 0 + 1{,}1 + \sum_{1}^{n} 1{,}5 \Rightarrow n \leq 7{,}27$$

- maximum 7 Power-i field devices type 1 or
- maximum 5 Power-i field devices type 2 are allowed;

with Power-i terminator:

$$12 \geq 5{,}0 + 1{,}1 + \sum_{1}^{n} 1{,}5 \Rightarrow n \leq 3{,}93$$

- maximum 3 Power-i field devices type 1 or
- maximum 2 Power-i field devices type 2 are allowed.

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