

## Session Three: The New Dimension of Intrinsic Safety

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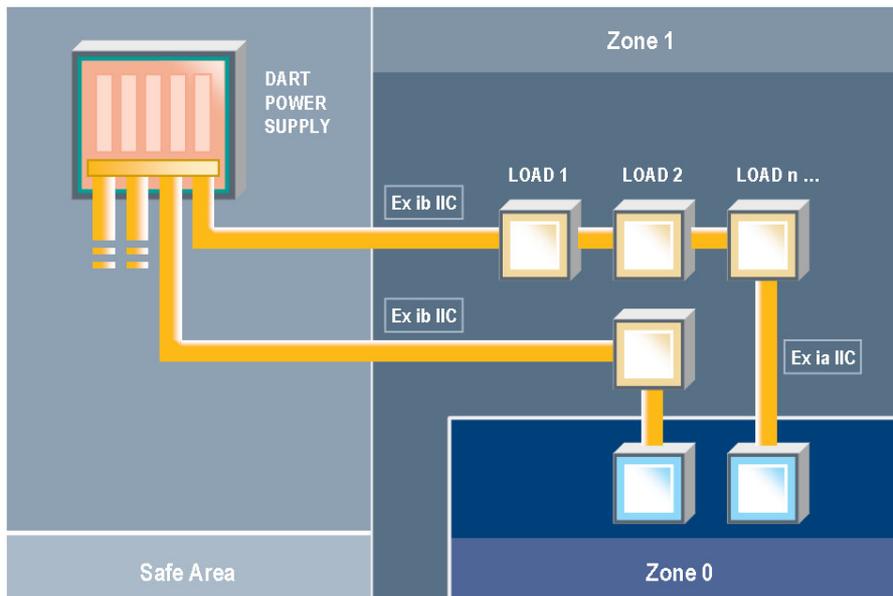
### Introduction

In an area endangered by the likelihood of an explosion (hazardous area) the type of protection known as intrinsic safety offers recognized advantages, such as its worldwide acceptance and the simple connection and installation technology. In addition, it is possible to carry out work on circuits and devices for the purpose of re-equipment, plant extension and maintenance, during actual operation and without a hot-working certificate. The intrinsic safety class of ignition protection is based on the principle, that sparks occurring in an electrical circuit are always limited in terms of their energy, so that they cannot cause an ignition to take place in an existing potentially explosive atmosphere.

The intrinsic safety type of protection is currently achieved by limiting the available power. This limitation of power – usually to less than 2 W – provides intrinsic safety (Ex i) and is therefore mainly employed in the area of control and instrumentation in the power supply to actuators and sensors with low connected load.

A significantly higher direct power with the simultaneous safeguarding of all the positive characteristics of intrinsic safety offers the user a new and essentially wider scope of application. These aims are achieved through DART technology (DART: Dynamic Arc Recognition and Termination). DART is a means of instantaneous tripping, which dynamically detects an undesired condition or a fault in the electrical system precisely as it occurs and instigates an immediate transition to a safe condition before any safety-critical parameters are exceeded. DART is based on the detection of fault conditions and their characteristic rate of rise of current.

Through the use of DART, systems can be operated at drastically increased direct power output compared to current intrinsic safety solutions. More available direct power opens the door to the use of the intrinsic safety type of protection in many applications relevant to the process industry. The following are some examples: Weighing equipment, lighting systems, valve control systems and fieldbus systems such as FOUNDATION Fieldbus H1 and PROFIBUS PA.



**Figure 1**

Block diagram: Power supply, cable and load, with Ex-Zones

## Basic Operating Principles

In the normal operating condition the DART power supply feeds the full nominal power, which depending on the application, can be greater by a factor of between 4 and 25 (8 to 50 W) compared to standards-related permissible values. DART detects at the very instant of the onset of a fault incident, due for example to the opening of the circuit, the resulting change in current and immediately switches off the power supply. In this way, the energy from the electrical system is effectively limited in just a few microseconds and thus a spark capable of causing an ignition is prevented.

This procedure is possible due to a very characteristic and therefore easily detectable change in current  $di/dt$  during the onset of a fault condition. The reaction of the power supply takes place very quickly – in approximately  $1.4 \mu\text{s}$ . On such a fast reacting system, an additional factor to be considered is the propagation time on the cable. The energy released is determined by the power converted at the point of the fault integrated over the time up to the effective disconnection. The following physical parameters are principally responsible for this:

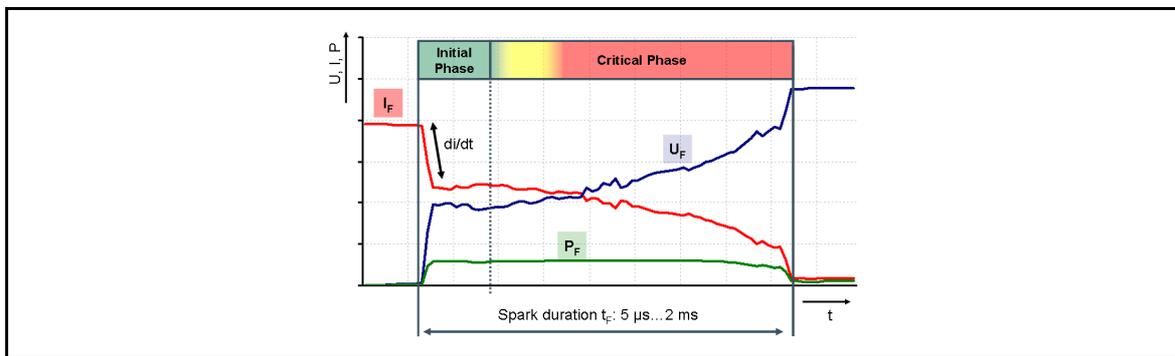
- The power – determined by the supply voltage and the load current
- The time – comprising the signal propagation delay in the cable and the reaction time of the power supply
- The energy stored in the connection cable
- The load behavior.

The energy liberated in the spark is determined by the power available, integrated over time. The relationships are explained below. Figure 1 shows the arrangement of the power supply, cable and devices in the hazardous area.

## Detecting the Ignition of a Spark

The determination of the intrinsically safe ignition limit values is made with the spark test apparatus specified in the standard IEC 60079-11 – in which these values are subjected to a specified ignition probability. It is important to distinguish make sparks and break sparks. Only break sparks are considered in this context.

A typical example of the behavior of the electrical parameters of a break spark is shown in Figure 2. A break spark commences with the voltage  $U_F = 0$  V and usually ends on reaching the open circuit voltage at  $U_F = U_0$ , in which the steady increase of the spark voltage is directly associated with a reduction in the spark current  $I_F$  in a linear circuit. The period of time in between depends on the circuit and is referred to as the spark duration  $t_F$ . Typical spark duration  $t_F$ :  $5 \mu\text{s} < t_F < 2 \text{ ms}$ .



**Figure 2**

Variation with time of the spark current, voltage and power of a linear limited break spark

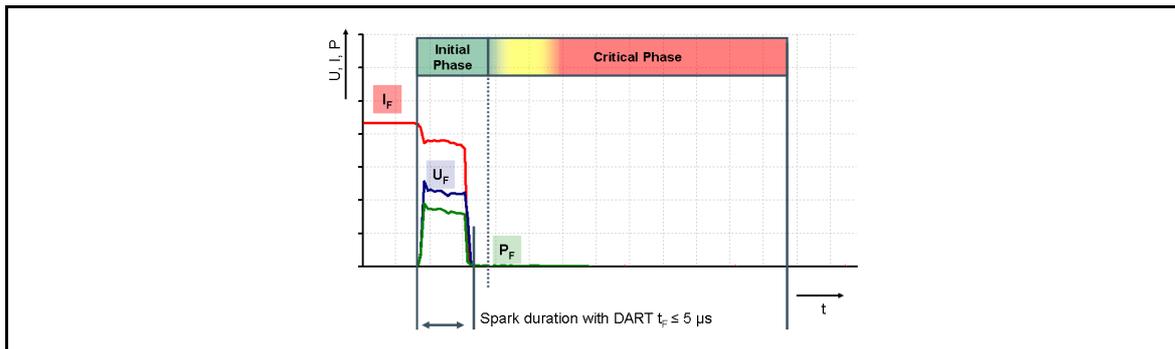
At the start of a break spark the spark voltage  $U_F$  jumps within a very short time ( $t \approx 1 \mu\text{s}$ ) from 0 V to  $U_F \geq 10$  V. The voltage change is directly linked with a characteristic and easily evaluated current jump  $di/dt$  (see curve  $I_F$ ). Directly after this jump in current the spark current and spark voltage remain relatively constant for approximately 1 to 5  $\mu\text{s}$ . During this period there is definitively no possibility of ignition due to the extremely low available spark energy  $W_F$  and it is referred to as the “initial phase“. There then follows a longer period of time, which as a maximum, persists up to the end of the spark duration  $t_F$ . This range is the “critical phase“ during which an ignition can occur. During this period the spark draws the necessary ignition energy from the system, i.e. from the source, the cable and the consumer loads.

From the knowledge of these variations with time it can be seen, that the rapid detection of sparks in combination with a means for the rapid disconnection of the source can be employed to reliably prevent the ignition of an explosive mixture. The task is principally to evaluate the current jump  $di/dt$ , while giving due consideration to the characteristic safety values.

Figure 3 shows the time history of a spark interrupted by a DART power supply. The current jump is clearly evident, which triggers the transition of the circuit into the safe condition. It is clear, that with DART a fault condition is not only already detected and evaluated within the “initial phase“, but that it also leads to the disconnection of the power

supply. The switch-off time available during this process depends on the system. A frequently used value, based on the physics of the spark is  $5 \mu\text{s}$ .

Due to the very short rise times of current and voltage during the onset of a spark, the connecting cable between the power supply and the load acts as a wave guide even when the cable lengths are very short. The information that a spark is in existence propagates as a traveling wave or surge on the connecting cable. Thus the power supply receives the information delayed – by up to one cable propagation delay period. The reaction of the power supply in turn becomes effective at the position of the spark only after one cable propagation delay period.



**Figure 3**

Time history of the spark current, voltage and power of a break spark with DART interruption

This delay is an important safety parameter. In a typical cable used for instrumentation electric waves travel at approx. half the speed of light or 160,000 km/s. Available power is approximately inverse proportional to the cable length. Further influencing factors to be considered are, for example, the stored energy in the connection cable and in the load.

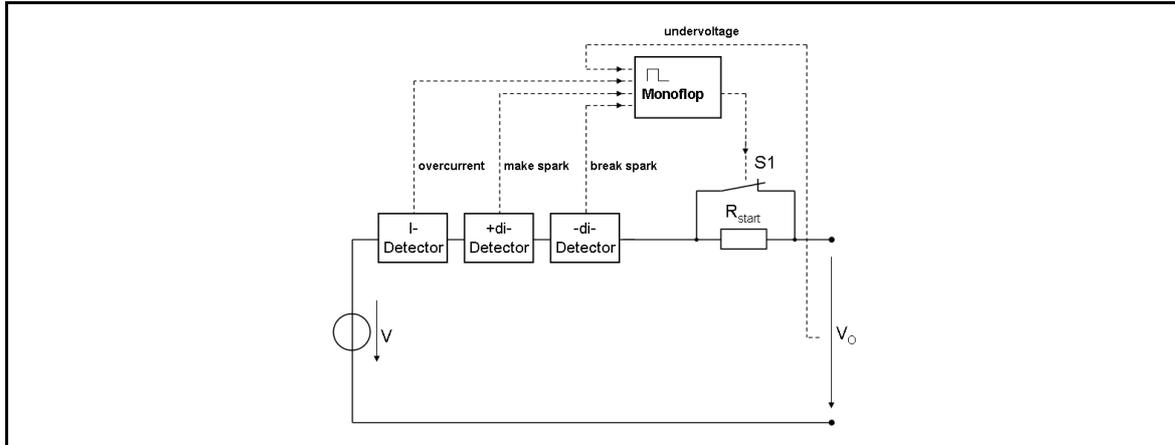
## Function of DART Components

A DART power system is comprised of three components – the power supply, the connecting cable/s and one or more loads. A system shall basically consist of only one source, which can however be provided in a redundant form for reasons of availability. The loads are connected to the power supply via a connecting cable with a fixed, defined surge impedance.

## The Power Supply

The output voltage is galvanically isolated from the station supply and limited by multiple redundant circuits. The DART specific behavior is achieved through the functions represented in the block diagram in Figure 4.

Coordination of functions integrated in the DART power supply leads to the output characteristics, in which the output voltage  $U_{\text{out}}$  is represented against the output current  $I_{\text{out}}$  described below. In addition to the safe permitted highest values  $U_{\text{lim}}$  and  $I_{\text{lim}}$  the characteristic is divided into the two operating ranges A and B:

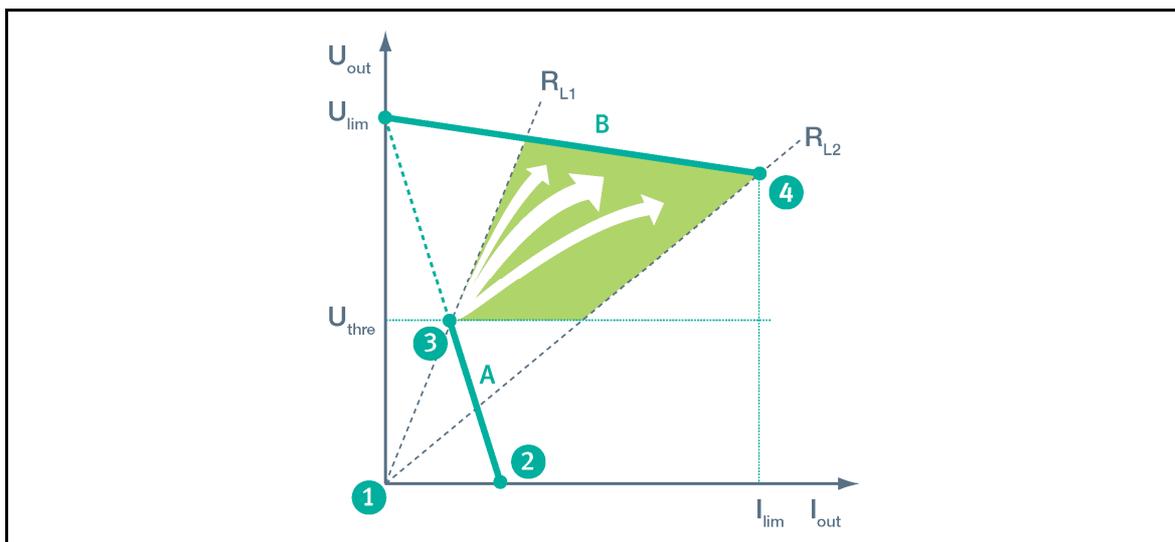


**Figure 4**

Block Diagram of Power Supply

### Safe Range A: Figure 5

This range, which is called the start-up and fold-back range, represents the characteristic curve of a linear voltage source with safe values. After switching on the source switch S1 is open (Point 1). A very low current of a few mA, the so-called “trickle current“ (Point 2) is made available at the output terminals across the resistance  $R_{start}$ . When the load resistance due to the combination of cable and load is sufficiently large ( $R_{Last} > R_{L1}$ ) it means that no fault is present. The output voltage reaches or exceeds a fixed threshold value  $U_{thr}$  (Point 3) and the source switches after a necessary safety period of approx. 3 ms to Range B, the operating range. However, this is only possible if the current variation  $di/dt$  due to the load lies below the prescribed detection threshold during the switch-on phase.



**Figure 5**

Output characteristic of a DART source with a representation of the transition from the safe range A to the optimum operating range B (Schematic representation)

## Normal – Working range (B): Figure 6

Range B represents an almost ideal voltage source with an internal resistance  $R_i \approx 0 \Omega$ . In the operating range the source can provide the optimum power to the load, by which means the maximum power conversion is possible at Point 4 with  $R_{L_{last}} = R_{L2}$ . Any variations in the load condition – including that due to faults – are associated with an immediate current variation  $di/dt$ . If at this point the prescribed maximum value of the current variation is exceeded in actual value, the source switches off and the operating point returns immediately from Range B to the safe Fold-Back Range A. This likewise takes place if the maximum permissible load current  $I_{lim}$  is exceeded. (see Point 4).

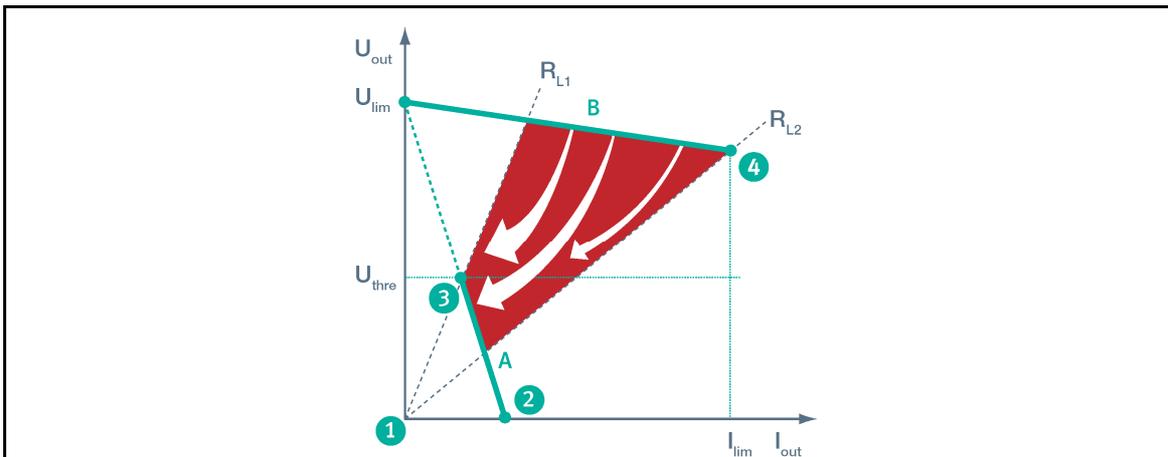


Figure 6

Behavior of the DART source in the event of a fault (Schematic representation)

In summary, the dynamic control behavior of a DART source can be characterized as follows: By contrast with customary electronic current limitation there are the following differences in the case of DART made from a safety viewpoint: a transition into the optimum operating range in the ms range and rapid turn-off to the safe Fold-Back Range in the  $\mu$ s range in the event of faults.

## The Loads

The following prerequisites have been taken into account in the DART concept with regard to the loads:

- The spectrum of loads that can be used should be as comprehensive as possible.
- It should be as simple as possible to integrate the loads into the system.
- It should be possible to operate already existing components / loads (including the customary field devices) with this technology in the same manner as is possible with previously customary technologies – e.g. FISCO (protection of stocks).
- In order to keep the safety considerations straightforward, only a line topology is envisaged.
- The loads must not have a negative influence either on the functional or the safety capability of the DART source or other loads (including the cable).

The following particularly applies to the loads: They must not restrict or absorb the propagation of information on the formation of sparks. In this context the load behavior must be accepted as not being exactly defined. The following two examples illustrate safety-critical cases, which demand additional measures.

## The Decoupling Module

A decoupling module ensures a well-defined electrical behavior both from a functional as well as a safety perspective. It permits operation of practically any load with DART. A decoupling module is integrated into the explosion-proof housing of the load and connected in series with it. The decoupling module essentially fulfills the following tasks:

- Soft start-up of the load with limited current rise  $di/dt$
- Well-defined electrical behavior
- Optional disconnection in the case of faults through  $di/dt$  detection.

## Testing DART

All the safety limit values for spark ignition given in the basic standard on “Intrinsic safety“ IEC/EN 60079-11 are based on the spark test apparatus defined there. This apparatus generates both break sparks and make sparks under prescribed constraints. During the time that passes up to the ignition of the explosive mixture, statistically evaluated predictions can be made on the ignition capability of different circuits. The ignition limit values obtained by this method can be found in the direct current reference curves and in the tables in IEC/EN 60079-11. In addition to this evaluation, the standard now permits the execution of various tests with the spark test apparatus in accordance with Appendix B of IEC 60079-11. A software test is also possible with the “ISPARK” program.

With none of the listed evaluation methods is it possible to carry out an objective safety assessment of dynamic, intrinsically-safe power sources - like DART – because the achievable ignition limit values with this new concept are way above the values in the standards. The intrinsic safety of these sources can only be ascertained by means of their dynamic principle of operation, i.e. their immediate reaction to fault conditions.

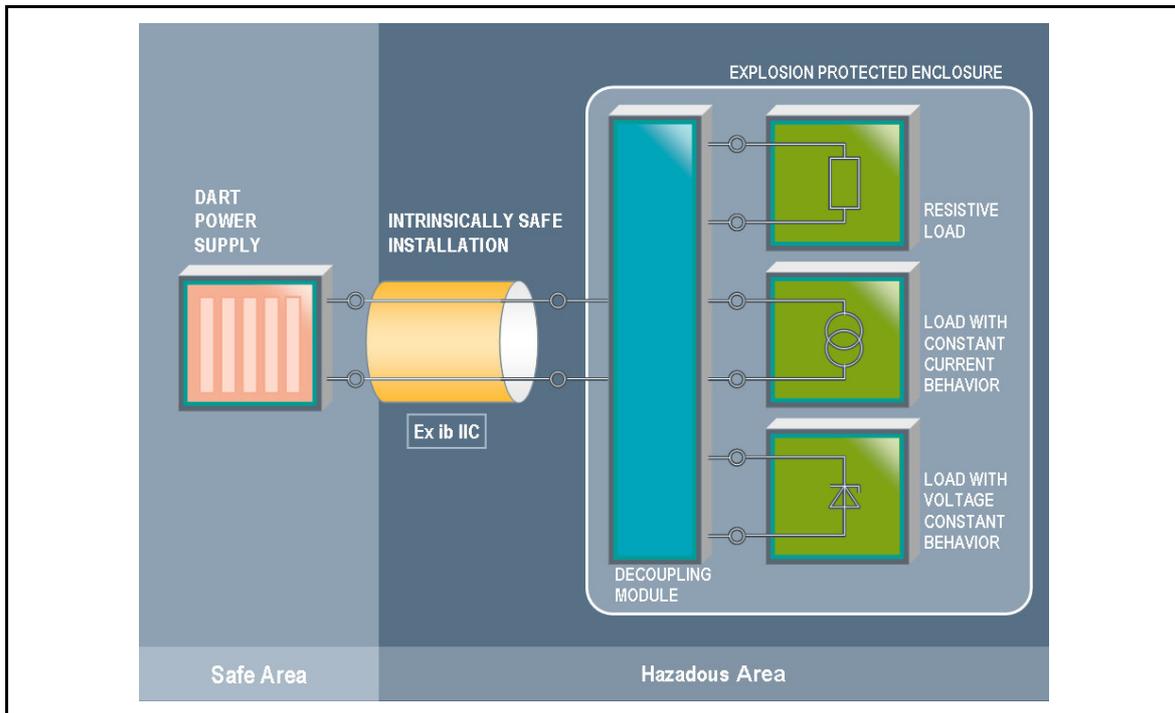
The necessary demonstration of proof demands the introduction of new types of test methods. These must target and reproduce the most critical cases that can be encountered in practice. In order to assess the ignition behavior of dynamically operating sources these have to be loaded by means of hardware before the occurrence of the fault (spark) with precisely defined scenarios for the especially critical conditions, i.e. a defined spark history must be created. The definition of a “worst-case“ scenario is already available. However, due to the complexity of the relationships further investigations are necessary.

In the 6th edition of IEC 60079-11, due for publication around 2010, section 10.1.2 will be supplemented. In cases, in which the spark test apparatus cannot be used – such as in the case of dynamically acting sources considered here - alternative test methods will be permissible. The test methods to be used will be incorporated into the standard at a later stage, when further assured knowledge of these is available. Thus the 6th edition will open up the way for the international application of the DART technology.

## DART – The Power Concept

The DART Power solution will be used as the focal point for the point-to-point supply from the power supply to the load. The resulting simple topology consists of the power supply, cable and the customary loads at the end of the cable, rendered possible by a simple means of the consideration of the complete system, to provide high intrinsically-safe direct power supplies to the loads.

The decoupling module enables both, the safety of the system and its functional operation to be achieved independently of the characteristics of the respective loads. Figure 7 shows an example of the interconnection of a DART-High-Power power supply with three loads via a connection cable and a decoupling module.



**Figure 7**

An example of the interconnection of a DART-Power-System

The decoupling module incorporates soft start and load. Due to the safety-related, easily described behavior of the system, at the point in time of this publication maximum output data is achievable as follows:  $U_{\max} = 50 \text{ V}$  and  $I_{\max} = 1.2 \text{ A}$  with a cable length of 100 m. Figure 8 shows the block diagram for a decoupling module.

The soft start and load switch-on components as well as a reservoir condensator, which provide for fault-free and straightforward switch-on of the load. The reservoir condensator takes care of switch-on over-currents and short periods of strong current fluctuations. From a safety perspective the combination of reservoir condensator, AC and reverse polarity protection provides for a defined DART system.

In order to be able to cover the widest possible range of applications, the possibility of the transfer of data on the power supply line was anticipated in the basic concept. The

decoupling elements required for this and the cable terminations to achieve a BPSK data transfer > 500 kbit/s are already available in the power supply and in the interface circuitry. A 500 kbit/s data transfer via a DART High-Power System has already been successfully tested. Further detailed information on the data transfer can be obtained via the PTB.

The following applications can be achieved with DART Power in the explosion group Ex ib IIC:

- Industrial PC, operating terminals and displays
- LED illumination system
- Sensors with high power requirements, e.g.: Coriolis flowmeters
- Analytical devices
- Magnetic actuators and high power solenoid valves
- Electrical heating systems

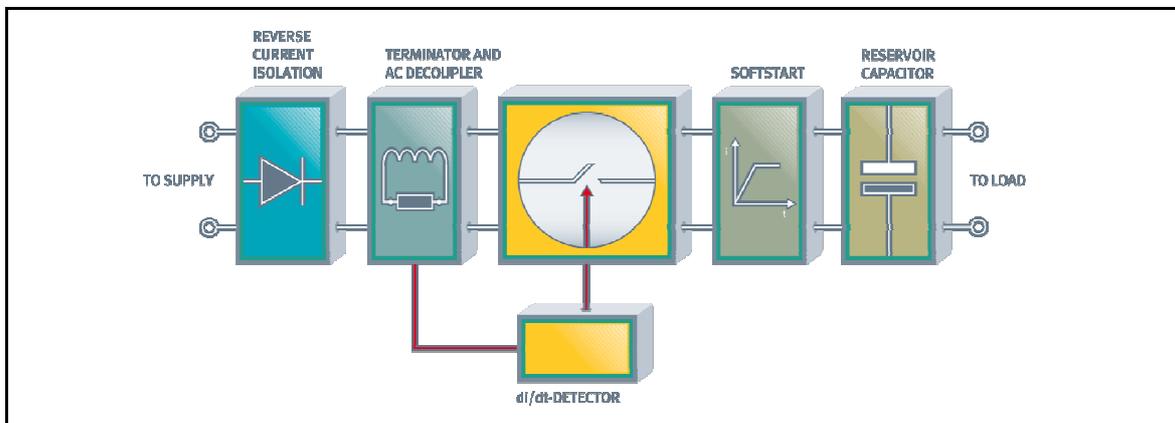


Figure 8

Block circuit diagram of the decoupling module with optional di/dt detection

## DART for Fieldbus

In the area of process automation the two fieldbus systems FOUNDATION Fieldbus H1 and PROFIBUS PA (MBP) as defined in IEC 61158-2 have been established as de facto standards.

A trunk-and-spur-topology is employed utilizing a home run cable, also referred to as trunk. Field devices are connected via spur lines to wiring interfaces with short-circuit protection, which can be connected to the trunk at arbitrary points. Figure 10 shows the principle electric circuit of a topology.

In comparison with existing intrinsically safe fieldbus solutions, DART enables four times as much power on the trunk line. Power is approximately the same compared to the well-accepted High-Power-Trunk concept, without the disadvantage with increased safety installation methods required for the trunk.

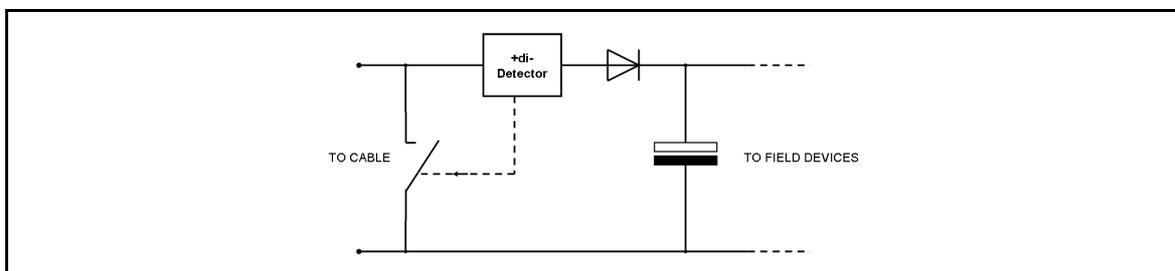
Though highest voltage values would be beneficial for maximum output power, the available power is selected to 24 V. Thus any existing field device conformant with the

Entity concept defined in IEC 60079-27 can be connected. Entity enables intrinsic safety to be validated for any topology through a simple comparison of values.

Frequently the plants that are to be automated extend over a wide area, which requires long cable connections. If the cable length is determined as being 1000 m, this results in an available effective power of 8 W. This output power is suitable for up to 24 loads per segment and corresponds with the available power on Fieldbus segments with the generally recognized High-Power Trunk concept.

## Decoupling the Field Devices

As already described in section 0 the dynamic behavior of loads is not defined from a safety standpoint. Decoupling circuits are built into the Segment Protectors as shown in Figure 9.



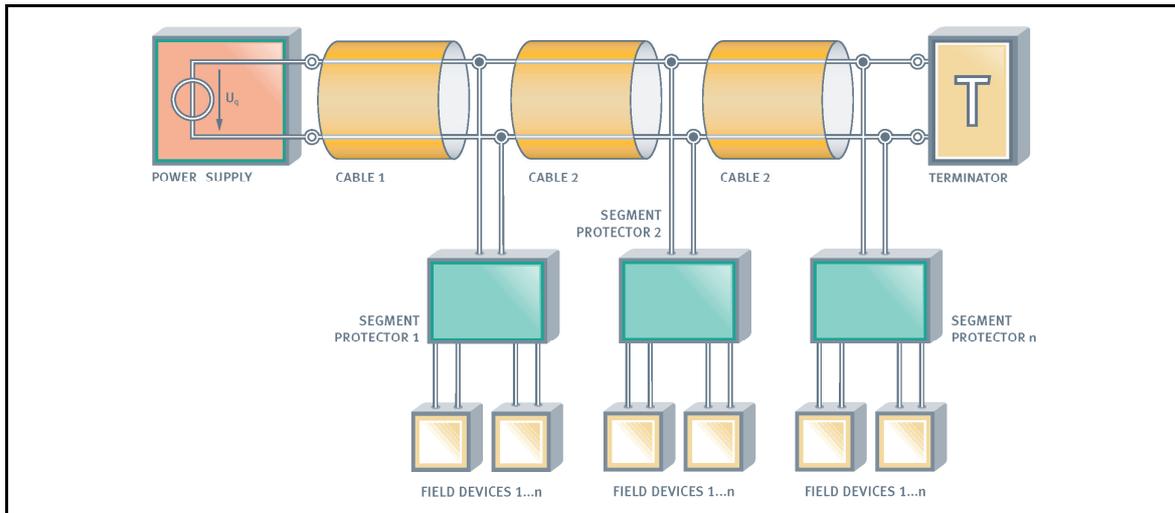
**Figure 9**

Decoupling circuit for DART Fieldbus

Irrespective of the actual electric characteristics of the field device, the storage capacitor ensures a defined load behavior at the cable input terminals.

## Communication

The communication, in the form of a trapezoidal alternating signal with a peak-to-peak value of 18 mA (+/- 9 mA) is superimposed on the direct current supply signal. The flanks of the signal can be several microseconds short. The system distinguishes these current variations unambiguously and reliably from those that occur in the generation of the spark.



**Figure 10**

DART Fieldbus system with multiple loads and segment protectors

## Summary and Outlook

Due to DART, very high intrinsically safe power is available for new applications in the process industry, depending on the length of cable employed. The maximum possible power output is strongly dependant on the delay times on the transfer cable. Solutions exist for two application areas: DART Power for maximum power output and DART for the Fieldbus, optimized for Fieldbus applications.

<b>Table 1: Maximum intrinsically safe output values of DART at typical cable length</b>			
	<b>Output Voltage <math>U_{out}</math></b>	<b>Active Power <math>P_{out}</math></b>	<b>Cable length</b>
<b>DART Power</b>			
	50 VDC	app. 50 W	100 m
	24 VDC	app. 22 W	100 m
	50 VDC	app. 8 W	1000 m
<b>DART for Fieldbus</b>			
	24 VDC	app. 8 W	1000 m

Suitable test methods have been developed for an exact safety evaluation of the energy-limiting behavior of dynamically operating power supply concepts. Changes to the currently applicable standards have already been investigated. Further steps will follow.

DART enables the use of intrinsic safety in applications with power requirements, which today necessitate other, typically inflexible or expensive types of explosion protection. By means of DART operating processes will become simpler and complexity is reduced. Operating safety will be increased.

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## **Literature**

- IEC 60079-11: Explosive atmospheres – Part 11: Equipment protection by intrinsic safety “i”
- IEC 61158-2: Digital data communications for measurement and control – Fieldbus for use in industrial control systems – Part 2: Physical layer specification and service definition
- PTB-Bericht PTB-Ex-1, Braunschweig, Juni 2007, 11. BAM/PTB-Kolloquium zu Fragen der chemischen und physikalischen Sicherheitstechnik; Beitrag von U. Gerlach und Th. Uehlken: Neue Herausforderungen bei Speisesystemen hoher Leistung in der Zündschutzart Eigensicherheit