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DART – Advanced Intrinsic Safety

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Abstract - Intrinsic safety (I.S) is a worldwide accepted standard to protect low power electrical circuits from the potentially explosive hazardous area. End users throughout the fieldbus world are demanding more power to connect more instruments to their Fieldbus segments in Class I, Division 1, and Class I, Division 2, hazardous location applications. The intention of this paper is to discuss the fundamentals and application of the recently developed High Powered Trunk (HPT) technology and Dynamic Arc Recognition and Termination Technology (DART) that gives engineers all the power they need to fully load a Fieldbus segment, even in a hazardous location than other. It also illustrates the essential technical safety aspects necessary for the demonstration of IS and explains the impact of these on the relevant international standards.

Key words - *Intrinsic Safety, HPT, DART.*

I. INTRODUCTION

In recent year, Fieldbus applications in the process industry started to gain popularity than 4-20mA analog signal because digital communications systems offer sizable advantages over analogue systems. Today's world of increasing process control in potentially explosive atmospheres has forced designers and engineers to give best solution for hazardous areas for fieldbus to protect both plant and personnel, to ensure that hazardous atmospheres cannot be ignited [1].

Figure 1 illustrates the effect of concentration on ignition energy. Every air/gas mixture has a certain concentration which is the most easily ignited concentration (MEIC). When trying to prevent an air/gas mixture from exploding, the safest approach is to assume the mixture is always at its MEIC. Therefore, the maximum energy you may safely allow must be less than the minimum ignition energy (MIE) of that specific air/gas mixture [2].

With respect to approach to prevent explosion IS removes the ignition source from the ignition triangle. An intrinsically safe system assumes the fuel and oxygen is present in the atmosphere, but the system is designed in such a way that electrical energy or thermal energy of a particular instrument loop can never be great enough to cause ignition. IS is defined as "Equipment and wiring which is incapable of releasing sufficient electrical or thermal energy under normal or abnormal conditions to cause ignition of a specific hazardous atmospheric mixture in its most easily ignited concentration." This is achieved by limiting the power available to (and used or generated by) the electrical equipment in the hazardous area to a level below that which will ignite the hazardous atmosphere. [3].

There are several ways to achieve safety in the hazardous condition. These techniques are:-

- Pneumatic (Air)
- Fiber Optics (Light)
- Explosion-Proof Enclosures (Electric)
- Purging or Pressurization (Electric)
- Encapsulation (Electric)
- Oil Immersion or Powder Filling (Electric)

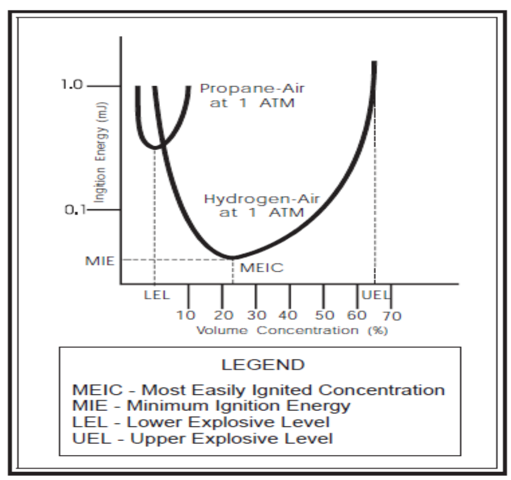

Fig.1 : The Effect of Concentration on Ignition Energy [2]

These techniques results in increased equipment size and weight, and does not allow live working when any degree of hazard is present.

But the Intrinsically safe systems offer a variety of advantages over these techniques.

- Safest technique available, inherently “Fault Tolerant”.
- A universally accepted protection method for all area classifications, a multitude of I.S devices is readily available.
- Allows the use of simple apparatus without formal certification.
- Live Maintenance can be performed without gas clearance or power shutdown, hot swap even in Class I, Division 1, Gas Group A.

II. INTRINSIC SAFETY EVOLUTION

In conventional non-fieldbus systems, typically only two devices are connected together the intrinsically safe apparatus in the hazardous area and the associated apparatus in the safe area.

In a fieldbus system works efficiently if the numbers of devices are connected together on a single segment. The IEC 61158- 2: 2000 Physical Layer Standard defines that several field devices could be supplied from one fieldbus power supply via one bus line. To achieve Intrinsic Safety, voltage, current and power on the bus cable have to be limited to a safe value. The intrinsically safe apparatus and the associated apparatus have to be designed, certified and applied taking into account the requirements for I.S.

(i) Entity concept

At the introduction of Fieldbus technology, the Entity concept with cabinet mounted barriers and a power supply was used as the standard solution for hazardous area applications. This type of solution barely supplied enough power for 3 or 4 instruments per segment and it was very cumbersome to match entity parameters of the devices and the power source.

(ii) Fieldbus Intrinsically Safe Concept (FISCO)

End users voiced their cancers and manufacturers responded with another solution for IS segments. The result was FISCO. This can result in 4 to 8 devices per segment. The current and voltage levels are still very low, which results in significantly shorter cable runs than the theoretical maximums. Live maintenance on the trunk cable is also not possible.

(iii) High Power Trunk

Entity concept and FISCO will not allow users to connect multiple devices to a single power supply on a fieldbus segment & power requirement also still far below. More recently, HPT concept provided users with safe installation in explosive environments with high power supplied to the fieldbus segment.

(iv) DART

I.S with all these concepts can be applied only to low voltage, low power equipment. Therfore in April 2008 Pepperl+Fuchs announced a new technology that can eliminate many of the previous power limitations with respect to installation of fieldbus devices in hazardous plant locations. DART allows higher-powered devices to be used in the hazardous areas.

III. HIGH POWER CONCEPT

In contrast to the FISCO/FNICO concepts, the HPT concept limit the energy on the Fieldbus spur to intrinsically safe, rather the controlling energy on the fieldbus trunk This allows to connect more no of devices and we can utilize whole length of the fieldbus trunk.

In this consist of short circuit-protected junction boxes with built-in barriers. This allows end users to get the maximum number of devices on a segment while also being able to achieve maximum cable lengths. [1].

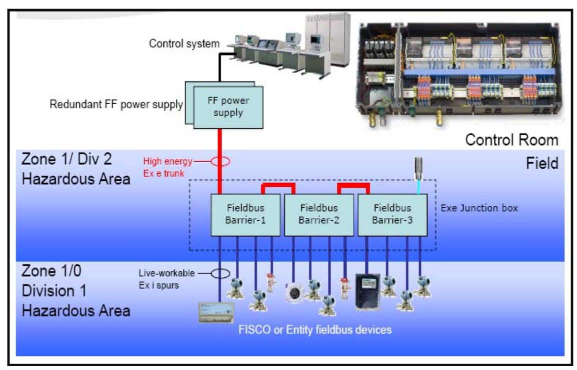

Fig. 2 : HPT for Zone-1[11]

HPT architecture can allow full complement of 1900 meters of cable and even the spur line length limitation of 60 meters is removed as each spur becomes its own FISCO domain isolated from the trunk line by the barrier Typical values for HPT solution are 30V at 500mA and products such as fieldbus barriers and fieldbus segment protectors make it easy to apply even in the most hazardous environments [4].With short circuit protected junction boxes with built-in barrier concept, fieldbus barriers and segment protectors move the energy limitation out of the control room cabinet and into the field. This enables users to fully distribute their fieldbus equipment around the plant, taking full advantage of Fieldbus technology.

A. Advantages

- HPT offers more cable length through accepting bigger voltage drops along the trunk cable.
- HPT concept is that it gives the end-user the freedom to choose any type of instrument entity, FISCO or FINCO.
- Fieldbus power conditioners with built-in redundancy and online physical layer diagnostics capabilities are available.[3]

IV. DART CONCEPT

In HPT concept, the trunk itself is not energy-limited, so live working isn't possible without obtaining hot work permits. But the design does accommodate fully redundant, load-sharing, segment power supplies, and as many devices as the host manufacturer can support (typically 16). Field couplers are fitted with energy-limiting circuitry so as to achieve the IS requirements for each spur, and the required parameters for maximum stored energy are enforced from the field junction box to the device.

All these solutions achieve I.S by ensuring any arc or spark from live working (e.g., installing or removing a device, or connecting test equipment leads) doesn't have enough energy to ignite the area's expected hazardous atmosphere.

DART which can deliver dramatically increased power for weighing systems, lighting and automated valve networks, as well as Profibus-PA and Foundation fieldbus, with the entire circuit meeting I.S requirements from the control house to the field device.

Because 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 related to the process industry.

There is very recognizable and repeatable phenomenon occurred every time an arc formed. It is relatively easy to detect a rapid increase in the rate of change of the loop current (di/dt), which preceded spark formation by a few microseconds. Also spark current and voltage remained constant for another 1 to 5 µs thereafter, before the critical phase when a spark could form. In the case of an unwanted, potentially threatening condition such as opening or closing of the electric circuit, DART is disconnect the power during the quiescent period after detection and before the spark forms, and then quickly restore it before any devices or communications are adversely affected.

The technology eliminates tight power limitations on existing intrinsically safe applications by enabling up to 50 Watts of effective power to be supplied in hazardous areas with I.S.

A. The operating principle:-Rapid switch-off instead of limitation

Traditionally, to safely prevent a spark capable of causing an ignition, the power available is limited to approximately 2 Watts. Thus, the protection category Ex i is typically limited to the areas of control and instrumentation technology and the power supply of actuators and sensors with low connected loads. In a circuit protected with DART, field devices in the explosion-hazardous area with power consumption between 8 to 50 W can be supplied under intrinsic safety conditions. Under normal circumstances the electric current flows without restriction. DART detects a fault in the electrical system at the outset and switches it off before the energy released reaches a safety-critical level. 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.

B. Spark electrical Behaviour:

A typical example of the behavior of the electrical parameters of a break spark is shown in Figure 3. A break spark commences with the voltage UF = 0 V and usually ends on reaching the open circuit voltage at UF = U0. In a linear circuit, spark voltage is increases as the reduction in the spark current IF. The time between this is called as the spark duration tF.Typical spark duration tF: 5 µs < tF < 2 ms.

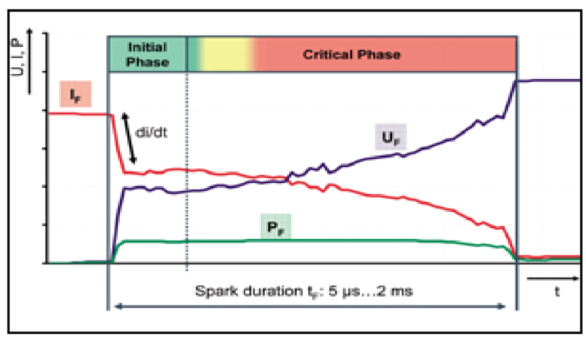

Fig. 3 : Variation with time of spark current [6]

At the start of a break spark the spark voltage UF increases in very short time from 0 V to UF=10 V which causes current jump di/dt as shown. Directly after this jump in spark current and spark voltage remain constant for approximately 1 to 5 µs.

During this period there will be no ignition because available spark energy is very small. This section is called as “initial phase”. Then there will be the continuous increase in spark voltage and current ignition can occur. This range is called as "critical phase". During this period the spark draws the necessary ignition energy from the system.The underlying physics are clear and simple:-

- The characteristic electrical signal of the forming spark.
- The wave velocity of more than 160,000 km/s, at which this signal is transmitted via the power supply cable.
- The electronic switch, which triggers within microseconds.[6]

From the knowledge we come to know that, that the rapid detection of sparks & in combination rapid disconnection of the source can prevent the ignition of an explosive mixture & this is done by DART. With DART a fault condition is not only already detected and evaluated within the "initial phase''. This action is takes place very quickly—in approximately 1.4 µs as shown in fig.4.

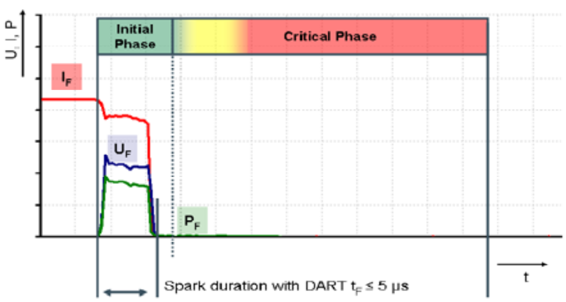

Fig. 4 : Time history of the spark current, voltage and power of a break spark with DART interruption [6]

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. There are some physical parameters are principally responsible for this:-

- Power—determined by the supply voltage and the load current.
- Time comprising the signal propagation delay in the cable and the reaction time of the power supply.
- Energy stored in the connection cable.
- Load behavior.

The energy liberated in the spark is determined by the power available, integrated over time. Because the wave velocity results in a very short propagation time, it must be considered from a safety standpoint. This is roughly proportional to the energy stored in the cable, which can escape from the electrical system in the case of a fault. This means, that the length of cable has a significant influence on the power available. Thus, DART satisfies the specification for an intrinsically safe circuit in accordance with IEC 60079-11.

A DART power system is comprised of three components are power supply, connecting cable/s and one or more loads Fig 5 shows arrangement of the power supply, cable and de-vices in the hazardous area.

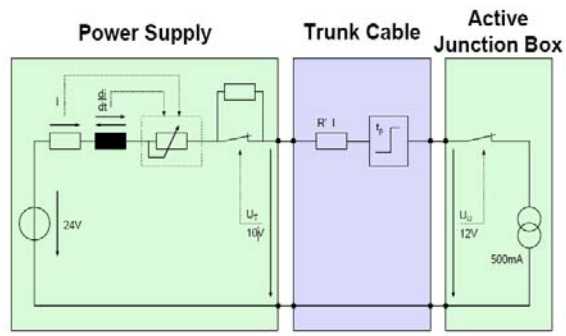

Fig. 5 :Arrangement of the power supply, cable and de-vices in the hazardous area [5]

(i) Power Supply:

Coordination of functions integrated in the DART power supply leads to the output characteristics, in which the output voltage Uout is represented against the output current Iout

In addition to the safe permitted highest values Ulim and Ilim the characteristic is divided into the two operating ranges A and B as shown in fig 6 shows safe range A & fig. 7 Shows normal working range B.

Range A shows the characteristic curve of a linear voltage source with safe values is called the start-up and fold-back range. After switching on the source ,switch S1 is open and very low current in few mA, called "trickle current" (Point 2) is made available at the output terminals across the resistance R Start. When RLast > RL1 there is no fault is present. The output voltage reaches a fixed threshold value Uthr (Point 3) .This is only possible if the current variation di/dt lies below threshold during the switch-on phase.

Range B represents an ideal voltage source with an internal resistance Ri =0. In the operating range, the source can provide the optimum power to the load cue to this maximum power conversion is possible at Point 4. Because of fault there will be the loads variation with an immediate current variation di/dt.

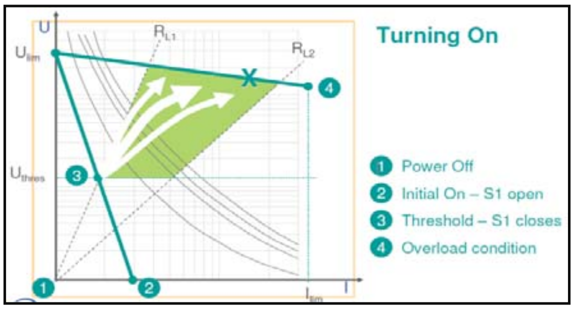

Fig. 6 : Output characteristics of Power supply during turning ON [6]

If at this point if the current variation increased than maximum 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 Ilim is exceeded. (See Point 4).

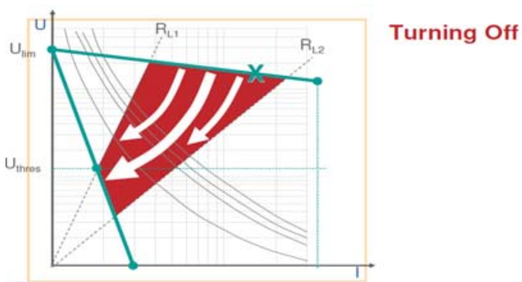

Fig. 7 : Output characteristics of Power supply during turning off [6]

(ii) Load-demands from pragmatisms:-

- Simple integration of loads
- Simple topology for straightforward safety considerations
- DART-Loads connect via decoupling module
- Must not influence spark detection.[8]

(iii) The Decoupling Module:-

A decoupling module ensures a well-defined electrical behavior. It permits operation of practically any load with DART. The block diagram of decoupling module is shown in fig 8.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.

The advantages of DART come into play where existing explosion protection methods make simple processes difficult or where the costs for explosion protection are comparatively high. Two versions are being developed at Pepperl+Fuchs: DART Power and DART Fieldbus.

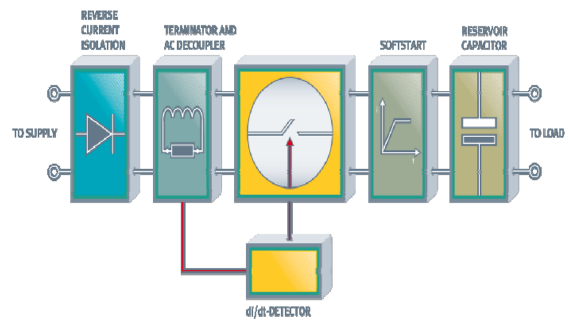

Fig. 8 : Block diagram of decoupling module.[6]

The DART Power version is tailored to transfer maximum power and provide simple adaptation for a wide range of applications. Depending on the supply voltage used and cable length, an effective power of up to 50 Watts can be achieved. With DART Power, devices with high power requirements can be supplied with energy in an intrinsically safe manner without special and expensive safety precautions with respect to installation techniques. Table 1 indicates possible applications. Also, the design of the field equipment can incorporate the intrinsic safety method of protection.

Table 1. DART application [8]

DART Application	DART Fieldbus	DART Power
Field instrumentation		
Valve control	■	■
Magnetic flow measurement	■	■
Corriolis flow measurement	■	■
Fire and gas detectors		■
Other applications		
Optical and acoustic sensors		■
Servomotors		■
Light		■
Analytical devices	■	■
Scales, balances		■
PCs and operator terminals		■

Users frequently want an I.S design for their fieldbus applications. However, the I.S protection classification considerably restricts the number of stations that can be connected and cable lengths.

The trunk is protected with DART while the energy limitation on the connection cabling in conventional intrinsic safety complies with Entity and FISCO, two versions of intrinsic safety that are described in IEC 60079 and developed especially for fieldbus. Since almost every intrinsically safe field device is available with Entity or FISCO compliance, compatibility with the basic installation is ensured [9].

DART provides a connected power of 8 W with a cable length of 1000 m. This is achieved only with the HPT, where the trunk satisfies the increased safety classification. DART offers complete intrinsic safety of the fieldbus segment and are the next logical step in HPT.Fig.9 shows the principle electric circuit of a topology.

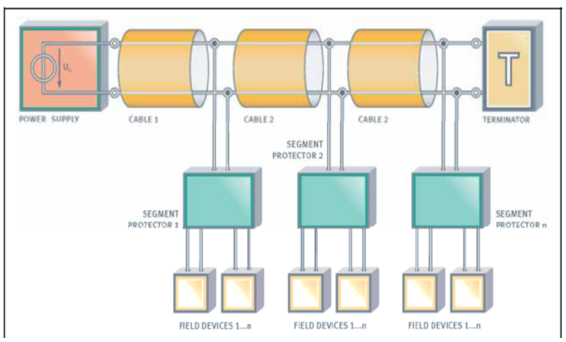

Fig. 9 : DART Fieldbus: Entity-conforming field devices can be operated in an intrinsically safe fieldbus network with 8 W of effective power and a segment length up to 1000 m [6]

DART Fieldbus for Zone 1, gas group IIC

Instrumentation connects to the fieldbus coupler, the DART Segment Protectors. The Segment Protectors are certified for installation in Zone 1 with outputs that are certified intrinsically safe Ex ib IIC. Fig 10 shows the trunk-and-spur topology with DART Fieldbus. DART protects plant from very explosive gasses of group IIC.

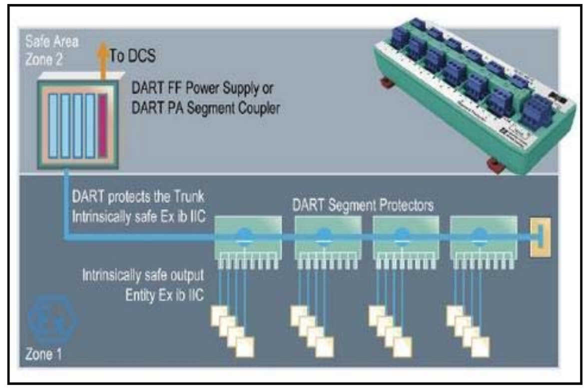

Fig.10:Trunk-and-spur topology with DART Fieldbus [10]

The DART Segment Protector provides sufficient power for device connections. Most importantly, it provides the short-circuit protection, which is critical when live maintenance is required on an instrument.

Up to 1000 m of homerun/trunk is permitted with DART Fieldbus. Up to four DART Segment Protectors can be connected to the trunk and provide devices with intrinsically safe power. Spur length is on top with up to 120 m per spur - double the length of FISCO.

Table 2 highlights the most important technical attributes of DART Fieldbus. With most attributes influenced by the fieldbus standard (IEC 61158-2), fewer regulations apply for fieldbus in Zone 1 compared to FISCO or HPT.

C. Advantages of DART:-

- Safest fieldbus installation with power – all intrinsically safe
- Working without hot work permit
- Same equipment for all gas groups: certified for gas group IIC
- Reduced planning risks without special considerations for the hazardous area
- Protection of investment: for intrinsically safe fieldbus instrumentation
- Higher plant availability through built-in supply redundancy
- Intrinsic safety with more power
- Long cable runs: up to 1000 m trunk / up to 120 m spur
- Optional advanced diagnostics for the physical layer
- Up to 32 instruments per segment[5]

Table 2.DART Specifications [8]

TECHICAL DATA	VALUE
Trunk output power	typ. 22 V / 360 mA
Spur output power	min. 10.5 V @ 34 mA
Impedance – Cable type: ’A’	100 Ohm
Trunk cable length, max.	1000 m
Overall cable length, max. (as per IEC 61158-2)	1900 m
Spur cable length, max. (as per IEC 61158-2)	120 m
Entity parameters for instruments Uo, Io	24 V / 250 mA

V. CONCLUSION

DART Fieldbus supports trunk cable lengths as long as 1,000 meters**.** Each spur length can be up to 120 m by a total length of 1,900 m. per segment, DART Fieldbus supports up to 32 devices which corresponds to the maximum permitted according to fieldbus specifications. This reduces capital costs by eliminating excessive fieldbus infrastructure. The higher device count per segment eliminates the problem of having to design complex network topologies with many sub-segments, each requiring its own power supply, junction boxes, and barriers. And all of this is permitted in the most sensitive gas group IIC. The maximum possible power output is strongly dependant on the delay times on the transfer cable. Solutions exist for two application areas: DART-High-Power for maximum power output and DART for the Fieldbus, optimized for Fieldbus applications .DART-High-Power for maximum power output and DART for the Fieldbus, optimized for Fieldbus applications.

Table 3 : Maximum intrinsically safe output values of DART at typical cable length [6]

Output Voltage U_{out}	Active Power P_{out}	Cable length
DART Power		
50 VDC	app. 50 W	100 m
24 VDC	app. 22 W	100 m
50 VDC	app. 8 W	1000 m
DART for Fieldbus		
24 VDC	app. 8 W	1000 m

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