Practical approach on surge protection device for Ex application

T.H. Kuan*
Department of Electrical and Electronic Engineering
Universiti Tunku Abdul Rahman
Sungai Long, Malaysia
thkuan@1utar.my

K.W. Chew
Department of Electrical and Electronic Engineering
Universiti Tunku Abdul Rahman
Sungai Long, Malaysia
chewkw@utar.edu.my

K.H. Chua
Department of Electrical and Electronic Engineering
Universiti Tunku Abdul Rahman
Sungai Long, Malaysia
chuakh@utar.edu.my

Abstract—**A reputable Surge Protection Device (SPD) manufacturer designed, tested and produced SPD complying with the internationally accepted standard such as UL 96A, UL1449, IEC 61643, IEC 62305 and etc., where this standard put in place the requirement on the thermal disconnect to prevent SPD from overheated catching fire, housing material from releasing toxic gases and so on. Therefore, when an SPD which carried international approval, the selection is mainly focused on the let-through voltage, kA rating and protection class or zone per ANSI/IEEE C62.4 and IEC 62305-4. This is sufficient when the application is for a safe area (no present of explosive gases). However, when the application involves the presence of explosive gas in a hazardous area, for example, in the Oil and Gas industry, additional consideration will be required. This paper discussed the application and consideration of SPD for hazardous areas with various explosion protection techniques.**

Keywords— Lightning, Surge Protection Devices (SPD), Hazardous area, Ex area, Overvoltage, Transient, Explosion Protection Technique

I. Introduction

Surge protection device (SPD) is used to protect equipment from transient overvoltage due to lightning, surges generated by load switching or power outrage. Figure 1-1 describes the working principle of the SPD. When no surge, the SPD will be transparent to the circuit. Once the surge appears, the SPD will spring into action by limiting the output voltage to a predetermined level and divert excessive current to prevent and protect equipment damage.

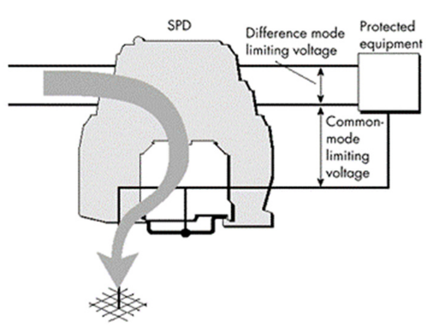

Figure 1-1: Working principle of SPD

When selecting an SPD for equipment protection, generally let-through voltage, kA rating, series or parallel connection is being considered. This is not sufficient if the application involved in a hazardous area (Ex area) as the SPD could be a source of ignition. Mounting location (hazardous area classification), method of explosion protection, surface temperature and heat dissipation also need to take into consideration so that the SPD can perform its intended function (protect equipment damaged) and itself do not become a source of ignition.

II. Selection Criteria For Ex Application

When applying the SPD for hazardous area application, all criteria for selecting SPD for use in a safe area are applied plus all factors where the SPD could be a source of ignition and the hazardous area mounting location should be considered.

A. Lightning Protection Zone and Types of SPD

IEC 62305-4 describes Lightning Protection Zoning (LPZ) concept. The idea is to divide or identify a structure area according to the level of risk posed by the Lightning Electromagnetic Impulse (LEMP) and to coordinate the type of SPD requirement (kA rating) within the zone. Figure 2-1 shows the LPZ concept. A similar concept can also be found at ANSI/IEEE C62.41 as by Figure 2-2.

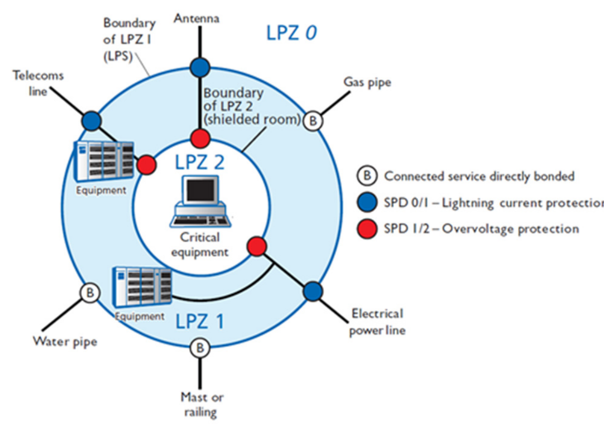

Figure 2-1: Lightning Protection Zones (LPZ) concept [1]

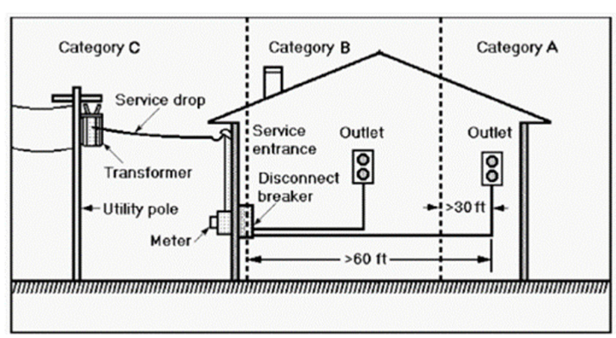

Figure 2-2: Surge protective operating environments as defined by ANSI/IEEE C62.41 [2]

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IEC 61643-11:2012 defined 3 types of SPD, namely Type 1, Type 2 and Type 3. Its mounting location, test waveform and typical technology use are summarized in Table 1. SPD could be selected according to the types.

Table 1: Types of SPD, test waveform and typical technology used [1]

	LPZ 0/1	LPZ 1/2	LPZ 2/3
Typical SPD Installation Point	Service Entrance (e.g. Main distribution board or telecom	Sub-distribution board or telecom PBX frame	Terminal Equipment (e.g. socket outlet)
Type of SPD	**1**	**2**	**3**
Surge Test Waveform	10/350 µS current	8/20 µS current	Combination 8/20 µS current and 1.2/50 µS voltage
Typical peak test current (per mode)	25KA	40KA	3KA
Typical Technology (Power Line)	Spark Gap	Metal Oxide Varistor (MOV)	Metal Oxide Varistor (MOV)

B. Lightning Protection Levels, LPLs

IEC 62305 defines four levels of lightning protection (Level I to IV). Each level has a set of maximum and minimum lightning current parameters as shown in Figure 2-3. The maximum values of the lightning current defined by LPL is used in the design and the selection of SPD. Protection against lightning in which the maximum and minimum lightning current parameters exceeding those relevant to LPL I is not considered in the IEC 62305 standard as the probability of occurrence of outside the range of values defined for LPL I is less than 2 %. The detail on LPL probability can be obtained on IEC 62305 Part 1.

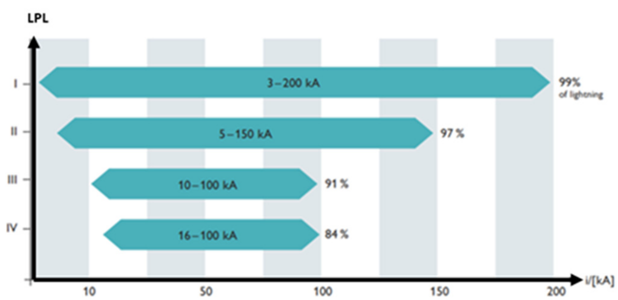

Figure 2-3: Lightning Protection Levels Parameters [3]

C. Parameter of SPDs

Below are the common specification applicable to SPD recognized by IEC 61643. It is used to size out the correct SPD.

- **Nominal voltage, U_N**
  The voltage of the system circuit based on. It is used to envisage for the SPDs.
- **Maximum Continuous Operating Voltage, U_C**
  Maximum voltage can be applied to the SPD without triggering the SPD into clamping action. U_C rating of the SPD should be selected slightly higher than the nominal operating voltage (U_N) of the equipment to be protected so that during normal operating the SPD is not triggered.
- **Voltage Protection Level, U_p**
  It is also known as Let-Through voltage in the industry (clamped voltage). U_p is the maximum voltage appear at the terminal of the SPD when tested with a specific waveform per IEC 61643. In practice, it will be treated as the maximum output terminal voltage of the SPD when subject to transient. SPD needs to be selected such that its U_p is lower than the withstand voltage of the equipment to be protected.
- **Nominal load current, I_L**
  Maximum continuous RMS current allowed passing through the SPD without damaging the SPD include withstanding the continuous thermal current load. It is only applicable when the SPD is connected in series. SPD connected in parallel will have unlimited load current.
- **Impulse Current, I_{imp}**
  Peak current with 10/350µs waveform flowing the SPD for the test of mains Type 1 SPD.
- **Nominal Discharge Current, I_n**
  Peak current with 8/20µs waveform flowing the SPD for the test of Type 2 SPD.

III. Application of SPD in Ex Area

To install SPD in the Ex (hazardous) area, all points mentioned in section II applied plus additional consideration factors to make sure that the SPD does not become a source of ignition.

A. Hazardous Area Classification

Hazardous area classification is a method to classify and analyze the explosive substance (vapor, gas or dust) environment that may present, to allow the optimum and proper selection of electrical apparatus to be installed in the Ex (explosive) environment. ATEX / IEC classifies the hazardous area into Industry Group, Gas Group, Temperature Classification and Zone. The selection of electrical apparatus in the hazardous area will be based on hazardous area classification.

- Industry Group: The type of hazard either a gas, vapor, dust or fiber. ATEX / IEC classified the industry to Mining (I) and Surface industry (II & III) as shown in Figure 3-1a and Figure 3-1b. Groups II & III surface industry is further divided again depending on the hazard. Group II gases are grouped together based on the amount of energy required to ignite the most easiest explosive gas-air mixture as shown in Figure 3-2. Group III is dust, they are subdivided according to the nature of the explosive atmosphere for which it is intended as described in Figure 3-1a.

Mining	Surface Industry			
Group I	Group II		Group III	
Electrical equipment for mines susceptible to firedamp	Electrical equipment for places with an explosive gas atmosphere		Electrical equipment for places with an explosive dust atmosphere	
	Sub-Division	Ignition Energy	Sub-Division	Explosive Atmosphere
	IIA	260 Microjoules	IIIA	Combustible flyings
	IIB	95 Microjoules	IIIB	Non-conductive dust
	IIC	18 Microjoules	IIIC	Conductive dust

Figure 3-1a: Industry Group I, II & III [4]

ATEX EQUIPMENT GROUPS & CATEGORIES

Mining			Industrial		
Equipment Group	Equipment Category	Protection Level	Hazard		Use
			Gas	Dust	
I Mining	M1	Very high	-	-	Operable in Ex atmosphere
	M2	High	-	-	De-energised in Ex atmosphere
II Surface Industries	1	Very high	Ga		Zones 0, 1, 2
				Da	Zones 20, 21, 22
	2	High	Gb		Zones 1, 2
				Db	Zones 21, 22
	3	Normal	Gc		Zone 2
				Dc	Zone 22

Figure 3-1b: Industry group based on ATEX definition [5]

APPARATUS/GAS GROUPS

Typical gas hazard	IEC 60079-0 IEC CENELEC	North America NEC Article 500 (Class I)	Minimum ignition energy (microjoules)
ACETYLENE	IIC	A	20
HYDROGEN	IIC	B	20
ETHYLENE	IIB	C	60
PROPANE	IIA	D	180

Figure 3-2: Gas Groups [5]

- Ignition Temperature: Flammable materials have a temperature at which ignition will take place, even in the absence of an external source. This temperature is called the Auto-Ignition Temperature (AIT) of that material. Apparatus must be selected such that it will not expose the gas-air mixture to a temperature exceeding the AIT. The maximum surface temperature of the hazardous apparatus under the normal or abnormal condition is known as Temperature Classification (also known as T Classification) and is given in Figure 3-3.

For hazardous area applications, the apparatus used within the hazardous installation must be given an appropriate temperature classification according to the hazard present to maintain the integrity and to prevent explosion due to AIT. For example, if the hazard is hydrogen, then all apparatus used in that environment must meet the “T6” rating (T6=85˚C). This also means that all apparatus used in that Ex area must not have a surface temperature greater than 85˚C. Any apparatus used which could generate 85˚C surface temperature or more will then increase the possibility of an explosion.

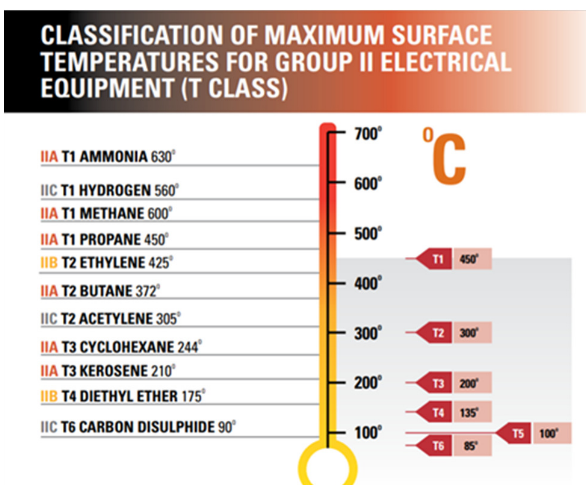

Figure 3-3: Equipment temperature classification [5].

- Zone: Classified with regard to the probability of a potentially explosive atmosphere being present and the length of time for which it is likely to exist. Figure 3-4 shows the Zoning classification of the hazardous area.

Hazard	Zone	Definition
Gas	0	in which an explosive gas-air mixture is continuously present or present for long periods
	1	in which an explosive gas-air mixture is likely to occur in normal operation
	2	in which an explosive gas-air mixture is not likely occur in normal operation, and if it occurs it will exist only for a short time
Dust	20	in which a combustible dust atmosphere is continuously present or present for long periods
	21	in which a combustible dust atmosphere is likely to occur in normal operation
	22	in which a combustible dust atmosphere is not likely occur in normal operation, and if it occurs it will exist only for a short time

Figure 3-4: Zone Classification [4,6]

- Marking of Apparatus: All hazardous area apparatus shall carry mandatory marking. Figure 3-5a and Figure 3-5b provide an explanation and sample of the manufacturer marking respectively.

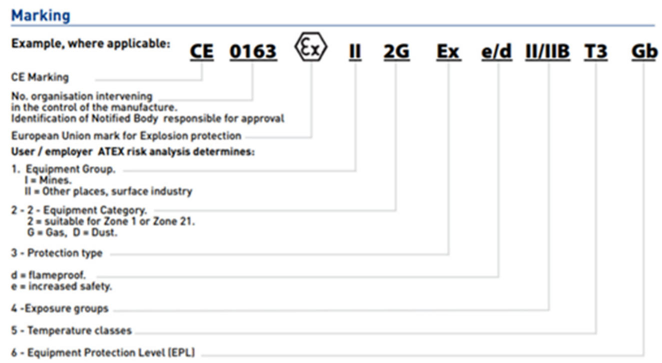

Figure 3-5a: Summary of Apparatus Marking [7]

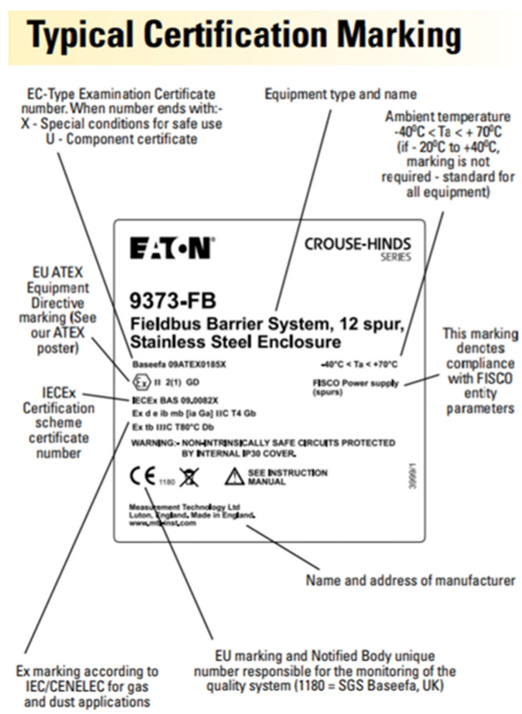

Figure 3-5b: Sample of the manufacturer marking [5]

IV. COMMON EXPLOSION PROTECTION TECHNIQUE USED WITH SPD.

There are many explosion protection methods, only three methods that are commonly used with SPD are discussed and two practical examples are quoted. The example is based on Intrinsic Safety (Exi) and Flameproof (Exd) explosion protection technique. Figure 4-1 provides a summary of the various explosion protection technique and its applicable zoning.

A. Intrinsic Safety, Exi

- Application Zone: 0, 1 and 2
- Live maintenance is allowed
- Uncertified Simple Apparatus could be used when connected via the safety barrier.

Bringing down the electrical energy for the apparatus in the hazardous area below the ignition curve so that any spark or thermal effect in any part of the system intended for use in hazardous areas is not able to cause an ignition. Therefore live maintenance is allowed. There are three categories of Ex i protection i.e. "Exia", "Exib" and "Exic". Type "Exia" protection allows for the occurrence of two faults during operation. Type "Exib" protection allows for the occurrence of one fault during operation. Type "Exic" does not consider fault tolerance. Only Exia is allowed to be used in Zone 0.

Exi allowed the use of Simple Apparatus (per IEC 60079-25: a device which does not generate and store energy more than 1,5V, 100mA and 25mW for example thermocouple, dry contact switches, PT100) without the need of additional certification when connected to the field (Ex area) via safety barrier. This will significantly bring down the implementation cost of the Exi system.

B. Flameproof, Exd:

- Applicable zone: 1 and 2
- No live maintenance. Power needs to be off to carry out maintenance work

Relies on construction to ensure that any ignition of the hazard inside the enclosure will not transmit to the atmosphere outside the enclosure. This is achieved due to the flamepath design. Possible design: Flanged Joint, Threaded Joint or Spigot Joint. The design on the flamepath plays a significant role so that hazard gas has sufficient time to cool down during the explosion. The enclosure design must also able to handle the pressure created by the explosion and prevents the hazardous atmosphere from entering into the enclosure, come in contact with equipment.

Flameproof enclosures generally supplied with a complete assembly where all internal components are fixed and wired by the manufacturer or its trained and approved agent. It is certified as a single entity (system approval) by an approved test authority. The testing procedure will need to take into consideration the free internal volume for ventilation after all the components have been wired and fitted, the temperature rise (Temperature Classification), creepage and clearance distances and the rise in pressure as a result of an internal explosion using a gas-air mixture in its most explosive proportions.

Replacement or component repair should be using the same or the original component. For example, a component having larger or smaller than the original will affect the internal geometry of the enclosure and hence the ventilation. If a larger replacement component is used, pressure piling will happen. If a smaller replacement component is used, it will have more free volume. On the other hand, a different product may have different heat dissipation which affecting the rated Temperature Classification.

Drilling and tapping for the cable entries, breather fitting and conduit can only be carried out by the manufacturer of the enclosure or its approved agent. The type of threads, thread pitch and the clearance tolerance must be compatible with the cable glands, breather or conduit as flamepaths exist at these points.

To improve the IP rating, weatherproofing materials such as non-hardening grease, non - setting grease or compounds could be applied. Gaskets can only be replaced, they must not be added retrospectively if not included as part of the original design as it affects the release of enclosure internal pressure during the explosion. Consult the manufacturer on the type of gasket that could be used.

C. Increased Safety, Exe

- Applicable zone: 1 and 2
- No live maintenance. Power needs to be off to carry out maintenance work
- Minimum IP54
- Mechanical resistance to impact (value depending on the exclosure size)

Relies on constructional safeguards to ensure that the apparatus does not contain normally arcing, sparking devices or hot surface that could cause ignition by using high integrity insulation, taking into consideration on temperature de-rating of the insulation materials, enhanced terminal creepage and clearance distance, terminal design, IP rating and impact test.

When applying the Exe protection method, measure should be taken to avoid possible spark created by friction.

Type of Protection Method	Equipment Code	Description	International Standard	Suitable for Zones
Intended to prevent a potential ignition arising	Ex e	Increased safety	IEC 60079-7	1, 2
	Ex nA	Type -n protection	IEC 60079-15	2
Intended to limit the ignition energy of the equipment	Ex ia	Intrinsic safety 'ia'	IEC 60079-11	0, 1, 2
	Ex ib	Intrinsic safety 'ib'	IEC 60079-11	1,2
	Ex ic	Intrinsic Safety 'ic'	IEC 60079-11	2
	Ex nL	Type -n protection	IEC 60079-15	2
Intended to prevent the explosive atmosphere contacting the ignition source	Ex p	Purge/pressurized protection	IEC 60079-2	1, 2
	Ex px	Purge/pressurized protection 'px'	IEC 60079-2	1, 2
	Ex py	Purge/pressurized protection 'py'	IEC 60079-2	1, 2
	Ex pz	Purge/pressurized protection 'pz'	IEC 60079-2	2
	Ex m	Encapsulation	IEC 60079-18	1, 2
	Ex ma	Encapsulation	IEC 60079-18	0, 1, 2
	Ex mb	Encapsulation	IEC 60079-18	1, 2
	Ex o	Oil immersion	IEC 60079-18	1, 2
	Ex nR	Type -n protection	IEC 60079-15	2
Intended to prevent an ignition from escaping outside the equipment	Ex d	Flameproof protection	IEC 60079-1	1, 2
	Ex q	Sand / powder (quartz) filling	IEC 60079-5	1, 2
	Ex nC	Type -n protection	IEC 60079-15	2
Special	Ex s	Special protection	See IEC 60079-0	0, 1, 2

Figure 4-1: Various Explosion Protection Methods and its applicable zone [4]

V. Protecting Assets in Hazardous Area

Figure 5-1 shows a typical process plant with hazardous areas. The plant is protected from surge with SPD mounted in a hazardous area.

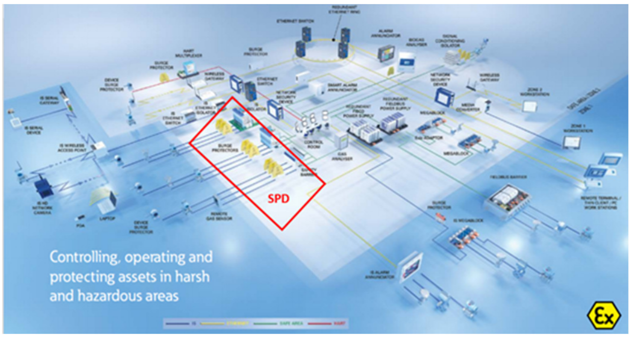

Figure 5-1: Typical Ex Process Plant with SPD [8]

A. Application of SPD in Exi Control Loop

- Applicable zone: 0,1 and 2
- Live maintenance is allowed

There are 2 concepts applicable to Intrinsically Safe System, namely System Approval and Entity Concept. System approval means the approval authority like BASEEFA or TUV issued a single certificate which includes the field device, SPD and the safety barrier (components inside the dotted box as shown in Figure 5-2) for use in a hazardous area. Uncertified control equipment is not covered by the system certificate and there is no requirement on certification (although there is installation code need to follow, for example, auto-transformer cannot be used), when a fault occurs, the energy going to the field is limited by the safety barrier. The certificate is issued after evaluation and tested by the approval authority and the equipment manufacturer. Users will have to install the system strictly according to the wiring diagram provided by the certificate. Any changes of the component during maintenance will have to replace with the exact model else the certificate will be void. This will post difficulty (not flexible) when the product is obsolete. When a product is not available then a completely new unit will be required or the system needs to re-certify with the installed new product.

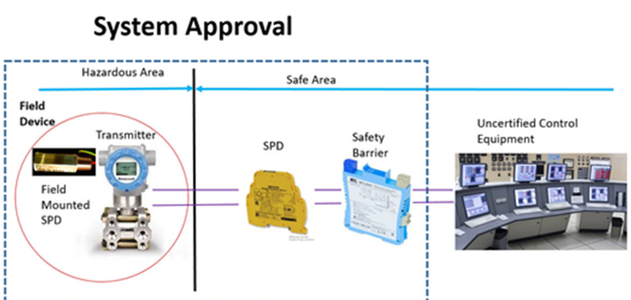

Figure 5-2: Component included in the "System Approval"

The advantage of a system certificate is that the design and the responsibility of the explosion protection are taking care by the equipment manufacturer and the approving authority. The disadvantage will be no flexibility on change of component when it is obsolete. User responsibility is to follow exactly the installation stated in the certificate/manual.

On the other hand, for the entity concept, all product shows on the dotted box in Figure 5-2 need to individually tested, an individual certificate will be issued with all safety parameters listed. Users will be required to match the safety parameter. The entity concept provides more flexibility in selecting and repair replacement of equipment. Any product that can match and fulfill the safety parameter could be used.

Entity / Safety Parameter

The entity safety parameter is described below:

$$\mathrm{Vmax} \geqslant \mathrm{Voc} \qquad (1)$$

Vmax = Maximum voltage that could be applied safely to the intrinsically safe equipment

Voc = Maximum open-circuit voltage appear at the output terminal of the safety barrier at fault conditions

$$\mathrm{Imax} \geqslant \mathrm{Isc} \qquad (2)$$

Imax = Maximum current that could be applied safely to the intrinsically safe equipment

Isc = Maximum output short-circuit current could be the source from the safety barrier at fault conditions

$$\mathrm{Ci} + \mathrm{Ccable} \leqslant \mathrm{Ca} \qquad (3)$$

Ci = Internal unprotected capacitance (at the field) of the intrinsically safe equipment

Ca = Maximum external capacitance (all equipment at the field which connected to the safety barrier) that can be connected safely to the safety barrier

$$\mathrm{Li} + \mathrm{Lcable} \leqslant \mathrm{La} \qquad (4)$$

Li = Internal unprotected inductance (at the field) of the intrinsically safe equipment

La = Maximum external inductance (all equipment at the field which connected to the safety barrier) that could be connected safely to the safety barrier

The system which fulfills equations (1), (2), (3) and (4) means they are safe to use based on entity concept from the safety point of view. The user also needs to consider operation requirement, for example, it has sufficient voltage to drive the field transmitter. Only systems that fulfill both safety and operational required will be implemented.

Figure 5-3 shows control drawing for an intrinsically safe apparatus examined under the entity concept.

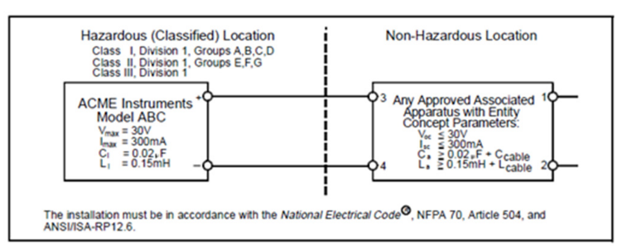

Figure 5-3: Control drawing for an intrinsically safe apparatus examined under the entity concept [9]

Since the SPD is mounted in the safe area (no hazard present) therefore temperature classification and the type of hazard (example: hazardous gas) will not be in the consideration. If it is field mounted SPD (hazard is present), temperature classification and type of hazard will have to take into consideration.

Figure 5-4a shows two SPDs connected in series while Figure 5-4b shows one of the SPD, field mounted SPD connected in parallel, the other SPD (mounted in a safe area) is connected in series. All SPDs mounted in the safe area have no requirement for temperature and hazard classification. SPDs mounted in the hazardous area will have temperate and hazard classification. The classification can be found in the Exi certificate. All SPDs in Figure 5-4a and Figure 5-4b are part of the Intrinsically Safe loop, therefore it will be required to perform the entity parameter check to ensure safety as shown in Figure 5-4a and Figure 5-4b.

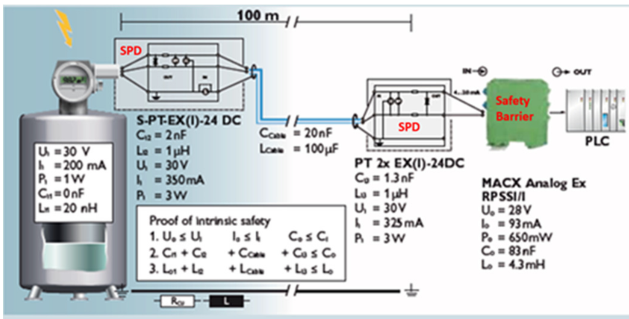

Figure 5-4a: Entity parameter matching for SPD connected in series at the field [10].

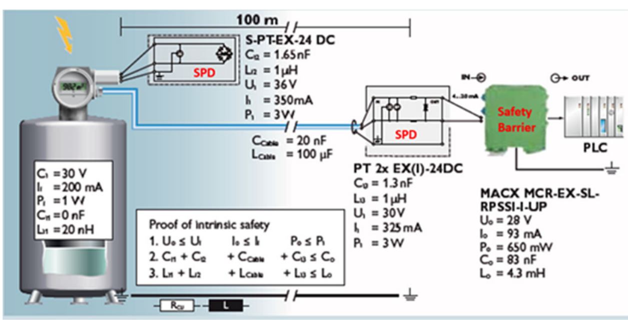

Figure 5-4b: Entity parameter matching for SPD connected in parallel at the field [10].

B. Application of SPD in Exd Control Loop

- Applicable zone: 1 and 2
- No live maintenance. Power needs to be off to carry out maintenance work

SPD going to use in a hazardous area is mounted in Exd enclosure. To size up the correct Exd enclosure, the following information will be required:

- Dimension on all components to be mounted in the Exd enclosure is required to determine the size of the enclosure. The size should also take into consideration of the circuit layout and ventilation.
- Temperature classification, heat or power dissipation information for all components to determine the temperature classification of the Exd enclosure. If the temperature, heat or power dissipation information is not available, the system needs to be powered on for a long period of time to determine the temperature profile via temperature probe. For a bigger system, it may be powered for many hours until the temperature is stable. As a general guide, the measured temperature needs to achieve equilibrium, stable, without further increase.
- Type of hazard could be present, IIA, IIB or IIC. The manufacturer uses this information to determine the design of the flamepath of the Exd enclosure.
- Mounting location: To determine the applicable explosion protection technique. Exd can only apply to Zone 1 or Zone.

During installation, if a solid obstruction like a steelwork, wall, brackets, conduit, weatherguards or any other electrical equipment in close proximity (as shown in Figure 5-5) to the opening of the joint, it could reduce the efficiency of the flamepath in the event of an internal explosion to the extent that ignition of the external gas or vapor could occur. Therefore minimum distances between the flamepath opening and the obstruction are required. Figure 5-5 provides the minimum distance as recommended by IEC 60079 - 14.

Group	Distance
IIA	10mm
IIB	30mm
IIC	40mm

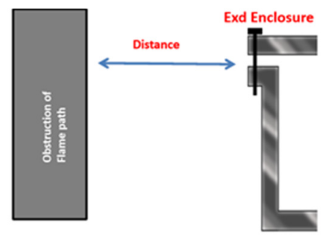

Figure 5-5: Obstruction of Flamepath

Figure 5-6 shows a number of typical Exd enclosures fitted with various components. It is a common practice that all the internal assembly or wiring work inside the Exd box needs to be carried out by the manufacturer or a certified center to ensure compliance.

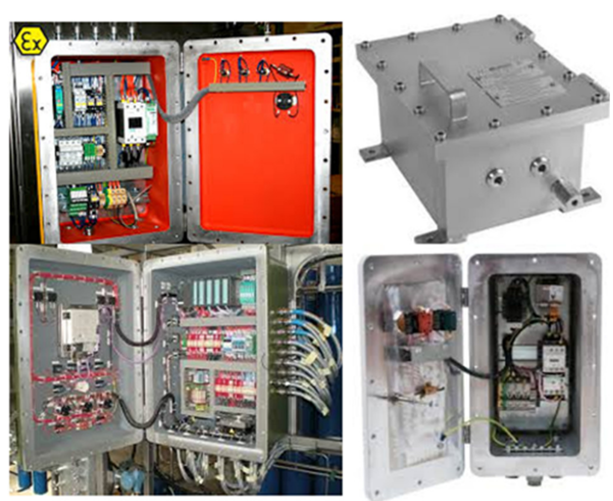
Figure 5-6: Typical Exd box

Summary:

- When selecting SPD for Ex application, besides considering the let-through voltage, kA rating, bandwidth and the types of SPD, the user also needs to consider Industry Group, Temperature Classification and the Zoning requirement.
- Industry Group I, II (IIA, IIB, IIC) and III (IIIA, IIIB, IIIC) provide information on the hazard substance (vapor, gas, dust) and on the amount of energy required to cause an explosion.
- Temperature classification provides the apparatus with maximum surface temperature information. Apparatus T rating should be below AIT of the hazard present.
- Zoning information provides the probability of a potentially explosive atmosphere being present. Types of explosion protection technique used will depend on the Zoning information
- The paper provides a systematic approach in applying both Ex and Non-Ex internationally accepted standards in selecting SPD for Ex area application.

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