Sam S. Khalilieh, P.E.. "Explosion-Proof Instruments."

Explosion-Proof Instruments

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Earth Tech

100.1 Introduction

Where hazardous atmospheres can exist, electricity should be a primary concern of every engineer and system designer. Hazardous atmospheres can exist not only in the more common surroundings of industrial, chemical, and environmental facilities, but also in many less obvious environs where dust is present, where gas can accumulate, and where combustible gas-forming reactions occur. To minimize risks in such areas, it is necessary to design specific hazard-reducing electric systems. Most electric equipment is built to specific standards aimed to reduce the incidence of fires and human casualties. The majority of such incidents can be attributed to poor or defective installations, improper use of approved equipment, deteriorated equipment, and accidental applications. In combination with an explosive atmosphere, these factors can result in extremely dangerous conditions. Designing an electric system for a hazardous location requires careful planning, research, engineering, and ingenuity in using proper protection techniques to develop better applications and classifications that reduce hazards.

100.2 Fundamentals of Explosion Protection

Safety of personnel and equipment present in hazardous area should never be taken for granted. In 1913 a massive methane gas explosion in a coal mine in Glamorganshire, South Wales claimed the lives of 439 mine workers. After months of research and studies, a group of experts and scientists concluded that the explosion was caused by a small amount of electric energy stored in the circuit. This small amount of energy combined with the presence of an explosive gas and air mixture and the absence of proper protection proved to be fatal for the mine workers.

To understand the dangers associated with electric equipment in hazardous areas, one must first understand the basics. Chemically speaking, **oxidation**, combustion, and explosions are all exothermic reactions where heat is given off at different reaction speeds. For these reactions to occur, three components must be present simultaneously in certain concentrations. These components are (1) fuel (liquid, gas, or solids), (2) a sufficient amount of oxygen (air), and (3) an ignition source (electric or thermal).

Some of the ignition sources that can be potentially hazardous include (1) hot surfaces (motor windings, heat trace cable, light fixtures), (2) electric sparks and arcs (when circuits are opened and closed, short circuits), (3) mechanic sparks (friction, grinding), (4) electrostatic discharge (separation process in which at least one chargeable substance is present), and (5) radiation, compression, and shock waves.

When dealing with electric equipment in hazardous locations, it is important to understand and to be familiar with the following terms:

1. *Flash Point* — the minimum temperature at normal air pressure at which a combustible or flammable material releases sufficient vapors ignitable by an energy source. Depending on the flash point (FP), flammable liquids are divided into four classes of hazard:
   a. AI (FP < 21°C),
   b. AII (21 < FP < 55°C),
   c. AIII (55°C < FP < 100°C), and
   d. B (FP < 21°C at 15°C dissolving in water).
2. *Ignition temperature* — the minimum temperature under normal operating pressure at which a dangerous mixture ignites independently of the heating or heated element.
3. *Flammable limits* — the upper explosive limit (UEL) or the maximum concentration ratio of vapor to air mixture above which the propagation of flame does not occur when exposed to an ignition source. Here, the mixture is said to be "too rich" to burn. The lower explosive limit (LEL) is the minimum concentration ratio of vapor to air mixture below which the propagation of flame does not occur when exposed to an ignition source. Also, here, the mixture is said to be "too lean" to explode. Significant attention must be given to LEL, since it provides the minimum quantity of gas necessary to create a hazardous mixture. Generally, the flammable limits are indicated in percent by volume, which is abbreviated % vol. Note that the explosion of a mixture in the middle the UEL and the LEL is much more violent than if the mixture were closer to either limit.
4. *Maximum surface temperature* — the maximum temperature generated by a piece of electric equipment under normal or fault conditions. This temperature must be below the minimum ignition temperature of the potentially explosive surrounding atmosphere. Equipment used in hazardous locations must be clearly marked to indicate class, group, and maximum surface temperature or range referenced to 40°C (104°F) ambient temperature. Table 100.1 shows that an apparatus with a specific T class can be used in the presence of all gases having an ignition temperature higher than the T temperature class of the device. For added safety, it is recommended that the maximum surface temperature be not more than 80% of the minimum ignition temperature of the surrounding gas. The reader is cautioned not to confuse maximum working (operating) temperature with maximum surface temperature, which is measured under worst-case conditions of the electric apparatus. An electric apparatus designed to operate with a maximum ambient temperature of 70°C — even in the worst conditions of the expected temperature range — must not have a temperature rise greater than a safety margin of 10°C to be classified as T6 or 5°C for classes T3, T4, and T5 (Table 100.1).
5. *Vapor density* — the weight of a volume of pure vapor gas compared with the weight of an equal volume of dry air under the same normal atmospheric pressure and temperature. It is calculated as the ratio of molecular weight of the gas to the average molecular weight of air (28.96). Methane gas (CH_4) with molecular weight of 16 and vapor density of 0.6 tends to rise, while acetone (C_3H_6O) with molecular weight of 58 and vapor density of 2 tends to settle closer to ground levels.

In the U.S., the National Electrical Code (NEC) defines a hazardous area as "an area where a potential hazard may exist under normal or abnormal conditions because of the presence of flammable, combustible, or ignitable materials" [1]. This general description is divided into different classes, divisions, and groups to assess the extent of the hazard properly and to design and specify safe operating electric systems.

TABLE 100.1 Maximum Surface Temperature Under All Operating Conditions

Maximum Temperature		
°C	°F	Identification Number
450	842	T1
300	572	T2
280	536	T2A
260	500	T2B
230	446	T2C
215	419	T2D
200	392	T3
180	356	T3A
165	329	T2B
160	320	T3C
135	275	T4
120	248	T4A
100	212	T5
85	185	T6

Note: Surface temperature of electric apparatus during operation must not exceed limitations of the hazard present. Reprinted with permission from NFPA 70-1996, the *National Electrical Code*®, Copyright© 1995, National Fire Protection Association, Quincy, MA 02269. This reprinted material is not the complete and official position of the National Fire Protection Association, on the referenced subject which is represented only by the standard in its entirety.

The need for classification is important not only for safety, but for economic reasons as well. Proper application, good engineering, and experience can reduce the extent of the most volatile areas (Class I, Division 1) within reasonably safe distances of potential leaks and ignition sources. Under Class I, Division 1, equipment and installation costs can become an economic burden because the equipment is considerably more expensive and must pass stringent tests to ensure proper and safe operation under normal or abnormal conditions. The National Fire Protection Association (NFPA 497 A & B) [2], and the American Petroleum Institute *Recommended Practice for Classification of Locations for Electrical Installations at Petroleum Facilities* (ANSI/API RP 500) [3] are excellent resources for defining hazardous area boundaries.

100.3 Classification of Hazardous Areas

Classification of a hazardous area within a facility is usually determined by highly qualified personnel including chemical engineers, process engineers, and safety officers. Their primary objective is to determine where a potentially hazardous atmosphere exists, under what conditions it exists, and how long it exists. Careful study and design of electric installations, especially in hazardous areas, are crucial for the safe operation of electric equipment and prevention of an accidental ignition of flammable materials. The NEC, which has been adopted by many states, agencies, and companies as the basis for inspections, describes the requirements and procedures for electric installations in hazardous areas. Articles 500–504 contain the requirements of electric equipment and wiring for all voltages in locations where fire or explosion hazards may exist due to flammable gases or vapors, flammable liquids, combustible dust, or ignitable fibers or flyings.

Table 100.2 describes hazardous locations by Class, Division, and Group. The Class defines the physical form of combustible material mixed with oxygen molecules. The Division defines the probability of an

TABLE 100.2 Area Classification Based on NEC

Division 1 — Hazard Is Present under Normal Operating Conditions	
Class I	Gases and Vapor
Group A	Acetylene
Group B	Hydrogen
Group C	E.g., ethylene
Group D	E.g., methane
Class II	Combustible Dusts
Group E	Metal dust
Group F	Coal dust
Group G	Grain dust
Class III	Fibers
Division 2 — Hazard Is Present Only under Abnormal Operating Conditions	

explosive fuel to air mixture being present. The Group indicates the type of vapor or dust present. The NEC gives the following definitions [1]:*

Class I, Division 1 Locations

1. Where ignitable concentrations of flammable gases or vapors can exist under normal operation conditions; may exist frequently because of repair or maintenance operations or because of leakage; and where breakdown or faulty operation of equipment or processes might release ignitable concentrations of flammable gases or vapors, and cause simultaneous failure of electric equipment.

Class I, Division 2 Locations

1. Where volatile flammable liquids or flammable gases are handled, processed, or used but where the liquids, vapors, or gases will normally be confined within closed containers or closed systems from which they can escape only in case of accidental rupture or breakdown of such containers or systems, or in case of abnormal operation of equipment;
2. Where ignitable concentrations of gases or vapors are normally prevented by positive mechanical ventilation, and where they might become hazardous through failure or abnormal operation of the ventilating equipment;
3. Adjacent to Class I, Division 1 locations, and where ignitable concentrations of gases or vapors might occasionally be communicated; unless such communication is prevented by positive-pressure ventilation from a source of clean air, and effective safeguards against ventilation failure are provided.

Class II, Division 1 Locations

1. Where combustible dust is in the air under normal operation conditions in quantities sufficient to produce explosive or ignitable mixtures;

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2. Where mechanical failure or abnormal operation of machinery or equipment might cause such explosive or ignitable mixtures to be produced, and also might provide a source of ignition through simultaneous failure of electric equipment, operation of protective devices, or from other causes;

3. Where combustible dusts of an electrically conductive nature may be present in hazardous quantities.

Class II, Division 2 Locations

Where combustible dust normally is not in the air in quantities sufficient to produce explosive or ignitable mixtures, and dust accumulations normally are insufficient to interfere with the safe dissipation of heat from electric equipment, or may be ignitable by abnormal operation or failure of electric equipment.

Class III, Division 1 Locations

Where easily ignitable fibers or materials producing combustible flyings are handled, manufactured, or used.

Class III, Division 2 Locations

Where easily ignitable fibers are stored or handled. Quantities and properties of hazardous materials are the basis upon which the NEC classifies hazardous locations. Each hazardous location must be evaluated carefully to determine the appropriate classification to facilitate the design process and to help specify the correct equipment.

100.4 Enclosure Types and Requirements

Choosing the proper type of enclosure for electric equipment is important for two reasons:

1. Personnel protection against accidental contact with enclosed electric equipment.
2. Protection of internal equipment against outside harm.

Enclosures are designated by a type number indicating the degree of protection and the condition for which they are suitable. In some applications, enclosures have a dual purpose and therefore are designated by a two-part type number shown with the smaller number first (i.e., 7/9). The following enclosure types, with their enclosed equipment, have been evaluated in accordance with Underwriters Laboratories, Inc. UL 698, *Industrial Control Equipment for Use in Hazardous Locations*, and are marked to show the class and group letter designations.

Type 7 Enclosures — Type 7 enclosures are nonventilated, intended for indoor applications, and classified for Class I, Group A, B, C, D as defined in Table 100.2. The letters A to D sometimes appear as a suffix to the designation Type 7 to give the complete designation. According to UL 698, Type 7 enclosures must be designed to withstand an internal explosion pressure of specific gases and to prevent such an explosion from igniting a hazardous mixture outside the enclosure (explosion test). In addition, Type 7 enclosures fabricated from sheet steel are designed to withstand two times the internal explosion pressure for 1 min without permanent deformation and three times the explosion pressure without rupture. If constructed of cast iron, the enclosure must be capable of withstanding four times the explosion pressure without rupture or deformation. This test may be waived if calculations show a safety factor of five to one for cast metal or four to one for fabricated steel. The enclosed heat-generating devices are specifically designed to prevent external surfaces from reaching temperatures capable of igniting explosive vapor–air mixture outside the enclosure (temperature test).

Type 8 Enclosures — Type 8 enclosures are nonventilated, intended for indoor applications, and intended for Class I, Group A, B, C, D as outlined in Table 100.2. The letters A to D appear as a suffix to the designation Type 8 to give the complete designation. According to UL 698, the oil-immersed equipment must be able to operate at rated voltage and most severe current conditions in the presence of flammable gas–air mixtures without igniting these mixtures.

Type 9 Enclosures — Type 9 enclosures are nonventilated, intended for indoor applications, and classified for Class II, Group E, F, G as outlined in Table 100.2. The letters E, F, or G appear as a suffix to the designation Type 9 to give the complete designation. According to UL 698, the enclosure with its enclosed equipment is evaluated in accordance with UL 698 in effect at the time of manufacture. This evaluation includes a review of dimensional requirements for shaft opening and joints, gaskets material, and temperature rise under a blanket of dust. The device is operated at full rated load until equilibrium temperatures are reached, then allowed to cool to ambient temperature over a period of at least 30 h while continuously subjected to circulating dust of specified properties. No dust shall enter the enclosure (dust penetration test). Furthermore, Type 9 enclosures must also pass the "temperature test with dust blanket," which is similar to the temperature rise test except the circulating dust is not aimed directly at the device during testing. The dust in contact with the enclosure shall not ignite or discolor from heat, and the exterior surface temperature based on 40°C (104°F) shall not exceed specific temperatures under normal or abnormal conditions. Where gasketed enclosures are used, gaskets shall be of a noncombustible, nondeteriorating, vermin-proof material and shall be mechanically attached. Type 9 ventilated enclosures are the same as nonventilated enclosures, except that ventilation is provided by forced air from a source outside the hazardous area to produce positive pressure within the enclosure. The enclosure must also meet temperature design test.

Type 10 Enclosures — Type 10 enclosures are nonventilated and designed to meet the requirements of the U.S. Bureau of Mines which relate to atmospheres containing mixtures of methane and air, with or without coal dust present.

It is important to note that enclosures for hazardous applications are designed for specific applications and must be installed and maintained as recommended by the enclosure manufacturer, since any misapplication or alteration to the enclosure may jeopardize its integrity and may eventually cause catastrophic failure of the system. All enclosures should be solidly grounded and properly labeled with a warning sign reminding the operator of the importance of deenergizing the incoming power to the enclosure prior to its servicing.

100.5 Protection Methodologies

Choosing a protection technique that suits each application can appear complicated because safety, reliability, cost, and maintenance factors must all be considered. Over the years, few hazardous area safety protection methodologies have been used. Although methodologies differ in application and principles of operation, they all have one thing in common: to eliminate one or more components necessary for combustion. Three of the most widely used methodologies are

1. Intrinsic safety
2. Explosion-proof
3. Purging and pressurization

Intrinsic Safety

Simply stated, intrinsic safety (IS) is all about preventing explosions. IS is based on the principle of limiting the thermal and electrical energy levels in the hazardous area to levels that cannot cause an ignition of a specific hazardous mixture in its most ignitable concentration. IS pertains to the minimum ignition temperature and the minimum ignition electric energy required to cause a specific group to ignite. The energy level provided by an IS circuit is low (≈1 W) and is used only to power up instruments with a low energy demand. An IS circuit incorporates an intrinsically safe apparatus (field device), an associated apparatus, and an interconnecting wiring system. Designing intrinsically safe systems begins with studying the field device. This will help determine the type of associated apparatus which can be used so that the circuit functions properly under normal operating conditions, but still safe under fault conditions. Field devices can be simple, such as **resistance temperature devices (RTDs)**, thermocouples, mechanical switches, proximity switches, light emitting diodes (LEDs), or they can be nonsimple, such as transmitters, solenoid valves, and relays. A field device is considered and recognized as a "simple device" if its energy storing or generating values do not exceed 1.2 V, 0.1 A, 25 mW (or 20 µJ) in an intrinsically safe system under normal or abnormal conditions.

The simple device may be connected to an intrinsically safe circuit without further certification or approval. The fact that these devices do not have the ability to store or generate high levels of energy does not mean they can be installed in a hazardous area without modification. They must always be used with an associated apparatus to limit the amount of energy in the hazardous area, since a fault outside the hazardous area can cause sufficient high levels of energy to leak into the hazardous area. A nonsimple device (i.e., relay, transmitter) is capable of generating and storing energy levels exceeding the aforementioned values. Such devices require evaluation and approval under the entity concept (described later) to be used in conjunction with an intrinsically safe circuit. Under the entity concept, these devices have the following entity parameters: V_{max} (maximum voltage allowed), I_{max} (maximum current allowed), C_i (internal capacitance), and L_i (internal inductance). Under fault conditions, voltage and current must be kept below the V_{max} and I_{max} of the apparatus to prevent any excess heat or spark, which can be disastrous in hazardous areas. C_i and L_i indicate the ability of a device to store energy in the form of internal capacitance and internal inductance, and their value must be less than C_a and L_a of the associated apparatus (Table 100.3).

TABLE 100.3 Comparison of Entity Values of a Field Device and a Safety Barrier

Field Device		Safety Barrier
V_{max}	$\geq$	V_{oc}
I_{max}	$\geq$	I_{sc}
C_i	$\leq$	C_a (maximum allowed capacitance)
L_i	$\leq$	L_a (maximum allowed inductance)

An associated apparatus (Fig. 100.1), also known as a safety barrier, is an energy-limiting device needed to protect a field device located in a hazardous area from receiving excessive voltage or current. An associated apparatus is normally installed in a dust- and moisture-free enclosure (NEMA 4) located in a nonhazardous area, as close as possible to the hazardous area to minimize the capacitance effect of the cable. If installed in a hazardous area, the associated apparatus must be installed in an explosion-proof enclosure (i.e., NEMA 7D).

Figure 100.1 shows the three major components of a Zener safety barrier. (Note that there are other types of barriers such as isolation and repeater types.) The components are

1. The resistor, which limits the current to a specific value known as short circuit current (I_{sc}).
2. The fuse, which acts as an interrupter or protective device in case of a diode failure (fuse will blow if diode conducts).
3. The **Zener diode**, which limits the voltage to a specific value known as open circuit voltage (V_{oc}). Zener diodes are unique in their ability to conduct current under reverse bias conditions. When voltage is applied to the Zener diode in the reverse direction, a small amount of current known as leakage current is passed through. This current remains small until the bias voltage exceeds the Zener breakdown voltage. Exceeding the breakdown voltage causes the inherently high resistance of the Zener diode to drop to a very low value, thus allowing the current to increase abruptly. This sudden current increase forces the Zener diode to become a conductor, thereby diverting the excess voltage to ground. If the current continues to flow above and beyond the fuse rating, the

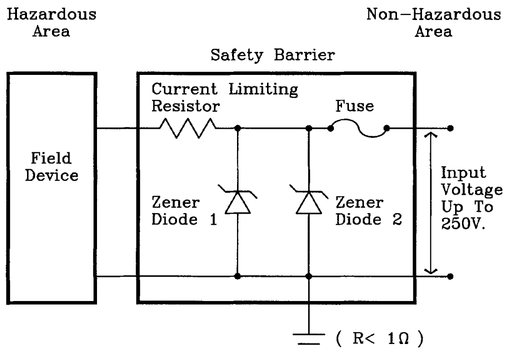


FIGURE 100.1 Major components of barrier circuit.

fuse will open and the circuit will be completely interrupted. Most safety barriers incorporate at least two diodes in parallel to provide maximum protection in case one diode fails (redundant safety).

In 1988, ANSI/UL 913 [5] allowed the use of intrinsic safety barriers with replaceable fuses as follows: "if it is accessible for replacement, and the fuse on a fuse protected shunt diode barrier shall not be replaceable by one of higher rating." The fuses are housed in tamper-proof assemblies to prevent confusion or misapplication. The diodes have specific power ratings which must not be exceeded. The Zener diodes and fuses are governed by a very specific set of parameters which allow the fuse to operate at one-third the power rating of the Zener diode and to avoid irreversible damage to the Zener diode. The power rating for the Zener diode can be determined as follows:

$$Z_w = 1.5 \times V_{oc} \times 2 \times I_f$$

where

Z_w = minimum power rating of the Zener diode
V_{oc} = maximum Zener diode open-circuit voltage
I_f = fuse current rating

Selecting the best barrier for the application depends on the field device and requires analysis to ensure proper operation of the intrinsically safe circuit under normal or abnormal conditions. Three of the more important characteristics requiring examination are (1) internal resistance, (2) rated voltage, and (3) circuit polarity. Regardless of the selected barrier, each has an internal resistance (R_i) which limits the short circuit current under fault conditions. As current passes through R_i, it creates a voltage drop across the barrier that must be accounted for ($V = IR$). The rated voltage of the safety barrier must be equal to or reasonably greater than the supply voltage. The word *reasonably* is significant because excessive supply voltage can cause the diode to conduct, rushing high current through the fuse and blowing it. The use of a regulated power supply can significantly reduce problems associated with excessive supply voltage. To complete an analysis, the circuit polarity must be established. While ac barriers can be connected with either positive or negative power supply, dc barriers can be rated to either positive or negative.

Making Field Devices Intrinsically Safe

RTDs and thermocouples can be made intrinsically safe by using isolated temperature converters (ITCs) that convert a low dc signal from the field device into a proportional 4 to 20 mA signal. These ITCs require no ground connection for the safe and proper operation of the IS circuit. Because of their ability to store energy, transmitters are considered nonsimple devices and must be approved as intrinsically safe. If they are third-party approved, their entity parameter must be carefully considered. Transmitters (4 to

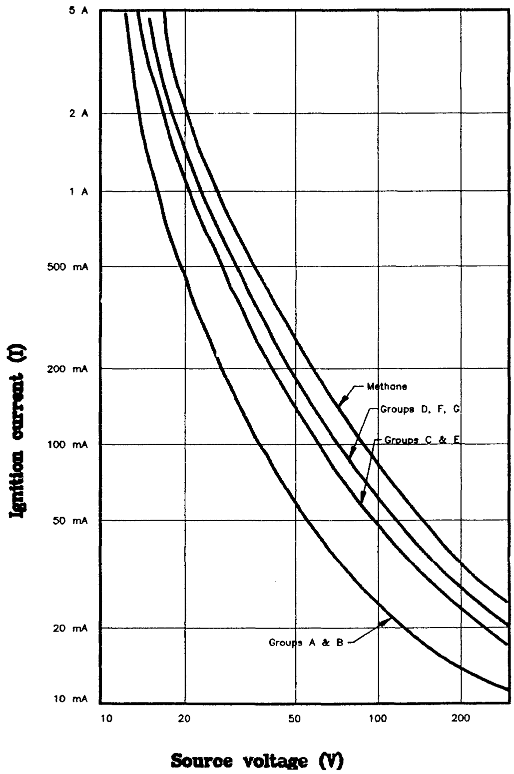
20 mA) convert physical measurements in hazardous areas, such as pressure and flow, into electric signals which can be transmitted to a controller in a safe area. Depending upon the conditions, 4 to 20 mA signals can be made intrinsically safe by using a repeater barrier which duplicates the output signal to match the input signal. Repeaters can be grounded or ungrounded. Ungrounded repeater barriers are known as "transformer-isolated barriers," since the incoming voltage or signal is completely isolated from the outgoing voltage or signal via a transformer. Digital inputs, such as mechanical and proximity switches, which are simple devices, can be made intrinsically safe by using a switch amplifier. A switch amplifier is simply a relay or an optocoupler (a high-speed relay that uses optical isolation between the input and the output) that transfers a discrete signal (i.e., on/off) from the hazardous area to a safe area. Grounded safety barriers are passive devices designed specifically to prevent excessive energy in a non-hazardous area from reaching a hazardous area. These barriers can be used with most field devices. In order for such barriers to function properly, there is emphatic need for a solid, low-impedance (<1 Ω) connection to ground to prevent ground loops and induced voltages which can hinder operation of the system.

Ignition Curves

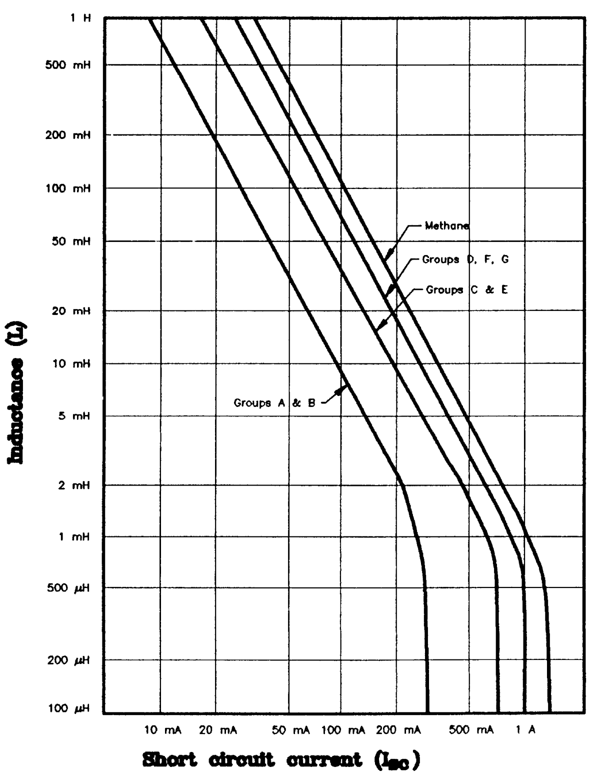
All electric circuits possess certain electric characteristics that can be classified under three categories: resistance, **inductance**, and capacitance. To some extent, all circuits possess these three characteristics. However, some of these characteristics may be so small that their effects are negligible compared with that of the others, thus the terms, resistive, inductive, and capacitive circuit. Since the concept of IS is based on the principle that a large electric current can cause an explosion in a hazardous area and the lack of it cannot, it is necessary to identify the ranges of currents that are safe and those that are dangerous.

What is a dangerous amount of electric energy? The answer lies in the ignition curves. Ignition curves are published in most IS standards, such as ANSI/UL 913 [5]. Three of the most referenced curves are shown in Fig. 100.2. The curves show the amount of energy required to ignite various hazardous atmospheric mixtures in their most easily ignitable concentration. The most easily ignitable concentration is determined by calculating the percentage of volume-to-air between the upper and lower explosive limits of a specific hazardous atmospheric mixture. In the three referenced curves, the energy levels (voltage and current) below the group curve are not sufficient to cause an ignition of the referenced group.

Since specific ignition temperature is directly related to the amount of voltage and current consumed, both V_{oc} and I_{sc} of the safety barrier must be less than V_{max} and I_{max}. When designing an intrinsically safe system, the cable resistance R (Ω/m), the inductance L (μH/m), and the capacitance C (pF/m), which are inherently distributed over the length of the cable, must be considered. The capacitance and inductance can be readily obtained from the cable manufacturer's literature. If these parameters are not available, certain default values can be used based on NFPA 493/78 (A-4-2). They are C_c = 200 pF/m (60 pF/ft), L_c = 0.66 μH/m, and (0.2 μH/ft). To determine the maximum wiring distance required to ensure proper operation, the capacitance and inductance must be calculated. One common approach uses "lumped parameters," in which the voltage and current of both the intrinsically safe apparatus and the associated intrinsically safe apparatus are compared and matched according to Eqs. 100.1 and 100.2. Any deviation from either Eqs. 100.1 and 100.2 can compromise the integrity of the system and introduce hazardous conditions. The reactive parts of the system must also be considered and verified to demonstrate that C_a and L_a values of the associated apparatus are not be exceeded by the field device and the field wiring values as shown in Eqs. 100.3 and 100.4. This method, although simple and effective, tends to exaggerate the wiring capacitance and inductance effect, which can be limiting in some applications. Another method takes advantage of the relation between the cable resistance and inductance. This method can be used if the L/R ratio of the associated apparatus is higher than the calculated L/R ratio of the cable. Under these conditions, the lesser D_a (maximum allowed distance) value can be ignored and the cable length can be extended to the higher D_a value. This method is more flexible where cable length is an issue. Figure 100.3 and the following example illustrate these methods.



(a)



(c)

FIGURE 100.2 (a) Resistance circuit ignition curves for all circuit metals. (b) Inductance circuit ignition curves at 24 V for all circuit metals. (c) Capacitance circuit ignition curves for groups A and B for all circuit metals.

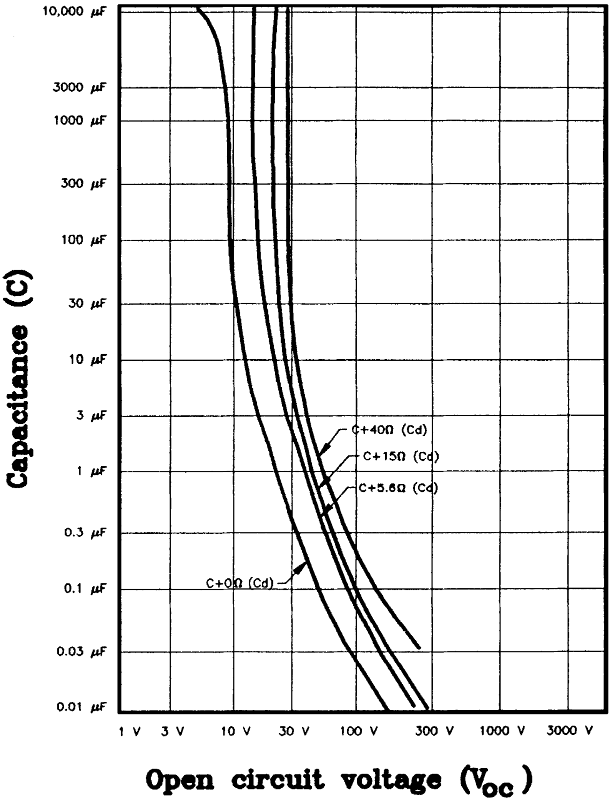


FIGURE 100.2c

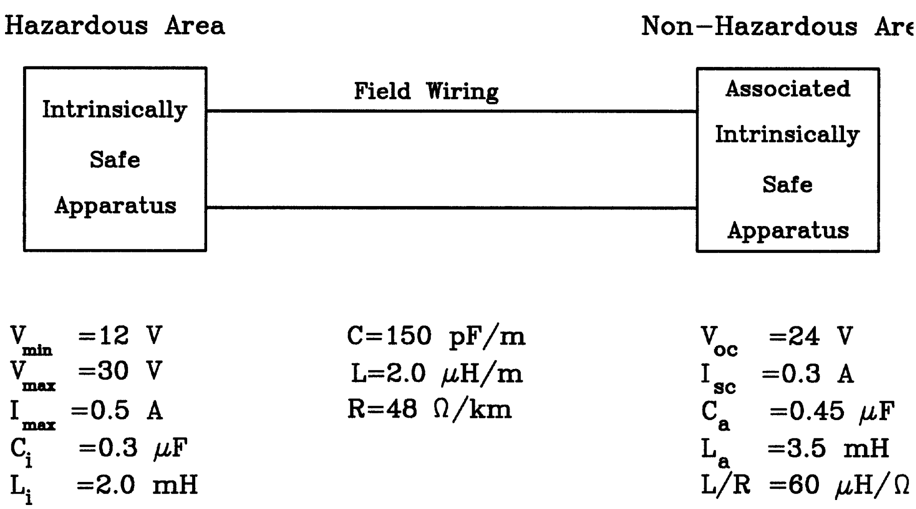


FIGURE 100.3 Analysis of an intrinsically safe system.

Lumped parameters method:

$$V_{oc} \le V_{max} \tag{100.1}$$

$$I_{sc} \le I_{max} \tag{100.2}$$

$$C_c \le C_a - C_i \quad 0.45\ \mu F - 0.30\ \mu F = 0.15\ \mu F \tag{100.3}$$

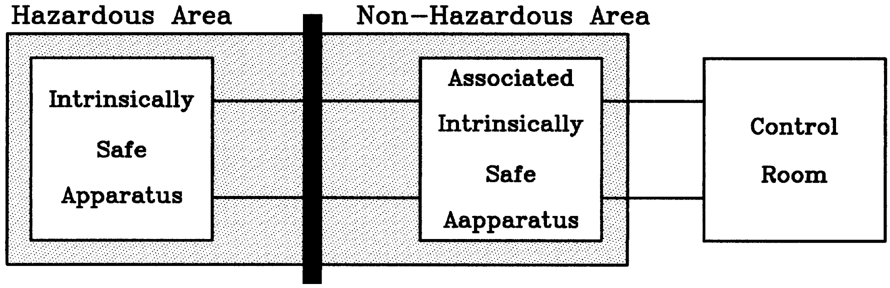


FIGURE 100.4 Loop approval. Intrinsically safe apparatus and associated apparatus are evaluated together. Shaded area indicates evaluated for loop approval.

$$L_c \leq L_a - L_i \quad 3.5 \text{ mH} - 2.0 \text{ mH} = 1.5 \text{ mH} \tag{100.4}$$

The maximum length of the field wiring, referred to its capacitance and inductance, is the lesser value of D_a.

$$D_a = 0.15 \ \mu\text{F}/150 \text{ pF/m} = 1000 \text{ m}$$

$$D_a = 1.5 \text{ mH}/2.0 \ \mu\text{H/m} = 750 \text{ m (maximum distance of field wiring)}$$

L/R *ratio method*:
Since the cable *L*/*R* ratio of 41.6 µH/Ω (2 µH/m/48 Ω/km) is less than the given associated apparatus *L*/*R* ratio, the inductive effect can be ignored and the maximum distance can be increased to 1000 m.

Certification and Approval

Although approval and certification processes help to provide safety, careful planning, designing, and engineering are still necessary. IS standards, procedures, and tests are recognized worldwide. Testing authorities include Underwriters Laboratories, Inc. (UL) and Factory Mutual Research Corp. (FM) in the U.S., Canadian Standards Association (CSA) in Canada, and Physikalisch-Technische Bundesanstalt (PTB) in Europe. Intrinsically safe products are suitable for all Classes, Divisions, and Groups outlined in Table 100.2. It is necessary to emphasize that the intrinsically safe product must be rated and classified for each specific application (Class, Division, and Group). In the U.S., FM adopted two methods for testing and approving equipment to be used in hazardous areas:

1. *Loop (System) Approval:* Where an intrinsically safe apparatus is evaluated in combination with a specific associated apparatus and is approved to be installed in this manner. Any changes to the circuit require reevaluation and certification (Fig. 100.4).
2. *Entity Approval:* Where an intrinsically safe apparatus and the associated apparatus are separately evaluated and given their own electrical entity parameters (Fig. 100.5). The correct application matches the entity parameters shown in Table 100.3. When examining the safety of a circuit, it is crucial to compare the entity values of an intrinsically safe apparatus with an associated apparatus.

Most safety barriers are entity approved for all hazardous locations. Since most field devices have the ability to store energy, they must have loop approval or entity approval for the proper construction and operation of an intrinsically safe system.

IS engineers often advocate the use of intrinsically safe equipment for the following reasons:

1. *Safety.* No explosion can occur in an intrinsically safe system under any operating condition. IS equipment operates on lower power levels and prevents shocks, excess thermal energy, and arcing. In different systems and under various scenarios, shocks, thermal energy, and arcing may cause a hazard.

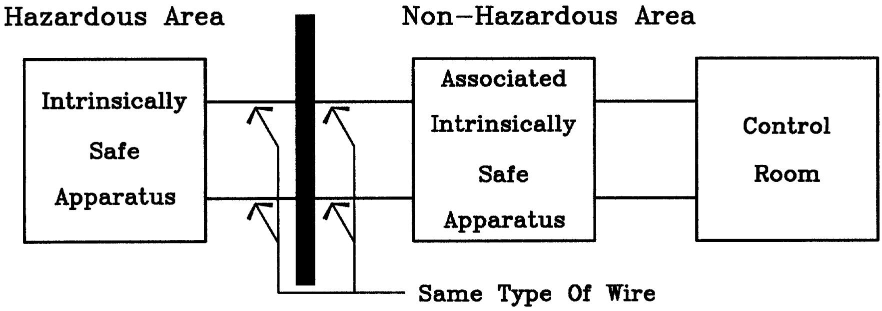


FIGURE 100.5 Entity approval. Intrinsically safe apparatus and associated apparatus are evaluated separately.

2. *Reliability.* The components and assemblies of intrinsically safe circuits are tested for reliability before they are labeled and certified. Most intrinsically safe equipment is designed with special circuitry to provide surge suppression and to prevent spikes and transients.
3. *Ease of handling and installation.* Intrinsically safe systems tend to be small and do not require expensive, bulky accessories such as enclosures, seals, and rigid metallic conduits which increase the initial investment.
4. *Economy.* In some geographic locations, facilities containing hazardous conditions must carry special liability insurance. With the proper installation of intrinsically safe circuits and equipment, the probability of an explosion is 10^{-18} [8], or nearly nonexistent. As a result, insurance rates tend to be lower.
5. *Maintenance.* Equipment may be calibrated and maintained without disconnecting power, thereby resulting in less downtime.

The wiring of intrinsically safe systems is similar to any other application, but to ensure a proper operating system, certain guidelines regarding identification and separation must be strictly followed. All intrinsically safe components including terminal blocks, conductors, and intrinsically safe apparatus must be explicitly marked and labeled. The conventional color used to identify intrinsically safe equipment is blue. In an open wiring installation, intrinsically safe conductors must be physically separated from nonintrinsically safe conductors by at least 50 mm (2 in.) so an induced voltage does not defeat the purpose of IS. Where intrinsically safe conductors occupy a raceway, the raceway should be labeled, "Intrinsically Safe Circuits." Intrinsically safe conductors should not be placed with nonintrinsically safe conductors. Where a cable tray is used, a grounded sheet metal partition may be used as an acceptable means of separation. Where intrinsically safe and nonintrinsically safe conductors occupy the same enclosure, a 50-mm (2-in.) separation must be maintained. In addition, a grounded metal partition shall be in place to prevent contact of any conductors that may come loose. Insulation deterioration of intrinsically safe conductors of different circuits occupying the same raceway or enclosure can be detrimental to the operation of the system. Intrinsically safe conductors must have an insulation grade capable of withstanding an ac test voltage of 550 V root-mean-square (rms) or twice the operating voltage of the intrinsically safe circuit. Nonintrinsically safe conductors in the same enclosure with intrinsically safe conductors must have an insulation grade capable of withstanding an ac test voltage of $2U + 1000$ V, with a minimum of 1500 V rms, where U is the sum of rms values of the voltages of the intrinsically safe conductors. A commonly used and highly recommended practice utilizes separate compartments for intrinsically safe and nonintrinsically safe conductors. In addition to physical separation of intrinsically safe conductors and nonintrinsically safe conductors, sealing of conduits and raceways housing intrinsically safe conductors is essential to prevent the passage of gases, vapors, and dusts from hazardous to nonhazardous areas. According to the NEC, seal-offs are not required to be explosion-proof. Where an associated apparatus is installed in an explosion-proof enclosure in a hazardous area, seal-offs must be explosion-proof. Although it is not required by Code, it is a good engineering practice to install explosion-proof seal-offs on conduits housing intrinsically safe conductors, as shown in Fig. 100.6.

FIGURE 100.6 Explosion-proof seal-off fitting. (Courtesy of Crouse-Hinds Division of Cooper Industries, Inc.)

Explosion-Proof Fundamentals

Explosion-proof design is a mechanical concept that relies heavily on the mechanical construction of an enclosure and the narrow tolerances between its joints, threads, and flanges to safely contain, cool, and vent any internal explosion that may occur. By definition, explosion-proof enclosures must prevent the ignition of explosive gases or vapors that may surround it (Type 7 and Type 10 enclosures only). In hazardous areas, Class I, Divisions 1 and 2, arcing devices, such as switches, contactors, and motor starters must be enclosed in an explosion-proof enclosure specifically rated for that area. Contrary to popular belief, explosion-proof enclosures are not and should not be vapor-tight. Succinctly stated, an explosion inside an enclosure must be prevented from starting a larger explosion outside the enclosure. Unlike IS, explosion-proof enclosures address the maximum internal pressure (see NEMA Type 7 enclosures). Figure 100.7 illustrates the rugged construction of a standard explosion-proof panel board.

In addition to its durability and strength, explosion-proof enclosures must also be "flame-tight." The joints or flanges must be held within narrow tolerances to allow cooling of hot gases resulting from internal explosions. In this way, if any gases are released into the outside hazardous atmosphere, they are cool enough not to cause ignition.

Explosion-proof enclosures tend to be bulky (making them easy to identify) and heavy, requiring conduit seals and careful handling. Unlike intrinsically safe equipment, explosion-proof equipment operates on normal power levels which are necessary due to the high power requirements of some circuits and equipment. With the proper equipment, installation, and maintenance, explosion-proof enclosures can safely and effectively distribute high levels of voltage and power into hazardous areas.

Where ignitable amounts of dust are present, enclosures housing electric equipment must be dust-ignition-proof. These enclosures must exclude combustible dusts from entering, while preventing arcs, sparks, or heat generated internally from igniting dust surrounding the exterior of the enclosure. These enclosures must also efficiently dissipate the heat generated internally, since many types of dust will ignite at relatively low temperatures. Unlike Class I, Division 1 explosion-proof enclosures (Type 7), Class II, Division 1 dust-ignition-proof enclosures (Type 9) are designed to prevent an explosion. Subsequently, dust-ignition-proof enclosures need not be as strong or have walls as thick as explosion-proof enclosures since there will be no internal explosion.

Purging and Pressurization

This methodology allows the safe operation of electric equipment where hazardous conditions exist and where no other methodology is applicable because of the imperative high-energy demands and actual

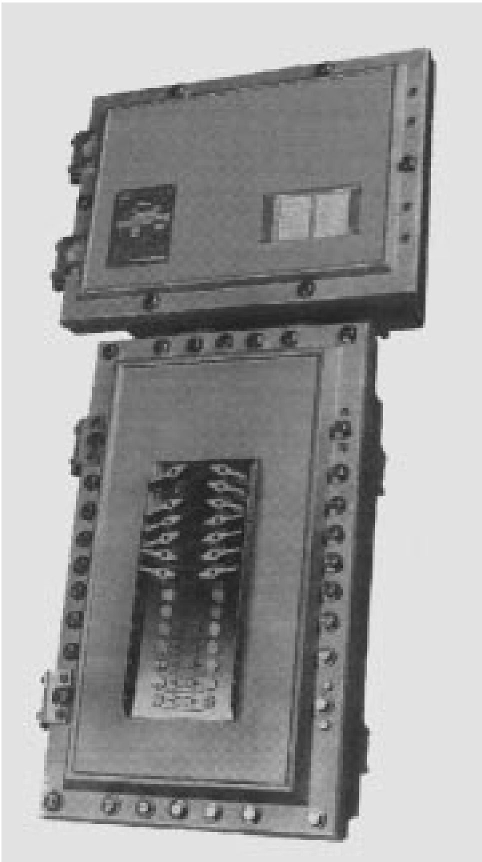


FIGURE 100.7 Explosion-proof lighting panelboard. (Courtesy of Crouse-Hinds Division of Cooper Industries, Inc.)

physical dimensions. This is true for large-sized motors and switchgear units where they are not commercially available for Class I, Group A and B. In addition, this methodology is used where control panels that house the instruments and electric equipment must be located in hazardous areas. Purging and pressurization is a protection method that relies on clean air or inert gas (i.e., nitrogen) to be continuously supplied to the enclosure at sufficient flow to keep the equipment adequately cooled and to provide adequate internal pressure to prevent the influx of combustible atmospheres into the enclosure. Although the enclosures are not explosion-proof, they must be relatively vapor-tight and must have adequate strength to perform safely and satisfactorily. The system consists of

1. *Clean Air (or Inert Gas) Supply:* Careful study and analysis is of crucial importance to this process since the air supplied must be reasonably free of contaminants. Finding a safe location for an air intake requires skill and ingenuity. Consulting with an HVAC specialist is recommended. Other factors such as vapor density, location, wind pattern, and surrounding environment should also be considered. Where compressors and blowers are used to supply compressed air, caution must be exercised when selecting the proper compressor or blower size and location in order to meet airflow requirements without compromising the main objective of safety and reliability.
2. *Purging:* A pressurized enclosure that has been out of service for some time tends to collect a combustible mixture. Before energizing, inert gas and positive pressure must provide a sufficient initial clean air volume to minimize the concentration of any combustible mixture that may be present. For typical applications, a flow of four times the internal volume of the enclosure is usually sufficient to minimize the concentration of combustible mixture that may exist. For unusual applications, the flow volume must be carefully calculated to ensure the success of the purging process.

3. *Pressurization:* This process uses the concept of pressure differential between the outside and the inside of the enclosure to keep flammable materials from entering. This is accomplished by maintaining a higher pressure on the inside of the enclosure. For safe operation, the protected enclosure must be constantly maintained at a positive pressure of at least 25 Pa (0.1 in. water) [2] above the surrounding atmosphere during the operation of the protected equipment.
4. *Signals and Alarms:* When positive pressure is lost, warnings and alarms are essential. Three types of pressurization and alarms can be used, depending on the nature of the controls of the enclosure and the degree of hazard outside. In addition, door interlocks are required to prevent opening of the protected enclosure while the circuit is energized.

According to NFPA 496, there are three types of pressurization. They are

Type X — Reduces the classification within the protected enclosure from Division 1 to nonclassified. This usually involves a source of ignition housed in a tight enclosure located in a potentially hazardous atmosphere. Type X requires a disconnecting means (flow or pressure switch) to deenergize power to the protected enclosure completely and automatically immediately upon failure of the protective gas supply (loss of either pressure or flow). The disconnecting means must be explosion-proof or intrinsically safe, as it is usually located in the hazardous area.

Type Y — Reduces the classification within the protected enclosure from Division 1 to Division 2. The protected enclosure houses equipment rated for Division 2 and does not provide a source of ignition. Therefore, no immediate hazard is created. Type Y requires a visual or audible alarm in case of system failure. *Word of caution:* Safeguards must be established to ensure that any malfunction in the system does not raise the external surface temperature of the enclosure to over 80% of the ignition temperature of the combustible mixture present.

Type Z — Reduces the classification within the protected enclosure from Division 2 to nonclassified. Type Z requires a visual or audible alarm to be activated if failure to maintain positive pressure or flow within the protected enclosure has been detected.

Recognizing and understanding the potential dangers associated with the use of electricity in hazardous areas is a crucial part of selecting the best protection. Techniques for most applications, where the need for different energy demands is required, will likely involve a combination of various methodologies and specialized technologies. Properly performed analysis and investigation may appear to be time-consuming and expensive, but for those who are willing to adhere to the established guidelines and solid engineering practices, the process will help ensure the highest level of compliance while yielding tremendous savings and preventing property damage and injuries.

Defining Terms

Inductance: The ability of an electric apparatus to store an electric charge (energy). An inductor will release this energy when the circuit is opened (broken).

Oxidation: The process where negatively charged ions (anions) lose electrons at the anode during electrochemical process. For anions to become neutral, they must lose electrons.

Resistance temperature device (RTD): A device that measures temperature based on change of resistance.

Zener diode: A nonlinear solid state device that does not conduct current in reverse bias mode until a critical voltage is reached. It is then able to conduct current in reverse bias without damage to the diode. Zener diodes have almost constant voltage characteristics in the reverse bias region (usual operation).

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