A survey of European and American standards concerning electrical systems in potentially explosive atmospheres

F. Muzi
Department of Electrical Engineering, L’Aquila University, Italy

Abstract

The technical and legal standards presently enforced in Europe and North America in connection with electrical systems in potentially explosive atmospheres are analyzed and compared so as to supply useful information about the classification of potentially explosive environments and the consequent design and update of electrical systems. Before European Directives 94/9/CE and 99/92/CE were enacted, safety in these environments was assured only on a national level, which involved different safety regulations for each State of the European Union and hindered free movement of products in the single local market. For this reason, the European Parliament established safety directives valid all over the European Union that each State was required to enforce passing specific local laws, standards and guidelines in substitution of the previous ones. Actually, the new European directives and consequently the new local rules leave the designer a wide range of choices and possibilities, including appropriate, individual approaches; for this reason the knowledge of American standards can help to develop the best solutions complying with the prescribed requirements within affordable costs. In this context, this paper aims at supplying useful practical procedures and suggestions to correctly apply the present prescriptions by highlighting the differences between European old and new approaches and the standards presently enforced in North America (the U.S.A. and Canada).

Keywords: electrical plants in explosive atmosphere, safety in industrial environment.

1 Introduction

European Directives are issued by the European Parliament and directed to member states with the aim to supply the minimum essential safety requirements
requested for specific products and systems. These Directives must then be adopted by each member state through national specific laws aimed at enforcing the Euro-norm (EN) version of the new standards within the specific country. The presently enforced European Directives regarding potentially Explosive Atmospheres are the following:
- 99/92/CE, concerning the minimum requirements to improve the safety and health protection of workers potentially at risk from explosive atmospheres (application due on July 2003).

Directives [1], [2], are also named ATEX Directives from the French “ATmospheres Explosible”. The EU ATEX Directive is part of the “CE” marking regulation.

The main purpose of the ATEX directive 94/9/CE, which can be defined “Product Directive”, is to harmonise technical and legal standards in order to facilitate the free movement across all EU member states of products to be used in potentially explosive atmospheres. This directive covers both the electrical and mechanical equipment as well as the protective systems that during normal use - or because of malfunctioning - might engender one or more ignition sources for the potentially explosive atmospheres created by the presence of flammable gases, vapours, mists or dusts. These products are required to exhibit the CE mark in their label, together with other specification such as the manufacturer’s name and address and production year. Furthermore, the Ex mark must follow with information about the group, category, protection modes, kind of potentially explosive substances for which the product is suitable, temperature class, identification code of the Notified Body involved with the manufacturing process and the standards to which the equipment complies.

These products can be subdivided into the following groups:
1) Group I, apparatuses/devices used in mines.
2) Group II, apparatuses/devices used in installations over the ground.

Categories concerning only group II (non-mining) are forwarded to the end-user with a selection of the equipments identifying the Zone where they can be properly installed, which is a major improvement over the old marking procedure that only listed the protection concepts used in the equipment design.

The 99/92/CE Directive, which can be defined as “Use Directive”, ensures that only ATEX certified, electrical, mechanical and safety related systems are installed in potentially explosive atmospheres.

2 Zoning classification according to European Directive 99/92/CE

Areas at danger for potentially explosive atmospheres (due to gas or dust) can be subdivided on the basis of the following factors:
- Type of the flammable substances present.
- Amount and storing method of the dangerous materials.
- Damages caused by a possible fire.
This preliminary subdivision is very useful to define all the specific standards to be used for each area and therefore to facilitate the subsequent classification procedure.

The 99/92/CE Directive requires a classification of the zones where an explosive atmosphere may be present. This classification lists three zone types for explosive atmospheres consisting of a mixture of air and flammables in the form of gas, vapours or mist (Zone 0, Zone 1, Zone 2), and three zone types for dusts and powders (Zone 20, Zone 21, Zone 22). In more detail, these zones are defined as follows:

- **Zone 0** and **Zone 20** (continuous hazard), areas where an explosive atmosphere is present permanently, either for long periods or frequently (i.e. 1,000 hours or more per year).
- **Zone 1** and **Zone 21** (intermittent hazard), areas where an explosive atmosphere is likely to be present during normal activities (i.e. 10-1,000 hours/year).
- **Zone 2** and **Zone 22** (hazard under abnormal conditions), areas where an explosive atmosphere is not likely to occur under normal activities, and in case it should occur, it would be only for a short period of time (i.e. less than 10 hours/year).

EN 60079-10, published by CENELEC (the European Committee for Electrotechnical Standardization) is the enforced European standard concerning the zoning classification of the areas where an explosive atmosphere consisting of a mixture of air and flammables in the form of gases, vapours or mist may be present [3]. Instead, the standard EN 50281-3 is the reference for the zoning classification of the areas where an explosive atmosphere in the form of flammable dust and/or powder may be present [7]. Flammable substances consisting of dust and/or powder with air may appear either as clouds or layers.

### 3 Comparisons of the European and American standards

A comparison between the classifications adopted in Europe and North-America points out a number of important differences, which will be conveniently highlighted in the following. The standards enforced in Canada and the U.S.A. concerning potentially explosive atmospheres are the NFPA 70 art. 500 NEC and C 22.1, Part 1, Canadian Electric Code [11], [12]. These standards include a further kind of hazardous substances classified as flammable fibres, which implies therefore not two (gas and powder) but three classes, each subdivided into different groups, four subgroups for gases and three for flammable powders.

The three classes, characterized by the physical state of the dangerous substance, are:

- Class I, for gases, vapours or flammable liquids.
- Class II, for flammable powders.
- Class III, for fibres.
In addition, the hazardous zones are classified into two categories: DIVISION 1, where the hazard may occur during normal activity, and DIVISION 2, where the hazard may occur only during a fault condition. As a consequence, the main difference in comparison with European standards concerns the absence of Zone 0.

Furthermore, differently from the European approach, the time interval during which the explosive atmosphere is present is not considered. As a matter of fact the North American standards emphasise only the presence of the flammable materials, whether appearing during normal activities (DIVISION 1) or in fault conditions (DIVISION 2).

Temperature classes are more finely subdivided if compared to the European classification, which allows the reduction of structure oversizing. Temperature classifications (i.e. admissible surface temperatures) for both the European and North American standards are reported in Tab 1.

Table 1: Temperature classification.

<table>
<thead>
<tr>
<th>Europe</th>
<th>North America</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1 (&lt; 450°C)</td>
<td>T1 (&lt; 450°C)</td>
</tr>
<tr>
<td>T2 (&lt; 300°C)</td>
<td>T2 (&lt; 300°C)</td>
</tr>
<tr>
<td>T2 (&lt; 300°C)</td>
<td>T2A, B, C, D (&lt; 280°C, ≤ 260°C, ≤ 230°C, ≤ 215°C)</td>
</tr>
<tr>
<td>T3 (&lt; 200°C)</td>
<td>T3 (&lt; 200°C)</td>
</tr>
<tr>
<td>T3 (&lt; 200°C)</td>
<td>T3A, B, C (&lt; 180°C, ≤ 165°C, ≤ 160°C)</td>
</tr>
<tr>
<td>T4 (&lt; 135°C)</td>
<td>T4 (&lt; 135°C)</td>
</tr>
<tr>
<td>T4 (&lt; 120°C)</td>
<td>T4A (&lt; 120°C)</td>
</tr>
<tr>
<td>T5 (&lt; 120°C)</td>
<td>T5 (&lt; 120°C)</td>
</tr>
<tr>
<td>T6 (&lt; 85°C)</td>
<td>T6 (&lt; 85°C)</td>
</tr>
</tbody>
</table>

As regards the electrical characteristics of powders, the American standards establish a subdivision into three groups (see Tab. 2).

Class III – Division 1 includes the areas where the manipulation, employment or production of fibres or materials create flammable volatile substances, while Class III – Division 2 comprises the areas where flammable fibres are manipulated or stored. Furthermore, Class III is not divided into groups and also the temperature classes are different, since the maximum temperature is limited to 165°C for apparatuses and devices not subject to overload and to 120°C for devices that can possibly become overloaded (Art. 503 del NEC).

Table 2: Powder groups (American standards).

| Metal conducting powders | Class II Group E |
| Non-metal conducting powders | Class II Group F |
| Non-conducting powders | Class II Group G |
4 Electrical plants in areas with potential explosive atmospheres

With reference to potential explosive atmospheres, the fundamental criteria to be adopted in the design and construction of electrical plants need to be examined. Since the European directives allow the designer a wide range of choices including also new, original solutions, the American standards might supply a valid reference point and truly help in building safe, cheap and standard-complying plants.

After the hazardous zones are classified, the next step is to choose suitable components and an adequate electrical plant design. Because limitations are usually enforced on personnel access into Zone 0 and Zone 1, receiving data from these hazardous areas is of paramount importance for the safe operation and asset management of the plant and instrumentation.

4.1 Presence of flammable gases, vapours and mist

An explosion might occur whenever flammable substances, oxygen and an ignition source of sufficient energy are present at the same time. To avoid an explosion it is therefore possible either to act on the concentration of substances or eliminate the possible ignition causes.

The nature of an ignition source can be electrical (e.g. an electric arc), mechanical (e.g. sparking due to static parts rubbing on rotating or moving parts), chemical (e.g. an exothermic reaction between substances), or free flames.

On the basis of the hazardous level of an area as defined within the zoning classification, the directive 94/9/CE defines both the quality and the protection level required for components and systems. Regarding mixtures of air and flammables in the form of gases, vapours or mist, the enforced European standards allow the following protection modes:

- Ex d: flame proof (EN 50018).
- Ex p: pressure resistant (EN 50016).
- Ex i: intrinsic safety (EN 50020 ed EN 50039).
- Ex o: oil immersion (EN 50015).
- Ex q: quartz/sand filled (EN 50017).
- Ex e: increased safety (EN 50019).
- Ex m: encapsulated (EN 50028).
- Ex n: protection type ‘n’ (EN 50021).

It is useful to deal in more detail with the Ex i “intrinsic safety” mode [5]. This protection mode employs a limitation of the energy below the maximum allowed standards as a prevention criterion. For an explosive atmosphere to be ignited, there must be sufficient energy in relation to the air concentration required by the flammable substances. This energy can be estimated by making reference to the explosion range limited by the so-called LEL and UEL. Inside this range there is a minimum, named Minimum Ignition Energy (MIE). LEL
and UEL represent respectively the lower limit below which an explosion does not occur because of flammable substance deficiency and the upper limit above which the explosion does not occur due to oxygen deficiency [4]. Fig. 3 shows these concepts for two types of particularly hazardous gases, and Tab. 3 offers a comparison between the European and North American standards concerning group classifications for typical gas hazards.

![Graph showing minimum ignition energies for propane and hydrogen.](image)

**Figure 1:** Minimum ignition energies for propane and hydrogen.

**Table 3:** Hazardous locations by gas groups.

<table>
<thead>
<tr>
<th>Type of gas hazard</th>
<th>CENELEC/IEC CENELEC, EN 50014, IEC 79-0</th>
<th>North America CEC, Section 18</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetylene</td>
<td>II C</td>
<td>A or IIC</td>
</tr>
<tr>
<td>Ethylene</td>
<td>II B</td>
<td>C or IIB</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>II C</td>
<td>B or IIC</td>
</tr>
<tr>
<td>Methane</td>
<td>I</td>
<td>Group D (gaseous mine) or I</td>
</tr>
<tr>
<td>Propane</td>
<td>IIA</td>
<td>D or IIA</td>
</tr>
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</tbody>
</table>
If the energy produced by an electric apparatus under normal operating conditions or particular fault conditions is lower than the minimum ignition energy, an explosive atmosphere (depending on the type of gas for which the device is built) will not be ignited.

According to the required behaviour in faulty conditions the intrinsic-safety apparatuses are subdivided into two categories:

- **ia** category, any combination of two faults does not cause the ignition of an explosive atmosphere.
- **ib** category, a single fault does not cause ignition.

The apparatuses of the “ia” category are admitted in Zones 0, 1 and 2 while those of the “ib” category are admitted only in Zones 1 and 2.

EN 50039 is the standard dealing with intrinsic safety (protection mode “Ex i”), which involves rules (and testing procedures) to be applied for plants completely or partially installed in areas where potentially explosive atmospheres are present. This standard is supported by both the EN 50020 standard [5], concerning “Electrical apparatus for potentially explosive atmosphere” Intrinsic Safety Ex i, and the EN 50014 standard, which deals with general rules for electrical apparatus in potentially explosive atmospheres.

The design and assembly of electrical plants with components of the Ex i type require particular attention on the characteristics and geometry of the connecting cables because the energy stored inside a cable is of fundamental importance. The cable parameters (for unit length) are the $R_c$ resistance, $L_c$ inductance and $C_c$ capacitance.

The coordination between cables and electrical apparatuses is satisfied if the following conditions are verified (EN60079-14, Attachment A), [6]:

\[
C_o \geq \sum C_i + C_{cable} \quad L_o \geq \sum L_i + L_{cable}
\]  

where $C_o$ and $L_o$ are the maximum capacitance and inductance of an intrinsic safety circuit, assembled by an Ex i associate apparatus and a cable, which can be accomplished without putting at risk the total circuit intrinsic safety; $C_i$ and $L_i$ are the internal equivalent capacitance and inductance measured at the terminations of the Ex i associate apparatus; $C_{cable}$ and $L_{cable}$ are the complete cable capacitance and inductance. In the most common cases, that is Ex i apparatuses without real inductors inside, relations (1) are verified if the following relation is satisfied:

\[
\frac{L_o}{R_o} \geq \frac{L_c}{R_c}
\]

where the ratio $L_o/R_o$ is shown on the label of each Exi apparatus and the ratio $L_c/R_c$ is measured between the cable conductors that must be supposed at the maximum reciprocal distance. The demonstration of relation (2) is based on the following two statements:
1) The energy stored inside a cable is of two types: electrical \((W_C)\) and magnetic \((W_L)\). The former is stored in the capacitance and depends on the applied voltage, the latter is stored in the inductance and depends on the current. These energies can be respectively calculated by means of the following relations:

\[
W_C = \frac{1}{2} \times C_{cable} \times V^2 \quad [J] \\
W_L = \frac{1}{2} \times L_{cable} \times I^2 \quad [J]
\]  

(3)

2) the magnetic energy stored in a cable is maximum when \(R_{cable}\) (total cable resistance) is equal to the \(R_o\) resistance of the supply equivalent generator that in this case is equal to the internal resistance of the \(Ex\) associate apparatus:

\[
R_o = R_{cable}
\]

4.2 Presence of flammable dusts and powders

A flammable dust/powder can be ignited by an electrical component for a number of reasons, such as electric arcs and sparks or overheating of the apparatus surface. The chemical and physical characteristics of a flammable powder are much more various than in the case of flammable gases; moreover, behaviours are almost unpredictable, since the flammable event depends on a number of variable factors. This is why there is presently no common, final agreement on the measures to be adopted to classify a system as a safe construction. Another difficulty is the great variety of dusts and powders that can be found on industrial plants. In order to achieve a wider, acceptable standardisation, specific laboratory tests ought to be performed in order to either establish the measures to be adopted to reduce the penetration of dusts/powders into the concerned apparatuses or to control the latter’s surface temperature \([8, 9]\).

As regards maximum surface temperature, the upper limits for clouds and layers are different. When the presence of layers is excluded and only dust/powder clouds are considered, the maximum admissible temperature \((T_{max})\) for each part of an apparatus must not exceed \(2/3\) of the flammable temperature of the cloud \(T_{Cl}\):

\[
T_{max} \leq \frac{2}{3} T_{Cl}
\]

where temperatures are expressed in °C.

Actually, also in these cases it can be very useful to refer to the North American standards, which are based on more detailed temperature ranges.

5 Conclusions

In connection with potentially explosive atmospheres the enforced European ATEX Directives concern both apparatus manufacture (94/9/CE) and the safety
and health protection of workers potentially at risk (99/92/CE). The ATEX Directives introduced a number of changes into the traditional classification of hazardous areas. For example, an additional classification was added for dust risk and new concepts on equipment categories were introduced with products specifically designed to comply with risk types. Another novelty concerned non-electric apparatuses and devices for which it is necessary to pay attention to the hot exposed surfaces and to the friction between metallic parts that might generate sparking. As concerns classification, the new approach is closer to the real problems and usually establishes hazardous zones of reduced extension. In addition, the present directives and consequently the national standards often offer innovative solutions but at the same time higher responsibilities to the plant designer. Under this point of view, the North American standards can be effective in reaching high safety levels at reasonable costs and at the same time complying with the enforced prescriptions. As an example, for an apparatus whose safety can be demonstrated with non-pre-established approaches, the NEC standard, Section 90-4, can be a very useful reference but in the presence of ignitable fibres and flyings not included in the European standards the NEC-NFPA 70 could be conveniently consulted.

References


[7] EN 50281-3 - Electrical Apparatus for use in the presence of combustible dusts. Part 10: Classification of areas where combustible dusts are or may be present.


