Lightning and surge protection for intrinsically safe circuits

by Manfred Kienlein

Special explosion protection measures must be taken in all industrial sectors where gas, vapour, fog or dust occurs during the processing or transport of flammable substances which, in combination with a mixture of air, may present a hazardous explosive atmosphere. In 2003, ATEX 137 (Directive 1999/92/EC) [1] was converted into several national laws (e.g. the Betriebssicherheitsverordnung - German Operational Safety Regulations; VEXAT – Austrian Operational Safety Regulations). In accordance with these regulations, the user is obliged to prepare an explosion protection document. This document is based on a risk assessment that assesses the potential hazards posed by the presence and expansion of potentially explosive atmospheres according to Ex-zones. Then possible ignition sources resulting from operating requirements are identified and corresponding equipment is selected. This paper deals with lightning-related ignition sources in compliance with EN 1127-1 [2].

Lightning currents and overvoltage in potentially explosive atmospheres

When assessing the risk for potentially explosive atmospheres, the following lightning-related ignition sources in accordance with EN 1127-1 must be observed:

> Melting at the point of strike,
> Heating of discharge paths,
> Uncontrolled flashover in case the separation distance is not maintained,
> Induced voltages in cables,
> Lightning strikes into metallic cables entering hazardous areas

In case of lightning-related risks (risk analysis in accordance with IEC 62305-2 [3]) all equipment, protective systems and components of all categories must be protected by adequate lightning and surge protection measures. It is vital that these are not damaged inside of zone 0 or 20 by lightning strikes outside of these zones.

Installation requirements with regard to atmospheric discharges (lightning strikes)

The applicable IEC 60079-14 [7] standard refers to the lightning protection measures specified in the standard series IEC 62305 Part 1 – 4 [3, 4, 5, 6].

The overall lightning protection concept includes:

> A risk analysis to determine the necessity of lightning protection and to select the required (technical and economic) lightning protection measures
> Measures to protect structures from material damage and to persons caused by direct lightning strikes by installing a lightning protection system (LPS) consisting of air-termination systems, down conductors, earth-termination system, lightning equipotential bonding and separation distance.
> Protection measures against the effects of lightning electromagnetic impulses (LEMP) by installing a LEMP protection system (LPMS) for structures with electrical and electronic systems. An individual combination of protection measures are
earthing and equipotential bonding, spatial shielding, cable routing and screening, coordinated protection by surge protecting devices (SPD).

The IEC 60079-14 [7] standard basically requires that the effects of lightning strikes are reduced to a safe level. In view of the fact that the ATEX Directive 137 calls for systems to be installed, mounted and operated according to the state of the art, the new lightning protection standards must be applied for explosion protection.

Not only the effects of a direct lightning strike, but also the electromagnetic effect of the lightning current on the installation of the electrical system present a risk in potentially explosive atmospheres. The steepness of the lightning current causes a high change velocity of the magnetic field, which in turn induces a high voltage (ignitable energy) in various cables (extraneous conductive parts) that form a loop. If an explosive atmosphere is present at the same time (for example on the terminals in the enclosure of an intrinsically safe equipment) this ignition energy may at any time cause fire or explosion. For this reason, it is vital to implement a consistent and harmonized protection concept. This protection concept, which is also referred to as lightning protection zones concept, is described in the standard IEC 62305-4 and forms the basis for the implementation of a LEMP lightning protection system. Intrinsically safe circuits are particularly at risk due to the induction effect of the lightning current. Subclause 12.3 of the IEC 60079-14 standard includes requirements for protecting intrinsically safe circuits against lightning, however, IEC 62305-4 is state of the art for coping with overvoltages in a system subject to explosion hazards.

To ensure safe operation of systems in hazardous areas it is decisive to harmonise the requirements of EN 1127, IEC 60079-14 and IEC 62305-4. This will be shown by the following example. It is assumed that a lightning protection system (LPS) with class of LPS II based on the relevant lightning protection level LPL II that was determined in a risk assessment has been installed to protect the intrinsically safe system and the hazardous area (zone 0, 1) from direct lightning strikes. The intrinsically safe measuring circuit is installed in LPZ 0B (LPZ: lightning protection zone; see Table 1).

The example shows a possible method to protect intrinsically safe measuring circuits from the direct and indirect effects of a lightning strike.

Figure 1 shows a typical installation of an intrinsically safe measuring circuit consisting of a combination of an isolating barrier, an intrinsically safe measuring circuit and a temperature transmitter (galvanically isolated from the sensor).

The isolating barrier is located in the measuring and control cabinet in the control room building (safe area). The temperature transmitter with the sensor is directly mounted to the tank containing flammable liquid. The sensor is located in Ex-zone 0, the transmitter itself is mounted in Ex-zone 1 and its metal enclosure is directly and safely connected to the metal tank on a permanent

<table>
<thead>
<tr>
<th>LPZ OA</th>
<th>Zone where the threat is due to the direct lightning flash and the full lightning electromagnetic field. The internal systems may be subjected to full or partial lighting surge current.</th>
</tr>
</thead>
<tbody>
<tr>
<td>LPZ OB</td>
<td>Zone protected against direct lightning flashes but where the threat is the full lightning electromagnetic field. The internal systems may be subjected to partial lightning surge currents.</td>
</tr>
<tr>
<td>LPZ 1</td>
<td>Zone where the surge current is limited by current sharing and by SPDs at the boundary. Spatial shielding my attenuate the lightning electromagnetic field.</td>
</tr>
<tr>
<td>LPZ 2, ..., n</td>
<td>Zone where the surge current may be further limited by current sharing and by additional SPDs at the boundary. Additional spatial shielding may be used to further attenuate the lightning electromagnetic field.</td>
</tr>
</tbody>
</table>

Table 1: Definition of lightning protection zones (LPZ) in accordance with IEC 62305-1 [3]
basis. The screened intrinsically safe cable (approximately 200 m long) connects these two pieces of equipment. The control room and the tank are incorporated in an intermeshed earth-termination system (mesh size of approximately 20 x 20 m).

The following lightning hazards may destroy or interfere with the measuring circuit (Figure 1) and present a risk of explosion for the system:

> Direct lightning strike into the air-termination system of the measuring and control circuit
> Lightning strike near the measuring and control circuit
> Direct lightning strike into the air-termination system of the measuring and control building
> Lightning strike near the measuring and control building
> Direct lightning strike into the tank
> Lightning strike near the tank

To provide protection against all lightning-related probabilities of damage to electrical equipment (in the control room and in the hazardous area), two surge protective devices (SPD’s) must be integrated in the intrinsically safe circuit, that is one SPD to protect the isolating barrier in the control room and one to protect the transmitter on the tank. The SPD on the tank equally prevents dangerous spark-over from the tank to the sensor line and additionally provide protection against explosion.

Selection criteria for surge protective devices installed in an intrinsically safe measuring circuit

Certain selection criteria must be fulfilled to ensure the protective effect of the selected SPD. Particularly intrinsically safe measuring circuits have their special features. These must be observed when selecting the protective devices since they may negatively affect the intrinsically safe explosion protection system.

Isolation from earth and dielectric strength of the intrinsically safe equipment

In accordance with the IEC 60079-25 [8] standard intrinsically safe circuits may be isolated from earth or connected to the equipotential bonding system at one point only. An intrinsically safe circuit is isolated from earth, if it withstands a dielectric test in accordance with IEC 60079-11 [10] with at least 500 V against earth. If this is not the case, it is to be assumed that the circuit is connected to earth.

Since multiple earthing of the measuring circuit is not allowed in all cases, a documented test on the effects of multiple earthing must be carried out for the measuring circuit with SPD’s or SPD’s (intrinsically safe equipment) that are approved for this special purpose and fulfil the requirements of isolation from earth are to be used. These SPD’s do not have to be disconnected from the intrinsically safe circuit during the dielectric test. The manufacturer of the intrinsically safe SPD’s must prove that they are isolated from earth. These SPD’s are only capable of reliably protecting intrinsically safe equipment with a dielectric strength > 500 V against earth. If

Figure 1: Application example of an intrinsically safe circuit
isolating barriers with a dielectric strength \(< 500 \text{ V}\) (for example Zener barriers) are used, other SPDs must be selected and adapted to the special requirements of the barrier.

**Equipment category and type of protection**

The entire intrinsically safe circuit has a type of protection ia. In our example both SPDs must have this type of protection (see EC-type examination certificate).

Since a sensor circuit entering zone 0 is connected to a SPD on the tank (Figure 1), the SPD must be additionally approved for this type of application. According to the EC-type examination certificate the SPD of type DPI MD EX 24 M 2 must have at least the following approval: II 2 (1) G Ex ia IIC T4 ...T6 (Table 2).

**Maximum permissible values for \(L_0\) and \(C_0\)**

Before an intrinsically safe measuring circuit is put into operation, its intrinsic safety shall be verified. The isolating barrier, transducer, cables and SPDs must fulfil the interconnection requirements. If required, the inductances and capacitances of the SPDs must also be considered.

According to the EC-type examination certificate, the internal capacitances and inductances of the BXT ML4 BD EX 24 (Figure 2) and DPI MD EX 24 M 2 surge protective devices from DEHN + SÖHNE (Figure 3) are negligible and do not have to be considered for the connection requirements.

**Maximum values for voltage \(U_i\) and Strom \(I_i\)**

According to its technical data for use in explosive atmospheres, the intrinsically safe circuit to be protected has a maximum supply voltage \(U_i\) max (29.4 V d.c.) and a maximum short-circuit current \(I_i\) max (130 mA). The rated voltage \(U_r\) of the SPD must be higher.

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**Table 2: Symbols used for intrinsically safe SPD Type DPI MD EX 24 M 2**

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
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<tbody>
<tr>
<td>I I</td>
<td>Apparatus group: for use in any area other than mining</td>
</tr>
<tr>
<td>2 (1)</td>
<td>Equipment category: Installation in Ex zone 1, the device to be protected may be installed in Ex zone 0</td>
</tr>
<tr>
<td>G</td>
<td>For use in explosive gas atmospheres</td>
</tr>
<tr>
<td>Ex</td>
<td>Electrical equipment built in compliance with the European standard</td>
</tr>
<tr>
<td>ia</td>
<td>Type of protection intrinsic safety: No ignition even if two faults are present</td>
</tr>
<tr>
<td>IIC</td>
<td>Subgroup: Also for use with extremely flammable gases such as hydrogen and acetylene</td>
</tr>
<tr>
<td>T4...T6</td>
<td>T4: Ambient temperature range -40 °C to +80 °C</td>
</tr>
<tr>
<td></td>
<td>T5: Ambient temperature range -40 °C to + 70°C</td>
</tr>
<tr>
<td></td>
<td>T6: Ambient temperature range -40 °C to +55 °C</td>
</tr>
</tbody>
</table>

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**Figure 2:** SPD with permanent monitoring (DRC MCM) in an intrinsically safe measuring circuit
than the maximum open-circuit voltage of the power supply system. The nominal current of the SPD must be at least as high as the maximum current $I_{\text{max}}$ to be expected in the event of a fault. The certificate becomes invalid, if these interconnection conditions are not observed when dimensioning the SPD.

**Coordination SPD with SPD and SPD with terminal equipment**

Another important criterion is the coordination of the relevant SPDs among one another and of the SPD with terminal equipment.

If the coordination requirements in accordance with IEC 62305-4 and IEC 61643-21 [9] are not fulfilled, the devices may be damaged even if SPD’s are installed, putting the installation into a critical state. The safest solution is to use devices from a single manufacturer. For this application, not only the coordination requirement for the induced overvoltages (8/20 µs impulse), but also a coordination test for the lightning impulse (10/350 µs impulse) are particularly important. The SPD installed on the tank is located in LPZ 0B and must therefore be capable of carrying partial lightning currents (Table 1). If the manufacturer is not able to provide a coordination test for both SPD’s installed, all cables and pieces of equipment must be routed and installed in LPZ 1 in accordance with the lightning protection zones concept. This may result in considerable additional installation work.

The following additional requirements in accordance with IEC 60079-14 must be fulfilled and proven in particular if a SPD is installed on the tank (lines from zone 0):

- Use of SPD’s with a minimum discharge capacity of 10 impulses with 10 kA each without failure or interfering with the protective effect.
- Installation of the SPD’s in a shielded metallic enclosure and earthing via a copper conductor of at least 4 mm².
- Installation of the cables between the SPD and the equipment in a metal tube earthed on both ends, or use of screened cables lines with a maximum length of 1 m.

In the application example described above (Figure 3) all these requirements are already fulfilled by using a surge arrester for field devices of type DPI MD EX 24 M 2. This eliminates significant follow-up costs for the installation.
Summary

The relevant standards describe the danger to chemical and petrochemical systems posed by a lightning discharge and the resulting electromagnetic interference. During the implementation of the lightning protection zones concept the risks of sparking caused by a direct lightning strike or discharge of conducted interference energies can be reduced to an acceptable level even at the planning and design stage of these systems. The SPD’s must both fulfil explosion protection requirements, coordination criteria and the requirements resulting from the operating parameters of the measuring and control circuits.

References

   – Explosion prevention and protection - Part 1: Basic concepts and methodology
[3] IEC 62305-1; 2006; Protection against lightning – Part 1: General principles
[4] IEC 62305-2; 2006; Protection against lightning – Part 2: Risk management
[5] IEC 62305-3; 2006; Protection against lightning –
   Part 3: Physical damage to structures and life hazard
[6] IEC 62305-4; 2006; Protection against lightning
   – Part 4: Electrical and electronic systems within structures
[7] IEC 60079 – 14; Explosive atmospheres – Part 14: Electrical installations design, selection and erection
[9] IEC 61643-21; 2000; Surge protective devices connected to telecommunications and signalling networks – Performance requirements and testing methods