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Galvanic separation – selected aspects of ATEX

The paper systematizes basic information on galvanic separation, describes reasons for its application and presents methods how to conduct it. The authors mentioned selected issues related to galvanic saparation in intrinsically safe automatic devices and systems. They also described the requirements of the PN-EN 60079-11 regarding measures that ensure intrinsic safety of particular galvanic-separation solutions as well as their impact on proper functioning of separation systems. The paper features the possibilities to limit parameter values of separation systems. These possibilities result from the application of intrinsic-safety measures [2].

keywords: intrinsic safety, automation, galvanic separation

1. INTRODUCTION

Galvanic separation is a kind of isolation which disables direct flow of electric current between at least two blocks of a system. Depending on its aplication, galvanic separation may apply to:

- energy transfer (separation of power supply),
- information transfer (separation of analogue or digital communication).

Information transfer is conducted by means of energy transfer too, however in this case the applied energy volume should be minimal to achieve this purpose.

In order to enable the transfer of energy or information without direct flow of electric current between the blocks of a system, one can use different kinds of couplings which operate on the basis of different physical phenomena.

In particular, the following kinds of couplings can be used:

- capacity coupling (voltage – electric field),
- inductive coupling (current – magnetic field),
- electromagnetic coupling (electromagnetic field),
- optical coupling (photoelectric effects, electroluminescent effects),
- electromechanical coupling.

Significant differences that can be found in relation to the use of physical phenomena have a direct impact on distinct properties of different separation methods which apply these phenomena and, at the same time, on the parameters that can be achieved in the course of these processes. For this reason, particular coupling methods are applied everywhere where it is possible to make use of their advantages and to accept their disadvantages. For information transfer, all above mentioned kinds of couplings are used, while for energy transfer – mostly inductive coupling, because it allows to achieve high energy efficiency.

2. REASONS TO USE SEPARATION

There are several reasons to use galvanic separation and they are not mutually exclusive.

1. **User's safety**. In this case separation aims at providing protection against electric shocks. For example, such a requirement is laid down with respect to biomedical apparatus where the use of 4 kV separation is stipulated by the IEC 60601-1 standard. Figure 1 features a sample medical system with computer devices and with a possibility to have separation in the system.

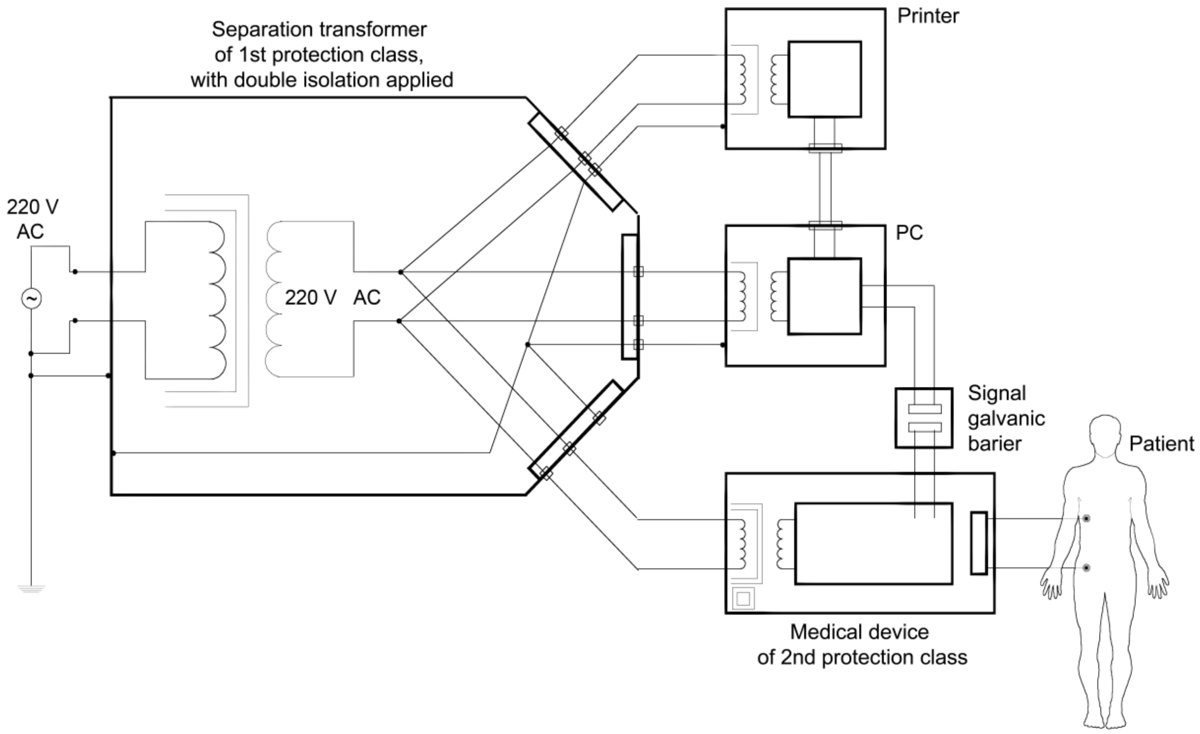

Fig. 1. Sample medical system with computer devices and with a possibility to have separation in the system [1]

2. **Protection against damage** – separation is used to prevent potential damages of devices, especially in distributed systems and high-power facilities.
3. **Electromagnetic compatibility** – limited propagation of electromagnetic disturbances; it is used both in connections between devices that make up a system and in single devices [3]. In environments with strong electromagnetic disturbances it is customary to use optical-fibre communication which is resistant to these disturbances. Optical fibres are used both at long distances and for local separation.
4. **Anti-explosion protection** – output energy of intrinsically safe power supply sources must be limited in order to provide anti-explosion protection. The admissible capacity and load inductance of an intrinsically safe source drop proportionally to the increase of its maximal voltage and output current. In complex and extended automation systems this feature implies the necessity to divide these systems into separate intrinsically safe circuits supplied from separate energy sources. This, in turn, makes it necessary to use separation in order to enable communication between these circuits as well as, after fulfilling certain requirements, between intrinsically safe and non-intrinsically safe circuits. The requirements on intrinsic safety are included in PN-EN 60079-11:2012 [4]. In addition, when there is optical-fibre transmission in an explosive zone, it is required to comply with the stipulations of PN-EN 60079-28:2010 [5].
5. **Measurement and testing systems** – In the devices which measure and test electrical properties, power supply separation is used (in the case of mains power supply connection) or the separation of measurement input(s) and output(s) which, apart from the benefits listed further in this section, significantly increases the configuration possibilities of a measuring/testing system. The separation allows to connect inputs and outputs of testing and measuring devices to any potentials. It also allows them to take different reference potentials. This way the measurements and tests are easier to carry out or are possible to carry out in situations in which they previously failed. A good example are oscilloscopes which have separate galvanic separation for each input.
6. **Possibility to connect buses** – In order to minimize the disturbance of a signal travelling along a transmission line, it is necessary to ensure the same impedance along the whole length of the line and to match the impedance at the ends of the line. In order to achieve this, one has to connect all devices into a common bus at the shortest po-

ssible branches. Due to specific arrangement of bus-connected elements in the object, the size of the object and the possibility to provide the connections, this procedure may cause some inconveniences. The use of separation allows to send a signal between two electrically separated buses in any place of these buses. However, the number of such branches that can be used in one system is limited and depends mainly on time dependencies, more specifically on permitted delays. This depends on the transmission standard, used protocols and the speed of data transmission. Figure 2 presents a topology of a typical bus and a topology of a bus with branches achieved due to separation.

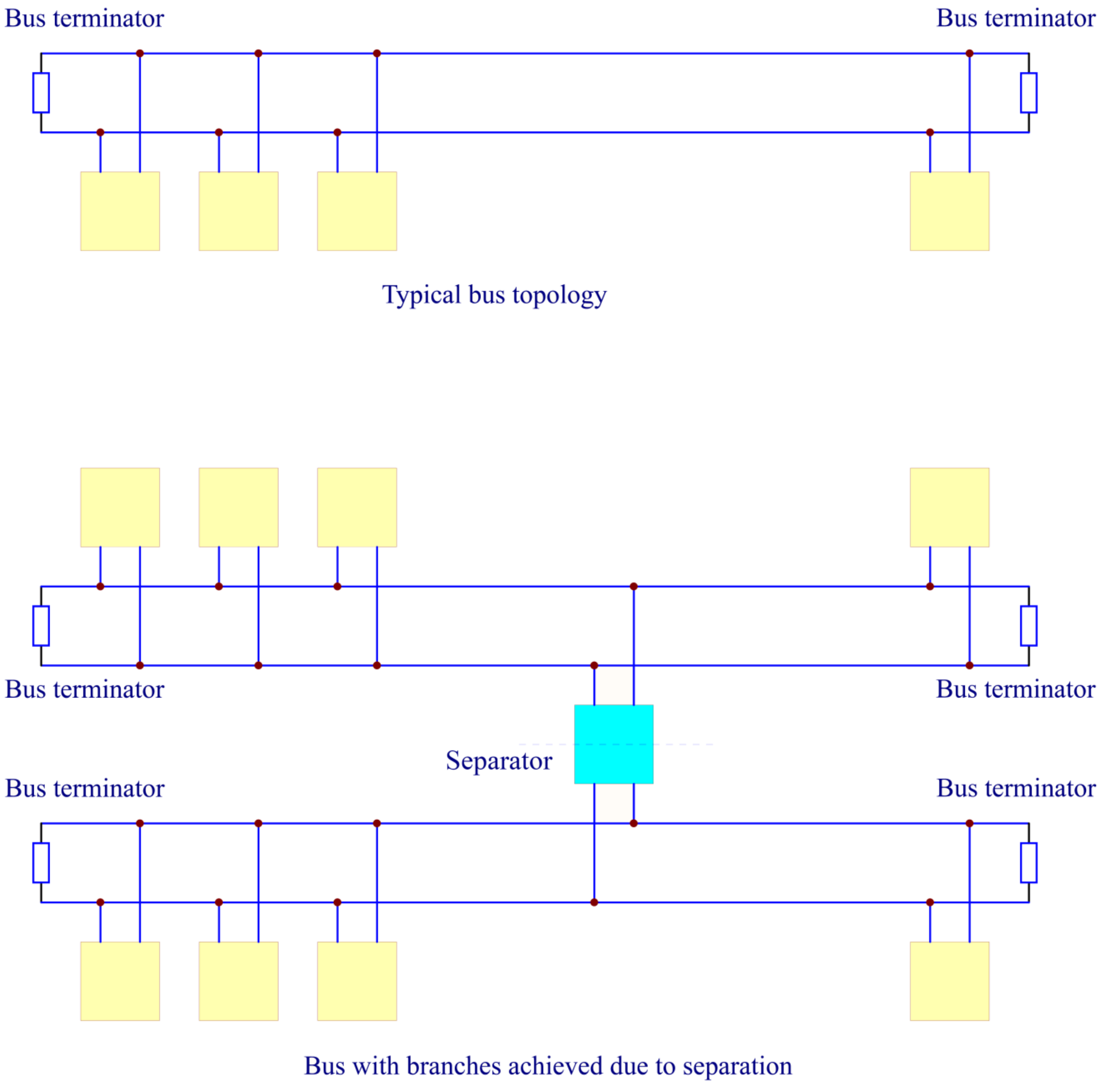

Fig. 2. Topologies of a bus without separation and a bus with branches achieved due to separation

7. **Power supply and/or communication between blocks located on objects which move with respect to one another**. This solution is used particularly when it is not possible to apply movable, flexible cable connections, for example in communication between blocks which rotate with respect to one another. Depending on the applied solution, energy and/or information transfer can take place in each or only in certain positions of mutually movable objects. To achieve this, different types of couplings are used.

3. GALVANIC SEPARATION IN INTRINSICALLY SAFE DEVICES AND SYSTEMS

Separation which is used to ensure anti-explosion safety in intrinsically safe devices has to comply with certain requirements. These requirements refer only to this separation which is responsible for intrinsic safety, while separation used for other purposes, e.g. to ensure electromagnetic compatibility, does not have to comply with them. Separation used for intrinsic safety can have beneficial influence on properties which are related to electromagnetic compatibility because here it eliminates the necessity to use extra separation.

Requirements specified for separation which decides about intrinsic safety are strictly determined in PN-EN 60079-11:2012 [4]. The standard says that undamageable separating elements are treated as such due to their undamageable separation. Different elements are subject to different requirements with respect to either separation which separates different intrinsically safe circuits or separation which separates an intrinsically safe circuit from a non-intrinsically safe one. These requirements are laid down in clause 8.9 of the standard, particularly:

– for elements which separate an intrinsically safe circuit from a non-intrinsically safe one – clause 8.9.2,
– for elements which separate different intrinsically safe circuits – clause 8.9.3.

3.1. Elements which separate an intrinsically safe circuit from a non-intrinsically safe one

In order to perform separation in accordance with PN-EN 60079-11:2012, it is necessary to fulfill certain conditions in which the parameters of separating elements will not be exceeded. This requires to apply elements which limit voltage, current and power. For this purpose Zener diodes are often used in signal lines of series and parallel resistors. These diodes sometimes introduce significant parasitic capacitance which may cause big deformations of transmitted signals and this way may limit the transmission speed.

The capacitance of Zener diodes in the given series of types depends on nominal voltage of the diode as well as reverse voltage by means of which the diode is polarized. This capacitance decreases proportionally to the increase of these voltages. The characteristics courses as well as capacitance and voltage values differ depending on the diode type. The manufacturers of Zener diodes rarely place their full capacitance characteristics in catalogue cards. They only tend to give the capacitance values of each diode in the series under certain conditions and, in many cases, do not even determine this parameter. This happends due to the fact that capacitance is not a significant parameter of Zener diodes and is not useful in the majority of their applications. Another disadvantage is the fact that Zener diodes with low nominal voltage are usually used as voltage limiters. Such diodes have big capacitance and two parallel diodes have to be used on the intrinsically safe side.

Depending on the above factors, the capacitance of a single Zener diode changes in a wide range. For example, for BZM55 diodes with nominal voltages of 5 V, the capacitance is 175 pF and drops quickly along with the voltage – down to about 20 pF for a diode with nominal voltage of 20 V (at polarization voltage of 2 V) [3]. For 1SMB59 diodes, the capacitance at polarization voltage of Vz/2 changes in the range from 700 pF for Vz of about 4 V to 40 pF at Vz of about 90 V**.** In the case of a frequently used 1N5338B diode (nominal voltage 5.1 V), the capacitance changes in the range from 4000 pF at polarization voltage of 0.1 V to 2000 pF at polarization voltage of 3 V. Such huge capacitance values, along with series resistance values of several hundred Ω to several kΩ and higher, create RC low-pass filters and make it difficult, or even impossible, to separate quick interfaces.

A way to avoid the application of parallel Zener diodes in communication lines is to design a topology of the devices and system in such a way that voltage limiters in the form of proper-voltage Zener diodes could be found only in the lines supplying power to all circuits to which separating elements are connected. Such a topology has certain limitations, though. Another solution is to force intrinsically safe input parameters of the device so that these parameters had low values which would ensure the undemageable quality of the separating element. This solution, however, may seriously limit the range of the device application. In addition to that, the input parameters may be forced due to the necessity to co-operate with another device. The above solutions may not be used in certain cases. It is much easier to design the given device concurrently with other devices with which it will co-operate, even if its application possibilities would be limited as a result of that.

3.2. Transmitters

Though the range of transmitters application has been limited in favour of semi-conductor elements, they remain indispensable in some cases and are used due to the possibility of ensuring separation. It is worth to have a look at bi-stable transmitters in which an important disadvantage was eliminated, i.e. high demand for energy (continuous power input) supplied to the coil. In bi-stable transmitters, the energy is supplied only during the switching operation, while in the static state the coil does not consume any energy and with the loss of supply the state of the transmitter remains the same. Bi-stable transmitters may have separate coils for on/off switching or single coils which need reverse-polarization impulses for this operation. In both cases the coils of bi-stable transmitters require more complex control systems which is clearly visible with the increasing number of transmitters.

Sometimes it is quite difficult to show the compliance with the standard solely on the basis of catalogue cards due to insufficient data about the transmitters mechanical structure and complex internal spacing. The catalogue cards usually determine only the parameters of contacts (admissible voltage and current) and the parameters of the coil. The transmitters manufactured by a Polish company Relpol are often used in intrinsically safe devices due to their detailed documentation and suitable insulation spacing.

3.3. Transformers

The requirements of the standard concerning mains transformers have influence on the exploitation parameters of these devices. The arrangement of windings on the magnetic core has impact on the electrical parameters of the transformers, such as mutual inductance values of the windings, since they depend on mutual inductive coupling between the primary and the secondary winding (i). From the point of view of utility, this coupling should be as big as possible (while the distribution inductance and the magnetic flux distribution should be as small as possible). In the case of transformers which ensure separation in compliance with PN-EN 60079-11, the structure possibilities are partly restrained. The standard allows alternative solutions. However, the coupling between the windings decreases in three cases: when the windings are placed on one column of the core and next to one another with proper insulation spaces, when they are placed on separate columns (structure type 1), or when the windings are wound on one another and separated by proper isolation or a screen of proper thickness (structure type 2). In all above mentioned cases it is necessary to provide sufficiently large distances between the windings as well as a sufficient distance between the windings and the core, due to the requirement of proper isolation or a screen.

In addition, the use of alternate sections of primary and secondary sandwich windings on one column is difficult as it is necessary to provide isolation between all neighbouring sections, in compliance with the requirements. As a result of that, the share of the isolation material in the carcass volume and length is big. What is more, such restrictions can make it more difficult to ensure the required symmetry of the windings.

Leakage fluxes of particular windings induce electromotive forces in these windings. The forces can be projected as voltage drops on leakage reactances. The distribution inductance should be as small as possible because the increase of the transformer loads results in the voltage drop on the secondary winding. Nominal output voltage is achieved at the given load for which the transformer was designed. When the loads are smaller and in the idle state, the output voltage is higher which results in lower efficiency of the power supply system in the case when a linear regulator is used behind the transformer and the rectifier. High values of distribution inductance bring some benefits too. Firstly, they limit short-circuit currents. Secondly, they enable to develop transformers which are unconditionally resistant to short circuits. Another advantage of the type-2 structure, i.e. the version with a grounded screen between the windings, is a significant decrease in capacity coupling between the windings. This results in better damping of electromagnetic interference which could be propagated this way. Figure 3 presents the variants of an undamageable transformer which ensures separation between the primary and the secondary side.

3.4. Transformers other than mains transformers

The standard requirements for transformers other than mains transformers have similar impact on their parameters as in the case of mains transformers. This refers mosty to the transformers which should have possible high efficiency to work in power support units, e.g. in separation converters. This efficiency is not that important in the case of transmission separation transformers. The necessity to provide isolation spaces limits the possibilities to have many windings wound close to one another which would ensure good coupling between the windings and more accurate symmetry.

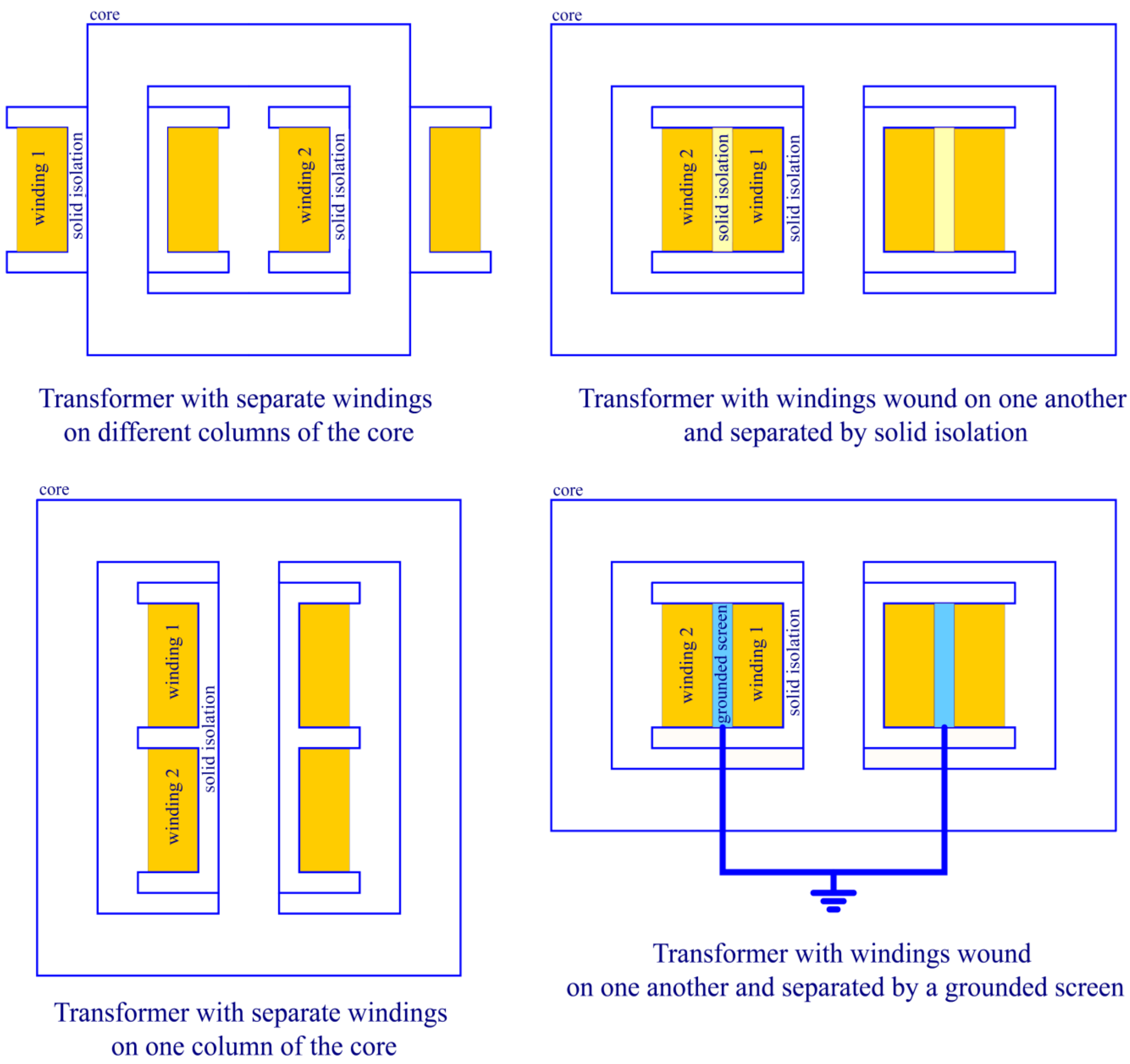

Fig. 3. Variants of an undamageable transformer

3.5. Blocking capacitors

According to clause 8.6.1 of the standard, an undamageable set of blocking capacitors should consist of two series-connected capacitors. These should be highly reliable capacitors with solid dielectrics. It is forbidden to use electrolytic capacitors or tantalum capacitors.

The isolation of the capacitor must comply with the requirements for electric strength. If the requirements are fulfilled for galvanically separating elements in clause 8.9, the system is recognized as the one that ensures undamageable galvanic separation for direct current.

3.6. Filter capacitors

Filter capacitors, connected between the housing of the device and the intrinsically safe circuit, have to comply with the clause 6.3.13 of the standard and must fulfill the same requirements as those stipulated for blocking capacitors in the clause 8.6.1, if their damages do not interfere with the elements on which intrinsic safety depends. In practice, these requirements are fulfilled by using two series-connected ceramic high-voltage capacitors. Their application ensure electromagnetic compatibility of the circuit.

4. CONCLUSIONS

There are different reasons why separation of circuits is used and there are different methods to do it. In intrinsically safe applications it is necessary to comply with the standard which often restricts the use of available solutions or limits the range of functional parameters which can be achieved for typical, non-intrinsically safe applications.

The requirements refer only to these types of separation that ensure intrinsic safety. It is particularly difficult to separate quick digital communication interfaces due to their narrow tolerance range of electric signal parameters. And one has to fit within this range in order to comply with the standard.

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The article was reviewed by two independent reviewers.