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Overview of Problems and Solutions in the Design of Intrinsically Safe Apparatuses

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***Abstract*—The article presents selected basic problems occurring in the design of intrinsically safe apparatuses, solutions to some of them, and points out mistakes made during their design. The article addresses selected issues related to the design of intrinsically safe apparatuses and systems and includes a systematisation of the news and conclusions. The article also presents several project solutions for hazardous areas.**

***Index Terms*—Active matrix liquid crystal displays; ATEX; Isolation; Isolators; EMC; Explosion protection; Hazardous area; Intrinsically safe apparatus; Intrinsic safety; Transmission lines; Wireless communication.**

I. INTRODUCTION

Intrinsically safe apparatus is apparatus with properly protected electrical circuits that are incapable of causing an explosion in the surrounding explosive atmosphere. Intrinsically safe apparatus is electrical equipment in which all circuits are intrinsically safe circuits. The intrinsically safe circuit is a circuit in which any spark or any thermal effect produced under the specified conditions, including normal operation and specified fault conditions, is enable to cause ignition of a given explosive atmosphere.

Intrinsically safe apparatus is generally subject to the *Atmosphères Explosibles* (ATEX) Directive 2014/34/EU [1] and the Electromagnetic Compatibility (EMC) Directive 2014/30/EU [2] or the Radio Equipment Directive (RED) 2014/53/EU [3] in the case of radio equipment. At the same time, associated equipment installed outside the hazardous area and having intrinsically safe circuits connected to the circuits of intrinsically safe equipment located in the hazardous area are also subject to Low Voltage Directive 14/35/UE (LVD) [4]. The formal and technical requirements for the construction of intrinsically safe equipment are specified in the EN IEC 60079-0 standard [5] and the EN 60079-11 standard [6] in detail.

Explosion-proof protection supported by the intrinsically safe design of electronic devices should be ensured by limiting the ignition capability initiated by sparks and heating, which is realised through the following measures:

– Power supply from an intrinsically safe power source;

– The absence of inductances and capacitances in the system that exceed those normative for the power source (no possibility of higher than normative ignition energies);

– Limiting the surface temperatures of the components to acceptable values that do not pose an ignition risk.

The article also presents several solutions for hazardous areas developed by the Łukasiewicz Research Network - Institute of Innovative Technologies EMAG.

For use in coal mines/salt mines, a mobile intrinsically safe seismic apparatus, PASAT M was designed. The apparatus is intended for underground measurement works for continuous operation in methane and/or coal dust explosive atmospheres.

The EkoDemeter project aimed to develop a system for measuring temperature in grain silos. The EkoDemeter system is a modular system whose structure can be adapted to the size of the installation to be monitored. The system is designed to be used in spaces at risk of explosions of combustible dust of grain origin.

Improving the performance of coal-fired power plants based on artificial intelligence in the KOTŁY project required data acquisition from sensors placed in flammable coal dust.

Hydrogen-related installations, such as hydrogen storage tanks or hydrogen-producing electrolysis systems, are an example of an explosion-hazard area - more so, as hydrogen characteristics place it among the most volatile gases, explosion-wise. The considerations presented are part of the design analysis prepared and used in the realisation of safe vehicle-purposed gaseous-hydrogen storage (MaWo) and closed water circulation system for hydrogen-based energy installations (WoDoWo) projects, developed within Łukasiewicz Research Network institutes.

II. DIVISION INTO INTRINSICALLY SAFE SUBCIRCUITS

Limiting the energy, power, and temperature released in the circuits is required by the standards and functionality of the device itself [7]. A natural way to limit power is to divide apparatuses or systems into smaller subcircuits.

The flow of power between individual subcircuits is limited, or, if full separation is used, completely eliminated. This solution makes it possible to ensure that the assumed limits of power that could be dissipated in individual subcircuits are not exceeded. Examples of the limitation of

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power transfer in the apparatus and in the system between intrinsically safe apparatuses are shown in Figs. 1 and 2.

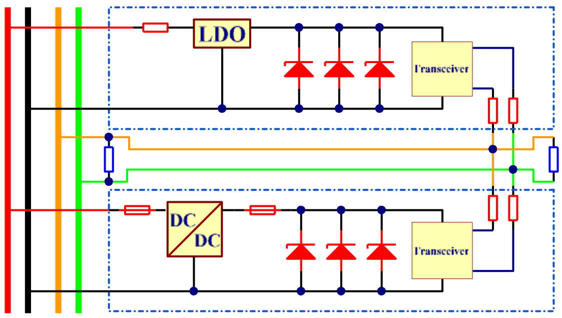

Fig. 1. Example of the limitation of power transfer in the system between intrinsically safe apparatuses.

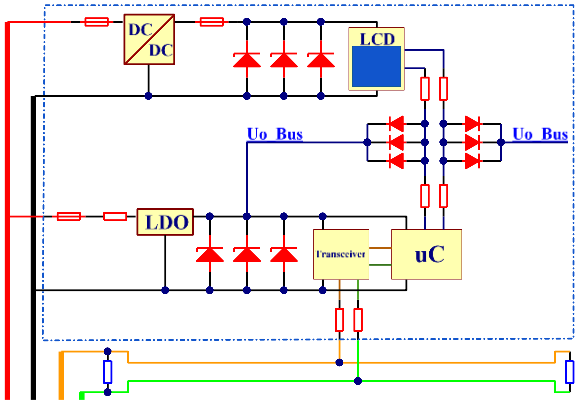

Fig. 2. Example of the limitation of power transfer in the intrinsically safe apparatus.

Despite the fulfilment of the basic conditions of EN IEC 60079-0 [5], EN 60079-11 [6], and, in addition, the system standard EN IEC 60079-25 [8], it can be shown that the compilation of an intrinsically safe system from intrinsically safe apparatuses having compatible intrinsically safe parameters is not the rule despite the fulfilment of the required ATEX standards.

Figure 3 shows the transfer of voltage from the intrinsically safe power supply to the transmission circuit. For correctly selected parameters of the apparatuses for the system, the parameter Uo of the power supply unit must not be greater than Ui_sup_app parameter of the apparatuses powered. For the shown noncountable faults (X) in the apparatuses, then with the declared apparatuses parameters, Ui_bus_app < Ui_sup_app power supply ceases to be true for the apparatuses and the system.

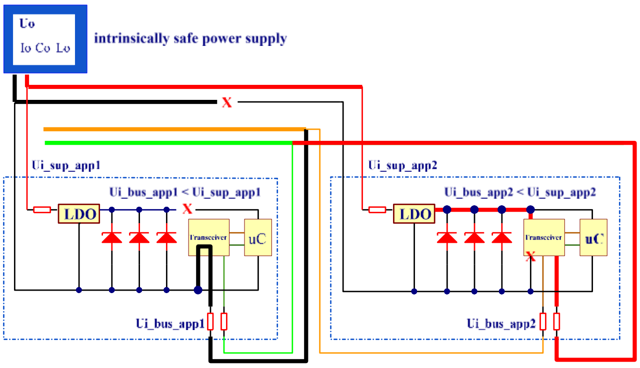

Fig. 3. Example of inconsistency of declared input, output parameters for noncountable faults inside device structures.

III. RECOMMENDATION TO USE GALVANIC ISOLATION

The solution to the problems mentioned in the previous section is most often the use of galvanic isolation [9]. Isolating components can be divided into several types: semiconductor, inductive, capacitive, and optical. They can be divided by the separated signal into analogue, digital, and mixed. When designing an intrinsically safe apparatus, isolation is used for explosion safety reasons. The output energy of intrinsically safe power sources must be adequately limited to ensure explosion safety. The permissible load capacitance and inductance of an intrinsically safe source decrease, respectively, with the increase of its maximum output voltage and current. This is the second factor in addition to the need to limit the power supplied to individual circuits, which in complex and extensive automation systems implies the need to divide them into separate intrinsically safe circuits supplied from separate sources. This imposes the need for separation to enable communication between these circuits, as well as, after meeting the relevant requirements, between intrinsically and nonintrinsically safe circuits. Modern components that allow for the isolation of digital transmission signals using either capacitive or inductive coupling are digital isolators. An important innovation in them is the integration of input/output interfaces with typical CMOS logic levels, along with the circuits that work with the coupling element and the coupling element itself, in a single integrated element [10]. Compared to alternative solutions for galvanic isolation of digital signals, integrated isolators allow separation to be realised with relatively low energy requirements in relation to the offered transmission rates and the number of separated channels. Their use in intrinsically safe applications for the separation of individual intrinsically safe circuits is possible provided that the requirements specified in EN IEC 60079-0 [5], EN 60079-11 [6], and EN IEC 60079-25 [8] are met. The means and circuit solutions used for this purpose partially limit their functionality and separation parameters with respect to the catalogue ones. Meeting the requirements imposed by the above-mentioned standards involves limiting the individual operating parameters of these elements to the values specified by the manufacturer and conditioning their safe use. Data sheets of digital isolators of the iCoupler® type from Analog Devices, and of the ISO type from Texas Instruments contain limitations of individual operating parameters of these elements, conditioning their safe use: 1) the power dissipated in the enclosure, 2) or supply current of the primary and secondary sides, 3) and the input or output current of the primary and secondary sides isolator, 4) supply voltage, input voltage, and output voltage [11].

Despite these inconveniences, digital isolators of iCoupler® and ISO technologies find applications, especially when separating high-speed interfaces with a large number of transmission lines for local signal transmission, usually within the printed circuit, possibly within the device. In a typical application, these isolators are used locally within a given device, e.g., between a microcontroller and the transceiver of a given bus [12].

The component that provides isolation in the power circuit is a transformer that meets the requirements of Section 8.2 of the EN 60079-11 [6] standard. Only transformers of the following design may be used as isolation transformers:

– With separate windings on different columns of the core;
– With separate windings on one column of the core;
– With windings wound one on top of the other separated by solid insulation;
– With windings wound one on top of the other separated by a grounded screen.

Isolation spacing is required for isolation transformers.

Transformers in power circuits should be as efficient as possible, both mains and those designed for converter systems. The need for isolation clearances limits the possibility of winding them with many closely spaced windings at the same time, which would ensure good coupling between the windings and the possibility of achieving more accurate symmetry in transformers with multiple windings or split windings [9].

When fibre-optic transmission is implemented in a hazardous area, it is necessary to meet the requirements of EN 60079-28 [13], such as limiting the power radiated by the fibre.

IV. DESIGN OF WIRELESS SOLUTIONS IN INTRINSICALLY SAFE APPARATUSES

For wireless solutions in intrinsically safe applications, the most common two alternatives are:

– Using a ready-made, commercially available wireless module;
– Using only the chipset itself, cooperating with external circuits is performed according to the recommendations of the chipset manufacturer.

Each of the above methods has both significant advantages and disadvantages. In the case of an intrinsically safe apparatus, the key advantage of using only the chipset itself working with external circuitry realised according to the recommendations of the chipset manufacturer is the full knowledge of the entire system, its topology, and the components used. In addition, it is also possible to make intentional modifications to the system dictated by intrinsic safety considerations. This provides an important facility to demonstrate compliance with EN IEC 60079-0 [5] and EN 60079-11 [6] for ATEX certification.

However, a device using this type of chipset is also a radio device, subject to the RED Directive [3], so the disadvantage of such a solution is the need to demonstrate compliance with the corresponding standard for it as well. With strict adherence to all recommendations of the chipset manufacturer, as well as the correct implementation of any modifications, this should not be a problem technically, but it always involves costs, increased implementation time, and the need for testing in an appropriately accredited body. Depending on the quality and extent of technical support, the documentation provided by the chipset manufacturer and the type and extent of any modifications, it may also be necessary to have appropriate laboratory and measurement facilities and relevant experience. Chipset manufacturers typically provide extensive support in the form of detailed documentation, design recommendations, component lists, reference designs, and evaluation kits, and often even provide implementation documentation, such as printed circuit board designs.

The above facilities go a long way toward meeting the requirements. In addition, the drive to reduce the cost and space occupied on the printed circuit also contributes to the development of the technology of RF chipsets themselves, so that their application requires few external components.

Fully programmable radio chips are becoming more and more widely used, and this concerns not only, e.g., the implementation of a ready-made protocol stack and the configuration of the communication parameters themselves, but also the possibility of software generation and processing of the transmitted signal, to some extent allowing without interference with the hardware to support various existing standards, as well as the creation of new ones. The more important in such a case is software support. The use of a commercially available wireless module, the manufacturer or distributor of which provides a declaration of conformity, ensures compliance with the requirements related to the RED Directive [3]. However, mainly the complete lack of data on the internal design of such a module or its limited knowledge significantly hinders the demonstration of compliance with intrinsic safety standards. This factor can significantly narrow down the set of possible modules to only those for which compliance with EN IEC 60079-0 [5] and EN 60079-11 [6] can be demonstrated once applied to the device. This usually requires close cooperation with the manufacturer or distributor of the module and involves obtaining from it the appropriate documentation, including a declaration of those parameters that are necessary to demonstrate compliance with the mentioned standards. The bulk of the market offer of wireless modules is aimed mainly at the consumer market, characterised by mass production. Therefore, with the low volume demand typical of industrial equipment in general and intrinsically safe apparatuses in particular, it can be difficult to establish cooperation and obtain relevant information. A separate solution remains the realisation of the wireless part of an intrinsically safe apparatus entirely from scratch, which makes it easier to demonstrate compliance with EN IEC 60079-0 [5] and EN 60079-11 [6], but places incomparably higher requirements related to the RED Directive [3].

A completely different solution can also be the use of any radio module and a type of explosion-proof construction other than intrinsic safety and the passing of the high-frequency signal to the hazardous area through a suitable barrier system. The market offers ready-made barrier systems dedicated to the most commonly used radio bands. Such a solution is particularly convenient when, for various reasons, it is necessary to use an explosion-proof construction other than intrinsic safety.

Regardless of the method of implementation chosen from among those described above, inductances and capacitances with relatively small values in terms of their ability to store energy in terms of their ability to cause an explosion hazard are used in high-frequency circuits.

As a result of the pursuit of high energy efficiency and at the same time miniaturisation in the case of power systems, pulsed converters operating at high frequencies (several hundred kHz or even above 1 MHz) are used, in which inductances and capacitances also have small values.

Distributed parameter systems in which an electric or magnetic field is present in the PCB environment limit the possibility of using the coatings and encapsulation provided for in EN IEC 60079-0 [5] since these agents have relative electrical and magnetic permeabilities and conductivities that differ from those assumed. For typically used coatings and encapsulations, the effect of their relative magnetic permeability is usually negligible, but the effect of their relative electrical permeability is significant. This issue can particularly affect high-frequency radio circuits, because the circuits used in them are realised in the form of printed tracks.

Due to the increasing speed of digital circuits, this problem may increasingly affect other devices as an increasing number of connections are realised in the form of transmission lines with assumed parameters. Assuming the use of either encapsulations or coatings, it is possible to route transmission lines on the inner layers of a multilayer printed circuit and use the outer layers as reference planes, thus eliminating the influence of the environment line parameters.

If off-the-shelf components are used, one should be mindful of the potential impact of the encapsulations or the coatings. When developing a custom solution, it would be possible to consider the target PCB environment at the design stage, but then it would be necessary to ensure:

- Knowledge of the electrical parameters of the PCB environment;
- The invariability of these parameters over time and under the influence of external factors;
- Conformity of dimensions and positions to the assumed ones, with specified tolerances.

There are also off-the-shelf radio modules realised based on a given chipset, as well as the chipset itself, which makes it possible, for example, to make models and carry out the necessary tests using off-the-shelf modules, while in the final application in the intrinsic application of the solution realised based on the chipset. However, the availability of such a possibility is mainly due to other reasons: it is a response to the needs of the market - with the increase in the number of manufactured devices and, to some extent, due to miniaturisation, it is becoming economically more reasonable to use a chipset instead of an off-the-shelf module, allowing to achieve a lower unit cost with higher development and implementation costs, but incurred only once.

Regarding explosion-proof radio devices design intended for use in underground parts of mines, a significant opportunity to improve their functionality arises from the provision of § 3, item 1, subsection 12 of the Decree of the Minister of Administration and Digitisation in Poland of December 12, 2014, on radio transmitting or transmitting-receiving devices that can be used without a radio permit [14]. According to this provision, the use of devices operating in the 29.7 MHz–3 GHz frequency bands in underground mine works with a power not exceeding 500 mW e.r.p. at a depth of more than 100 m below ground level and at a distance of not less than 100 m from a vertical shaft tunnel does not require a radio licence.

Regulations regarding the need for licencing in different countries vary, of course.

In addition, market conditions mean that the widest range of off-the-shelf modules includes standardised solutions for which in many countries no radio licencing is required (meeting certain requirements, including the appropriate power of the transmitting part), while the range of other modules is not so wide. To take advantage of the opportunity provided by the regulation, in addition to developing a custom solution from scratch, it is possible, e.g., to use a chipset with the recommended external circuitry, but in combination with an additional output power amplifier, which of course involves the need to meet the requirements associated with the RED directive [3].

The simplest solution may be to use an off-the-shelf module with an antenna connector, combined with an antenna with a gain higher than that allowed for typical surface applications. An important aspect, in this case, is the direction of transmission. With unidirectional communication, the way to obtain a certain effectively radiated power (ERP) (the share of transmitter power and antenna gain) does not matter in terms of the link budget. When communicating bidirectionally, it is advantageous to use antennas with the highest possible gain because when receiving it affects the level of the received signal - for the link budget it is considered twice. In addition, since the limitation applies to the effective radiated power, with bidirectional communication in the optimal case each side of the radio link should use an antenna with as similar gain parameter as possible because, assuming equal radiated power by both sides of the link, as the difference in antenna gains increases, the difference in the signal level received by a given side increases in favour of the side equipped with an antenna with higher gain. As a result, with a large difference in antenna gains after a certain route attenuation is exceeded, only unidirectional communication is already possible (and only in the case where higher-layer protocols do not require bidirectional communication links for operation). The above recommendations apply to the simplest case and are not always possible to meet for practical reasons, such as limited antenna sizes and power consumption. In the case of the implementation of a multi-device wireless network, which may be characterised by a complex topology, both spatially and logically and functionally, the aforementioned aspects and their impact should also be kept in mind.

Spectrum management requirements for short range devices (SRD) related to assigned frequency bands, maximum power levels, channel spacing, or a modulation/maximum occupied bandwidth and duty cycle are described in ERC Recommendation 70-03 [15], and most commercially available solutions meet the requirements of the recommendation.

In addition to the intrinsic safety aspects described above, many other factors influence the choice of specific wireless connectivity solutions:

- Typical radio parameters: frequency bandwidth, link budget, data rate;
- Functional - software characteristics: interface, available libraries, protocol stacks, offered functionality, support, documentation;
- Implementation: availability, price.

V. GRAPHIC DISPLAYS

One group of components particularly problematic in terms of use in intrinsically safe applications are liquid crystal displays. This is due to the specific power and control requirements for them, which depend on the technology and operating principle used and is due to the need to develop appropriate control signals for individual electrodes. In the early days, e.g., for 7-segment displays with a small number of positions usually power and control circuits were designed from scratch, which, despite their complexity, gave full knowledge and control of their parameters in terms of intrinsic safety. Nowadays, the clearly dominant trend is to equip displays with integrated controller chips that require a single supply voltage and offer popular data exchange interfaces. This significantly speeds up and simplifies the applicability of these displays but is a major impediment to demonstrating compliance with intrinsic safety standards. Such displays usually contain power conversion circuits, usually converters and/or voltage multipliers.

Depending on the solution, power supply and interface circuits can feature varying degrees of integration: from implementation on a separate printed circuit connected to the display to a specialized integrated circuit requiring only the attachment of certain external components.

The documentation provided by manufacturers is often limited to the parameters of the display as a whole, dealing only with the interface, and does not include information on details and internal solutions. Then only in unusual cases, it is possible to obtain additional, more detailed documentation from manufacturers/distributors. The availability of documentation allows to determine whether the use of a particular display is possible and what measures, if any are required to ensure intrinsic safety.

An exemplary solution may involve either limiting the relevant parameters of existing systems by means permitted by the standard or completely replacing them with intrinsically safe circuits with known and controlled parameters. Sometimes it is necessary to separate the display circuit using either suitable limiters or complete galvanic isolation, which is a severe problem in the case of high data rate digital interfaces used today [12]. The above case usually occurs when the voltage required for proper operation of the display is higher than in the other circuits and is acceptable only in the display circuit (Fig. 2). The described difficulties increase significantly with increasing diagonal and/or resolution. The use of the above-described measures can adversely affect the performance and functional characteristics of displays to varying degrees and imply the use of specific hardware and even software design solutions.

Altered or replaced converter or voltage multiplier circuits may, due to intrinsic safety parameters, have lower voltages and/or current output compared to either the original or recommended circuits. Depending on the type of display and conditions, this can result in, e.g., reduced contrast, reduced viewing angles, and/or increased response time of display elements. Some of these effects may only be apparent under special circumstances, such as lower ambient temperatures. On the other hand, limiting circuits and interface isolation circuits located between the displays and the rest of the equipment cause degradation of the parameters of the transmitted signals [12], in particular, they limit the transmission rate significantly reducing the potential functional capabilities of the displays and, moreover, can increase the susceptibility of the interface to electromagnetic disturbances [16] (Fig. 2).

For practical reasons, limiting or isolation circuits are easier to use for serial transmission than for parallel transmission, further limiting the speed of communication. Depending on the solution and interface, these circuits may allow only unidirectional communication, e.g., which can complicate the operation of the display compared to a solution where bidirectional transmission is available. For example, there is often a need to modify a small part of the image located in the local display memory. With bidirectional transmission, it is possible to read the corresponding area of this memory, modify it, and then write it. When only unidirectional communication is available, all displayed content must be stored in the memory of the display control system, which in turn requires its specific capabilities and resources. The above aspects of the solution should be anticipated as much as possible as early as possible in the design and model stage, which is not always possible without testing. The above-mentioned atypical solutions for other applications also greatly affect the firmware of the devices, e.g., preventing the use of off-the-shelf libraries and forcing the development of their own, tailored to the atypical hardware.

The short time of availability on the market for some displays can also be a problem after deployment, as it is then not enough to find a functional replacement, but it is also necessary to re-do the intrinsic safety analysis, apply appropriate measures (which, for the reasons described above, can entail significant changes) and complete the required formalities (either recertification or obtaining a supplement). Flexible and rigid-flexible PCBs are commonly used in LCD displays, and there is no specific way of temperature classification for these solutions.

A change in the way standards are interpreted among certifiers in certification bodies occurred when the provisions of EN 60079-11 [6] were revised and allowed modern displays to be used in hazardous areas under certain restrictions. Precedents similar to RAM memories can be treated display with a converter without converted voltage external chip lead in EN 60079-11 [6] Section 7.6 “Failure of components, connections and separations”, point d:

d) <…> - when considering the voltage available on the external pins of an integrated circuit can exist between their external voltage converters (for example for voltage increase or voltage inversion in EEPROMS), the internal voltages need not be considered, provided that in normal operation the enhanced voltage is not present at any external pin and no external components like capacitors or inductors are used for conversion. If the enhanced voltage pin, then the enhanced voltage shall be assumed to be present on all external pins of the integrated circuit;

NOTE It is not a requirement of this standard that the manufacturer’s specification for the integrated circuit needs to be verified.

VI. INTRINSIC SAFETY IN THE ASPECT OF ELECTROMAGNETIC COMPATIBILITY

Every intrinsically safe system and apparatus should be designed in such a way that, while strictly meeting the requirements of intrinsic safety standards, it remains electromagnetically compatible. However, this can affect both the intrinsic safety parameters themselves (provided that they are maintained, of course) and the functional parameters. However, it should be kept in mind that of the measures used to ensure intrinsic safety, only a few improve electromagnetic compatibility properties, and reconciling the two requirements can sometimes be very difficult [16].

If there is such a possibility, it is also worth considering beforehand to obtain intrinsic safety parameters that allow the widest possible range of application of the apparatus, even when it is designed for the specific requirements of a particular system or a single application.

In special cases, it is also possible to achieve electromagnetic compatibility by appropriately changing the device software, which can be an extremely desirable solution, as it does not affect intrinsic safety [17].

There is a clear need to consider the specifics of the electromagnetic environment found in underground mines [18]. The types and levels of exposure and emissions should be appropriate for these conditions, as there have been cases of difficulty in achieving electromagnetic compatibility under actual operating conditions of the device, despite its meeting all requirements during laboratory testing. This is because power supply voltages of several kV are used in mines and currents can reach values of several hundred amperes. Variations in magnitude cause strong disturbances both conducted and radiated.

Galvanic isolation used solely to meet intrinsic safety requirements can also be helpful in ensuring electromagnetic compatibility, limiting the propagation of disturbances between devices in the system and within a single device. If such a need arises, provided that intrinsic safety is maintained, it is possible to use additional isolation, introduced solely to ensure electromagnetic compatibility.

A form of galvanic isolation can be considered fibre-optic transmission, whose resistance to electromagnetic disturbances is a great advantage.

Table I summarises the properties of various isolation methods taking into account the aspects of electromagnetic compatibility and intrinsic safety [16].

TABLE I. COMPARISON OF FREQUENCY BANDWIDTH LIMITATIONS OF CIRCUIT ISOLATION AND EMC ASPECTS FOR DIFFERENT TYPES OF ISOLATION.

Type of isolation	**Frequency band limitations, applications**	**Intrinsic safety aspects of circuit separation**	**EMC aspects**	**Energy consumption**
Transformer coupling	Limiting the transmitted bandwidth on the low and high-frequency side, use only for analog signals	Ability to separate both intrinsically safe circuits and between intrinsically and nonintrinsically safe circuits (isolation clearances can be provided). Introduction of additional inductance into the circuit	Limits the propagation of disturbances by suppressing components with frequencies that lie outside the transformer’s passband	No
Capacitive coupling	Limiting the transmitted bandwidth on the low and very high-frequency side, use only for analogue signals	Ability to separate both intrinsically safe circuits and between intrinsically and nonintrinsically safe circuits (isolation clearances can be provided). Introduction of additional capacitance into the circuit	Reduces propagation of low-frequency disturbances	No
Optocoupler	Limitation of the transmitted bandwidth on the high-frequency side, application usually for two-state signals (need to compensate for nonlinearities for analog signals)	Ability to separate both intrinsically safe circuits and between intrinsically and nonintrinsically safe (limited ability to provide isolation clearances)	Very good disturbance suppression properties for separation of two-state signals	Medium, possibility limit
Digital isolators	Limiting the transmitted bandwidth on the high-frequency side, use only for binary signals, with the possibility of converting logic levels	Possibility to separate only intrinsically safe circuits (lack of adequate isolation distances)	Very good disturbance suppression properties	Low
Fiber optic link	Limitation of the transmitted bandwidth on the high-frequency side, application usually for two-state signals (need to compensate for nonlinearities for analog signals)	Possibility of separation of both intrinsically safe circuits and between intrinsically and nonintrinsically safe (practically any possibility of realisation of isolation distances)	Very good disturbance suppression properties for separation of two-state signals. Achievable minimum coupling between separated sides due to the possibility of obtaining large gaps	High, possibility limit

VII. PROJECT SOLUTIONS

For proper operation of our mobile intrinsically safe seismic apparatus, PASAT M, reliable and interference-resistant data transmission is required [19]. Interference immunity is provided by a fibre-optic physical layer for the CAN bus.

The microcontroller used provides hardware support for the CAN bus for the data link layer (according to the ISO/OSI layer model), which ensures error-free communication ensured by, among other things: checksum, collision avoidance, and filtering of data frames at the hardware level. The transmission connection between the modules is made via plastic optic fibre, which provides 10 Mbit/s bandwidth transfer over up to 30 m. The cable lengths between modules are 20 m, and a typical design has 24 modules. The result is that the certified intrinsically safe apparatus is immune to electromagnetic disturbances and has a basic operating range of 500 m with the possibility of increasing the number of modules and range.

For designed intrinsically safe apparatuses that form an intrinsically safe system, the use of isolators would increase the cost of implementation. For the implemented project EkoDemeter, the problem shown in Fig. 3 has been eliminated. The basic assumption for solving the indicated problems is that the maximum input voltage of transmission is the same as the input maximum voltage of the power supply Ui_bus_app = Ui_sup_app. Both voltages are the same as the maximum output voltage of the intrinsically safe power supply (Fig. 4). An additional advantage of the solution is the ability to limit the maximum output current and power supplied to the sensor circuit. The latter is particularly important for devices operating in hazardous areas at higher than typical ambient temperatures.

The above solution reduces the electromagnetic emission of the transmission lines by increasing the duration of the signal edges. The limitation introduced by this solution is the reduced transmission speed, but EkoDemeter systems do not require a high transmission speed due to the slow-variable nature of the measured parameters.

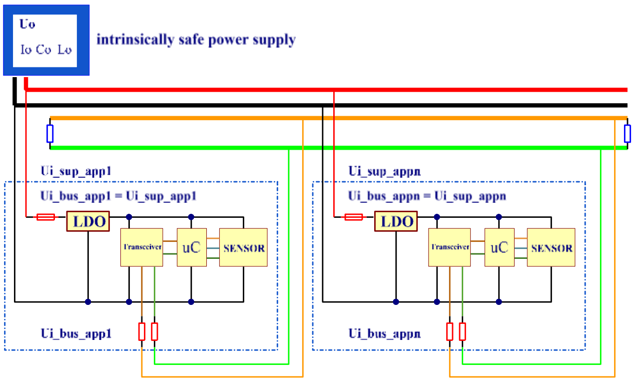

Fig. 4. Solution for the implemented projects: EkoDemeter.

In Kotły projects (Fig. 5), the analogue sensors installed in the hazardous area require a higher power supply than those measuring their signal in the associated equipment. To optimise costs and enforce proper connection by the installer, it was decided to use two types of intrinsically safe power supplies with different supply voltages. In the case of the Kotły project implemented, the problem shown in Fig. 3 was also eliminated. In the associated equipment, the ground of the power supplies was connected and a set of signals was derived for the analogue sensor.

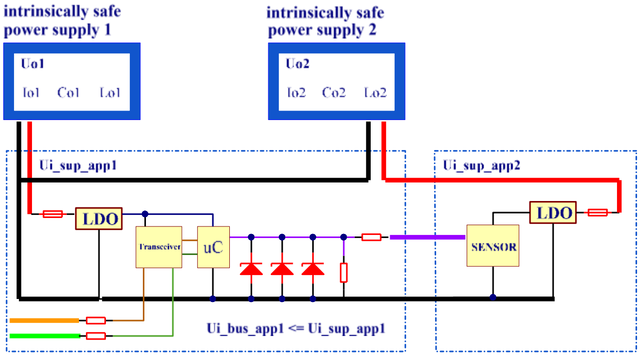

Fig. 5. Solution for the implemented projects: Kotły.

The first solution is used for Kotły projects with digital sensors (Fig. 4). MaWo, WoDoWo hydrogen projects and combinations of these solutions are expected to be used.

VIII. CONCLUSIONS

This article discusses selected problems and the most common errors in the design of intrinsically safe devices and systems. The topic is very extensive, so it is impossible to complete the topic in a single article.

Finally, an interesting fact. The progression of changes in the analysis of intrinsic safety standards, the approach in the certification bodies, and the habits of employees in these bodies have not kept pace with the rapid technological development. The best example is the digital isolators, which have been well known for almost 20 years, and practical guidelines for the possibility of their use are not expected to appear until the latest version of the EN 60079-11 issue [6]. The authors independently interpreted the requirements following the regulations, adjusted the safeguards to meet the requirements, and conducted tests to use digital isolators correctly and effectively [11], [12].

The article dropped the point of battery application and charging in a hazardous area for intrinsically safe applications because the authors recognised that it was a topic for an entirely larger article and not just a point.

CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

REFERENCES

[1] *Directive 2014/34/EU of the European Parliament and of the Council of 26 February 2014 on the harmonisation of the laws of the Member States relating to equipment and protective systems intended for use in potentially explosive atmospheres*.

[2] *Directive 2014/30/EU of the European Parliament and of the Council of 26 February 2014 on the harmonisation of the laws of the Member States relating to electromagnetic compatibility*.

[3] *Directive 2014/35/EU of the European Parliament and of the Council of 26 February 2014 on the harmonisation of the laws of the Member States relating to the making available on the market of electrical equipment designed for use within certain voltage limits*.

[4] *Directive 2014/53/EU of the European Parliament and of the Council of 16 April 2014 on the harmonisation of the laws of the Member States relating to the making available on the market of radio equipment and repealing Directive 1999/5/EC.*

[5] *EN IEC 60079-0:2018-03 Explosive atmospheres - Part 0: Equipment - General requirements*.

[6] *EN 60079-11:2012 Explosive atmospheres - Part 11: Equipment protection by intrinsic safety "i"*.

[7] S. Chmielarz, T. Molenda, W. Korski, and K. Oset, "Formal aspects of designing intrinsically safe explosion-proof apparatus", *Przegląd Elektrotechniczny (Electrical Review)*, vol. 94, no. 10, pp. 221–225, 2018. DOI: 10.15199/48.2018.10.51.

[8] *EN IEC 60079-25:2023-02 Explosive atmospheres - Part 25: Intrinsically safe electrical systems.*

[9] T. Molenda and S. Chmielarz, "Galvanic separation – Selected aspects of ATEX", *Mining – Informatics, Automation and Electrical Engineering*, vol. 522, no. 2, pp. 35–41, 2015.

[10] S. Chmielarz and T. Molenda, "Modern technologies of galvanic separation of digital signals and their possible applications in intrinsically safe devices", *Mining – Informatics, Automation and Electrical Engineering*, vol. 523, no. 3, pp. 12–20, 2015.

[11] S. Chmielarz, T. Molenda, P. Szymała, and W. Korski, "Conditions for using digital isolators in intrinsically safe applications", *Mining – Informatics, Automation and Electrical Engineering*, vol. 529, no. 1, pp. 43–48, 2017. DOI: 10.7494/miag.2017.1.529.43.

[12] S. Chmielarz, T. Molenda, P. Szymała, and P. Loska, "Digital isolators in intrinsically safe applications", *Przegląd Elektrotechniczny (Electrical Review)*, vol. 94, no. 5, pp. 190–195, 2018. DOI: 10.15199/48.2018.05.34.

[13] *EN 60079-28:2015-12 Explosive atmospheres - Part 28: Protection of equipment and transmission systems using optical radiation*.

[14] *Dziennik Ustaw Rzeczypospolitej Polskiej Warszawa, dnia 19 grudnia 2014 r. Poz. 1843 Rozporządzenie Ministra Administracji i Cyfryzacji) z dnia 12 grudnia 2014 r. w sprawie urządzeń radiowych nadawczych lub nadawczo-odbiorczych, które mogą być używane bez pozwolenia radiowego*. [Online]. Available: https://isap.sejm.gov.pl/isap.nsf/download.xsp/WDU20140001843/O/D20141843.pdf

[15] ERC Recommendation 70-03. [Online]. Available: https://efis.cept.org/sitecontent.jsp?sitecontent=srd_regulations

[16] T. Molenda and S. Chmielarz, "Intrinsic safety and electromagnetic compatibility - Selected issues", *Mechanizacja i Automatyzacja Górnictwa*, vol. 50, no. 8, pp. 19–25, 2012.

[17] M. Kryca, A. Kozłowski, and R. Pietrzak, "Consideration of EMC aspects during process of embedded software design of industrial gamma radiation analyzer", *Przegląd Elektrotechniczny (Electrical Review)*, vol. 88, no. 6, pp. 234–239, 2012.

[18] M. Kałuski, M. Michalak, M. Pietranik, K. Skrzypek, and M. Szafrańska, "The need of changes in EMC testing standardization in special environments", *Przegląd Elektrotechniczny (Electrical*

Review), vol. 88, no. 2, pp. 79–81, 2012.
[19] K. Oset, S. Chmielarz, and A. Augustyniak, “New solutions in mobile seismic apparatus - PASAT M”, *Mechanizacja i Automatyzacja Górnictwa*, vol. 474, no. 8, pp. 18–29, 2010.