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SEPARATION FAULT SCENARIOS IN INTRINSIC SAFETY CIRCUITS

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Abstract

The intrinsic safety type of protection significantly increased in complexity during the last decades. Thus, it even provides the opportunity to use highly complex electronic circuits without involving a significant explosion risk within the oil industry or in power plants, but not limited to those two. In order to achieve this performance, the type of protection is based on three pillars: limiting of energy, heat and also fault tolerance. The potential failure of components, connections, and separations are taken into consideration for intrinsic safety evaluations. This paper focuses on scenarios of separation faults in intrinsic safety circuits.
The introduction part of the paper provides a summary of requirements for the intrinsic safety type of protection. The separation requirements are also highlighted. This part also explains the „countable" concept regarding the separation faults. The second part of the paper is dedicated to the fault scenarios assessment. Also, this part shows the theoretical model which yields the magnitude of the fault scenarios group.
The built-up algorithm for effective localization of the separation faults on a real electronic board is presented in the second part of the paper. This algorithm was implemented using Visual Basic for Applications script and National Instruments Ultiboard software. In the third part of the article, the obtained results are reported and discussed. In order to have a comprehensive image, there was proposed a graph in which links are considered separation distances and elements conductive tracks. Another tool proposed and used was separation distances histogram. The influence of increased finesse on the number of non-countable separation faults was also discussed.
The main outcome of the paper is represented by the high impact of non-countable separation faults number over the number of separation failure scenarios. For example, the circuit analysis showed the potential for over sixteen million failure scenarios.

Key words: assessment, fault scenarios, intrinsic safety, separation distances

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1. Introduction

The current trend in the electronics industry causes virtual pressure toward upgrading the processes perceived by the economic operators of installations in hazardous locations (Călămar et al., 2017) including biogas (Schroeder et al., 2014) in context of explosion risk (Burian et al., 2014; Csaszar et al., 2012; Ghicioi et al., 2014; Jurca et al., 2014; Moraru et al., 2014; Tomescu et al., 2017; Şuvar et al., 2017). The class of equipment and installations which are using electricity for the purpose of information transfer are low current equipment and installations (Gerlach et al., 2008). They also need to comply with specific requirements (Burian et al., 2016) imposed by working in the presence of explosive atmospheres (Păsculescu et al., 2017).

Even if the equipment and installations are of low current type, they have ignition potential (Ghicioi et al., 2017) due to the low energy threshold needed to ignite the explosive atmospheres (Prodan et al., 2014, 2016). The ignition threshold values vary between 20 to over 180 μJ. This fact involves the necessity of using low current equipment and installations, which

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do not cause the ignition of the surrounding explosive atmospheres (Darie et al., 2017).

The access to European market of those installations and equipment are covered by the European Directive 2014/34/EU (2014), so called ATEX Directive and by the technical characteristics which implement the non-ignition capability and which are detailed by the specific standards family coded (IEC) EN 60079-**. The ignition prevention of atmospheres containing flammable substances involves limiting the flowing energy, stored energy and also, limiting the dissipated power in the electronic components of the equipment.

Currently, the explosion protection assessment process involves the direct action of the human assessor, which is a high-time consumer (even months) and has a high rate of rejected equipment. Intrinsic safety type of protection is often used to implement explosion protection for low-current equipment and installations (EN 60079-11, 2011; Niculescu et al., 2014). In the designing process, all explosion protection scenarios are implemented both in normal and in failure operation modes. In this way the requirements of Directive 2014/34/EU (2014) concerning the classification into categories (1, 2 or 3) as well as protection levels (a, b and c) according to IEC standard (EN 60079-11, 2011) are implemented.

The equipment which cannot be assessed by using ignition curves (EN 60079-11, 2011) (as example those of increased complexity or those having nonlinear sources) shall be tested using spark test apparatus and other applicable procedures. Current trends in the explosion protection assessment of an electric low current equipment protected by intrinsic safety is represented by the increase of using tables and diagrams included in the specific standards (EN 60079-11, 2011) and reducing the number of tests. A major but still under-exploited advantage of the above is the possibility of assessing the explosion protection of the equipment in the design stage. This approach has a significant potential for reducing the approval time for low current equipment intended for use in explosive atmospheres. Another major advantage is the decreased rate of rejected equipment in the process of assessment and testing.

Behind the simplicity of the intrinsic safety concept stands a complex assembly of requirements. The main requirements imposed by specific standards are grouped into two parts: apparatus construction and apparatus tests. Among apparatus construction requirements those regarding separation distances play an important role. A special type of apparatus construction requirements are those applicable to components on which intrinsic safety depends.

The following are examples of construction requirements: regarding enclosures, facilities for connection of external circuits, protection against polarity reversal, earth conductors, connections and terminals, encapsulation, rating of components, connectors for internal connection, plug-in cards and components, primary and secondary cells and batteries, semiconductors, piezoelectric devices and electrochemical cells for detection of gases.

Intrinsic safety has a specific approach regarding the fulfilment of ATEX classification in categories or IEC classification for equipment protection levels. It uses the concept of countable or non-countable faults for components, connections, or separations, according to section 7.6 of the specific standard (EN 60079-11, 2011). A countable fault is a fault occurred at a component that complies with constructional requirements or at separation distance in between one-third of the specified values and specified values. Higher values than the ones specified are considered infallible distances, but all values lower than one-third of the specified values are considered non-countable separation faults.

In the process of certification of explosion-proof equipment, various assessments and tests are carried out. Some specific aspects should be mentioned here. A favourable one is that because of the high quantity of technical data available in the field of intrinsic safety equipment, many assessments could be done just by calculation. An unfavourable one, is that even low complexity circuits could give a high number of failure scenarios needed to be analysed.

The specific standard for intrinsic safety type of protection takes into account all applicable scenarios resulted by taking into account all combinations of faults in the equipment.

The aspects mentioned above lead to the impossibility of humans to assess the entire set of failure scenarios. Therefore, current in the assessment process, equivalent circuits are actually used in order to drastically reduce the number of analysed scenarios. Using this method, equipment that is truly explosion-proof has an increased probability to be rejected.

2. Material and methods

2.1. Theoretical model of magnitude

For estimating the number of fault scenarios group, a theoretical model based on combinatorics was employed. As a first step, the number of all possible failure scenarios is computed. Those scenarios, according to the intrinsic safety type of protection, shall include all combinations of non-countable faults for "*ic*" level of protection. Consequently, the number of all possible failure scenarios may be computed using Eq. (1).

$$N_{ic} = \sum_{i=0}^{N_2} C_{N_2}^{i} = 2^{N_2} \quad (1)$$

For the "*ib*" level of protection, the number of scenarios should include also one countable separation fault added to those mentioned in Eq. (1). The number of all possible failure scenarios may be computed using Eq. (2).

$$N_{ib} = N_1 \cdot N_{ic} + N_{ic} = (N_1 + 1) \cdot 2^{N_2} \quad (2)$$

The number of all failure scenarios for a "*ia*" equipment may be computed using Eq. (3).

$$N_{ia} = C_{N_1}^2 \cdot N_{ic} + N_{ib} = (N_1^2 + N_1 + 2) \cdot 2^{N_2 - 1} \quad (3)$$

In Eqs. (1-3), N_1 is the number of countable faults and N_2 is the number of non-countable faults.

2.2. Method for separation fault place identification

As mentioned above, the number of failure scenarios may be computed using Eqs. (1-3) but the exact localization of the separation faults is also required. A printed circuit board (PCB) execution element for a circuit consisting of operational amplifiers and a transistor was generated for the purpose of fault localization. The used electronic circuit was a band pass filter. The generated PCB – components side - is presented in Fig. 1 using colours: blue and pink for traces and red for components contour and labels.

The National Instruments ecosystem was used for conducting experiments and due to the fact that the Ultiboard (the PCB tool for creating boards) does not have an application programming interface (API) a keyboard and mouse simulators from a Visual Basic for Applications macro (VBA) were used. The flow chart built-up of the algorithm used to identify the localization of all distances between conductive traces is presented in Fig. 2. In the algorithm, input parameters are the range and step of distances iterated by the algorithm. In the loop, the Ultiboard is invoked to find the trace collisions at each step. In this way, the distances between traces are found. After finishing the loop, a report is generated. The fields of this report are the nets (traces) names and the distance between them.

3. Results and discussions

In order to easily view the obtained results, they have been presented in Fig. 3 in graph form. In this figure, all traces are symbolized as circles and distance in between them are symbolized by links. Additionally, in Fig. 4 has presented a histogram of separation distances found. By using the histogram drawn in Fig. 4 one could estimate the impact of chosen separation distance threshold over the number of separation faults scenarios. As an example, according histogram in Fig. 4, the choosing of a threshold around 1.3 mm could reduce or increase the number of separation fault scenarios by 2^{15}=32768 times.

Within the specific standard (EN 60079-11, 2011) are specified distances for the separations as function of voltage across. Within this standard two different sets of required distances are mentioned. One of them is found in Table 5 and another one is found in annex F of the standard. As a comparison between these sets, annex F specifies lower values for distances of the same voltage value but request additional requirements. As an example, it is required a higher ingress protection level etc.

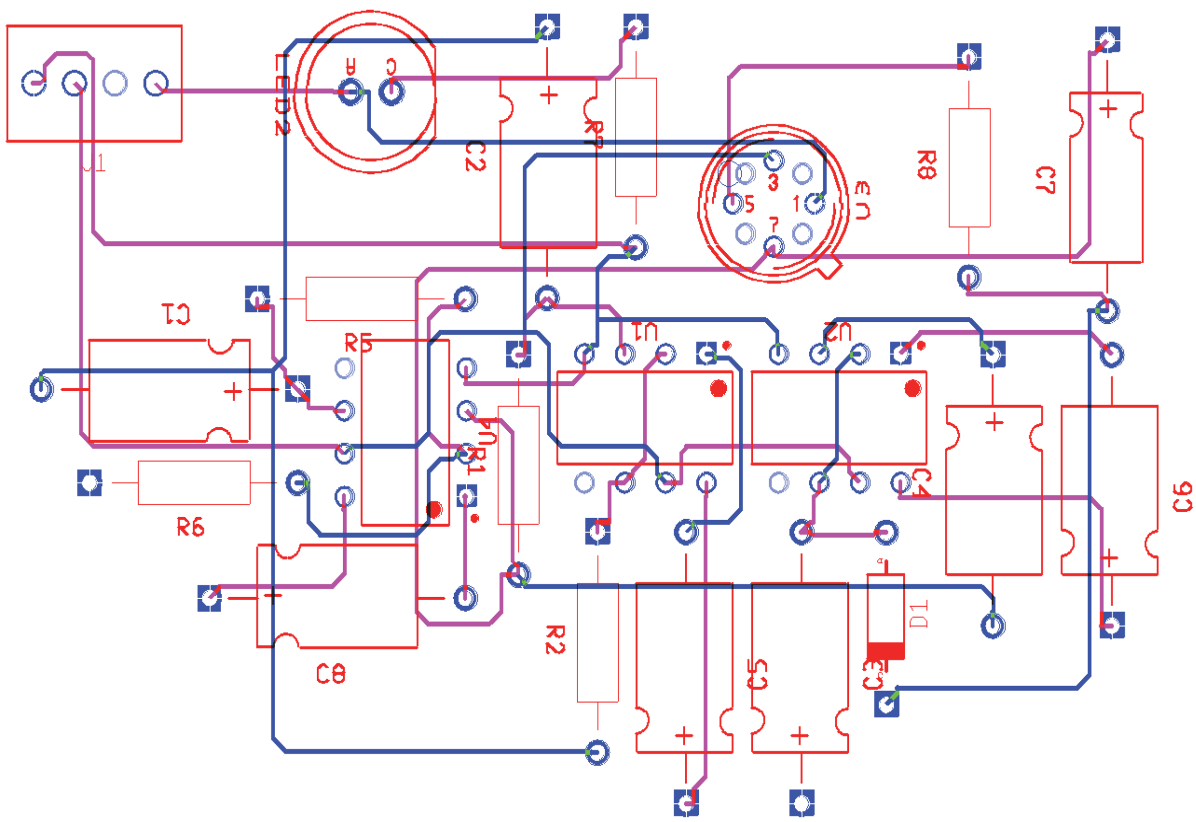

Fig. 1. Experimental PCB loaded in Ultiboard

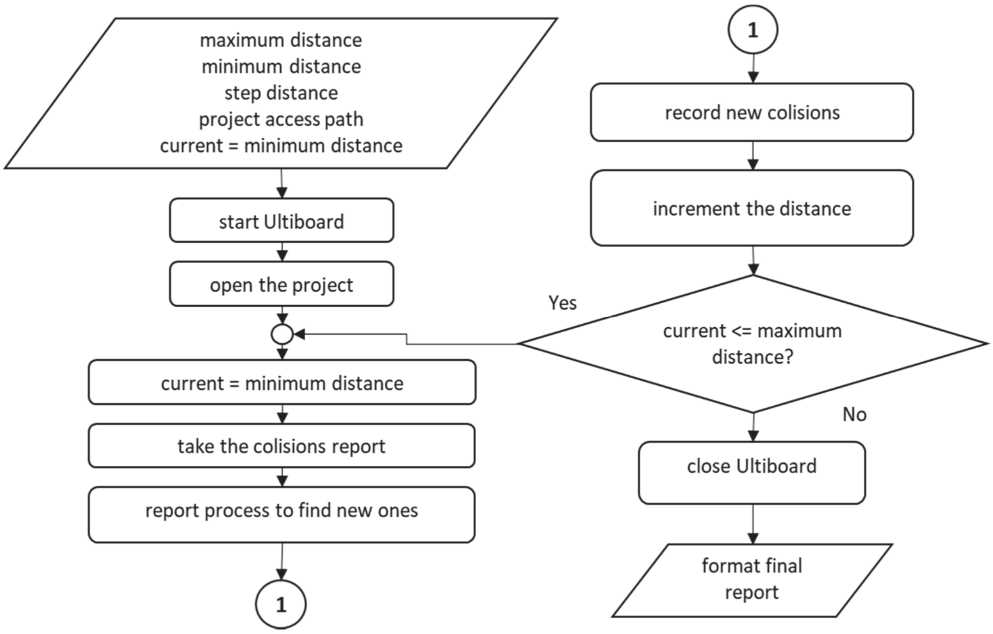

Fig. 2. Flow chart algorithm for separation faults discovering

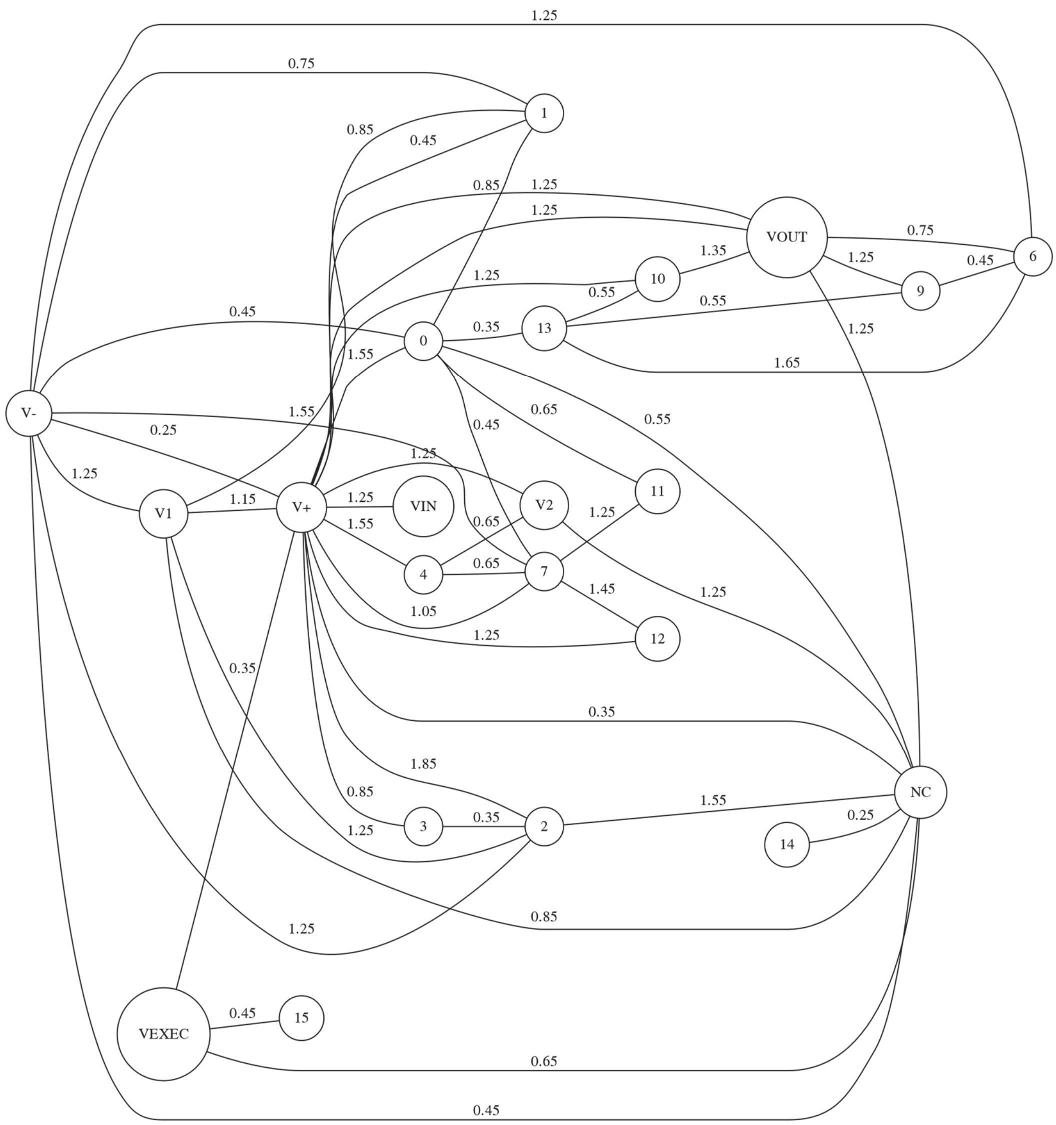

Fig. 3. Graph of separation distances between nets, measured in millimetres

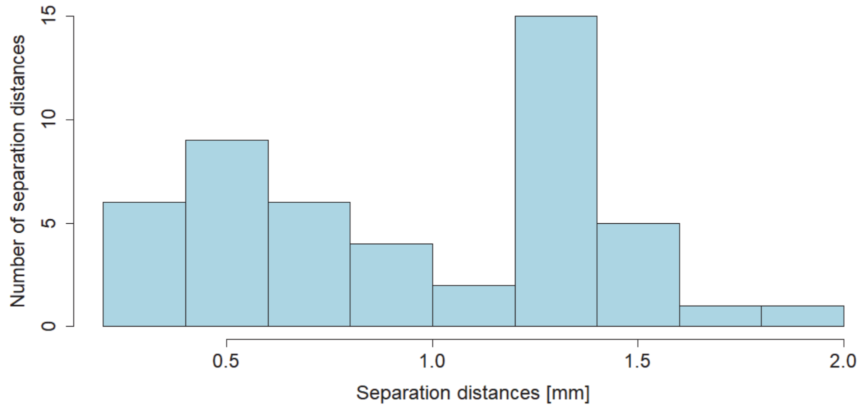

Fig. 4. Histogram of separation distances found

After all separation distances were found in the circuit, they were compared with a threshold obtained according the voltage in the circuit by using Fig. 5. This figure was obtained by interpolation of the values presented in Table 5 in the specific standard (EN 60079-11, 2011). By using the interpolation, the finesse is increased and this fact could lead to a lower number of non-countable separation faults.

Having in view the theoretical model presented above, for finding the total number (magnitude) of separation fault scenarios, it is obvious that non-countable faults has an exponential effect. On the other hand, the number of countable faults influence on magnitude is linearly for "*ib*" level of protection and quadratic for "*ia*" level of protection. These levels of protection "*ia*", "*ib*" and "*ic*" are specified in section 5 of the specific standard (EN 60079-11, 2011) and means a kind of fault tolerance for the explosion protection in which "*ia*" is the best.

Using the histogram mentioned in Eq. (4) the separation distances are divided in countable faults and non-countable faults. The distances having values in between the d_{lim} and $d(U)$ are considered countable faults. All distances below the d_{lim} are considered non-countable faults. Both separation distances are measured in millimetres.

$$d_{\lim} = \frac{d(U)}{3} \tag{4}$$

The $d(U)$ is the value of separation distance imposed by the value of voltage across it. The value of $d(U)$ is obtained using the Fig. 5. Having in view "*ib*" level of protection, after comparison of the separation distances, with the threshold established above, there were obtained 31 countable faults and 19 non-countable faults. Consequently, using Eq. (2) and calculation in Eq. (5) the number of failure scenarios generated is over sixteen million.

$$N_{ib} = (N_1 + 1) \cdot 2^{N_2} = 31 \cdot 2^{19} = 16252928 \tag{5}$$

In order to achieve an assessment for such magnitude of scenarios it should be necessarily to have in view the option of automatic assessment of circuits.

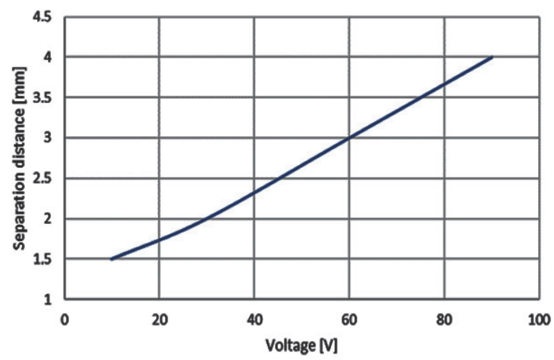

Fig. 5. Separation distances as function of voltage across them

Alternatively, using the separation distances from annex F of the specific standard (EN 60079-11, 2011) all fault separation distances became countable faults. Consequently, the number of all applicable scenarios is calculated using Eq. (6).

$$N_{ib} = (N_1 + 1) \cdot 2^{N_2} = 50 \cdot 2^0 = 50 \tag{6}$$

The big differences observed between the numbers of failure scenarios obtained using Eq. (5) and Eq. (6) could be explained by additional requirements imposed if F annex (EN 60079-11, 2011) is used. The proposed method could also be used for discovering the separation faults location. This result could be an input for further explosion protection assessment.

4. Conclusions

The proposed theoretical model for computing the number of failure scenarios underlines the huge impact of non-countable separation faults number. It was also found that the number of countable faults has a linear influence for "*ib*" level of protection and quadratic for "*ia*" level of protection.

Over sixteen million failure scenarios were identified for the relatively simple circuit modelled in the present work. Even if the experimental model has a relatively low complexity, the computed number of failure scenarios may be very high.

Increased finesse of separation distances, by interpolation, has the potential for reducing the non-countable faults number and therefore the failure scenarios number.

The uses of peaks from histogram of separation distances helps to find the separation distances thresholds which imply huge variations in the number of separation failure scenarios.

The proposed method could also be used for discovering the separation faults location. This result opens the way for further explosion protection assessment.

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