Explosion safety in industrial electrostatics

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Abstract. Complicated industrial systems are often endangered by electrostatic hazards, both from atmospheric (lightning phenomenon, primary and secondary lightning protection) and industrial (technological problems caused by static charging and fire and explosion hazards.) According to the classical approach protective methods have to be used in order to remove electrostatic charging and to avoid damages, however no attempt to compute the risk before and after applying the protective method is made, relying instead on well-educated and practiced expertise. The Budapest School of Electrostatics - in close cooperation with industrial partners - develops new suitable solutions for probability based decision support (Static Control Up-to-date Technology, SCOUT) using soft computing methods. This new approach can be used to assess and audit existing systems and - using the predictive power of the models - to design and plan activities in industrial electrostatics.

1. Introduction
Many industrial processes are extremely sensitive to electrostatic hazards, and the consequences of the events can be very severe, ranging from huge financial loss to possible human injury. Therefore there is a clear need on part of the industry to provide the necessary toolset to effectively protect against the effects of this sort of risk. In order to design effective protection, a method for gauging the risk is needed, so that the risk before and after applying the protective measure can be accurately assessed, thereby enabling the expert to choose the best set of protective devices for a given process. The complex nature of electrostatic risk however provides a challenge for those trying to model it.

Electrostatic risk can arise from atmospheric sources, including both primary and secondary effects of lightning, or from industrial electrostatics, where as a by-product of certain processes a charge accumulation and eventual discharge may occur, leading to the inflammation or explosion of the surrounding atmosphere. In both cases, the factors influencing the probability of these events are various, their interdependence complex and highly nonlinear. Also, the severity of the outcome in the different scenarios can vary over a large range, from mild inconvenience to debilitating consequences.

In case of both types of hazard it is clear that some form of protection against these damages are needed, however electrostatic protection usually does not constitute an integral part of the design effort for the process, but is rather added as a mere afterthought. It is difficult to appreciate the severity of risk in a complex industrial system, because only the effects or symptoms of the electrostatic charging can be detected.

From the above properties it can be seen that specialized and carefully controlled methodologies are needed to accurately assess and thus control electrostatic risk [1].
2. The optimisation of the protection and/or prevention strategy
When faced with the task of designing an optimal protection or prevention method for a production line or industrial process, ideally the designer has at their disposal a wide variety of sources to gather information about the system. Generally the underlying physical processes can be identified and therefore for many hazards exact models can be obtained and these can be validated against experimental data. Complex interactions of several hazards are described poorly using these exact models.

It is evident that model computations provide an efficient and valuable tool in the hands of the expert, because they aid the understanding of the phenomenon as well as having their use in simulations for the more integrated effects, thus leading to the development of new protection schemes and new process technologies.

The traditional approach to designing protective measures relies on well-educated and experienced experts applying the accepted knowledge in the field in order to reduce electrostatic risk [2]. Because there is no quantitative risk assessment or target value, over- (and in the unlucky case) under engineering of the protective methods is possible.

3. Novel approach to electrostatic hazards
The authors propose that a novel approach to assessing the electrostatic risk in a given situation that relies on a more formal protocol and focuses on quantitative risk calculations can create a situation in which overall risk can be more accurately controlled than using the traditional approach, leading to both efficient use of resources and increased safety (by choosing the most appropriate protective method) and savings (by preventing spurious measures).

Figure 1 and figure 2 illustrate the differing approaches taken by the traditional and the novel method to electrostatic risk assessment. It can be readily seen, that the specific strategy of the risk taker is explicitly included in determining the acceptable risk level, along with the particular characteristics of the possible damage.

![Figure 1. Traditional approach to electrostatic risk management.](image)

It is also very important, that the parameter that describes the acceptable risk is in the dimension EUR/year, which is readily understood by all parties involved in decisions regarding process planning. Should the calculated risk be higher than the acceptable, it is natural that protective or preventive measures have to be taken. There is usually a range of preventive measures that can influence the calculated risk in a favourable way, including those that prevent the damage by making the event less frequent, and those that decrease the cost associated with each of these occurrences (often including measures that do not increase process safety in the eye of the engineers, such as purchasing additional insurance.)
The proposed novel approach, as its central element, involves the use of an auditing process. To start this process, the client gives a declaration of its objectives regarding process safety, based on which an independent auditor examines all relevant aspects of the system and gives assurance that the given objectives are met. During the audit a fixed protocol and high standards for documentation are used in order to ensure the integrity of the process. Also very important as a basis for estimation is the use of a database of electrostatic hazards, their models and associated experimental data.

4. Fault diagnostics

While all methods outlined above to manage the risk associated with a given process in important, the part relevant in our current paper is the usage of technological methods to decrease the frequency and severity of damage events. Through the process of fault diagnostics a given electrostatic hazard is identified, evaluated and managed. This means that based on quantitative examination probability based calculations have to be performed in order to make a decision regarding the protective or preventive measures; finally an audit of the modified process has to be carried out in order to verify and document the gains of the diagnostic process and the decreased risk estimate.

During the diagnostic process the current risk level and the risk reduction in case of the different protective measures should be estimated. The focus of fault diagnostics is to determine the optimal set of measures that ensure the appropriate risk level. It is clear that applying all candidate measures is very inefficient due to primarily to financial reasons – however quantitative analysis of the appropriate risks lets us determine which measures are necessary, and which are the ones that are worth or not worth using.

All of the above support that the key factor in successfully managing electrostatic risk is the ability to accurately estimate the exact risk level, and thus be able to quantify in a robust manner the gains (in the form of risk reductions) from applying different measures. This information is crucial, because it allows the export to make informed and well supported decisions even though no direct measurement of the involved probabilities can be carried out.
5. Event and fault trees

Event and fault trees are widely used in the industry to estimate the probabilities of events in cases where we have no prior information of these probabilities, however through knowledge of the physical model describing the events leading to the events is available. An event tree describes - through the use of logical operators - the relationship of the top event to basic events. In figure 3 an example event tree can be seen.

![Figure 3. Event tree for an electrostatic explosion.](image)

It is clear that by assuming the independence of these events and applying the ‘and’ (conjunction) and ‘or’ operations from probability calculus, the probability to the top event can be connected to the probabilities of base events - this is done in case of fault trees. Naturally, we hope that the probabilities of the base events are better known or easier to estimate than the probabilities of the top event.

A newer proposal is the usage of fuzzy numbers to represent the probabilities that are involved in the calculation. The rational for this is that the probabilities of the base events are generally only estimates, and fuzzy numbers provide a means for representing the inherent inaccuracy. When the calculation is performed using fuzzy numbers, the resulting probability for the top event is also a fuzzy number. This has several advantages. By examining the variance of the fuzzy result, the inaccuracy of the estimate is revealed, which quantifies the trust that should be placed in that value. A more interesting use is that the sensitivity of the inaccuracy of the top event probability to the base event inaccuracies can be studied, which can guide the expert in choosing to measure and/or control the relevant parameters better.

Possibly the greatest difficulty in using fault trees is the estimation of the probabilities of basic events. This estimate may be obtained by using parameters derived from similar processes, or by statistical evaluation of a significant number of measurements. Very often, a physical model for the system can be constructed, giving an estimate of the parameter. Very often however the only means to estimate a parameter remains evaluation by an expert based on experience.

6. On-line fault diagnostics

In the previous sections we have discussed the process of fault diagnostics as performed by field experts. This sort of off-line diagnostics treats all conditions of the industrial process as being static - in case of changing circumstances naturally the worst condition is assumed. It is evident that the diagnosis of faults can be done in an on-line manner where subsequent preventive actions are based on real time data about the process. This, of course, requires that an adequate expert system is constructed that is made aware of the observations about the system, and according to a set if inference rules is able to determine when and what intervention to the process is necessary.
The schematic diagram of such a system is presented in figure 4. It is clear that because observations are not exact, and they do not reveal the complete state of the system that is being observed, and additionally our model of the system is almost certainly imperfect, the evaluation of the observations can only be done by soft computing methods, such as fuzzy logic.

The system of figure 4 uses knowledge of the system to - via inverse reasoning - substantiate probable faults from the observations. Such a system - because of its on-line property - promises timely evaluation of faults, and therefore increased safety. Also, the soft computing element makes it able to adapt to situations in which imperfect observations and knowledge is present.

![Figure 4. Schematic of an on-line diagnostic system.](image)

7. **The SCOUT system**

In the previous sections we have discussed how new quantitative methods, many of them based on soft computing methods, allow us to more precisely assess electrostatic risk. The SCOUT (Static Control Up-to-date Technologies) is a procedure of risk estimation based on audits that not only help for planning, but also guidelines for decision makers and auditors.

The SCOUT system incorporates a preparatory pre-audit step, based on which sets of complex of protective measures may be proposed, and risk estimation for these alternatives can be carried out.

Based on the data collected in the preparatory phase a decision can be made that is both technically and economically optimal. According to the SCOUT procedure, the chosen technological measures are then applied, and their effectiveness is verified and documented via a post-audit (third party audit).

8. **Preventive lightning protection**

When designing lightning protection solutions, we must take into account not only the primary, but also the secondary effects of lightning that through conductive, inductive and capacitive means are coupled with our electrical systems.

The traditional means of primary lightning protection are the lightning arrestors. There is less agreement on how and how many of these should be placed on a structure to adequately elongate the mean strokeless period. The electrogeometric theory can be used to estimate this period (interval), and is based on the attractive volume concept - the volume, which once lightning enters is attracted to the structure rather than the ground. From the difference of the attractive volumes of the structure and its arrestors, an equivalent land area can be calculated, which receives the lightning strikes with the same frequency as the structure under examination [3].

Modern electronic equipment is usually very sensitive to the secondary effects of lightning. These are usually dealt with by reducing the coupling between a lightning and the sensitive equipment, and installing protective circuit elements that dissipate the energy of the lightning strike. Some equipment,
such as radio transmitters and receivers, or radar equipment pose a difficult problem, when designing lightning protection.

Often the level of protection that is desired for a structure is very different for different time intervals. As an example, a transmission line should generally only have very basic protection, however when maintenance work is performed on it, then a lightning strike may endanger the maintenance workers, thus much better protection would be preferable.

A possible solution to these problems is preventive lightning protection. The preventive lightning protection method means avoiding damage of a lightning strike with special preventive actions. The preventive actions can be of various types, and the primary goal of preventive lightning protection is to decrease the risk of damage due to lightning for the duration of the thunderstorm. The preventive action shall be initiated before the beginning of the lightning activity, and shall be discontinued after the end of the thunderstorm [4].

This system uses on-line information from lightning detectors or meteorological radars to give warning to operators about the increased probability of a lightning strike, thereby the system can be transferred to a state in which potential damages are reduced (third party audit).

9. Conclusion

It was established that for both sources of electrostatic risk (both atmospheric and industrial) new methods for estimating and controlling the risk level are available. In the case of atmospheric effects, preventive lightning protection, and in the industrial case, new methods of computation, fault diagnostics are available. The latter serve as a basis for the new SCOUT procedure of industrial process auditing and a new method for helping the work of decision makers and risk takers.

In both the atmospheric and industrial cases, the usage of soft computing, such as fuzzy numbers, fuzzy inference systems and expert systems seems very useful in creating algorithms that can cope with the imperfect conditions of complex applications.

It is crucial to recognize the importance of the human element in applying protective measures – without the precise work of the experts and continuing human support no protection can operate properly, even though many technical equipment and devices are used. Also critical is that well-educated partners are available, who understand the characteristics of risk, and that meaningful information about the risk level is provided to support their decisions. This can be achieved by the ability to provide quantitative estimates in dimensions that are universally understood: EUR/year.

References

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