Advanced Risk Analysis for the Application of ESP-s to Clean Flammable Gas-pollutant Mixtures

István Kiss, Tamás Iváncsy, Bálint Németh, István Berta
(Budapest Univ. of Technology and Economics. Dept. of Electric Power Engineering. 1521 Budapest, Hungary)

Abstract: There are several processes, in which risk of fire or explosion in electrostatic precipitator must be analyzed, like at certain types of biomass fired boilers, fine particle removal in pharmaceutical processes, etc. Appropriate, reliable risk analysis of such systems is vital to ensure safe operation. Application of fault tree analysis for risk calculation is a well known method, but in some cases it is difficult to identify all of the significant events and it is more difficult to determine the initial probability values for the basic events of the fault tree. When the determination of the probabilities contains uncertain information, it is necessary to evaluate the reliability of the result or to decrease uncertainty of initial probability values. This paper represents an advanced method based on fuzzy logic, that is capable to estimate the effect of uncertainty, and determine reliable input parameters for the fault tree analysis in such cases, when risk of fire or explosion in the electrostatic precipitator must be taken into consideration. The paper represents the process of the creation of fault tree, the determination of fuzzy membership functions for the input probabilities, the calculation process and the evaluation of the final result of the analysis.

Keywords: Risk analysis, fault tree, ESP explosion

1 INTRODUCTION

It is known, that in some cases risk of fire or explosion must be reduced in electrostatic precipitators. However estimation of risk and selection of preventive measures are often based on qualitative analysis instead of quantitative one. The basis of the analysis in both cases is the systematic overview of possible events that can lead to explosion or fire.

The widely used mathematical method for this is the event tree that describes the logical relationship between the events leading to the fire or explosion as "top event". Adding probabilities to the events results in the fault tree and replacing simple probability values with fuzzy membership functions results in the fuzzy fault tree [1, 2].

In case of fire or explosion the top event is the result of an “and” relation of three subsequent events (they must happen at the same time and place):

- existence of flammable material in appropriate concentration;
- existence of oxygen;
- ignition source.

In the following chapters it will be analyzed, how these events can appear in case of electrostatic precipitators.

2 GENERAL CONSIDERATIONS

Examining the three necessary components of the formation of fire or explosion, it can be said, that presence of ignition source has high probability. It is typically the breakdown between the corona electrode and the collecting one, but in some cases electrostatic discharge (typically back corona,) can be also act as an ignition source. Oxygen is practically always present, only its amount is depending on the technological process used.

Regarding, that the previous two components has high probability of occurrence, usually the presence of flammable material must be disclosed. Especially flammable dust can be problematic because of the risk of dust explosion [3].

That is the reason why flammable materials are usually filtered by bag filters, not by ESP-s. Such bag filters are constructed strong enough to resist a potential explosion and / or having well-defined parts to be broken by reducing the pressure. Regarding, that even this case the loss of material to be filtered and the cost of stopping the process can be very high, in several cases inert gas is applied to avoid the presence of oxygen.

However there are some processes when possible flammable material can appear in the electrostatic precipitator. Mainly CO concentration can reach the critical level, typically in cement plants, boilers when burning process is not appropriate, etc.

Several explosions happened in electrostatic precipitators. A typical example is an ESP explosion during the testing period of a boiler, when different type of fuel were used to analyze the performance of the boiler. Due to the incomplete combustion explosive gas-oxygen mixture was accumulated in the precipitator which was ignited by a breakdown. As a result explosion occurred that totally destroyed the electrostatic precipitator.

Similar danger is present at electrostatic precipitators used to collect particles at cement kilns. During the warming up period of the kiln complete combustion of the fuels does not occur, therefore combustible gases can appear inside the electrostatic precipitator. To avoid explosion the precipitator is switched off during the warming up period. In steel mills gas emitted from blast furnaces results in a permanent risk of presence of CO, usually wet ESP-s are used to remove particulate matter.

As a summary it can be said, that incomplete combustion is always a risk factor in electrostatic precipitator.

To reduce risk of fire and explosion, there are many possibilities. One of them is to equip electrostatic precipitators with CO sensors that give signal to a safety system to stop the process when CO concentration exceeds the critical limit. This solution reduces the risk dramatically, but not to zero. To estimate the actual risk level, detailed analysis is necessary.

Consequence of a fire or explosion can be reduced by applying weakened parts to direct the path of overpressured gas or producing such construction that can withstand the overpressure, as it was mentioned before.

It is important to note, that the events in the fault tree must be independent from each other. If the case is not that, it must be taken into consideration during the creation of the fault tree.

.3 APPLICATION OF FAULT TREE ANALYSIS FOR ESP-S

Reliability of fault tree analysis strongly depends on the represented knowledge. It means, that all significant events must be identified and the appropriate connection between these events has to be mapped.

In addition to, appropriate probability values have to be assigned to the basic events of the fault tree. If we want to represent how exact these probability values are, the simple probability values can be replaced by fuzzy membership functions. Easiest way is the application of triangular membership functions, as it is represented in Fig. 1. Such a membership function expresses the degree of truth of statement "probability p is nearly value px”. As it was mentioned before, determination of p_x and the connecting minimal and maximal values for the basic events is very important to obtain reliable result for the top event. The membership functions can be constructed based on statistical data, numerical modeling or it can be estimated by experts.

Table 1 contains a strongly simplified fuzzy fault tree for a case study.

In the table first column contains the number of the event. These numbers are used for further identification of the event. Column 3 shows whether the event is a basic one or its membership function is a result of a fuzzy operation.

Table 1 Simplified fuzzy fault tree

No. of event	Name of event	type of event or relation	No. of event1	No of event2	min. probability of event	med. probability of event	max. probability of event
1	Fire or explosion	and	2	3	1,99E-06	1,44E-05	4,94E-05
2	Atmosphere in ESP chamber is inflammable	and	4	5	1,70E-04	2,70E-04	4,70E-04
3	Ignition source is present	or	6	7	1,17E-02	5,34E-02	1,05E-01
4	Presence of oxigen	basic			1,00E+00	1,00E+00	1,00E+00
5	Presence of flammable material	or	12	13	1,70E-04	2,70E-04	4,70E-04
6	Breakdown in ESP chamber	basic			1,00E-02	5,00E-02	1,00E-01
7	ESD	or	8	9	1,70E-03	3,55E-03	5,59E-03
8	Intensive back corona	and	10	11	1,60E-03	3,40E-03	5,39E-03
9	Other ESD source	basic			1,00E-04	1,50E-04	2,00E-04
10	ρε of dust is high	basic			8,00E-01	8,50E-01	9,00E-01
11	no measures against back corona	or	14	15	2,00E-03	4,00E-03	5,99E-03
12	Other flammable material	basic			1,00E-04	1,50E-04	2,00E-04
13	Presence of CO	and	16	17	7,00E-05	1,20E-04	2,70E-04
14	Malfunction of rapping control	basic			1,00E-03	2,00E-03	3,00E-03
15	Malfunction of poer supply control	basic			1,00E-03	2,00E-03	3,00E-03
16	Malfunction of CO detection	basic			1,00E-04	1,50E-04	3,00E-04
17	CO formation in the ESP	basic			7,00E-01	8,00E-01	9,00E-01

Column 3 shows whether the event is a basic one or its membership function is a result of a fuzzy operation. In the first case probability values describing the membership function are determined by experts taking into consideration statistical data. In the second case the operation in column 3 is made on the values connected to Event 1 and Event 2.

The values connecting to the last 3 columns give the min, max. and medium points of the functions as it was presented in Fig. 1.

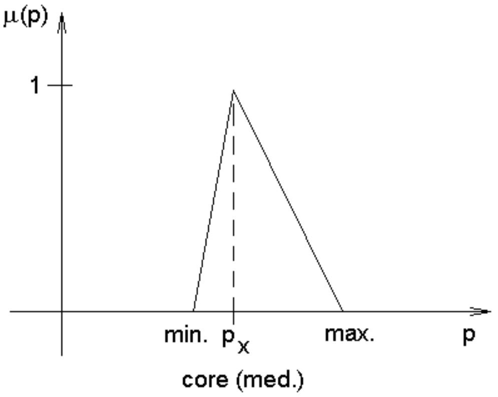

Fig. 1 Membership function for probability "*p* is nearly p_x"

In the case study presence of CO is the main problem, therefore basic event connecting to that has high probability values at the breakpoints of the membership function.

Using preventive measures (CO detection, etc.) this high probability is reduced. Appearance of breakdown is estimated based on the operation of the ESP. (Taking into the consideration that power supply control increases the voltage up to the breakdown level with a given periodicity then decreases it to the "working point")

Presence of back corona is also considered due to the high value of $\rho\varepsilon$, the product of the specific resistance and the permittivity giving the time constant of charge loss of a powder layer. "High" in this case means that specific resistance $\rho > 10^{11}$ Ω·cm at a relative permittivity *pf* 5-10. The probability value connecting to the event can be determined according to the results of the measurements on test samples.

Min. and max. value for the probability of the event takes into consideration that the physical parameters of the dust to be precipitated can change as a function of time.

Note, that fuzzy membership functions can be used even in that case defining a function similar to the one in Fig. 2.

Final result of fault tree analysis is a probability value (or membership function). To obtain risk (*w*), it is necessary to multiply its value (*p*) to the relative cost of damage (*c*), *w=pc*.

Relative cost *c* is the ratio of the actual cost of damage divided by the total possible cost [4] including the cost of damaged precipitator, outage of the system, etc. using artificially weakened surfaces to direct high pressure gas generated due to the explosion, creating constructions withstanding high pressure, etc.

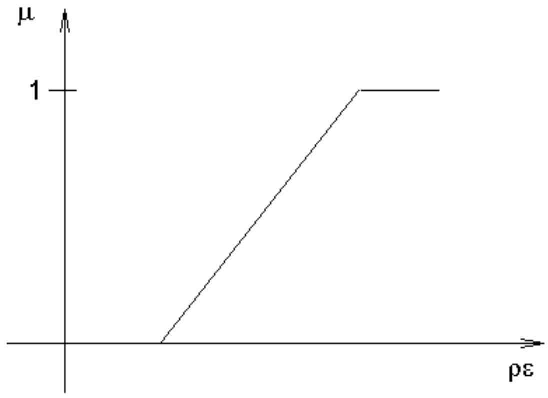

Fig. 2 Membership function for "$\rho\varepsilon$ is high"

As it was mentioned before, value of *c* can be reduced by

4 DECISION MAKING BASED ON THE FUZZY FAULT TREE ANALYZIS

Using fault tree analysis it is possible to compare the effect of different measures, upgrading, etc. on the risk of fire or explosion. One example is presented below.

Let us suppose, that the CO sensing device will be replaced by a more accurate one. In this case uncertainty connecting to the sensing will be decreased, resulting in a smaller (less wide) membership function, as it can be seen in row 17 in Table 2. The core (medium value) of the membership function is the same as it was before.

After the calculation it can be analyzed, how did the change influenced the top event, was the change of the membership function significant or not. It can help decision making to evaluate, whether an investment will be reduce (or increase) the risk of fire or explosion significantly or not. In Table 2. it can be seen that the selected event has significant influence, the difference between the min. and max. value decreased significantly.

5 CONCLUSIONS

Risk of fire or explosion exists in several electrostatic precipitators, mainly because of the production of CO. In the handling and quantitative estimation of this risk fault tree analysis is a useful tool that can help decision making.

In the paper the creation of a simplified fuzzy fault tree was presented illustrating the application of this method for electrostatic precipitators.

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Table 2 Effect of modification in the membership function of a basic event

No. of event	Name of event	type of event or relation	No. of event1	No of event2	min. probability of event	med. probability of event	max. probability of event
1	Fire or explosion	and	2	3	2,15E-06	1,44E-05	3,80E-05
2	Atmosphere in ESP chamber is inflammable	and	4	5	1,84E-04	2,70E-04	3,62E-04
3	Ignition source is present	or	6	7	1,17E-02	5,34E-02	1,05E-01
4	Presence of oxigen	basic			1,00E+00	1,00E+00	1,00E+00
5	Presence of flammable material	or	12	13	1,84E-04	2,70E-04	3,62E-04
6	Breakdown in ESP chamber	basic			1,00E-02	5,00E-02	1,00E-01
7	ESD	or	8	9	1,70E-03	3,55E-03	5,59E-03
8	Intensive back corona	and	10	11	1,60E-03	3,40E-03	5,39E-03
9	Other ESD source	basic			1,00E-04	1,50E-04	2,00E-04
10	$\rho\varepsilon$ of dust is high	basic			8,00E-01	8,50E-01	9,00E-01
11	no measures against back corona	or	14	15	2,00E-03	4,00E-03	5,99E-03
12	Other flammable material	basic			1,00E-04	1,50E-04	2,00E-04
13	Presence of CO	and	16	17	8,40E-05	1,20E-04	1,62E-04
14	Malfunction of rapping control	basic			1,00E-03	2,00E-03	3,00E-03
15	Malfunction of poer supply control	basic			1,00E-03	2,00E-03	3,00E-03
16	Malfunction of CO detection	basic			1,20E-04	1,50E-04	1,80E-04
17	CO formation in the ESP	basic			7,00E-01	8,00E-01	9,00E-01

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