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RELIABILITY AND SAFETY ANALYSIS OF THE PROCESS PLANT

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Abstract

A safety model involves qualitative and quantitative information processing was derived in this paper. Process safety analysis which including qualitative fault event identification, relative frequencies and event probability function as well as consequence analysis was provided. As a case study the ammonia plant production was used. The obtained results have shown successful application cognitive modelling to process reliability analysis. The highest possible uncertainty was obtained when all probabilities are equal one, and zero entropy is ecountered for relationship that are totally deterministic. For accidents detection the model was forcasted the future behavior of the system and than compared this with the actual situation. The obtained results were illustrated useful estimation of the system behaviour during abnormal situation.

Keywords: process safty, reliability, cognitive modelling, fault, frequency event.

1. Introduction

Methods for analyzing system safety and the synthesis for the construction of fault tolerant system are of elementary importance for equipment in the chemical industries. Process safety analysis begin with plant, materials and environmental definition. It includes system components, topology, input and output attributes, state variables, behavior rules and initial scenarios. The control features are qualitative variables description and logic rules for manipulating variables values between systematic states.

The goal of process cognitive reliability analysis is to capture the benefits of common sense reasoning about process malfunction as displayed in human behavior[1-4]. The study of fault detection and diagnosis is concerned with designing that can assist the human operator is detecting and diagnosing equipment faults in order to present accident [5-10]. In this paper process cognitive modeling for safety protection was performed. As case study the ammonia production plant was used. Industrial activities related to ammonia production and processing. The considered system is composed of numerous mutually connected process units: scrubbers, converters, pumps, compressors, coolers, heaters, tank storage and streams.

2. Events model analysis

Frequency and probability analysis involve frequency values of hazards, magnitude identification of each hazard and development a sound criteria for quantification of logic reliability tree.

All hazard, major and minor need to involve. The relationship between hazard and risk must be defined. Consequences modeling develops troubleshooting system, formalizing as a learning tool and creates recommendation to tolerant system building.

The fault event of a system are in the first instance generally formulated in an IF-THEN form. This can be immediately reformulated using the operators AND, OR and NOT in Boolean form, if one can assume that the primary events have only two states existence and non existence.

Starting with the basic variables and their interrelations, the qualitative event model of the system can be formulated successfully in the form of Boolean functions. To make the qualitative model quantitative, the independent variables should be replaced by relative frequencies of the events p_i. Boolean operators AND or OR should be replaced by the algebraic operators $AND(p_1, p_2, p_3,....p_n)$ and $OR(p_1, p_2, p_3,...p_n)$ producing the output frequency p_y from the input frequencies $p_1, p_2, p_{3.},...p_n$.

For quantitative model the term relative frequency instead event probability was used. A probabilistic variables must fulfill this

$$\overline{p_i} = 1 - p_i \tag{1}$$

The possibility membership function of the fuzzy $AND(p_1, p_2, p_{3,}...p_n)$ and $OR(p_1, p_2, p_3,...p_n)$ operators can be obtained considering the variables in eqs(1)-(4) and as fuzzy variables[11-12] and substituting the algebraic operations with the fuzzy operations[6, 11,12]. The $AND(p_1, p_2, p_3...p_n)$ operator assigns for p_y the value *n,*

$$p_y = \prod_{i=1}^{n} p_i \tag{2}$$

For the $OR(p_1, p_2, p_3,...p_n)$ operator should be analogously:

$$p_y = \sum_{i=1}^{n} p_i \tag{3}$$

Eq.(3) does not fulfill the requirement that the relative frequencies must lie in the $0 \le p_i \ge 1$. Therefore, one transforms in the form:

$$p_y = 1 - \prod_{i=1}^{n} (1 - p_i) \tag{4}$$

Function of the event frequency can have a great variety of forms. The width of the membership function is the measure of the spread is infinitely small, the value of the fuzzy is identical to that of the crisp one.

The fuzzy form of the eqs.(2) and (4) using the rule has given in eqs.(5) and (6). The fuzzy value of the relative event frequency must fulfill the requirements: $0 \le p_i \ge 1$ similarity to its crisp value. It should be considered as best estimates in a possibility sense.

$$\overline{p_y} = ANF(\overline{p_1}, \overline{p_2}, \overline{p_3}, ...\overline{p_n}) = \prod_{i=1}^{n} \overline{p_i} \tag{5}$$

The fuzzy form of the eq.(4) is:

$$\overline{p_y} = ORF(\overline{p_1}, \overline{p_2}, \overline{p_3}, ...\overline{p_n}) = 1 - \prod_{i=1}^{n} (1 - \overline{p_i}) \tag{6}$$

The following faults are considered: blockage, leakage, malfunction or missoperation. The study of fault detection and diagnostic is concerned with designing that can assist the human operator detecting and diagnosing equipment faults in order to prevent accidents system.

In this paper the qualitative fault tree and corresponding qualitative model was derived for ammonia plant system. This system represents qualitative events model expressed by logic algebra. M, B, and L are independent logic variables representing the basic events malfunction, blockage and leakage, respectively. Frequencies of the basic events are defined. The middle frequency of leakage for all component was taking to be equal 0.0007. The middle frequency of blockage for all components was assuming to be equal 0.0004, and for malfunction or miss operation was 0.0005. Frequencies of induced events are derived based on frequencies of the basic events. The reliability model was derived by substituting for the logic variables the appropriate event frequencies and using instead of the logic operators Boolean or fuzzy the probability frequency operators as show systems equations (7)-(9).

3. The ammonia plant

As a case study production of the ammonia has been chosen. The plant consists of a ammonia converter, ammonia storage tank, centrifugal circulator, nitrogen wash tower, four scrubbers, exchanger liquid N_2/O_2, shift converter, two dryers, one gas -fired preheated, gas generator, two chiller coolers and two coolers as well as four reciprocating compressors as shown in Fig.1.

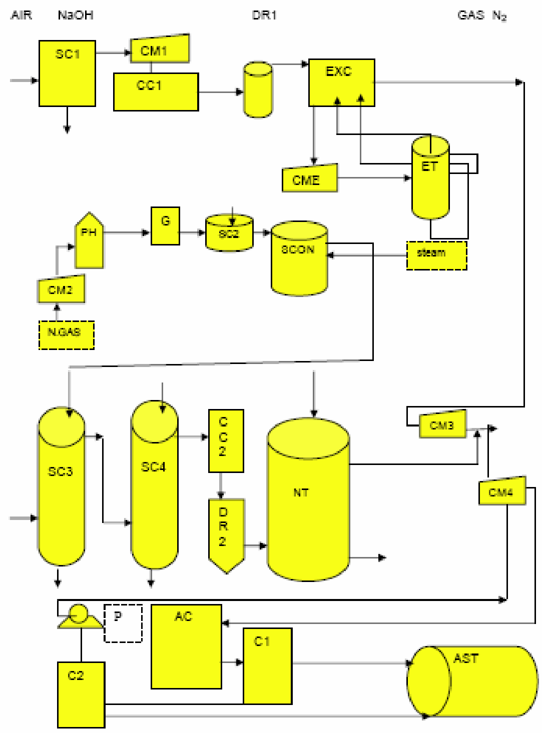

Fig. 1. Ammonia production plant

Also, the system can diagnose for causes of faults associated with state variables pressures, flow rates and temperatures. The qualitative variables are described in three discrete values low, medium and high. Equipment states are also described in qualitative term such as closed, open, failed, blocked and leak. The following faults are considered: blockage, leakage, malfunction or miss operation.

4.The plant reliability

The system topology or component interconnections are defined by the process connections of the working process model.The level of aggregation is defined by the modular component interconnections which define propagation paths of attributes within the system.

The qualitative event model is givenby expression (7) and (8). Fault event tree of the ammonia plant is shown in Fig.2. The quantitative reliability model is given by expression (9). The system equations can be easy solved for all unknown frequencies using the values of the frequencies of the basic events are given. The crisp values of the basic frequencies i should be considered as the best estimated. The unit of the middle frequency of the basic events is in the number of faults per 10^4 hours.

For the fuzzy analysis of the event tree, the Boolean operators were replaced by the fuzzy frequency operators ORF (...) and ANF(. ...). The fuzzy reliability model is given by expression (8).

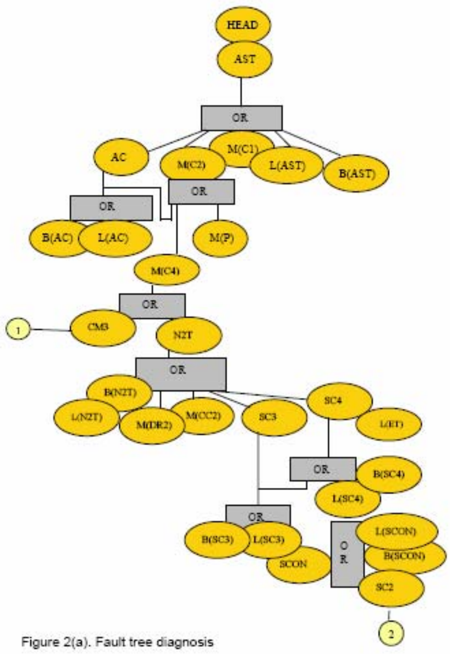

Figure 2(a). Fault tree diagnosis

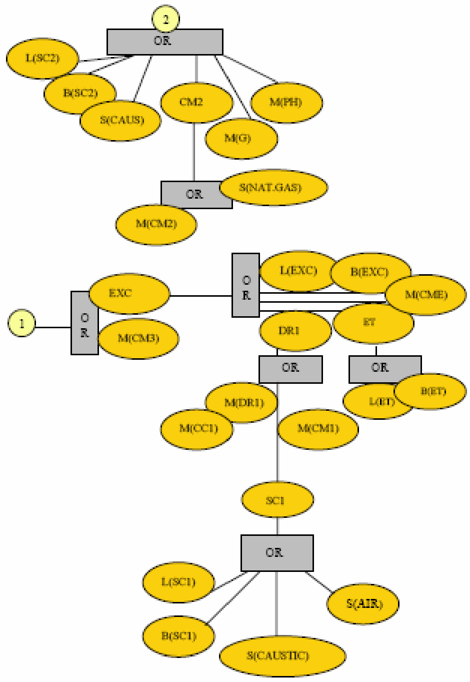

Figure 2(b). Fault tree diagnosis

The qualitative model event equations:

HEAD = AST
AST = B(AST) ∪ L(AST) ∪ M(C1) ∪ M(C2) ∪ AC
AC = B(AC) ∪ L(AC) ∪ M(CM4)
M(C2) = AC ∪ M(P) ∪ M(CM4)
M(CM4) = CM3 ∪ N2T
N2T = L(N2T) ∪ B(N2T) ∪ M(DR2) ∪ M(CC2) ∪ SC4 ∪ SC3
SC4 = L(SC4) ∪ B(SC4) ∪ SC3
SC3 = L(SC3) ∪ B(SC3) ∪ SCON
SCON = L(SCON) ∪ B(SCON) ∪ S(STEAM) ∪ SC2
SC2 = L(SC2) ∪ B(SC2) ∪ S(CAUSTIC) ∪ M(G) ∪ M(PH) ∪ CM2)
CM2 = M(CM2) ∪ S(NAT.GAS)
CM3 = M(CM3) ∪ EXC
EXC = L(EXC) ∪ B(EXC) ∪ $M(CM_E)$ ∪ ET ∪ DR1
ET = L(ET) ∪ B(ET)
DR1 = M(DR1) ∪ M(CC1) ∪ M(CM1) ∪ SC1
SC1 = L(SC1) ∪ B(SC1) ∪ S(AIR) ∪ S (CAUSTIC) (7)

The corresponding fuzzy model:

HEAD = AST
AST = ORF(B(AST), L(AST), M(C1), M(C2), AC)
AC = ORF(B(AC), L(AC), M(CM4))
M(C2) = ORF(AC, M(P), M(CM4))
M(CM4) = ORF(CM3, N2T)
N2T = ORF(L(N2T), B(N2T), M(DR2), M(CC2), SC4, SC3)
SC4 = ORF(L(SC4) ,B(SC4), SC3)
SC3 = ORF(L(SC3), B(SC3), SCON)
SCON = ORF(L(SCON), B(SCON), S(STEAM), SC2)
SC2 = ORF(L(SC2), B(SC2), S(CAUSTIC), M(G), M(PH), CM2)
CM2 = ORF(M(CM2), S(NATGAS))
CM3 = ORF(M(CM3), EXC)

EXC = ORF(L(EXC), B(EXC), M(CM_E), ET, DR1)
ET = ORF(L(ET), B(ET))
DR1 = ORF(M(DR1), M(CC1), M(CM1), SC1)
SC1 = ORF(L(SC1), B(SC1), S(AIR), S(CAUSTIC)) (8)

The quantitative reliability model:

pHEAD = 1-pAST
pAST = 1-(1-pB(AST)) (1-p L(AST))(1-pM(C1))(1- pM(C2)) (1- pAC)
pAC = 1-(1- pB(AC))(1-pL(AC))(1-pM(CM4))
pM(C2) = 1-(1-pAC) (1-pM(P)) (1-pM(CM4))
pM(CM4)= 1-(1-pCM3)(1-p N2T)
pN2T = 1-(1-pL(N2T)),(1-p B(N2T))(1-pM(DR2)) (1-pM(CC2))(1-p SC4) (1-pSC3)
pSC4 =1-(1-pL(SC4)) (1-pB(SC4)) (1-pSC3)
pSC3 = 1-(1-pL(SC3)) (1-pB(SC3)) (1-pSCON)
pSCON = 1-(1-pL(SCON))(1-pB(SCON))(1-p S(STEAM) (1-pSC2)
pSC2 = 1-(1-pL(SC2))(1-p B(SC2)) (1-pS(CAUSTIC))(1-p M(G)) (1-pM(PH))(1-pCM2)
pCM2 =1-(1-pM(CM2))(1-p S(NAT.GAS))
pCM3 = 1-(1-pM(CM3))(1-p EXC)
pEXC =1-(1-p L(EXC)) (1-pB(EXC))(1-pM(CM_E)) (1-pET)(1-p DR1)
pET = 1-(1-p L(ET))(p B(ET))
pDR1 = 1-(1-p M(DR1)) (1-pM(CC1))(1-pM(CM1))(1-pSC1)
pSC1 =1-(1-p L(SC1)) (1-pB(SC1))(1-pS(AIR)(1-pS (CAUSTIC)) (9)

C++ programming language was hosen for the development simulation model.

5.The cognitive model

The quality of a structural relationship is determined through entropy of the state transition matrix, which determines its forecasting power over a single step[1,4,5,13,14]. The new information value is obtaining from information streams. The formed information value is:

$$I_{v(new)} = H = -\sum_{i=1}^{n} p_i\,(output\ /\ input)\log_2 p_i(output\ /\ input) \qquad (10)$$

where I_v new information value, H entropy and p probability of scenario occurring.

$$\Phi_i = \frac{I_v}{N \times t} \qquad (11)$$

where N number of sequencies, t time and Φ_i information flux, *Byte /s.*

If it is employed the methodology which including ratio of observation, then observed ratio Q_r can be introduced as an additional contributor to the overall quality of measure. That reduces the mask quality if states exist that have been observed less than eight times.

$$I_m = HQ_r$$

where Q_r = (8e +7d+6j+5s+4m+3k+2l+1i)/8n, and n is the total number of legal input states, e is the number of input states observed eight times, d is the number of input states observed seven times, j is the number of input states observed six times, s is the number of input states observed five times, m is the number of input states observed four times, k is the number of input states observed three times, k is the number of input states observed three times, l is the number of input states observed two times, and i is the number of input states observed only once.

Further, information capacity can be defined as:

$$C_i = (I_m + I_v)Nxt \qquad (12)$$

The probability that each malfunction will take place and information value for each functionality event can be determined trough entropies of the state transition matrix.

The highest possible uncertainty is obtained when all probabilities are equal one, and zero entropy is ecountered for relationship that are totally deterministic.

6.Results

The outlet results are shown in Figure 3 –Figure 5. The fault event analysis for nitrogen tower is shown in Figure 3. When leackage is occurs in the upstream unit, the influence of leakage on the up stream unit can not be removed by closing the equipment. However, when the leackage occurs in the down stream unit the influence of leakage on the down stream unit may be removed by closing the equipment.

Figure 4 shows SC4-scrubber faults qualitative occuring analysis. In Figure 5 the effect of the supply is not occuring to the head event was shown.

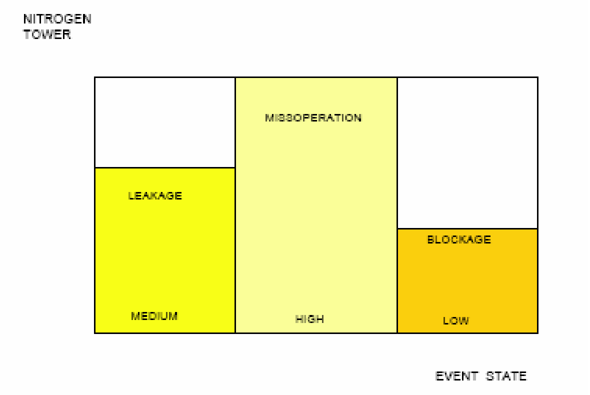

Figure 3. The outlet results for nitrogen tower

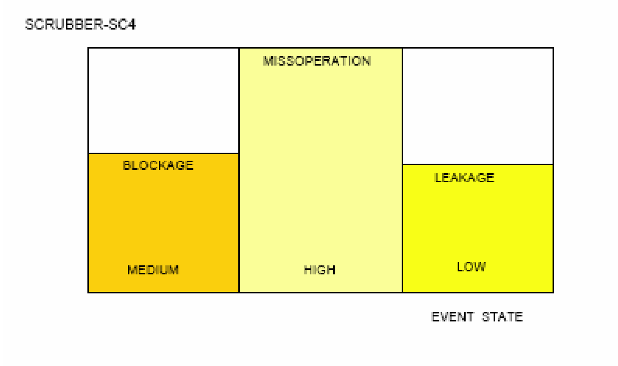

Figure 4. Scrubber-SC4 analysed faults

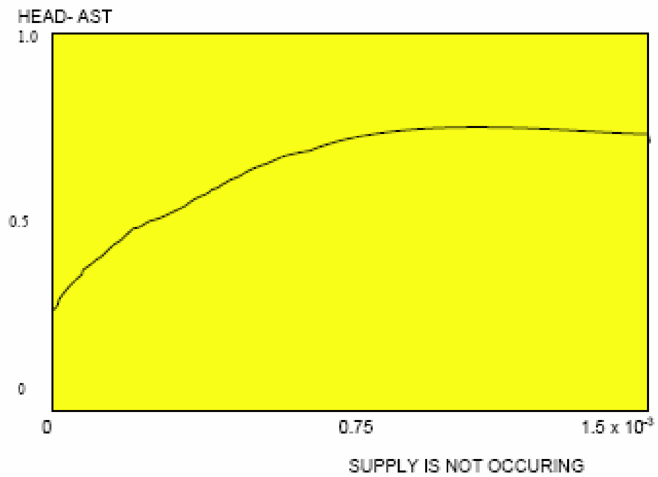

Figure 5. Head event frequency vs. supply basic frequencies

7.Conclusions

In this paper the process plant safety protection model was derived. Also, information flux and capacity for information streams were derived. The new information value is obtaining from information streams.

This paper illustrates hazard identification, frequencies and probability functions and reliability analysis for the ammonia production plant. The simulator for reliability system and prevention of accidental situation is realized through development of logical frame. Its knowledge base is composed of material streams and equipment units, and database is composed of occurred events and faults at a single unit and process variable state data. The paper has given the additional information value obtaining. If the difference n information between scenarios is high, and the amount of time needed to observe this symptom is low, then the information value of the tested symptom is high. Expressions for information flux and capacity were derived. The obtained results have shown successful application cognitive dispersion modeling for process reliability analysis and safety protection.

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Symbols

B	blockage	M	malfunctionor missoperation
C	capacity	L	leakage
Φ	information flux, Byte/s	*N*	number of sequencies
H	uncertainty (entropy)	*P*	probability of scenario occuring
I	information value, Byte	Q_r	observed ratio

Abbervation

AC	ammonia converter	G	gas generator
AST	ammonia storage tank	N.GAS	natural gas
C	cooler (condenser)	NT	nitrogen tower
CC	chillercooler	P	pump
CM	compressor	PH	preheater
DR	drayer	SC	scrubber
ET	expander tower	SCON	shift converter
EXC	exchanger		

References

[1] Savkovic-Stevanovic J.: Cognitive Reliability Analysis of the Process Plant, *Computer, Aided Process Engineering-15*,(ED.L.Puijagner, A.Espuna), Elsevier,Vol.20, 342-347,2005.

[2] Savkovic-Stevanovic, J., Krstic, S.:Risk reduction support system of the phenol recovery plant , Petroleum & Coal, 48,6-13,2006.

[3] Savkovic-Stevanovic, J.: Process plant risk analysis and modelling, *Computer Aided Process Engineering -17*,(V.Plesu and P.S.Agachi, Elsevier,Vol.24, 1229-1234,2007.

[4] Savkovic-Stevanovic, J.: Process Plant Cognitive Modeling, *Computers & Ecological Engineering*, 1, 23-28,2005.

[5] Savkovic-Stevanovic, J.: The chemical plant management qualitative support system, *Chem. Ind.,*58,123-127,2004.

[6] Savkovic-Stevanovic, J.: Fault locator of an allyl chloride plant, *Chem. Ind*., 58,401-408,2004., *Ind.*,58,123-127,2004.

[7] Carter, D. A., Hirst I.L., Maddison T.E., Porter S.R.: Appropriate risk assessment methods for major accidents establishment, Tran IChem, Part B, Process Safety Environmental Protection, 81, 12-18,2003.

[8] Albornoz, A., Cellier F.E.: Qualitative simulation applied to reason inductively about the behavior of a quantitatively simulated aircraft model, *Proceedings of QUARDET'93- Qualitative Reasoning and Decision Technology,* Barcelona, Spain, pp.711-721,1993.

[9] Savkovic-Stevanovic J.: A framework for qualitative simulation in process engineering, *Computers & Chemical Engineering*,16,127-134,1992.

[10] Savkovic-Stevanovic, J.: A qualitative model for estimation of a plant behavior, Computers *& Chemical Engineering*, 18,713-717,1994.

[11] Zadeh, L.A.: *Fuzzy Set Systems,*11,1199-1227,1983.

[12] Zimmermann, H.J.: *Fuzzy sets, decision making and expert systems,*Kluwer Nijhoff, Boston,1987.

[13] Savkovic-Stevanovic,J.: *Informatics,* FCT, Belgrade, Serbia,2007.

[14] Savkovic-Stevanovic, J.: Capacity information modelling of the process plant, *Computers & Ecological Engineering*,2,1-7,2006.