A Short Report

Determination of Safety Integrity Level (SIL) using LOPA method in the Emergency Shutdown System (ESD) of Hydrogen unit

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ABSTRACT
Petrochemical plants are high risk, high parameter, and high-energy units, with the potential risks of fire, explosion and poisoning. The severe accidents at Bhopal, Mexico City, Samton, Brazil, Panipat, Mumbai and many others have increased the public awareness of the health, property and environmental risks posed by chemical installations. The recent years have seen a convergence of scenario-based Hazard and Operability (HAZOP) studies, Layer of Protection Analyses (LOPAs), and Safety Integrity Level (SIL) determinations. The aim of the research was to study the hazardous scenario identified in the hydrogen unit of petrochemical plant and to determine the SIL for ESD system. 20 hazardous scenarios identified by HAZOP study and determined by SIL by applying the LOPA method for ESD system, were used to control the hazardous scenarios. KS-1, KS-2 and KS-3are three ESD systems applied in the hydrogen unit. The maximum SIL determined for ESD system was SIL3. Since the rise in SIL can be quite costly for the industry, adding other layers of protection can reduce the level of SIL for ESD (SIS).

Key words: HAZOP study, LOPA, SIL, ESD

INTRODUCTION
The chemical process industries are characterised by the use, processing, and storage of large amounts of dangerous chemical substances and/or energy [1]. The severe accidents at Bhopal, Mexico City, Samton, Brazil, Panipat, Mumbai and many others have increased public awareness towards the health, property and environmental risk posed by chemical installations [2]. Petrochemical plants are high risk, high parameter, and high-energy units, with the potential risks of fire, explosion and poisoning. Intrinsic safety for the petrochemical plant is to use technological measures to eliminate or control risks and to prevent accidents, as to avoid damages and losses [3]. The basic concept behind HAZOP studies is that processes work well when operating under design conditions. When deviations from the process design conditions occur, operability problems and accidents can occur. The HAZOP study method uses guide words to assist the analysis team in considering the causes and consequences of deviations. HAZOP (Hazard and Operability Study) is a systematic safety study, based on the systematic approach toward an assessment of safety and operability of complex process equipment or the production process [4]. Various types of process hazards analyses (PHA) are currently in widespread use throughout the process industry. The PHA process can be supplemented with Layers of Protection Analysis (LOPA) to provide an order of magnitude estimate of the hazardous event frequency by assessing the frequency of the initiating events that lead to the hazardous event and the probability that the safeguards fail [5]. LOPA is a simplified form of risk assessment. LOPA is an analysis tool that typically builds on the information developed during a qualitative hazard evaluation, such as a process hazard analysis [6]. LOPA is one of a number of techniques developed in response to a requirement within the process industry to be able to assess the adequacy of the layers of protection provided for an activity [7]. In chemical processes several protection layers are used, and in LOPA the number and the strength of these protective layers are analyzed. LOPA can be considered as a simplified form of a quantitative risk assessment. It can be used after a hazard and operability analysis (HAZOP), and before a quantitative risk analysis (QRA). A difference between LOPA and other tools is that LOPA analyzes the different protective layers individually, and the mitigation they lead to [8]. Using a multi-disciplined team, the consequences identified in the HAZOP are listed as impact events and are classified for severity level. The initiating causes are listed for each impact

event and likelihood is estimated for each initiating cause. Independent Protection Layers (IPLs) are listed, including process design, basic process control system, alarms and procedures, safe instrumental systems, and additional mitigation (Figure.1).

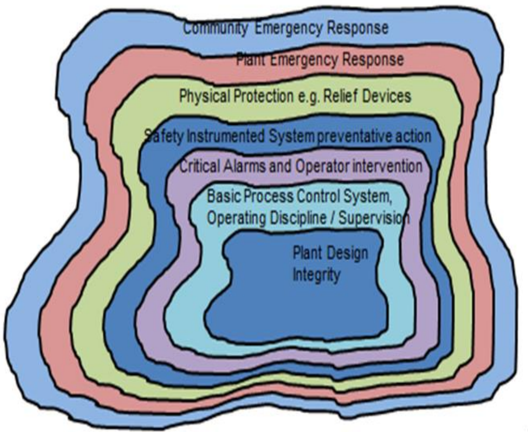

Fig. 1: .Layers of protection in process industries. (CCPS, 2001)

Each IPL is assigned a probability of Failure on Demand (PFD) [9]. Recent years have seen a convergence of scenario-based Hazard and Operability (HAZOP) studies, Layer of Protection Analyses (LOPAs), and safety integrity level (SIL) determinations [10]. Safety Instrumented Systems (SISs) is commonly used in the process industry, to respond to hazardous events. In line with the important standard IEC 61508, SISs are generally classified into two types: low-demand systems and high-demand systems. SIS reliability is quantified by the probability of failure on demand (PFD) and the frequency of entering a hazardous state that will lead to an accident if the situation is not controlled by additional barriers [11].

MTERIALS AND METHODS

This study is one of risk assessment studies used particularly in the petrochemical industry.

Some methods of risk assessment are limited to certain industries and are not applicable in others this study uses two techniques of risk assessment, HAZOP study to determine the hazardous scenario and the Layers of Protection Analysis (LOPA) to determine the SIL required for ESD System (SIS). HAZOP study is a risk assessment method that is commonly used in process industries to determine deviations of normal operations by application of a guide word and process parameters.

Guide words+ Parameters = Deviations
Example: NO/Less + Flow = No/Less Flow

Also, LOPA is a method of risk assessment for process industries, which are usually carried out after the HAZOP study or before the FTA technique. The information required for HAZOP study of the process unit includes:

• Process flow diagram (PFD)
• Piping & instrument diagram (P&ID)
• Cause & Effect Chart
• Plot Plan Diagram
• Comprehensive Process Description
• Material & Energy Balance

This unit has been designed with the following headings of ESD system as marked in the P & ID drawings:

1) KS-1: Signal from ESD system (Reformer shutdown)
2) KS-2: Signal from ESD system (PSA shutdown)
3) KS-3: Signal from ESD system (Startup compressor auto start/stop)

Hazardous scenarios were identified from HAZOP studies and were used as inputs for the LOPA method. This dangerous scenario is expressed as deviations in HAZOP studies. In LOPA method, the initiating event should be determined for each of the hazardous scenarios and constitute the equivalent expression for the deviation in the HAZOP method. To determine the frequency of initiating event in the table series summarized in data bases and handbook of equipment process was used. These data bases were obtained from different references including the Center for Chemical Process Safety (CCPS) and OREDA data book. Effectiveness of layers of protection is expressed as the probability of failure in demand time (PFD) and the malfunction of a system is defined as the time required.

Intermediate Event Frequency (IEF) was calculated from the following formula:

Intermediate Event Frequency (IEF) = Initiating Event Frequency × PFD1 ×PFD2 × … × PFD n

To determine the tolerable frequency the risk criteria were used in the following risk matrix (Table1).

Risk reduction factor (RRF) was obtained from the following formula and by application of the two parameters including the Intermediate Event Frequency (IEF) and the tolerable frequency risk criteria.

RRF= (Intermediate Event Frequency / Tolerable Frequency Criteria)

PFD avg. =1/RRF

SIL for SIS (ESD) was determined from RRF calculated by used of table 2.

Table 1: LOPA risk matrix

Likelihood	1	2	3	4	5
>1/10(year)	M	M	H	H	H
>1/10=<1/100	L	M	M	H	H
>1//100=<1/1000	L	L	M	M	H
>1/1000=< 1/10000	L	L	L	M	M
>1/10000	L	L	L	M	M
	Severity of Consequences				

Risk Ranking	Description
L(Low)	Acceptable Level of Risk
M(Medium)	ALARP Region
H(High)	Risk not Acceptable

Table2: Safety Integrity Level (SIL)

SIL **Safety integrity level**	**PFD$_{avg}$** **Average probability of failure on demand per years(low demand)**	**RRF** **Risk Reduction Factor**
SIL4	$\geq 10^{-5}$ and $<10^{-4}$	100000 to 10000
SIL3	$\geq 10^{-4}$ and $<10^{-3}$	10000 to 1000
SIL2	$\geq 10^{-3}$ and $<10^{-2}$	1000 to 100
SIL1	$\geq 10^{-2}$ and $<10^{-1}$	100 to 10

RESULTS

In HAZOP studies of PSA, a part of the hydrogen unit in the Tower 2001 A was as selected the node and the high pressure was examined as the deviation (Table3). In this study, the risks of lower rupture and explosion in the tower were examined and it was proposed to install the PSV on the tower to mitigate the high pressure in it. This node was chosen as a dangerous scenario and entered the LOPA method to evaluate for the Independent Protection Layers and to determine the SIL for ESD system used to shut down the unit in dangerous state (Table4).

Table 3: A typical of HAZOP worksheet

Node: 20. T2001A					Drawings: 10-SFC/20-A1PR-0001	
Type: Tower					Equipment ID: 2001A	
Design Conditions/Parameters: ASME Standard design for pressure vessels(11BAR/40C)						
Deviation: 1. High Pressure						
Causes	**Consequences**	**Risk Matrix**			**Safeguards**	**Recommendations**
		S	L	RR		
Control valve (PV2504) Fail	1 Fire and Explosion	4	3	12	1.Gas Detector installed 2. Fire proofing the Tower	PSV Installed on 50-P2103 Header Line
	2.Tower Rupture	3	3	9	1.same as above	

Table 4: A typical of LOPA worksheet

Node: 20. T2001A

Critical Hazardous Scenario	Initiating Event		Consequence		Independent Protection Layers					Intermediate Event Frequency	Risk Tolerance Criteria (Frequency per	Risk Reduction Factor	SIL for SIF	Action Required
	Description	Freq	Description	S	Description	Types of IPLs	PFD	TPFD	1/Total PFD	IEF	Tolerable			
High pressure in Tower 2001A	PT2504 control loop with PV2504 fail	1.00E-01	Tower rupture, leakage of gas & fire and explosion	4	N/A	Non-IPL Safeguard	1.00E+00	1.00E+00	1	1.0E-01	1.00E-04	1.0E+03	3	SIL 3 needed for KS-2 ESD but by use of the PSV installed on header line,SIL2 adequate for KS-2 ESD

DISCUSSION

In HAZOP study of this node, the high pressure deviation due to PV2504 failure was studied. This pressure controls valve along with the pressure transmitter and the logic solver constitute the pressure control loop. Consequences of high pressure deviation in the tower included tower rupture, fire and explosion so, with such consequences, level of risk will increases. Existing safety system includes a gas detector and fire proofing system for high pressure in the tower. Existing safeguards to prevent this deviation is low and in HAZOP study, installing of PSV recommended on the tower. Insufficient independent layer of protection for process deviations can lead to dangerous scenarios that must be considered by the designer in the process design [6].The determination of safety integrity level by using LOPA, independent layers of protection against dangerous scenario could not be determined. This hazardous scenario evaluated that the basic process control system and F&G system used for control and mitigate in consequence event. F&G systems are considered of mitigate and independent layer in LOPA that can be effective in reducing the safety integrity level. In LOPA method, the initial event was the pressure control loop failure, for which an independent layer of protection against dangerous scenario was determined. According to evaluation of F&G system, this system has no condition of independent protection layers. Without sufficient IPLs to control and mitigation of hazardous scenario, initiating event has led to severe consequences, such as release of flammable and toxic materials, fires and explosions, and threats to human lives, properties and the environment [12]. Based on the Intermediate Event Frequency (IEF) formula, the value was calculated as 1.0E-01. Risk Tolerance Criteria value was equal to 1.00E-04 and finally. The SIL3 was determined for the ESD system used for high pressure deviation in the tower [14]. Lack of independent protection layers can reduce the number of IEF and therefor RRF increased, As a result, the safety integrity level for ESD systems will increases. However, by adding layers of protection such as pressure safety valves on the tower, IEF amount reduced, As a result of the IEF decreased, the safety integrity level reach to SIL2.

CONCLUSION

Risk of fire, explosion and toxic releases in petrochemical plant is high. Therefore, risk assessment is a requirement in process industries and HAZOP study is the common method of process risk assessment used by these industries. To identify the dangerous scenario of HAZOP study, a risk matrix needs to be selected; however the deviations are not within the acceptable level of risk. For closer examination of the adequacy of the existing safety system, the LOPA method, which is a semi quantitative technique, was applied. LOPA can be used to determine the SIL for SIS. The independent protection layers were identified and finally, the Risk Reduction Factor (RRF) was calculated according to the initiating event frequency, the PFD of independent protective layers and the tolerance risk criteria, and the required SIL for the SIS was determined on the basis of RRF (Table4). Since the rise in SIL can be quite costly for the industry, adding other layers of protection can reduce the level of SIL for ESD (SIS).

REFERENCE

[1] Adam S, Markowski and M, Sammanan. ExSys-LOPA for the chemical process industry. 2010; 23(6): 688-96.
[2] Faisali, Khan .S, A, Abbasi. Opt-HAZOP an effective and optimum approach for HAZOP study.1997; 10(3): 191-04.
[3] Feng Wang. Yajun Chen. Haochen Wang. Cunyin Chen. Bin Shi. The Intrinsic Safety Engineering Design Method for the Petrochemical Plant. 2012; 43: 156 – 61.
[4] U.S. Department of Energy Washington. DC.20585. Chemical Process Hazards Analysis. 1996.
[5] Angela Summers. William Vogtmann. Steven Smolen. Improving PHA/LOPA b consistent consequence severity estimation. 2011; 24(6):879-85.
[6] Arthur M, Dowell. Dennis C, Hendershot. Simplified Risk Analysis-Layer of Protection Analysis (LOPA). 2002; 281a.
[7] Andrew Franks. Lines of Defense/Layers of Protection Analysis in the COMAH Context.1999.
[8] Christopher A, Lassen. Layer of protection analysis (LOPA) for determination of safety integrity level (SIL). 2008.
[9] Arthur M, Dowell. Layer of protection analysis for determining safety integrity level. 1998; 37(3): 155-65.
[10] Robert W, Johanson. Beyond-compliance uses of HAZOP/LOPA studies. 2010; 23(6): 727-33.
[11] Yillin Liu. Marvin Rausand. Reliability assessment of safety instrumented systems subject to different demand modes. 2011; 24(1): 49-56.
[12] Chunyang Weia. William J, Rogersb. M, Sam Mannanb. Layer of protection analysis for reactive chemical risk assessment. 2008; 159(1): 19–24.
[13] Clementina Ramírez-Marengoa. Julio de Lira-Floresa. Antioco López-Molinaa. Richart Vázquez-Romána. Victor Carreto-Vázquezb. M. Sam Mannanb. A formulation to optimize the risk reduction process based on LOPA. 2013; 26(3): 489–94.
[14] IEC 61508. Functional safety of electrical/ electronic/programmable electronic Safety-related systems International Electro technical Commission. 2003; Geneva.