Assessment of Safety Integrity Requirements for Fired Heater System in Accordance with IEC 61508

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Abstract**—** *The present paper aims to describe the key concepts of Safety Integrity Level (SIL) of identified Safety Instrumented Functions (SIFs) in accordance with various national and worldwide safety standards such as ANSI/ISA84 and IEC 61508/61511, to process industry fired heater installed in the existing crude distillation unit, which is located in industrial zone at Skikda in Algeria. Then, discusses the application of the two approaches for SIL determination, the popular quantitative method FTA (Fault Tree Analysis) which designed to calculate SIL requirements and semi quantitative method adopted for SIL Target determination of various identified SIFs. Finally, it provides the reduction of risk to an acceptable level and show that the equipment is suitable for use in safety integrity level.*

Keywords— *risk assessment, safety integrity level, fired heater, quantitative and semi quantitative methods.*

I. INTRODUCTION

Safety requirements for people, equipment and the environment follow state-of-the-art technology, as a binding and legal requirement. That is why companies are now actively taking steps to comply with multitude safety standards for risk assessment [1]. The Instrument Society of America (ISA) [2] enacted this standard ISA S84.01, to evaluate the safety integrity level (SIL) of the safety instrumented system (SIS) for the process industry, to accomplish the desired safety target. Subsequently, the International Electro-technical Commission (IEC) enacted international industry standards IEC 61508 [3] and IEC 61511 [4]. The IEC 61508 standard addresses electrical, electronic and programmable electronic safety related systems (E/E/PE SRS) and represents a guide for design, operation, validation and verification of a safety-instrumented system by introducing the concept of a life cycle model which main purpose is to bring the plant to a safe state if an undesirable event occurs. The standard defined four discrete levels (1 to 4) for safety integrity named “safety integrity level” (SIL), where level 4 (SIL 4) corresponds to the higher level and level 1 (SIL 1) to the lowest one. The four levels are indexed to a specific probability to fail on demand (PFD) which a SIL assignment is based on the required risk reduction measures [5]. The standard 61511 [4], functional safety - safety instrumented systems for the process industry sector, is an international standard designed to be used as a companion to IEC 61508, for safety instrumented system integrators and designers, in the process control sector. Standards applied for risk management based on SIL differ in methods used for risk evaluation and SIL determination, such as, the Risk Graph method, the Management Oversight and Risk Tree (MORT) method, the Safety matrix method, the Layer Of Protection Analysis (LOPA) method, the Fault Tree Analysis (FTA) or Event Tree Analysis (ETA) method, and Safety layer matrix method. Are some of the methods used to study and determine the SIL requirements [5]. In this study, the methodology used is quite similar to the Bendib et al [6]’s work. The proposed one is structured to take into account the dangerous failures of SIF (consequences related to personnel health and safety, consequences related to production and equipment loss, and consequences related to the environmental impact) for the determination of safety performance of each safety function from the risk assessment in accordance with IEC 61508. For the instrumentation classification and evaluation in the process industry fired heater, the process SIL must still be determined by simplified calculations, fault tree analysis.

The present paper is organized as follows. The second section, gives a brief description of concepts and methods used to find the levels values of safety integrity for process industry. In the third section, a methodology used and the operation of process system were presented. The fourth section summarizes the SIL results. The final section concludes this current study.

II. Safety Performances

Safety is defined as the absence of any unacceptable risk of physical injury or to personnel health injury. A risk is defined as the product of the frequency and consequence of an event. It can be evaluated qualitatively or quantitatively [7].

A. Safety Instrumented System

A safety-related system, which referred to as an SIS (safety instrumented system), and ESD (Emergency Shutdown System), has three elements: sensors, logic solvers, and actuators. The first element detected the occurrence of a hazardous event, the second one present to decide what to do (programmable logic devices, multi-agent structure, etc.), and the third element performed one or more safety instrumented functions [5]. An SIS designed to prevent the hazardous event by reducing the risk [7].

B. Safety Function

Safety Function is part of the overall safety that depends on a SIS, it designed to ensure or maintain a safe state of the SIS when a dangerous event occurs, and each SIF has a safety integrity level (SIL) [7].

C. Safety Integrity Level

Safety integrity level is a statistical representation of integrity of the SIS when a process demand occurs. SIL used to evaluate electrical/electronic/programmable electronic (E/E/PE) systems in terms of the reliability of safety functions. The safety integrity level is a classification of a safety instrumented function (SIF). The SIL is determined by the estimation of the probability of failure on demand (PFD), when a low demand mode occurs, or by the probability of failure per hour (PFH), when a high demand mode occurs, that an SIS can satisfactorily perform the required safety function. In the low demand rate, the average probability of failure on demand (PFDavg) is likelihood that a SIS component will not be able to perform its safety action when called upon to do so. Hence, the appropriate measure of performance of the function is PFD, or its reciprocal, risk reduction factor (RRF). When a high demand occurs (operate continuously), the probability of a dangerous failure per hour (PFH) is sometimes referred to as the frequency of dangerous failures, or as the dangerous failure rate. Provided failures are exponentially distributed. Table 1 shows the safety integrity levels in accordance to IEC 61508 for the two situations above mentioned. Since, SIL 3 is the highest safety level used in the process industries. Of the three commonly used levels, SIL3 has the greatest safety availability, and therefore the lowest average probability of failure on demand (PFD) [3], [5], [7].

TABLE 1. Definitions of SILs for Low & high Demand

SIL	Low demand mode	High demand mode
	Range of PFDavg	*Range of PFH*
4	$10^{-5} \leq PFD < 10^{-4}$	$10^{-9} \leq PFD < 10^{-8}$
3	$10^{-4} \leq PFD < 10^{-3}$	$10^{-8} \leq PFD < 10^{-7}$
2	$10^{-3} \leq PFD < 10^{-2}$	$10^{-7} \leq PFD < 10^{-6}$
1	$10^{-2} \leq PFD < 10^{-1}$	$10^{-6} \leq PFD < 10^{-5}$

III. Methodology

The feedstock for the existing crude distillation unit of Skikda refinery plant is raw crude oil, which is either indigenous or imported. This crude oil was separate into various fractions as given: Fuel Gas, LPG, C6 Cut, Naphtha A, Naphtha B, Naphtha C, Kerosene, Light Gas Oil, Heavy Gas Oil, RCO. The crude unit is the mother unit in any petroleum refinery, and the design of fired heater in particular remains one of the most important applications of heat transfer. Therefore, the methodology adopted for the SIL classification study is to investigate the SIL for fired heater 10-F1A of the crude distillation unit-I (CDU-I, Unit No. 10) of Skikda refinery [8].

A. Application Study

Fired heater or Furnace, is equipment used to provide heat for a process [9]. Today many of the refinery processes require hydrogen, and a lot of the hydrogen-rich off gases, which were previously used as heater fuel, are now needed to meet this demand.

In the atmospheric heater section, the preheated crude is heated and partially vaporized in the existing charge heaters 10-F1A. The heater outlet temperature, which is indicated by 10-TI-48 and 10-TIC-13, and controlled through temperature pressure cascade control in burner fuel gas line 10-PIC-5, is 359 degree c [10]. The heater 10-F1A has eight no. of passes with an individual flow control and low flow cut off. A pass balancer has been added for heater to achieve uniform coil outlet temperature, the input to pass balancer is the total crude flow to the heater. The fired heater has 32 burners capable to be supplied by natural gas or fuel gas of refinery; also, it has its pilot burner supplied by gas. Gas pressure for pilot burners of furnace is controlled by 10-PCV-1 and indicated by 10-PI-37, total fuel gas entering to the heater is indicated by 10-FI-14 and 10-FI-39. Over-heating coil of low-pressure steam has been installed in the high zone of heater to improve the heat recovery. LP steam is superheated to 505°C. At the outlet of steam line the ATM heater-A steam desuperheater 10-X-51 has been located, it performs desuperheating of the outgoing steam by injecting MP-BFW, and it reduces the temperature of steam to 330°C [8].

To prevent major accidents from occurring and ensuring the safe design and operation of a system in process is the performance objective of process heater by maximizing the safety integrity levels [6]. The global view of the equipment study is shown in Figure 1. Therefore, all heaters had similar configuration of instruments that should be controlled, and same operation philosophy.

B. Safety Integrity Level Determination (SIL Target)

Risk matrix is used for SIL target determination of various identified safety instrumented functions in the process; this methodology comprises the classification of SIF dangerous failures. Which take into account: consequences related to personnel health and safety, consequences related to production and equipment loss, and consequences related to the environmental impact [3].

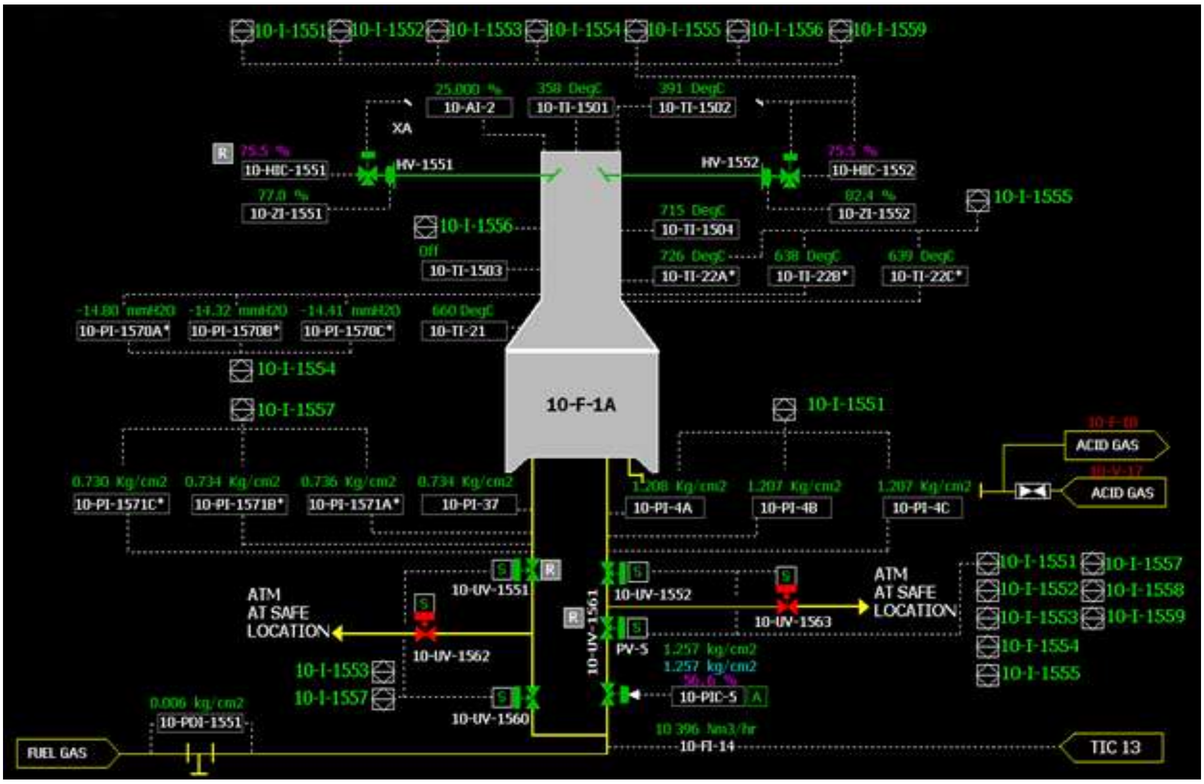

Fig.1. Instruments configuration of fired heater 10-F1A.

TABLE. 2. DANGEROUS FAILURE CLASSIFICATION MATRIX

Consequence Severity	Consequence Category			Demand Rate Category				
	S	*E*	*L*					
	Health & Safety	*Environment*	*Economic*	*D0*	*D1*	*D2*	*D3*	*D4*
C0	S0	E0	L0	-	-	-	-	-
C1	S1	E1	L1	-	-	a1	a2	a2
C2	S2	E2	L2	-	a1	a2	1	2
C3	S3	E3	L3	-	a2	1	2	3
C4	S4	E4	L4	-	1	2	3	4(X)
C5	S5	E5	L5	-	2	3	4(X)	X

Where:

S0: No injury or health effect
S1: Slight injury or health effect
S2: Minor injury or health effect
S3: Major injury or health effect
S4: Between 1 and 3 fatalities
S5: Multiple fatalities
D0 = Negligible
D1 = > 20 years
D2 = 4 – 20 years
D3 = 0.5 – 4 years
D4 = 0 – 0.5 years
a1,a2 = No special safety requirement
1,2,3,4 = SIL value
4 (X) = SIL-4 functions are to be avoided

E0: No effect
E1: Slight effect
E2: Minor effect
E3: Localised effect
E4: Major effect
E5: Massive effect
L0: No loss
L1: Slight loss
L2: Minor loss
L3: Local loss
L4: Major loss
L5: Extensive loss

The resulting risk reduction of the potential health and safety consequences is concluded in Table 3.

TABLE. 3. REDUCTION OF PERSONNEL HEALTH AND SAFETY

		Exposure		
		F1	*F2*	*F3*
Possibility to Avert Danger	*P3*	-1	0	0
	P2	-1	-1	0
	P1	-2	-1	-1

Where:

F1: Very rare (<10 man-minutes per day)
F2: Occasional (<6 man-hours per day)
F3: Frequent to continuously (> 6 man-hours per day)
P1: In almost all circumstances
P2: In some circumstances
P3: Little or none

By using the results of a hazard and operability study from experienced experts [10], the event scenarios were extracted. Then the corresponding safety integrity level was determined. As an example, the termination of SIL for the SIF, FALL, is shown in Table 4. Accordingly, SIL for such SIFs have been classified considering worst possible hazard consequences.

TABLE. 4. SIL CLASSIFICATION

SIL Classification			
System	*Atmospheric Heater-A Section*	*SIF No*	*10-I-1552*
SIF Definition	**Low -low flow of crude for each pass (FALL-2A-1-2H-1)**		Fired Heater
	Close Fuel gas supply to 10-F-1 A (10-UV-1552, 10-UV-1561), Open (10-UV-1563) to atm, Close acid gas supply (10-XX-1)		(10-F1A)
	Open dampers for atmospheric heater (10-HV-1551, 10-HV-1552)		
	Start RCO circulation by Opening 10-UV-1751 and Close RCO rundown by closing 10-UV-1752.		
Causes	Tripping of crude supply pumps (10-P-72A/B/C or 10-P-61A/B/C) or malfunction of pass flow control loop.		
Protection Layers	FALL-2-1 provided on booster pump discharge line (This protection layer may not be applicable when flow is low in any single pass).		
Hazardous Scenario	Carryover of lighter fraction. Possible flammable hazard.		
Risk of injury to people			
S-Value	S0	**S-Justification**	No injury to the personnel in the vicinity.
P-Value	NA	**P-Justification**	
F-Value	NA	**F-Justification**	
S Reduction	NA	**MOD S-Valeur**	S0
D-Value	D3	**D-Justification**	Considering no protection layer is provided for low flow in individual passes.
Risk SIL	-	(Refer Risk Matrix)	
Economic Risk			
L-Value	L4	**L-Justification**	Major damage to the heater, shut down of CDU and downstream units for a long period.
D-Econ Value	D3	**D Econ-Justif**	Considering no protection layer is provided for low flow in individual passes.
Econ SIL	3	(Refer Risk Matrix)	
Environment Risk			
E-Value	E0	**E-Justification**	No environment is expected.
D-Env Value	D3	**D-Env-Justif**	Considering no protection layer is provided for low flow in individual passes.
SIL Env	-	(Refer Risk Matrix)	
OVERALL SIL CLASSIFICATION			**3**

C. Safety Intedrity Level Determination (SIL Calculated)

Quantitative risk assessment performed by modeling the SIS system using the classical method FTA. To understand how to make use of the FTA information outlined in this report, a typical study for simple SIS is given in Figure 2. The system consists of two redundant transmitters, logic solver and one shut-off valve including the solenoid [8]. In this demonstrative example, the average PFD for the SIF of interlock I-1552 which actuated by FT is 5.6128 E-04 that is correspond to a SIL value equal to 3 according the IEC 61508.

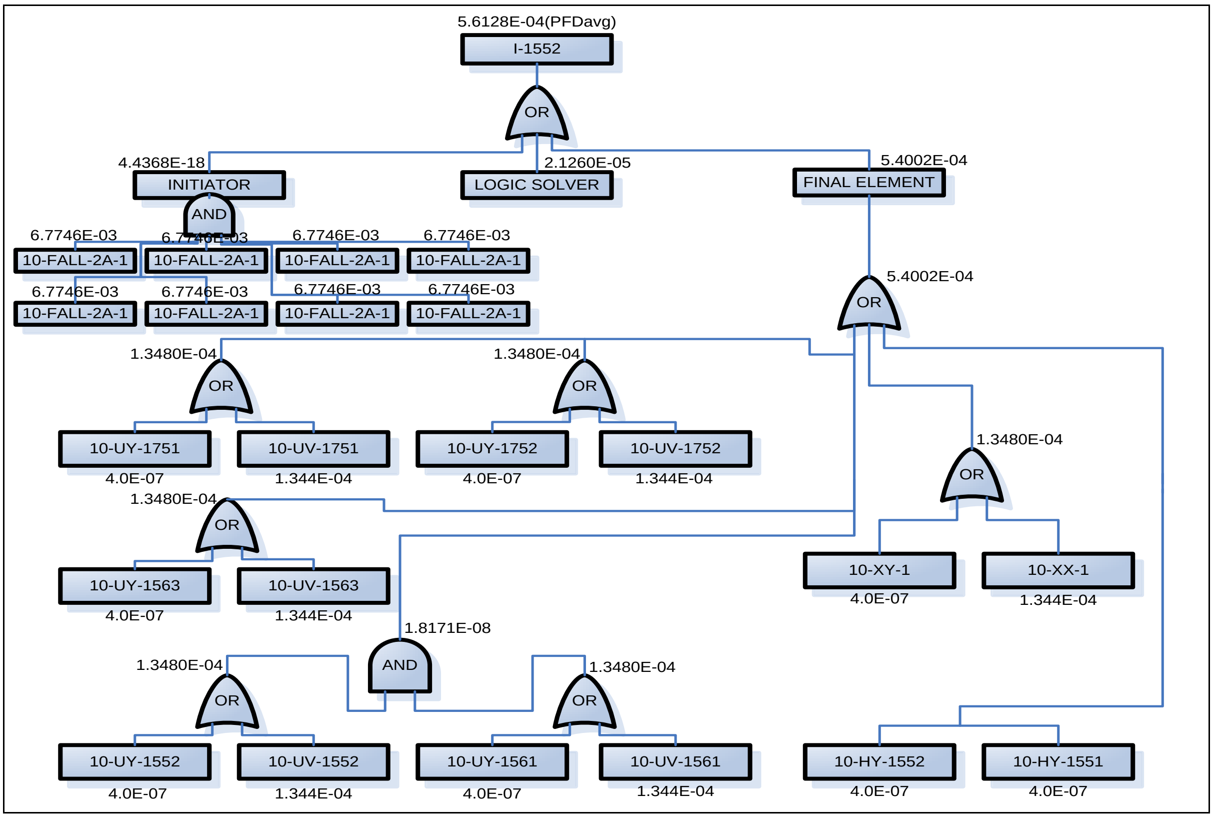

Fig. 2. Fautl tree analysis for FALL-2A

IV. Results

A SIL level determination has been carried out to identify the SIL levels for various instrument protective functions (IPFs) for the fired heater, to reduce risk in this process industry. Table 5 summarizes the results for different SIL of the remaining interlocks.

TABLE. 5. SIL TARGET AND CALCULATED FOR THE INTERLOCKS

Interlock	Actuated By	SIL Target	SIL Calculated
I-1551	PSLL-4	2	3.9496E-03(PFDavg) >>> SIL 2
I-1552	FT-2A-1	3	5.6128E-04(PFDavg) >>> SIL 3
I-1553	HS-1551	2	7.2216E-04(PFDavg) >>> SIL 3
I-1554	PSHH-1559	2	5.6948E-04(PFDavg) >>> SIL 3
I-1555	TSHH-22	2	3.1024E-03(PFDavg) >>> SIL 2
I-1556	PSH-1567	1	3.4104E-03(PFDavg) >>> SIL 2
I-1557	PSLL-1558	2	3.6792E-03(PFDavg) >>> SIL 2
I-1558	ZSL-1552	2	1.5648E-04(PFDavg) >>> SIL 3
I-1559	TAHH-48	2	3.6792E-03(PFDavg) >>> SIL 2

V. Conclusions

This work investigated methods of determining safety integrity levels for various safety instrumented functions identified according to a hazard and operability analysis. Provide the findings of SIL classification study carried out for the fired heater in crude distillation unit of Skikda refinery at Algeria, including the record sheets of the different components of the interlocks, which referred to the details of each SIF, using the methodology based on the guideline provided in IEC standards. Hence, the determined SIL levels ensure that the appropriate SIF achieves the target probability of failure on demand as required by SIL study. Therefore, level three selected as the higher level.

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