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Evaluation Safety Integrity Level Using Layer of Protection Analysis in Recycle Gas First Stage Cycle Compressor at PT.Pertamina Persero

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ABSTRACT

The objective of this research is to Safety Integrity Level (SIL) using Layer of Protection Analysis (LOPA) for Compressor 013K101A. The advantage using this method is identifying hazard and providing evaluation Independent Protection Layer (IPL) management for compressor unit refinery IV Cilacap, PT.Pertamina Persero. HAZOP of compressor is used for identify hazard in Compressor process. Identify every IPL which prevent hazard at compressor. Determine target mitigated event likelihood (TMEL) and initiating event likelihood (IEL). The comparison of TMEL and IEL will determine target SIL. The result from SIL evaluation using will determine SIL for SIS which used for recommendation for hazard at compressor process. SIS Recommendation is done with calculates Probability failure demand $(PFD)_{SIS}$ with various combinations of sensors and emergency shutdown valves (ESDV) configuration. Recommendation is the combinations which SIL target which identifies 3 hazards level. Case 1 needs SIL 2 with PFD value 0.0063. Case 2 got no SIL with PFD value 0.3600; therefore SIS isn't needed for condition. Case 3 got no SIL with PFD value 3.6000. Therefore SIS isn't needed for Case 3. SIS recommendation for case is PLC logic will trip emergency shutdown valve with 1oo1 configuration at high 013V104 level using a high level switch LSH. This SIS can fulfill the requirement of target SIL 2 with PFD value 0.0087

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INTRODUCTION

Compressors are grouped into two types: centrifugal compressors and reciprocating compressor. Reciprocating compressors often used to compress the gas in the range of (20-60) kg/cm2. This compressor has a main component in the form of; pistons, connecting rods, piston cylinder, suction valve, pressure valve, and the crank shaft. This compressor has work principle where the air compressor (gas) consists of a piston. The first principle works the piston will be drawn to increase the volume and pressure. The gas pressure will enter the cylinder through the valve, and then the piston will compress the gas to the pressure specified. The high pressure gas will flow through valve pressure. Cross section reciprocating compressor can be seen in Figure 1. In the Atmospheric distillation unit (ADU) process in units of 013 plant Fluid Catalytic Cracking (FCC) II RU Cilacap refinery, compressors used are reciprocating compressor.

LOPA method is used to evaluate SIL of compressor 013K101A process. This method needs HAZOP and IPLs (Independent Protection Layer) data to identify hazard event and protection for risk reduction. The result from evaluation is target SIL of SIS for each hazard.

The advantage for this method is hazard identification and basic rational for IPLs management which out of service. Safety Integrity Level (SIL) is a level of safety provided by safety components which forms a SIS. SIL is determined from PFD (Probability Failure on Demand) value of SIS. SIL is started from the lowest level SIL 1 to highest SIL 4. The SIL value consist SIL 1 with *Probability of Failure on Demand Average* (PFD_{avg}) = 0.1-0.01; SIL 2 with (PFD_{avg}) = 0.01-0.001; SIL 3 with (PFD_{avg}) = 0.001-0.0001 and SIL 4 with (PFD_{avg}) = 0.0001–0.00001

MATERIAL AND METHODS

This compressor is used to compress the H2 gas. H2 gas is derived from the first stage product separator 013V103 [13]. This .Gas flow in to first stage recycle gas compressor suction drum 013V104

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to separate the gas from the liquid with demister. Then H2 gas is supplied to the compressor for compressed up to a certain pressure.

Pressurized gas with range (20– 60) kg/cm^2 is often needed in oil refinery process. To meet these needs a compressor is used in oil refinery. Compressor is used for increasing the pressure of the gas. Unit 013 FOC II Cilacap refinery process is kerosene treatment.

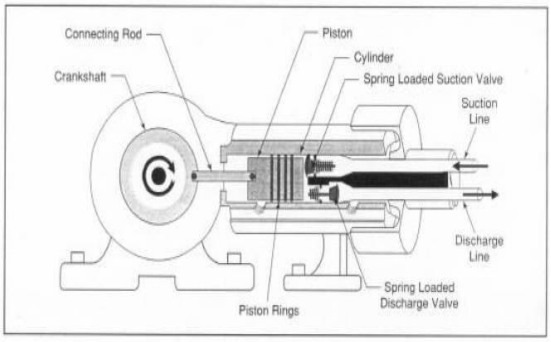

Fig. 1: Component of reciprocating compressor

This process is used for increasing kerosene quality. High pressure H_2 gas is needed for treatment process. Compressor 013K101A is used to compress H_2 gas (Allen-Bradley, 2010). Disturbance at compressor can disturb the treatment process. Therefore a SIL evaluation is needed for compressor 013K101A process.

PFD is probability of failure from a system or component on demand. These are several configurations with PFD equation of SIS (CCPS, 2007):

1oo1. System has one channel [4]. The equation is.

$$PFD_{avg} = \lambda^{DU} x \frac{Ti}{2} \quad (1)$$

1oo2.System needs one output from two channels for shutdown (CCPS, 2010). The equation is.

$$PFD_{avg} = \frac{(\lambda^{DU} xTi)^2}{3} \quad (2)$$

1oo3. System needs one output from three channels for shutdown (CCPS, 2010). The equation

$$PFD_{avg} = \frac{(\lambda^{DU} xTi)^3}{4} \quad (3)$$

2oo2. System needs 2 output from 2 output for shutdown (CCPS, 2010). The equation is: (CCPS, 2010)

$$PFD_{avg} = \lambda^{DU} xTi \quad (4)$$

2003. System needs 2 output from 3 output for shutdown (CCPS, 2010). The equation

$$PFD_{avg} = (\lambda^{DU} xTi)^2 \quad (5)$$

Where:

λ^{DU}: Failure rate dangerous undetected.

Ti : Time interval

PFD of SIS is a calculation from PFD of each individual component which forms a SIS. The equation is (ISA, 2002):

$$PFD_{SIS} = \Sigma PFD_S + \Sigma PFD_A + \Sigma PFD_L + \Sigma PFD_{PS} \quad (6)$$

Where:

PFD_A : Valve from $PFD_{avg}$of a SIF

PFD_S : sensor from PFD_{avg} of a SIF

PFD_L : logic solver from $PFD_{avg}$of a SIF

PFD_{PS} : power supply from $PFD_{avg}$of a SIF

PFD_{SIS} : $PFD_{avg}$of a SIS.

LOPA is one of method to evaluate SIS. Analysis needed for this are:

- Severity each hazard
- Initiating likelihood for each hazard
- Capability for each IPL determined by its PFD value
- TMEL (Target Mitigated Event Likelihood) compared to IEL (Intermediate Event Likelihood). This will determine the PFD of target SIL.

The equation for PFD calculation for PFD of target SIL is shown below (Musyafa, A. et al., 2013):

$$PFD_{SIL} = TMEL/IEL \quad (7)$$

Where:

TMEL = PFD TMEL

IEL = PFD IEL

TMEL is target probability hazard to occur. The value is determined from severity level from hazard event. IEL is probability hazard to occur after IPLs

work. The equation to determine IEL is shown in Equesiton 8.

$$IEL = fi \times \Sigma PFD_{AMD} \times \Sigma PFD_{AR} \times \Sigma PFD_{AMR} \times \Sigma PFD_{GPD} \times \Sigma PFD_{BPCS} \quad (8)$$

Where:

Fi = Initiating Causes Likelihood
PFD_{AMD} = PFD Additional mitigation dike
PFD_{AR} = PFD Alarms and operator response.
PFD_{AMR} = PFD Additional Restricted Access
PFD_{GPD} = PFD general process design
PFD_{BPCS} = PFD basic process control system

Methodology:

This research use HAZOP data and P&ID compressor 013K101A. Table 1 shows the HAZOP compressor 013K101A.

a. ***Calculation of SIL Target using LOPA Method:***

Table 1: HAZOP of Compressor 013K101A

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Table 1. HAZOP of Compressor 013K101A

Deviation	Causes	Consequences	Risk Matrix			Safe-guard	Recommendations
			S[1]	L[2]	RR[3]		
High flow, high level	High upstream flow	013-V-104 high level lead to *liquid* carry over to suction compressor (Comp. Damage)	4	3	12	1.013LI-006C 2.013LAH-006	Shall provide 013 LSH 006 (tripping system at 013-K-101 A)
High temperature	1. High up-stream temperature 2. 013-K-101A loader valve passing	013-K-101A potential mechanical damage due to high temp	3	2	6	013TI-040	
High Pressure	High upstream pressure	Equipments (Compressor, Exchanger) potential damage	3	2	6	013PSV-004A	

1. [1]S -Severity; [2]L -Likelihood; [3]RR -Risk Ranking.

b. ***LOPA method is done with several steps:***

Identify hazard using HAZOP Table 1. For every consequence at HAZOP, severity level must be classified. Severity can be classified using Table 2.

Table 2: Target mitigated event Likelihood for safety hazards adapted from Nordhagen (2007)

S	Severity Level	Safety consequence	Target mitigated event likelihood
1	C_A	Single first aid injury	3.10^{-2} per year
2	C_B	Multiple first aid injuries	3.10^{-3} per year
3	C_C	Single disabling injury or multiple serious injuries	3.10^{-4} per year
4	C_D	Single on-site fatality	3.10^{-5} per year
5	C_E	More than one and up to three on-site fatalities	1.10^{-5} per year

Identify Impact event description and Initiating Cause according consequence and cause description of HAZOP Table 1. Initiating Likelihood can be determined using Table 3.

Table 3: Initiation likelihood Probability Failure of Demand

Initiation Likelihood				
Like-li-hood	*Description*	*Probability occurrence in year*	*sample*	fi
1	Not expected to occur during facility life	$\geq$20 year	40.0 year	0.025
2	Could occur once during facility life	4-20 year	12.0 year	0.083

Determine existing IPLs for every hazard which has been identified using safeguard description of HAZOP Table 1. And P&ID compressor. Next determined PFD value for each IPL Table 4. Can be used for determines IPL. PFD value for IPLs which don't reduce hazard risk IPL will be given Table 4.

Table 4: Probability Failure of Demand for IPLs

No	IPL	PFD
1	BPCS	0.10
2	Operator response to alarm with response time at least 10 minute	0.10
3	Relief valve/PSV	0.01
4	Rupture disk	0.01
5	NRV or check valve	0.10
6	Bund/dike	0.01
7	Inherently Safe Design	0.10

PFD_{SIS} can be calculated using equation (7). Equation (8) is used for calculate IEL. TMEL can be determined using Table 2. The result of PFD can be classified into SIL. SIS is needed if target SIL isn't NO SIL.

c. ***SIS Recommendation:***

The result of target calculation can be used for determined sensor, logic solver and, (ESDV) Emergency Shutdown Valve. The first step is creating a group SIL according to PFD_{SIS} calculation using equation (6). For PFD sensor and PFD ESDV, λ^{DU} sensor and λ^{DU} ESDV with range $4x10^{-3}$ to 10^{-1} is used for calculation. The PFD value of logic solver used in this research is 0.00002.240516. PFD_{SIS} is classified into SIL using standard. The combinations of configuration sensor and ESDV used in this research shown in Table 5.

Table 5: Combination of Configuration of sensor and ESDV

No.	*Area*
1.	Combination Sensor 1oo1 with ESDV 1oo1
2.	Combination Sensor 1oo2 with ESDV 1oo1,
3.	Combination Sensor 1oo3 with ESDV 1oo1,
4.	Combination Sensor 2oo2 with ESDV 1oo1,
5.	Combination Sensor 2oo3 with ESDV 1oo1,
6.	Combination Sensor 1oo2 with ESDV 1oo2,
7.	Combination Sensor 1oo3 with ESDV 1oo2,
8.	Combination Sensor 2oo2 with ESDV 1oo2,
9.	Combination Sensor 2oo3 with ESDV 1oo2,
10.	Combination Sensor 2oo2 with ESDV 2oo2,
11.	Combination Sensor 1oo3 with ESDV 2oo2,
12.	Combination Sensor 2oo3 with ESDV 2oo2,
13.	Combination Sensor 1oo3 with ESDV 1oo3,
14.	Combination Sensor 2oo3 with ESDV 1oo3,
15.	Combination Sensor 2oo3 with ESDV 2oo3,
16.	Combination Sensor 1oo1 with ESDV 1oo2,
17.	Combination Sensor 1oo1 with ESDV 2oo2,
18.	Combination Sensor 1oo2 with ESDV 2oo2,
19.	Combination Sensor 1oo1 with ESDV 1oo3,
20.	Combination Sensor 1oo2 with ESDV 1oo3,
21.	Combination Sensor 2oo2 with ESDV 1oo3,
22.	Combination Sensor 1oo1 with ESDV 2oo3,
23.	Combination *Sensor* 1oo2 with ESDV 2oo3,
24.	Combination *Sensor* 2oo2 with ESDV 2oo3
25.	Combination *Sensor* 1oo3 with ESDV 2oo3

The calculation is done using Matlab Software. The result is plotted in 3D graphic. Next step is determined components recommendation and combination of configuration of sensor and ESDV using graphic of group SIL. Recommendation SIS is verified with fault tree analysis. Component data used for recommendation is shown at Table 5.

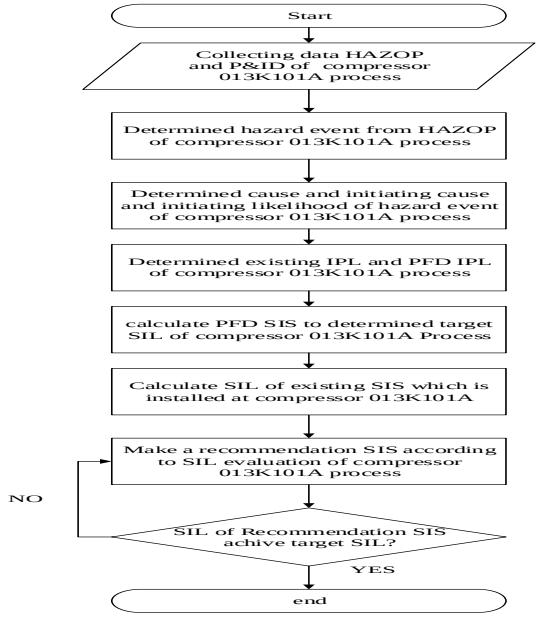


Fig. 1: Research flowchart

RESULTS AND DISCUSSION

a. Result of SIL Evaluation with LOPA Method at Compressor 013K101A process:

HAZOP compressor 013K101A shows 3 case hazards. According Table 2, hazard case 1has severity level 4 which listed CD. Initiating cause likelihood case 1 is 0.44. Initiating cause likelihood is determined using Table 3. Compressor 013K101A P&ID for case 1 is shown at Figure 2.

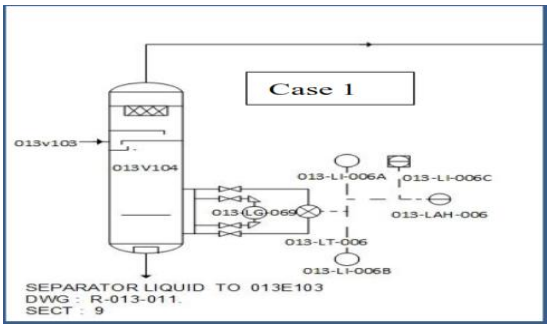


Fig. 2: Compressor 013K101A P&ID for case 1

According Figure 2, a 013LAH-006 is installed which design as high level alarm. According Table 5, PFD_{AR} and PFD_{GPD} are 0.1. PFD_{BPCS}, PFD_{AMR} and, $PFD_{AMD\ are}$ given 1 because they don't prevent the hazard case 1.Using equation (8), IEL calculations 0.00444. According Table 3, TMEL is 0.00003 as severity level is CD. Using equation (7), PFD calculation is 0.00628. According Table 1 PFD are around 0.01 – 0.001 so the target SIL is SIL 2. According Figure 2, 013V104 doesn't have SIS for hazard high level. Therefore Existing SIL is NO SIL. Because Existing SIL doesn't achieved Target SIL 2, a recommendation SIS with SIL 2 is needed for case 1. According Table 2, hazard case 2 has severity level 3 which listed CC. Initiating causes likelihood case 2 is 0.083. Initiating cause likelihood is determined using Table 3. Compressor 013K101A P&ID for case 2 is shown at Figure 3.

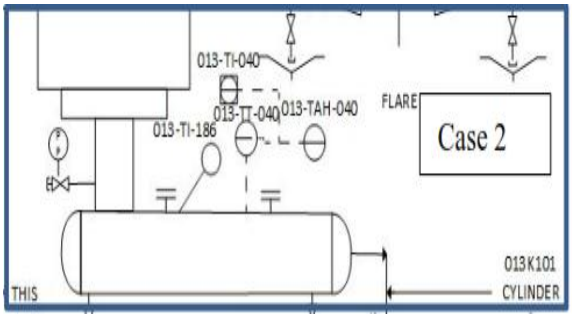


Fig. 3: Compressor 013K101A P&ID for case 2

According Figure 3, a 013TI-040 connected with 013TAH-040 is installed which design as high temperature alarm. According Table 5, PFD_{AR} and $PFD_{GPD}$are given 0.1. PFD_{BPCS}, PFD_{AMR} and, PFD_{AMD} are given 1 because they don't prevent the hazard case 2. Using equation (8), IEL calculation is 0.00083. According Table 3, TMEL is 0.0003 as severity level is CC. Using equation (7), PFD calculation is 0.36.

According Table 1 PFD isn't included in SIL classification. Therefore target SIL for case 2 is NO SIL. According Figure 3, discharge compressor 013K101A doesn't have SIS for hazard high temperature. Therefore Existing SIL is NO SIL. Because Existing SIL achieved Target SIL, recommendation SIS isn't needed for case 2.

According Table 2, hazard case 3 has severity level 3 which listed CC. Initiating causes likelihood case 3 is 0.083. Initiating cause likelihood is determined using Table 4. Compressor 013K101A P&ID for case 3 is shown at Figure 4.

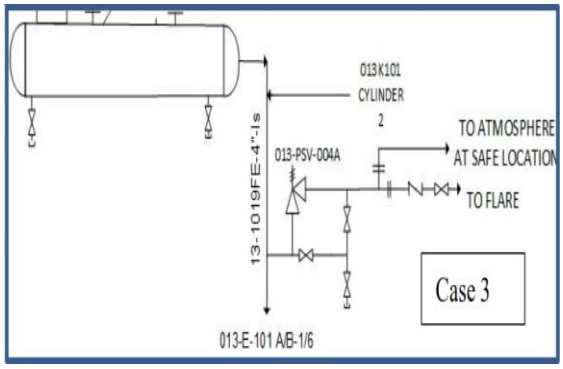


Fig. 4: Compressor 013K101A P&ID for case 3

According Figure 4, a pressure relief valve 013PSV-004A is installed which design to relief gas to atmosphere when gas pressure exceed the determined pressure. According Table 5, PFD_{AMD} is given 0.01 and PFD_{GPD} is given 0.1. PFD_{BPCS}, and PFD_{AR} are given 1 because they don't prevent the hazard case 3 PFD_{AMR} using equation (8), IEL calculation is 0.000083. According Table 2, TMEL is 0.0003 as severity level is CC. Using equation (7), PFD calculation is 3.6. According Table 1 PFD not include in SIL classification. Therefore target SIL for case 3 is NO SIL. According Figure 4, discharge line compressor doesn't have SIS for hazard high pressure. Therefore Existing SIL is NO SIL. Because Existing SIL achieved Target SIL, recommendation SIS isn't needed for case 3. The overall result of evaluation SIL is shown at Table 6.

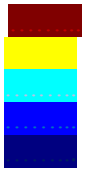
Tabel 6: MTTF and λ of Safety Integrity System components

Instrument	*MTTF (years)*	*λ*	*Source*
Switch/sensor	60	0.01667	CPPS
XV/ESV incl. actuator	50	0.02000	TR84.00.02 data
Logic incl. I/O card (single PLC)	34.16	0.02927	Allen-Bradley

b. SIS Recommendation:

The configuration for Sensor and ESDV of SIS are determined using group SIL. The Group SIL is represented as 3D graphics. λ^{DU} ESDV is plotted at X axis, λ^{DU}*sensor* is plotted Y axis and, PFD is plotted at Z axis. Because paper limitation only several graphic are shown. The color meaning in graphic are:

- Color indicates PFD is NO SIL.
- Color indicates PFD is SIL 1.
- Color indicates PFD is SIL 2.
- Color indicates PFD is SIL 3.
- Color indicates PFD is SIL 4.



Result of Graphic PFD_{SIS} combination Sensor 1oo1with ESDV 1oo2 shown at Figure 5. This Combinationhas84.20%SIL 1 and 15.80% SIL 2. This combination needs a sensor and two ESDVs.

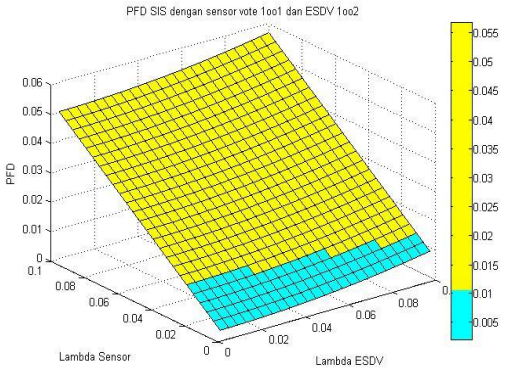


Fig. 5: PFD_{SIS} combination sensor vote 1oo1 and ESDV 1oo2

Result of Graphic PFD_{SIS} combination Sensor 1oo1with ESDV 1oo3shown at Figure 6. This Combinationhas79.69 % SIL 1 and 20.31% SIL 2. This combination needs a sensor and three ESDVs.

Table 7: SIL Evaluation with LOPA method for compressor 013K101A

C_1	1	2	3	4	5	6			7	8	9	10	11
					PFD IPL[10]								
	IED[3]	SL[2]	IC[4]	IL[5]	GP[6]	BP[7]	AR[8]	AM[9]	AD[11]	IEL[12]	TMEL[13]	PFD[14]	SIL[15]
1	013-V-104 high level lead to liquid carry over to suction compressor (Comp. damage)	CD	High upstream flow	0.44	0.1	1	0.1	1	1,00	0.00440	3.10^{-5}	0.00628	SIL 2
2	013-K-101A potential mechanical damage due to high temp.	CC	1. High upstream temperature 2.013K101A loader valve passing	0.083	0.1	1	0.1	1	1,00	0.00083	3.10^{-4}	0.36000	NO SIL
3	1.Equipments (Compressor, Exchanger) potential damage	CC	High upstream pressure	0.083	0.1	1	1,0	1	0.01	0.00008	3.10^{-4}	3.60000	NO SIL

[1]C	: Cause	
[2]SL	: Severity Level	
[3]IED	: Impact event description	
[4]IC	: Initiating cause	
[5]IL	: Initiation cause Likelihood	
[6]GP	: General Process Design	
[7]BP	: Basic Process Control System	
[8]AR	: Alarms and operator response	
[9]AM	: Additional Mitigation. Restricted Access	
[10]IPL	: Independent Protection Layer	
[11]AD	: Additional Mitigations Dike (Bunds).	

	Pressure Relief
[12]IEL	: Intermediate Event Likelihood
[13]TM	:Target Mitigated Event Likelihood EL
[14]PFD	: Probability Failure on Demand
[15]SIL	: Safety Integrity Level

Result of Graphic PFD_{SIS} combination Sensor 2oo3 with ESDV 2oo3shown at Figure 7. This Combination has 42.01% SIL 1, 53.13% SIL 2 and, 4.86% SIL 3. This combination needs three sensors and three ESDVs. Table 7. Shows the Component data that will be used for recommendation SIS. According Table 7. , λ^{DU} ESDV value is 0.0200 and λ^{DU} sensor value is 0.0167.

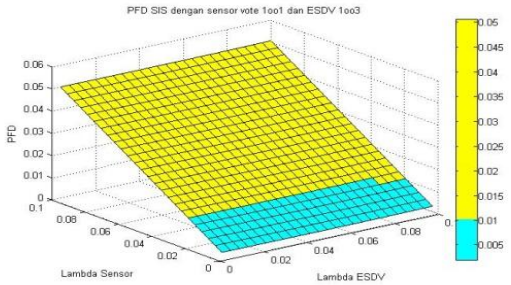


Fig. 6: PFD_{SIS} combination*sensor* vote 1oo1 and ESDV 1oo3

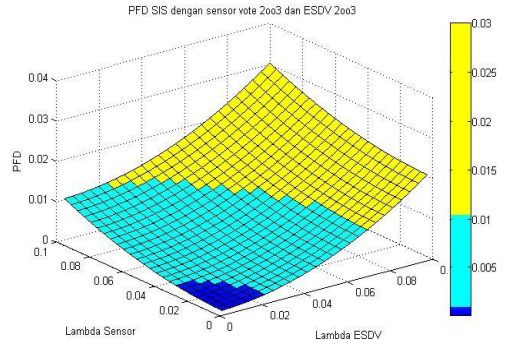


Fig. 7: PFD_{SIS} combination sensor vote 2oo3 and ESDV 2oo3

c. Overall result for group Safety Integrity Level is shown at Table 8:

The result SIL of SIS using component Table 7. And group SIL graphic scan be shown at Table 8. [5]n – the number of component used for SIS.

Table 8: Overall result group Safety Integrity Level

Sensor		ESDV		Percentage (%)				
vote	n[4]	vote	n	NO SIL	SIL 1	SIL 2	SIL 3	SIL 4
1oo1	1	1oo1	1	22.92	76.39	0.69	0.00	0.00
1oo1	1	1oo2	2	0.00	84.20	15.80	0.00	0.00
1oo1	1	1oo3	3	0.00	79.69	20.31	0.00	0.00
1oo1	1	2oo2	2	63.55	36.45	0.00	0.00	0.00
1oo1	1	2oo3	3	0.00	9.20	90.80	0.00	0.00
1oo2	2	1oo1	1	0.00	7.64	92.36	0.00	0.00
1oo2	2	1oo2	2	0.00	0.00	85.41	12.85	1.74
1oo2	2	1oo3	3	0.00	0.00	51.39	43.58	7.81
1oo2	2	2oo2	2	50.00	46.01	3.99	0.00	0.00
1oo2	2	2oo3	3	0.00	32.12	44.97	12.85	0.00
1oo3	3	1oo1	1	0.00	91.67	8.33	0.00	0.00
1oo3	3	1oo2	2	0.00	0.00	66.66	28.30	5.04
1oo3	3	1oo3	3	0.00	0.00	0.00	71.70	28.30
1oo3	3	2oo2	2	50.00	45.83	4.17	0.00	0.00
1oo3	3	2oo3	3	0.00	29.17	50.00	20.83	0.00
2oo2	2	1oo1	1	45.14	54.69	0.17	0.00	0.00
2oo2	2	1oo2	2	0.87	92.53	6.60	0.00	0.00
2oo2	2	1oo3	3	0.00	91.67	8.33	0.00	0.00
2oo2	2	2oo2	2	74.65	25.35	0.00	0.00	0.00
2oo2	2	2oo3	3	5.03	9.37	4.34	0.00	0.00
2oo3	3	1oo1	1	1.91	7.47	5.56	0.00	0.00
2oo3	3	1oo2	2	0.00	34.00	65.13	0.87	0.00

According SIL Evaluation, case 1 needs SIS with SIL 2. Table 9**.** shows three combinations that satisfied target SIL. They are combination vote sensor 1oo1 with ESDV 1oo2 shown at Figure 5, combination vote sensor 1oo1 with ESDV 1oo3 shown at Figure 6**.** and, combination vote sensor 1oo1 with ESDV 2oo3 shown at Figure 7. Combination vote sensor 1oo1 with ESDV 1oo2 is chosen for recommendation SIS. The reason is this combination satisfied SIL 2 and has low requirement of component. This will reduce the maintenance and installation cost for component SIS. The proposed SIS can be shown at Figure 8**.** as the red part.

Table 9: SIL of SIS using group SIL Graphic and component data.

	Sensor (λ^{DU}= 0.01667 years^{-1})		ESDV(λ^{DU}= 0.0200 years^{-1})		SIL
No.	Vote	n[5]	Vote	n	
1.	1oo1	1	1oo1	1	1
2.	1oo1	1	1oo2	2	2
3.	1oo1	1	2oo2	2	1
4.	1oo1	1	2oo3	3	1
5.	1oo2	2	1oo1	1	1
6.	1oo2	2	1oo2	2	3
7.	1oo2	2	1oo3	3	3
8.	1oo2	2	2oo2	2	1
9.	1oo2	2	2oo3	3	3
10.	1oo3	3	1oo1	1	1
11.	1oo3	3	1oo2	2	3
12.	1oo3	3	1oo3	3	4
13.	1oo3	3	2oo2	2	1
14.	1oo3	3	2oo3	3	3
15.	2oo2	2	1oo1	1	1
16.	2oo2	2	1oo2	2	1
17.	2oo2	2	1oo3	3	1
18.	2oo2	2	2oo2	2	1
19.	2oo2	2	2oo3	3	1
20.	2oo3	3	1oo1	1	1
21.	2oo3	3	1oo2	2	3
22.	2oo3	3	1oo3	3	3
23.	2oo3	3	2oo2	2	1
24.	2oo3	3	2oo3	3	2
25.	1oo1	1	1oo3	3	2

The recommended SIS is verified using Fault Tree analysis. PFD for each component is calculated. The result is shown at figure 9. SIS will fail on demand if one of these following events occurs:

LSH fails to detect abnormal high level, PLC fails to generate trip signal, ESDV 1 and Solenoid 1 fail, ESDV 2 and Solenoid 2 fail, ESDV 1 and ESDV 2 fail. And Solenoid 1 and Solenoid 2 fail. Figure 8**.** shows PLC logic will trip ESDVs on high 013V104 level using a high level switch LSH. This SIS still funtion even one of ESDV fail.

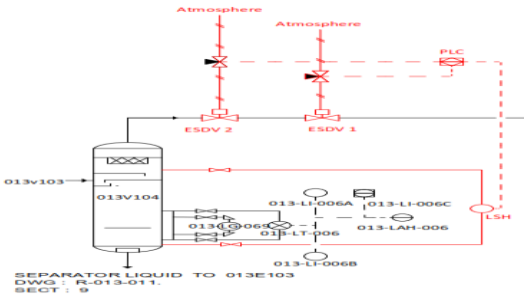


Fig. 8: Proposed SIS at Compressor 013K101A case 1

The recommended SIS is verified using Fault Tree analysis. PFD for each component is calculated. The result is shown at figure 9. SIS will fail on demand if one of these following events occurs: LSH fails to detect abnormal high level; PLC fails to generate trip signal; ESDV 1 and Solenoid 1 fail; ESDV 2 and Solenoid 2 fail; ESDV 1 and ESDV 2 fail. Solenoid 1 and Solenoid 2 fail. The result of Fault tree analysis Verification shows this SIS has SIL 2.The recommended SIS satisfied target SIL shown in Figure 9.

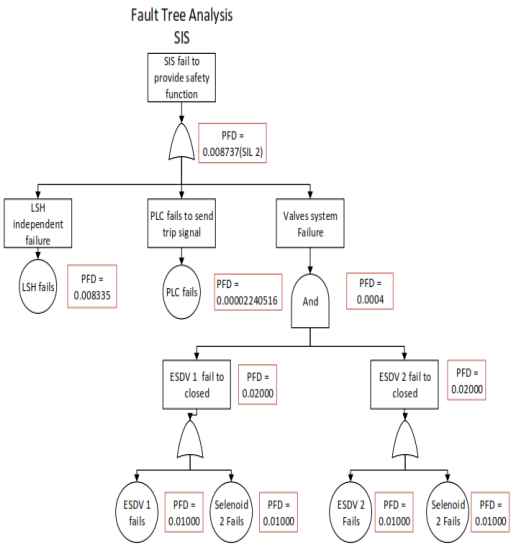


Fig. 9: Fault Tree Analysis SIS

Conclusion:

The safety integrity level evaluation with LOPA method at compressor 013K101A shows case 1 has target SIL 2 with PFD 0.00628. Therefore SIS with SIL 2 is needed for case 2. Target PFD for case 2 is 0.36. Therefore SIS isn't need for case 2. Target PFD for case 3 is 0.36. Therefore SIS isn't need for case 3. SIS with SIL 2 is proposed for case 1. The result of SIS recommendation for case 1 shows SIS is composed of 1 component LSH with 1oo1 configuration, a PLC and, 2 ESDV swith 1oo2 configurations. The proposed SIS is shown in red part at Figure 8. This SIS achieved target SIL 2 with PFD 0.00874.

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