HAZOP Study and SIL Verification of Fuel Gas System in ORF Using IEC 61511 Standard and FTA Method

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Abstract— Safety is an important aspect of the industrial process. Failure of system and mechanism endanger both human and environmental safety. Safety is obligated to be implemented precisely and thoroughly to prevent failure consequences. One of the preventive implementations is to map out safety devices in the form of SIS (Safety Instrumented System) and other layers of protection. However, to acknowledge this safety device performance used SIL (Safety Integrity Level). This final research is intended to analyze Fuel Gas systems on Onshore Receiving Facilities (ORF). HAZOP (Hazard Operability Study) as process hazard analysis with deviation during the operation so that the risk level is known. SIL verification towards SIL target is SIL-2 refer to IEC 61511 standards by FTA (Fault Tree Analysis) method. From the HAZOP study can be concluded that over-pressure becomes a top hazard to all nodes due to the most severe consequences, the highest likelihood (medium risk). The calculation result of PFDavg is Node 1 (Fuel Gas Scrubber V-6060) is 6,22E-03, Node 2 (Fuel Gas Filter Separator S-6060A) is 1,24E-03, Node 3 (Fuel Gas Filter Separator S-6060B) is 1,24E-03, Node 4 (Fuel Gas Superheater E-6060) is 1,21E-03, and Node 5 (Instrument Gas Receiver V-6070) is 2,23E-03. The conclusion of this research shows that five components of the Fuel Gas System fulfill the SIL-2 target, therefore, doing a re-design to add a safety device is unnecessary.

Keywords—failure rate, node, over-pressure, probability of failure on demand, process hazard analysis, safety device.

I. INTRODUCTION

The importance of safety process production knowledge can be initiated with identifying danger, assessing and doing risk assessment effectively and efficiently. The important part of process safety is to keep processing material safe, therefore, it is always in the main container and comes out controllably through design principal, operating, inspecting, and well preservation [1].

Safety device failure is going to give a negative effect on the facility, humans, and environment. It has been happening in the nylon plant production explosion at Flixborough in 1974, 28 died and 36 in the serious wound. It was caused by plant modification without reassessment through risk potency [2].

Gas which derives from offshore transferred through the pipeline towards Onshore Receiving Facilities (ORF). A fuel Gas System is a utility system that works to process the side products becomes machine fuel, turbine, or generator [3].

Implementing work safety, ORF applied work procedure in plant activities and designed to have safety, which are valve safety (such as PSV, SDV, ESD), PPE (Personal Protective Equipment), firefighting equipment, and alarm. That equipment are intended as preventive as well as mitigation towards risk potencies, such as leakage, fire, explosion, and work accident.

To acknowledge safety level and equipment safety system, using SIL (Safety Integrity Level). SIL is a method in measuring the performance of safety devices in the form of SIS (Safety Instrumented System) or IPL (Independent Protection Layers) that has SIF (Safety Instrumented Function). The parameter to know SIL level is PFDavg (Probability Failure on Demand Average) or RRF (Risk Reduction Factor) from the safety device used in the system [4].

The purpose of this research is to study HAZOP towards fuel gas systems in ORF facilities. On the other hand, this research is to verify PFDavg safety device on fuel gas system in ORF facility so that it can be fulfilling SIL-2 target based on IEC 61511 standard.

II. METHOD

The research method used in this final assignment is the whole activities have done through the process of analyzing each problem that exists in this research.

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Figure 1 is the plot scheme of research execution. This is the explanation of the research method plot scheme.

A. Literature of Study

Literature of study is research done by the researcher by collecting several books related to the problem and the purpose of research. This phase is the early activity to look for all information related to final task processing [5]. Literature of study is done by examining standards, papers, journals, and books related to this research. Examine the paper and journal as the process to look for alternatives to solve the problem. Standard as the reference in problem-solving and achieving this research goal.

Some of the literature used in this final assignment is shown below:

1) British Standard IEC 61511 (2003), Functional Safety - Safety Instrumented systems for the process industry process.
2) British Standard IEC 61882 (2001) Hazard and Operability (HAZOP Studies)– Application Guide.
3) ISA TR84.00.02 (2002) Part 4, Safety Instrumented Functions, Safety Integrity Level (SIL), Evaluation Techniques: Determining the SIL of a SIF via FTA.
4) Guidelines for Process Hazard Analysis, Hazard Identification & Risk Analysis, Nigel Hyatt (2004).
5) Some of other journals references related to explain the definition, work steps, and SIL analysis example.

B. Data Collection

Data collection is the activity to get the information needed to achieve the research goals [6]. In the data collection phase, data can be gotten from 2 data sources, which are, primary data and secondary data. Primary data is data gotten independently live by the researcher by interview, observation, questionnaire, measurement, as well as experiment. Meanwhile, secondary data is gotten by other sources [7] such as data from CAS (Central Agency on Statistics), OREDA 2002, and NPRD 1991.

From the literature study, the researcher got the data and parameters needed to solve the problem in this final project. The following is the data used for this research:

1) PFD Drawing (Process Flow Diagram) and PID Drawing (Piping and Instrumentation Diagram) fuel gas system ORF.
2) OREDA 2002 (Offshore Reliability Data).
3) NPRD 1991 (Non-electronics Part Reliability Data).

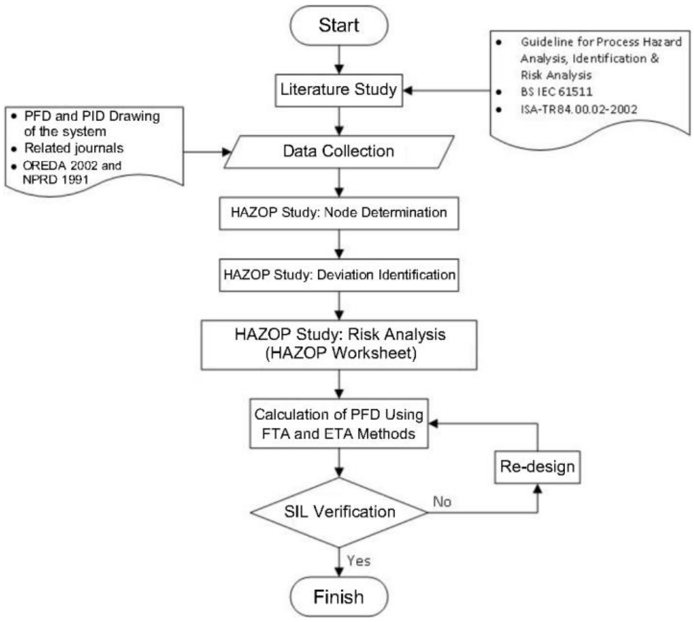

Figure. 1. The Methodology Flowchart of The Research

Researchers in collecting data using secondary data, namely data obtained from companies in the form of drawing PFD (Process Flow Diagram) and PID fuel gas system of the ORF. Other data is collected from an institution, a secondary database of failure rate from OREDA 2002 dan NPRD 1991.

C. HAZOP Study: Node Determination

HAZOP study can be done based on PID drawing. HAZOP study is expected all-hazard that can be identified appropriately and in detail. The first step from the HAZOP study is to determine the node.

Node (study point) is the separation of the process unit into some parts so that study can be done systematically [8]. Titik studi atau nodes. Study point or node can be defined as pipe segment and vessel exist in the process. Process defines nodes (nodding) as the phase in doing study in process function [9].

The process of performing node determination (called nodding) uses the PFD and PID drawing of the fuel gas system. In the PFD drawing, it can be seen how the process flow of a system as a whole. But a more detailed drawing that includes the components in the system, along with the equipment attached to these components, is in the PID drawing. The noding process is carried out by giving a box with a dashed line on each component, both in PFD and in PID. Then provide a connecting line on the pipe that flows fluid from one component to another.

If different components are used, different colors (contrast) are used, this aims to make it easier to distinguish between components and the direction of flow. For pipes leading to and leaving a component, the color is the same as the component. However, in determining a node, a component that is inactive or not operating, then the component is not included/recorded as a node.

D. HAZOP Study: Identification of Deviation

At this stage, identify deviations or conditions that do not match expectations that may occur while the facility is operating. The PID image where the study point (node) has been determined is used as a reference for identifying the deviation in each component.

The methodology to determine deviation is to find between two things, namely guideword and property. The property itself is divided into 3 types, namely parameters (such as flow, pressure, reaction), operation (such as transfer, empty), and material (such as steam and diluent) [10]. When the guideword (example: high) meets a property with parameters (example: pressure), then the deviation is the result of the meeting between the two, namely high pressure.

In general, 10 deviations appear in the HAZOP study, which is as follows:

1) No flow
2) High flow
3) Low flow
4) High contaminant
5) Less level
6) High level
7) Low pressure
8) High pressure
9) Low temperature
10) High temperature

Deviation identification can be started by knowing the type of each component. Components can be in the form of a vessel, separator, filters, scrubbers, tanks, pumps, and manifolds. The following is an understanding of several components:

1) Vessel/tank: a closed container that functions to store fluid.
2) Pressure vessel: a closed container that functions to store fluid that has a pressure different from the ambient pressure.
3) Separator: a tool that functions to separate steam from the well into gas and liquid.
4) Filter: a device used to separate solid contaminants, oil, and water from a gas vapor.
5) Scrubber: a tool that aims to remove dirt, water, foreign substances, and unwanted liquids from a gas stream.
6) Pump is a device designed to speed up the fluid transfer process from one location to another.
7) Manifold: functions to flow an oil or gas from one component to several other components at once.

Deviation can occur due to environmental factors, human error, or component damage. Deviation should be further analyzed considering that deviation has consequences and the likelihood that will give rise to a risk. Therefore, the HAZOP study does not stop after knowing the possible deviations. However, the study process was continued by analyzing the risk of a deviation, both the cause of the deviation and the impact of the deviation.

E. HAZOP Study: Risk Analysis

The concept of risk starts from a hazardous event. A hazardous event is the release of a material or energy which has the potential to cause adverse impacts on plant facilities, workers, and the environment. This explains that material has risks if it is not managed properly and according to procedures.

Risk can be defined as the product of consequences and frequency [10]. Risk is the result of something that is not certain [11]. Risk is a result of a meeting between sources of risk and causes of risk [12].

The source of risk is the source of the cause of a risk. In the fuel gas system on the ORF, the products and materials that are managed are a source of danger and a source of fuel that can trigger flames either by accident or by accident. In addition, leaks in pipes can also be a source of risk.

Cause of risk is a trigger that can cause risk to occur. In the fuel gas system at ORF, the sources of risk include overpressure, incorrect operational procedures, lack of maintenance, and other causes. When that happens, of course, there will be a danger because leaks and even fires can occur.

Risks can occur when a deviation occurs. Certain deviations cannot be ignored and are easy to avoid. Because deviation is closely related to safety devices, safety equipment should work optimally when deviation occurs. But if the opposite happens, where deviation occurs and the safety component also fails, it can certainly lead to an unfortunate event. SIL is present as a way to measure the performance of a safety device so that you can find out what level of security is it along with mitigating the risk of deviation.

The risk analysis stage can be carried out if the deviations have been identified in each component (node). At this stage, the analysis will be carried out in a systematic worksheet, starting from the analysis of possible causes, consequences, existing safeguards, to the risk matrix. In addition, to be able to use the risk matrix, input data from the API 581 standard are used.

The risk analysis carried out begins with identifying possible causes, the cause of a deviation occurring in a component. Then perform a consequence analysis, which is the result of what appears when the risk occurs. Then it is related to the impacts that may occur after the occurrence of these consequences so that it must be classified and categorized from consequences that have a large-scale to small-scale impact, namely with a level from 5 to 1.

The likelihood analysis is carried out in the next step to find out how often the events in this case are deviations or deviations during operations. The things that are used to carry out the likelihood analysis are the records of events in the field/facility. The data were taken from existing databases, namely OREDA 2002 and NPRD 1991 as an approach to failure frequency. Then do the likelihood categorization from high to low with a level of 5 to 1.

After knowing the categories of consequence and likelihood, the next step is to determine the risk matrix. The matrix used is a 5 x 5 matrix which refers to the API 581 standard. Both consequence and likelihood have been categorized with a level of 1 to 5, then they are converted into the matrix so that it will produce several risk categories (risk ranking), namely between low risk, medium risk, medium-high risk, or high risk. Risk ranking is needed to sort out and find out which possible causes have the greatest risk.

F. Calculation of PFD Using the FTA and ETA Methods

At this calculation stage, the deviation that has been categorized as high risk from the results of the risk analysis in the previous stage can be used as a reference for calculating PFD (Probability of Failure on Demand). The category for which the calculation is carried out is the deviation of high, medium-high, and medium-risk. In calculating and finding the SIL level, the point is to find the PFDavg in an SIS. To determine it, several methods can be used, such as simplified equation, fault tree analysis (FTA), Markov analysis [12].

PFD can be analyzed using the FTA of each component or safety equipment that has the same safety function. The failure rate data to be used refers to the OREDA 2002 data. FTA is a method of determining the probability of failure of a system using logic gates arranged in a top-down manner. The quantitative calculation of FTA in this final project uses a numerical approach. The numerical approach was chosen because it is easy to use and can refer to the 2002 OREDA data obtained.

Fault Tree Analysis is a structured diagram analysis that identifies the elements that can cause a system failure. The mechanism for using the FTA method to calculate PFDavg is in the ISA-TR84.00.02-2002 standard - Part 3. The following are the steps [13]:

1) The first step is to obtain the required information and data for calculations using FTA, such as PID images, failure mode, failure rate, and several other data.
2) Then identify the top event, the parameters that can be used as top events are such as deviation.
3) Next is to compile a fault tree, namely top-down and simultaneously conduct a review of the structure (qualitative review).
4) After the fault tree structure is composed, the failure rate data can be input to calculate, the data is obtained from OREDA 2002.
5) The final step is to calculate the overall failure rate (the top event's failure rate) to produce an estimate of PFD in every node.

ETA functions to analyze and calculate the chance of failure of safety devices when needed [14]. ETA consists of a chart where the input is the top event failure rate, then several layers of system security along with the chances of success (0.9 non-SIS and 0.99 SIS) and failure (0.1 non-SIS and 0, 01 SIS). After passing through several branches of the chart, at the end of the chart, there is a description of the outcome/consequence. The output of the ETA is the failure probability according to each scenario.

G. SIL Verification

Safety Integrity Level (SIL) is a ranking level (from 1-4) to specify the safety integrity requirements for a safety device. Safety Integrity is the probability of a SIF having the right performance and by its function in all predetermined conditions at one time. Verification means a process of confirming with several stages of the safety lifecycle to achieve the expected goals [12].

According to ISA TR84.02.2002, SIL is a specification of a level of SIF's ability to carry out its function to reduce the required risk. SIS is an instrument that can implement SIF. In conducting SIS analysis, it will be combined with IPL so that the definition of the Safety Integrity Level becomes a specification of the ability of a series of safety devices to perform their duties as a safety device.

From the PFD or the RRF, it can be used as a reference in choosing the SIL class. **Table 1** shows the level of SIL according to the class or level based on the IEC 61511 standard.

The activity in this step is to verify SIL with SIL required or SIL targets based on those in this facility. The SIL existing level has been obtained from the previous stage. So the verification process only matches it with the SIL target level, namely SIL-2.

The data shown is that it is said in the notes in the PID room that the transmitter component is included in the SIF with the SIL-2 level. Minimum SFF (Safety Failure Fraction) of 60% for type A and 90% for type B with HFT (Hardware Fault Tolerance) = 0. Referring to the Reliability, Maintainability, and Risk (Eighth Edition) 2011 book by David J. Smith, the provisions are categorized at the SIL-2 level [15]. Then the SIL existing level must meet the SIL-2 target.

At this stage, it is hoped that a result will appear in the form of a recommendation to safety devices. If the SIL calculation obtained has met the SIL target, the process ends at this step. If SIL existing does not meet

TABLE 1.
THE VALUE OF PFD AND RRF RELATED TO SIL LEVEL

Level SIL	Availability (%)	PFD Value	RRF Value
1	90,00-99,00	E-002 to E-001	100 to 10
2	99,00-99,90	E-003 to E-002	1.000 to 100
3	99,90-99,99	E-004 to E-003	10.000 to 1.000
4	>99,99	E-005 to E-004	100.000

the SIL target, it will continue to the re-design stage, where several recommended options can be proposed to increase the SIL level.

III. Results and Discussion

This section discusses and describes the steps taken to solve the problem based on the available data. These steps have been described in the previous chapter in detail. This section also analyzes and processes the data that has been obtained until the results and conclusions come out.

A. System Description

The system analyzed in this final project is the Fuel Gas System. The system is a utility system found in the ORF (Onshore Receiving Facilities) facility. Gas fluid originating from the WHP (Wellhead Platform) flows to the ORF Pig Receiver R-2930, then the gas flows into the Inlet Separator V-2010 which is then distributed to the Fuel Gas System, Liquid Burner System and Sales Gas Pipeline. In addition, there is a pipe that can directly flow gas fluid from the WHP to the Fuel Gas System.

In the Fuel Gas System, the gas enters the Fuel Gas Scrubber V-6060 for the filtering and separation of the gas from the pollutant particles in the gas. Then the gas goes to the Fuel Gas Filter Separator S-6060A or S-6060B to get an advanced filtering process. After the gas has been filtered twice, then the gas goes to Fuel Gas Superheater E-6060 for heating so that the output temperature is 52° C.

Gas that has been heated to a temperature of 52 ° C can be distributed to the Instrument Gas Receiver V-6070, Liquid Burner, Flare Header, Flare Ignition Panel, and Microturbine Generators. From the Instrument Gas Receiver V-6070, the gas is then distributed for use in the operational activities of the ORF facility. In **Table 2** the following shows a list of the components contained in the Fuel Gas System which is the scope of the HAZOP study.

B. HAZOP Study: Determination of Nodes

Node is the term used to describe the selection of one or more components that will be the focus of the study. A node can be a line, a pump, a vessel, a heat exchanger, or a collection of items. The first step of the HAZOP study is carried out by determining the (node) [16].

In the PFD drawing, it can be seen how the process flow of a system as a whole. But a more detailed image that includes the components in the system, along with the equipment attached to these components, is in the PID image.

The noding process is carried out by giving a box with a dashed line on each component, both in PFD and in PID. Then provide a connecting line on the pipe that flows fluid from one component to another. However, with different components, different colors (contrast) are used, which aims to make it easier to distinguish between components and the direction of flow. For pipes leading to and leaving a component, the color is the same as the component. However, in determining a node, a component that is inactive or not operating, then the component is not included/recorded as a node.

5 nodes are included in the HAZOP study. From the data obtained, 5 nodes are declared to be active (active) and none are declared inactive. Each node that is the focus of the study can be a line or a pressure vessel. A summary of the node descriptions for this study can be seen in **Tabel 3**.

Table 2.
Equipment List of Fuel Gas System

No.	Tag Number	Equipment
1	V-6060	Fuel Gas Scrubber
2	S-6060A	Fuel Gas Filter Separator
3	S-6060B	Fuel Gas Filter Separator
4	E-6060	Fuel Gas Superheater
5	V-6070	Instrument Gas Receiver

Table 3.
Nodes List of Fuel Gas System

No.	Nodes	Type	Comment
1	Fuel Gas Scrubber V-6060	Vessel	Active
2	Fuel Gas Filter Separator S-6060A	Vessel	Active
3	Fuel Gas Filter Separator S-6060B	Vessel	Active
4	Fuel Gas Superheater E-6060	Heat Exchanger	Active
5	Instrument Gas Receiver V-6070	Vessel	Active

Table 4.
The Example of Deviation in Node 1: Fuel Gas Scrubber V-6060

Node	Guide Word	Parameter	Deviation
Fuel Gas Scrubber V-6060	As well as	Composition	High Contaminant
	High	Level	High Level
	High	Pressure	High Pressure
	As well as	Flow	Leak
	Low	Level	Low Level
	Low	Pressure	Low Pressure

C. HAZOP Study: Identification of Deviation

The deviation is the input for the HAZOP analysis to simulate the abnormal behavior of the analyzed nodes. The deviation is derived from a combination of guide words and parameters. Initially, determining the deviation is to find between two things, namely guideword and property. The property itself is divided into 3 types, namely parameters (such as flow, pressure, reaction), operation (such as transfer, empty), and material (such as steam and diluent).

Deviation identification can be started by knowing the type of each component. Components can be a vessel, separator, filter, scrubber, tank, pump, and manifold. Then identified whether a component is likely to experience a deviation, such as high contaminant, high level, and high pressure. The deviation is closely related to keywords (guidewords) and parameters.

A component is identified with a deviation in the form of high pressure, then there is a guideword, namely high, and a parameter in the form of pressure. The identification process is carried out on all components that have been determined in determining the node. For example, if a guideword (example: high) meets a parameterized property (example: pressure), then the deviation is the result of the meeting between the two, namely high pressure. **Table 4** shows an example of the deviation for node 1.

D. HAZOP Study: Risk Analysis (HAZOP Worksheet)

HAZOP worksheet contains the results of the analysis of the causes of deviation and the consequences if this deviation occurs at each node. The safeguards in place to prevent this deviation from occurring are also analyzed. To determine the level of criticality of each series of analyzes, the risk level is measured the probability of deviation, and the effect.

The risk analysis carried out begins with identifying possible causes, the cause of a deviation occurring in a component. Then perform a consequence analysis, which is the result of what appears when the risk occurs. Then it is connected to the impact that might occur after the consequence occurs, so that it must be classified and categorized from consequences that have a large-scale to small-scale impact, namely with a value from 5 to 1. In **Table 5**, it can be seen that the justification of the assessment of the consequence.

The likelihood analysis is carried out in the next step to find out how often the events in this case are deviations or deviations during operations. The things that are used to carry out the likelihood analysis are the records of events in the field/facility. In addition, it is also necessary to justify the likelihood value by looking at **Table 6**. Then categorizing the likelihood from high to low with a value of 5 to 1.

The next step is to determine the risk matrix. The matrix can be seen in **Figure 2.** The matrix used is the

TABLE 5.
CONSEQUENCE RATING DETERMINATION CRITERIA

Rating	Descriptor
1	There are no people injured or lightly injured, the gas release does not cause pollution to the environment, failure has no effect on operations.
2	People with injuries need to be hospitalized, the release gas will quickly decompose by air / water, failure requires repair until the next scheduled shutdown.
3	Injury serious enough to cause disability, gas releases take a long time to neutralize, failure requires repair at an additional cost.
4	One person dies or is permanently disabled, gas release (medium) takes a long time to neutralize, failure causes plant shutdown in a short time.
5	More than one person dies, gas releases (high) and cannot be neutralized easily, failure causes plant shutdown for a long time.

TABLE 6.
LIKELIHOOD RATING DETERMINATION CRITERIA

Rating	Descriptor
1	It is hoped that this will never happen as long as the facility is operational.
2	It may happen once while the facility is operational.
3	May occur several times while the facility is operational (about once every 3 - 5 years).
4	Maybe it will happen once a year.
5	May occur several times a year (about up to 10 times a year).

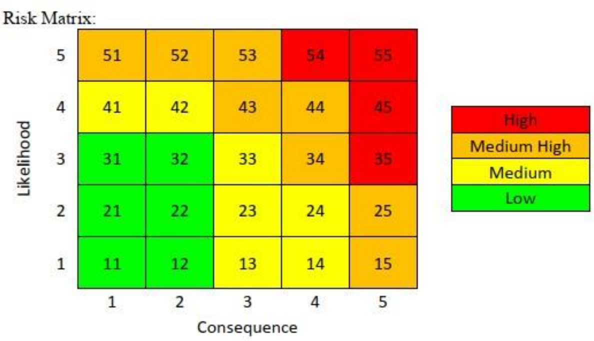

Figure. 2. Risk Matrix Used in the HAZOP Study

5x5 matrix which refers to the API 581 standard. Both consequence and likelihood have been categorized with values 1 to 5, then they are converted into the matrix so that it will produce several risk categories (risk ranking), namely between low risk, medium risk, medium-high risk, or high risk.

Risk ranking is needed to sort out and find out which possible causes have the greatest risk. If necessary, recommendations will also be made to reduce the risk level of a deviation**. Table 7** on the next page shows an example of the HAZOP Worksheet at node 1 for the deviation of high contaminants and high levels.

The results of the risk analysis through the HAZOP Study Worksheet, it can be concluded that the HAZOP Study results show that the total hazard that can occur is 84 events, with a risk ranking of 28 low risks and 56 medium risks. Next is to determine what hazards are often encountered (high likelihood) and which have high consequences as well. The summary of the risk analysis can be seen in **Table 8.**

TABLE 7.
HAZOP STUDY WORKSHEET NODE 1 FOR HIGH LEVEL DEVIATION

Cause	Consequence	Risk Matrix			Safeguard
		L	C	RR	
1. Excess feed (gas) supply from Inlet Separator V-2010	Higher feed (gas) supply can make the amount of gas is increased. Possibly the pressure at Fuel Gas Scrubber V-6060 is over design pressure.	2	3	Medium Risk	LG 6060 at V-6060, PG 6060 at V-6060, LCV 6060, PCV 6060A/B, PSV 6060A at V-6060, SDV 6060
2. Level control valve fails (stuck closed)	Scrubbing liquid is trapped in the Fuel Gas Scrubber V-6060 with no flow. Feed (gas) supply still go on, increasing the level of scrubbing liquid. Leading to increased pressure then over design pressure.	2	3	Medium Risk	LG 6060 at V-6060, PSV 6060A at V-6060, Valve VX-6421, Valve VX-6415

TABLE 8.
SUMMARY OF THE HAZOP STUDY WORKSHEET

Node	Low Risk	Medium Risk
1	5	12
2	7	11
3	7	11
4	6	11
5	3	11

E. Calculation of PFD with FTA and ETA Methods

The calculation of the PFD value requires failure rate data and is processed using the FTA method then ETA [17]. Fault Tree Analysis is a method used to identify the causes of failure of an equipment/system. Meanwhile, ETA is a simulation method to determine the chance of a failure event after going through several layers of security in a system. ETA calculates the chance of failure of the safety device when needed. In other words, through ETA, the PFD value can be found.

The analysis of the FTA method has top-down characteristics, where the peak event or what is commonly called the top event is described in advance. This incident was obtained from the results of the HAZOP study in the previous stage. After that, describe what initial events have the potential for a top event to occur, the initial event is called a basic event. Next is to form a connecting framework from basic events to top events with the appropriate lines and logic gates.

From each basic event, then determine the failure rate. The failure rate is obtained from secondary data, namely OREDA 2002 and NPRD 1991 [18]-[19]. With the help of software to analyze and calculate the failure rate in the FTA, calculate the failure rate for the top event in units per year. Meanwhile, the failure rate for the external event is 1.8×10^{-2} [20]. The failure rate at the top event obtained is then used in the calculation of the ETA analysis.

Figure 3 shows one of the results of the FTA analysis for Node 1: Fuel Gas Scrubber V-6060. The top event for the V-6060 component based on the results of the HAZOP study is overpressure. The failure rate for the top event based on the calculation result is 5.71E-02 failure events/year.

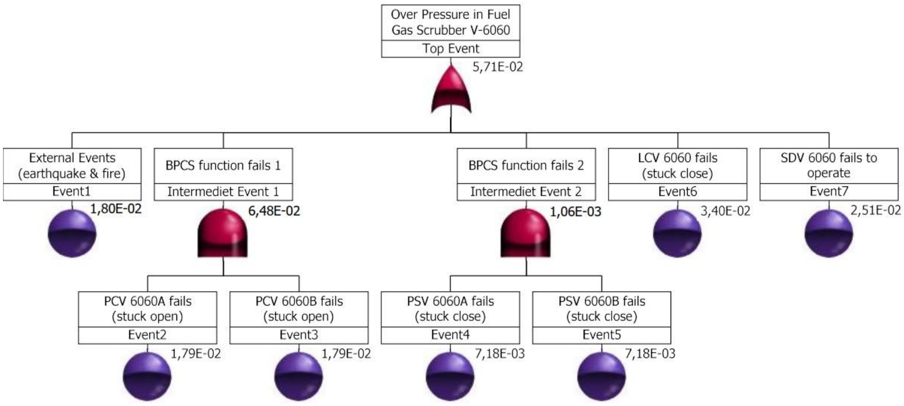

Figure. 3. The Results of The Analysis and Calculation of FTA for Node 1

The next stage is to analyze and calculate using the ETA method. The failure rate at the top event generated from the previous step is used as input in this step. If there is a deviation or deviation in the operation process of a component, of course, there will not be an immediate hazard event, as long as there is a safety device. Safety equipment attached to the components will protect the components from bad impacts due to a deviation.

ETA functions to analyze and calculate the chance of failure of safety devices when needed. ETA consists of a chart where the input is the top event failure rate, then several layers of system security along with the chances of success (0.9 non-SIS and 0.99 SIS) and failure (0.1 non-SIS and 0.01 SIS). After passing through several branches of the chart, at the end of the chart, there is a description of the outcome. The output of the ETA is the failure probability value according to each scenario. **Figure 4** on the next page is a PFD calculation with ETA for Node 1: Fuel Gas Scrubber V-6060.

In the ETA analysis for Node 1, if there is a deviation which is the basic event of the peak over-pressure event, the first system security layer is responsible, namely the HP Alarm (High-Pressure Alarm). If the alarm is successful, then the operator will take action, at that time the operator (Opt. Response) acts as the second layer of system protection. If the operator takes appropriate action, the consequence is that no gas is exhausted into the flare. If the alarm does not work, the operator cannot respond and continue to the third layer, namely Prot. Layer (Protection Layer) in the form of BPCS such as PSV, PCV, and LCV. If the third layer of protection fails, then the fourth and final layer is the Safety Func. (Safety Function) is an SIS safety device that has SIF-like SDV.

From the seven consequence scenarios, seven Probability of Failure values will be generated (probability of failure). The failure probability value for each system protection layer failure scenario when needed is the PFD (probability of failure on demand)

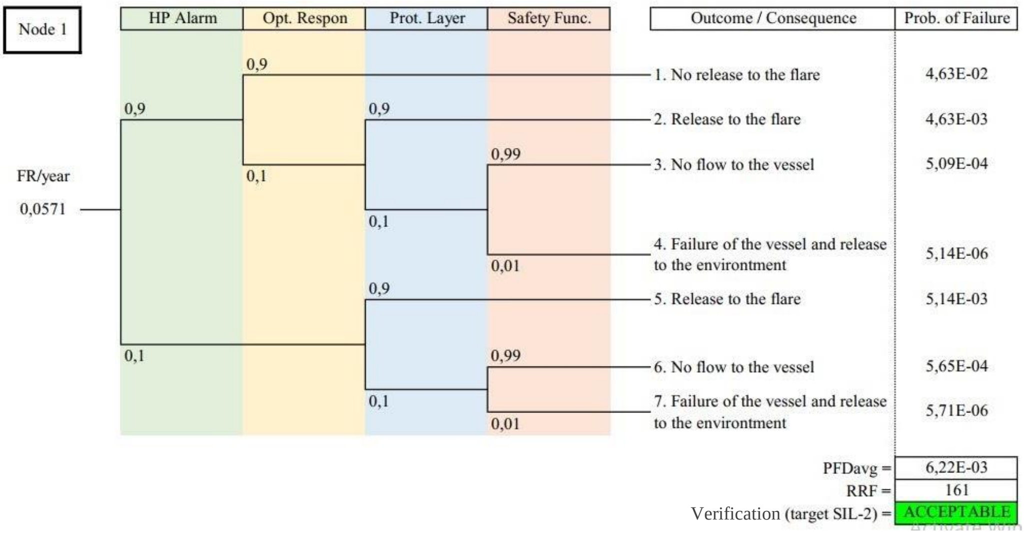

Figure. 3. The Results of The Analysis and Calculation of FTA for Node 1

TABLE 9.
THE RESULT OF SIL VERIFICATION FOR ALL NODES IN FUEL GAS SYSTEM

Node	Target SIL			Existing SIL			SIL Verification
	Level	PFD	RRF	PFD	RRF	Level	
1	2	1E-03 to 1E-02	1000 to 100	6,22E-03	161	2	ACCEPTABLE
2	2			1,24E-03	805	2	ACCEPTABLE
3	2			1,24E-03	805	2	ACCEPTABLE
4	2			1,21E-03	827	2	ACCEPTABLE
5	2			2,23E-03	448	2	ACCEPTABLE

value. Figure 4.4, is included in the PFD scenarios 3 to 7. Finally, the PFDavg value is obtained, which is the sum of the total PFD in scenario 3 to scenario 7, which is 6.22E-03. The RRF (Risk Reduction Factor) value is 1/PFD, so the RRF for Node 1 is 161.

F. Verification of SIL and SIL Target

The SIL level can be determined by using the PFDavg or RRF values. The SIL level in this study is the existing SIL value, which must be verified against the SIL target value. The SIL target is the SIL value claimed by the company or the SIL value when the facility was first built, namely SIL-2.

At this verification stage, the PFD or RRF values obtained in the previous stage are used to determine the SIL existing level. This value is checked with the SIL level interval value according to the IEC 61508 and IEC 61511 standards. **Table 9** shows the SIL verification results for each node.

The target SIL level for all nodes is the SIL-2 level. The results of the analysis and calculation of PFDavg, namely Node 1 Fuel Gas Scrubber V-6060 is 6.22E-03 with an RRF value of 161, Node 2 (Fuel Gas Filter Separator S-6060A) is 1.24E-03 with an RRF value of 805, Node 3 (Fuel Gas Filter Separator S-6060B) is 1.24E-03 with an RRF value of 805, Node 4 (Fuel Gas Superheater E-6060) is 1.21E-03 with an RRF value of 827, and finally, Node 5 (Instrument Gas Receiver V-6070) is 2.23E-03 with an RRF value of 448.

From the SIL verification results, it was found that Node 1 to Node 5 the existing SIL level was by the SIL target level. All nodes are at the SIL-2 level according to the SIL target. The lowest RRF value is the Node 1 component with a value of 161 and the highest in the Node 4 component with a value of 827.

Based on these results, there is no need for a re-design stage for all the safety devices of the components studied.

IV. CONCLUSION

Based on the results of the analysis and discussion that has been carried out in this study, the following conclusions can be drawn:

1) From the results of the HAZOP study, which is a hazard analysis process, there were 84 hazard events in total. The level of risk (risk ranking) with the low-risk category was 28 events and the medium risk category was 56 events.
2) Based on the HAZOP study, it can be concluded that the danger of over-pressure is a hazard with the most severe consequence, the highest likelihood, and the risk level is medium risk. *Over-pressure* is a top hazard for all nodes or components in the Fuel Gas System.
3) Calculation of PFDavg from the safety device in the Fuel Gas System using the FTA and ETA methods, the PFDavg results are as follows:
   a. Node 1 Fuel Gas Scrubber V-6060 is 6,22E-03
   b. Node 2 (Fuel Gas Filter Separator S-6060A) is 1,24E-03
   c. Node 3 (Fuel Gas Filter Separator S-6060B) is 1,24E-03
   d. Node 4 (Fuel Gas Superheater E-6060) is 1,21E-03
   e. Node 5 (Instrument Gas Receiver V-6070) is 2,23E-03
4) SIL verification results with SIL targets based on the PFDavg results obtained and IEC 61511 standards for all nodes are appropriate. All Fuel Gas System components in the ORF meet the SIL-2 target level so the re-design stage is unnecessary.

Suggestions and recommendations that can be given from researchers are as follows:

1) At Node 1 (Fuel Gas Scrubber V-6060) has a PFDavg value of 6.22E-03 and an RRF value of 161 which is still by the range value for the SIL-2 level. However, this value is in the lower range approaching the SIL-1 level range. It can be suggested to add a safety device or even SIS to Node 1 so that the PFDavg value decreases or the RRF increases and the system will be safer on SIL-2.
2) The Fuel Gas System in ORF will be better if some of the existing safety devices are upgraded to SIS so that the system security level will also increase.
3) Research can be developed again if the failure rate data is obtained directly from the company (not using secondary data). This will result in calculations that are closer to the real conditions of the safety equipment.

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