Risk Analysis on Modified Offloading System of LNG FSRU

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Abstract. Electricity needs in various islands that are difficult to reach, prompting PT X to assist PT PLN in supplying natural gas fuel for power generation, using LNG technology. Small LNG carriers are designed to reach shallow water. Due to the height difference in the LNG carrier manifold being designed with the West Java FSRU manifold, it is not possible to carry out the loading and unloading process. Therefore the modification of loading and unloading equipment is needed. The modification of the West Java FSRU loading and unloading system was done to add the loading arm range to the small LNG carrier manifold. In 2013 WOAD (World Offshore Accident Data) stated, 9 accidents occurred during the process of loading and unloading liquid and 7 accidents that ended in fire. This study discusses a risk analysis on the loading and unloading system of West Java FSRU after modification. This study begins with hazard identification using HAZOP (Hazard and Operability Study) method by analyzing the P&ID of modified loading and unloading system. Frequency analysis is done in to calculate an annual frequency of identified hazards and done using FTA (Fault Tree Analysis) and ETA (Event Tree Analysis) methods.

1. Introduction

The need for electricity from various islands in Indonesia pushed PT. X to supply natural gas as fuel for power plants. The use of natural gas in power plant fuels is supported by the business sector of PT X itself and also the increasing natural gas production. Natural gas is sent in liquid form, which is often known as Liquified Nature Gas (LNG). LNG has a volume of 600 smaller than natural gas which is very profitable in long-distance shipping. LNG is supplied to areas that have shallow waters and are difficult to reach by large vessels. Therefore, to reach the shallow waters can use several facilities such as pipelines or smaller LNGC.

In this case, PT X chose to use LNG carriers because the use of LNGC vessels has higher flexibility compared to pipelines. In carrying out this project, an LNG carrier with the height of the ship by with the intended waters is needed. The LNG ship to be used has been designed by Moss Maritime, ships to be designed with a capacity include 3600 m³, 8000 m³ dan 10000 m³[1] the ship is designed to have a height variation so that the height of the manifold is different. The ships designed for this project are three ships with a manifold height from the water surface of 6.25 m, 7.3 m, 17.8 m.
LNG carriers receive LNG from the FSRU by Ship-to-ship (STS) process. However, with the current condition, the FSRU loading and unloading facility is not possible to send LNG to the LNG carrier which will be built because the height of the loading arm is located at height 30m from the water surface. Whereas the manifold height of the designed LNG ship is 7.3 m. So the height difference between the FSRU manifold and the new LNG ship is 20 m, while the loading arm which currently has a range of only 4 meters.

From this, the FSRU will be modified with the addition of a flexible hose at the end of the loading arm so that the FSRU loading and unloading tool can reach the LNGC manifold to be made. The loading and unloading process can be processed after the modification is complete, but of course, there are work risks that need to be considered during the loading and unloading process. Not a few accidents in offshore buildings or ships caused by several causes such as unsafe working conditions, component reliability, improper maintenance of equipment, and lack of training for workers.
Based on WOAD data (World Offshore Accident Data) 9 accidents occurred in 2013 in the process of loading fluids. This certainly needs to be taken into account given the project work carried out by PT X as well as carrying out the LNG loading and unloading process.

Then in 2013 WOAD also stated 7 offshore accidents affected the fire. From this, it is of course necessary to know the potential dangers that cause fires in this FSRU, to prevent losses from various parties in these operations. Therefore, the study discusses the analysis frequency of fire risk on the FSRU that will be modified.

![Diagram showing offshore building accidents](#)

**Figure 3.** The Offshore Building Accidents Based on Occurring Activities

**Figure 4.** Offshore Building Accidents Based on the Impact that arises

### 2. Methodology

In this study, FSRU is used as the main object. This study discusses fire and explosion frequency analysis. The method used to identify problems is to use HAZOP. Frequency analysis using the Fault Tree Analysis (FTA) and Event Tree Analysis (ETA) methods.
2.1 Conversion Design

At present conditions, the FSRU functions as a recipient of the LNG Aquarius with a capacity of 125,000 m$^3$, but with the new project, the FSRU becomes a supplier of LNGC with a small capacity of 3600 m$^3$, 8000 m$^3$, and 10000 m$^3$. For an illustration of the loading and unloading process between FSRU and LNGC Aquarius can be seen in Figure 5.

![Figure 5](image.jpg)

**Figure 5.** Ship to Ship Between FSRU with LNGC 8000 m$^3$ (Before Conversion)

The picture above is an illustration of the loading and unloading process with Aquarius LNGC with a manifold height of 18 m above sea level. With a height of 18 m, the loading arm can reach that distance, whereas in a new LNGC with a manifold height of 7.3 m, the loading arm is unable to reach that distance. An illustration of the process of loading and unloading between FSRU with small LNGC can seem in Figure 6.

![Figure 6](image2.jpg)

**Figure 6.** Process of loading and unloading between FSRU with small LNGC
After the conversion is done there are additional components such as flexible hose and Pipe Spool, Pipe Spool functions to connect the loading arm with a flexible hose which is then flexible hose connected to LNGC.

2.2 Hazard Identification

Hazard and Operability is an initial method in risk analysis research to identify problems. The HAZOP that will be used is the British HAZOP BS IEC 61882: 2001 standard HAZOP. Based on these standards the first thing to do is divide the system into several parts or nodes. After that, it can be continued with failure analysis and the consequences that will occur.

2.3 Frequency Analysis

This study analyzes the frequency of failures using the Fault Tree Analysis (FTA) method. Fault Tree Analysis (FTA) is a method used to identify risks that contribute to failure. This method is carried out with a top-down approach that begins with the assumption of failure or loss from a peak event (top event) then details the causes of a top event to a basic failure. Followed by using event tree analysis (ETA), event tree analysis is a method used to identify and evaluate a sequence of events in a potential hazard scenario of an initial event. Event Tree is also a diagram that shows all the events that might occur in the system.

2.4 Consequence Analysis

In this study the consequences carried out are social risks or consequences that impact on humans, so the results of this method are victims of human deaths. At this stage the analysis is done using fire modeling, fire modeling is a way to simulate the consequences of danger. Fire modelling can be used by computer software. Fire modeling is done based on a scenario that has been made before. By entering the required number of parameters by the specified scenario, it will show the area affected. Fire modeling is done using Shell FRED software, also known as Shell Fire, Release, Explosion, Dispersion Hazard Consequences of modeling software.

3. Hazard Identification

Hazard and Operability (HAZOP) is an initial method in risk assessment to identify problems. HAZOP problem identification is widely used in systems processes. Based on the HAZOP standard used things are must do is divide the processing system into a section or node [2]. Table 1 is the division of nodes on the FSRU.

| Description | Node |
|-------------|------|
| FSRU Tank - Loading Arm (LNG) | 1 |
| Loading Arm – LNGC manifold (LNG) | 2 |
| LNGC manifold – Loading Arm (Vapor) | 3 |
| Loading Arm – FSRU Tank (Vapor) | 4 |

After the division of nodes can analyze potential failure as well as the consequences of a failure the process to be analyzed. HAZOP is packed in report form or form. The contents of HAZOP are guidewords, deviation, possible causes, consequences, safeguards, comments, and action required.

4. Frequency Analysis

Frequency analysis is carried out to determine the magnitude chance of failure of the functioning of a component in a system. If a system failure occurs, it can initiate a hazard event. The standard used in
frequency analysis is Det Norske Veritas (DNV) Failure Frequencies Guidelines Process Equipment Leak Frequency Data for Use in Quantity Risk Assessment (QRA). The frequency analysis method used is a fault tree analysis (FTA) and event tree analysis (ETA). This method uses a bottom-up approach where the analysis begins with the chance of failure of a component that initiates a system failure and continues with the event a danger. In analyzing the frequency of this study the beginning of the fire incident was caused by the incident gas leak. Gas release events are caused by system leakage (system leakage) and system failure (system failure). Table 2 is the recapitulation results FTA. From the FTA results, the frequency of each node is obtained caused by system leakage and system failure. So the frequency of each node is obtained by producing a scenario the size of the gas release leakage is 10-50mm, 50-150mm, and >150mm. The results of the FTA recapitulation can be seen in table 2.

**Table 2. FTA Analysis Result**

| Node | Bore Scenario | 10-50 mm | 50-150 mm | >150 mm |
|------|---------------|----------|-----------|---------|
| 1    |               | 2.62E-03 | 6.13E-04  | 9.38E-05|
| 2    |               | 1.03E-03 | 2.42E-04  | 3.62E-05|
| 3    |               | 1.41E-03 | 3.30E-04  | 4.95E-05|
| 4    |               | 2.62E-03 | 6.15E-04  | 9.10E-05|

Event Tree Analysis (ETA) is a method used to determine the probability of an event in a system [3]. The use of ETA in this study is to calculate the modeling of events that cause fire and explosion. The fire and explosion itself start with ignition or in this study the ETA modeling scheme starts with a gas release event which is the final result of the FTA analysis. The scenario used as the final consequence of fire and explosion in the study is flash fire, jet fire, and gas dispersion. To find out the frequency of occurrence of ignition causes of fire and explosion used secondary data from the Chemical Process Quantitative Risk Analysis 2nd Edition. Based on the types of hazards that have been determined, the frequency can be determined based on secondary data. In table 3 [4].

**Table 3. Hazard and Its Probability**

| Hazard     | Ignition | Probability | Description                                                                 |
|------------|----------|-------------|-----------------------------------------------------------------------------|
| Jet Fire   | Immediate Ignition | 0.1 | The resulting fire from igniting the gas the easy one burning from equipment leak process |
| Flash Fire | Delayed Ignition    | 0.75 | A fire that spreads quickly without producing damaging pressures.               |
| Gas Release| No Ignition         | 0.25 | Dispersed and spilled gas leak in the processing system                        |

ETA analysis was carried out using three leak diameter hole scenarios. Based on the results of the ETA analysis that has been done at each node with three types of hazards and three scenarios, ETA can be done, so that the results of the frequency of fire events on the FSRU can be seen in table 4.
5. Consequence Analysis

Fire modeling conducted (jet fire, flash fire, and gas dispersion) study object is FSRU. Where the FSRU is generally fully operational for 24 hours. So the scenario used in the analysis is the operating time at day time and night time for nodes 2 & 3. For weather conditions adjusted to the operational location of the FSRU, while for the wind direction the wind rose scenario uses the FSRU operational location. For nodes 1 & 4 using location-dependent scenarios, the scenario is placed in 2, the first scenario is the fire that occurs at the front of the ship (tank 1/2/3) and the second is the explosion that occurs at the rear of the ship (tank 4 / 5/6). The purpose of fire modeling is to determine the magnitude of the impact caused by the fire on the environment around the FSRU, more specifically in this study is the impact of losses on humans or crew members on the FSRU. In fire modeling or analysis of the consequences of this final project, it is important to know the value of the heat flux that is scattered [5], while the provisions of the flux value can be seen in the Table 5.

### Table 5. The Amount of Flux and the Impact Caused

| Heat flux value [kW/m²] | Effect |
|------------------------|--------|
| 1.6                    | Will cause no discomfort for long exposure |
| 4                      | Sufficient to cause pain to personnel if unable to reach cover within 20 seconds |
| 4.7                    | Accepted value to represent injury |
| 10                     | Pain threshold after 8 seconds; second-degree burns after 25 second |
| 12.5                   | The Minimum energy required for piloted ignition of wood, melting plastic |

In the event of gas dispersion, the danger posed to humans comes from the amount of gas concentration per million (ppm). Gas dispersion in general from LNG does not have the impact of death on humans but at a certain level can hurt human respiratory function. The following is the amount calculated ppm to humans which can be seen in table 6.

### Table 6. The Amount of Gas and the Impact Caused

| Kadar % | Ppm | Impact on Human |
|---------|-----|-----------------|
| <5      | 50000 | Non-toxic |
| 14      | 140000 | Methane gas can reduce oxygen levels in the atmosphere |
| 30      | 300000 | Central nervous system depression |

At this stage the fire modeling is carried out with SHELL FRED software, the following is an example of modeling the results of a Jet Fire on node 1 with a scenario occurring at the front of the ship and with a 150 mm hole, the result can be seen in figure 7.
In the picture above there are 3 areas, areas with purple, green, and blue lines. The line shows the amount of flux scattered on the fire, the blue line is worth 12.5 kw / m2, the green line is 10 kw / m2 and the purple line is 4.7 kw / m2. From this modeling we can know the number of victims of the Jet Fire impact based on the area exposed by the green or blue lines. After analysis, the recapitulation is then performed, to recapitulate the analysis results can be seen in table 7.

**Table 7. The Result of Consequence Analysis**

| Node | Scenario       | Jet Fire | Flash Fire | Gas Dispersion |
|------|----------------|----------|------------|----------------|
|      | 10-50mm  | 50-150mm | >150 mm | 10-50mm | 50-150mm | >150 mm | 10-50mm | 50-150mm | >150 mm |
| 1    | Tank1/2/3 | 2         | 2         | 4       | 2        | 2        | 2        | 2        | 4        | 4        |
|      | Tank 4/5/6 | 7         | 7         | 7       | 2        | 6        | 9        | 2        | 8        | 8        |
| 4    | Tank1/2/3 | 2         | 2         | 2       | 2        | 2        | 2        | 2        | 2        | 2        |
|      | Tank 4/5/6 | 7         | 7         | 7       | 2        | 6        | 9        | 2        | 8        | 8        |
| 2    | Day Time   | 5         | 5         | 8       | 5        | 2        | 3        | 5        | 5        |
|      | Night Time | 5         | 5         | 8       | 5        | 2        | 3        | 5        | 5        |
| 3    | Day Time   | 3         | 5         | 5       | 3        | 3        | 3        | 3        | 5        |
|      | Night Time | 3         | 4         | 5       | 3        | 3        | 3        | 3        | 5        |

**6. Conclusion**

At this stage also cannot be started because at the analysis stage of consequences that have not worked

- **a.** Hazard identification carried out on the system using the Hazard and Operability (HAZOP) method is divided into four nodes and raises 3 potential hazards that might occur Jet Fire, Flash Fire & Gas Dispersion.

- **b.** Frequency analysis produces frequencies at hazard, the most frequent frequency at jet fire is at node 3 leak holes 10-50 mm, then the frequency most often occurs at flash fire hazard is at node 1 at 10-50 mm leak holes and the frequency most often occurs at danger Gas dispersion is found in node 1 of leak hole 10-50 mm.

- **c.** Consequence analysis produces risks or impacts caused by hazards in the form of fatalities, the most frequent Jet Fire victims are at node 2 leak hole > 150 mm with night scenarios, then the Flash...
Fire hazard most victims occur at 1 leak hole > 150 mm with 4/5/6 tank scenarios and for the most hazardous gas dispersion victims occur at node 4 leak holes > 150 mm with 4/5/6 tank scenarios.

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