Fire risk assessment on Floating Storage Regasification Unit (FSRU)

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Abstract. Floating Storage Regasification Unit (FSRU) is a variety of facilities that support Liquefied Natural Gas (LNG) supply chain activity. There are several potential fire hazards which could be harmful to human and cause death by the FSRU. This paper will discuss a fire risk assessment on the FSRU loading arms and gas export metering system. To begin, fire risk assessment is carried out in several stages. The first step is to identify hazards using Hazard and Operability. Then, frequency analysis out of hazards events are complying by the Fault Tree Analysis and the Event Tree Analysis, these methods are to determine the type of potential hazards and to estimate frequencies of events. Henceforth, consequences analysis will be performing by fire modeling software. Finally, the result of the fire risk assessment can be carried out using risk mapping using standard f-N curve UK Offshore, if the risk mapping illustrates unacceptable condition, it is necessary to carry out a mitigation action using the Layers of Protection Analysis. Fire risk assessment indicates that the potential fire hazards which occur are jet fire, flash fire, and gas dispersion. Each hazard has leakage scenarios which are, small-bore (10-50 mm), medium bore (50-150 mm), and full bore (>150 mm). Thereupon, the result of consequence analysis indicates a various form of fire and expose areas which have an impact on marine crews. Based on the risk mapping, the results show that the fire risk assessment which has been carried out is in acceptable conditions and as low as reasonably practicable.

1. Introduction
Liquefied Natural Gas (LNG) is one type of natural gas that becomes a breakthrough in the present. It is a type of natural gas that being cooled until -160°C in atmosphere pressure and their major contents are methane. Thus, LNG has 600 lesser volumes from the previous form. As a result, gas distribution work more efficient. The supply chain on LNG begins with natural gas production using platform facility whether in onshore or offshore fields [1]. The process of natural gas is continued by the liquefaction process to change form into LNG and then it stores in storage tanks. LNG is frequently distributed by LNG carrier to end-user which is a power plant in the receiving terminal. When turning up, LNG is repressurized again to become a natural gas engaging regasification facility and finally being distributed to the end-user [2]. Generally, LNG was distributed using vessels instead of land vehicles. However, in the present time LNG are not yet widely used due to the expenses for the supporting facility. To reduce expense factors, there is a new facility that could be built namely the Floating Regasification Storage Unit (FSRU). The main function of the FSRU is to have a regasification plant to convert LNG to NG. The Process system in the FSRU starts from LNG transfer from LNG Carrier to the FSRU tanks.
The LNG is being stored in the FSRU tanks to be prepared for the regasification plant. After LNG is changing into natural gas form, natural gas is continued moving for gas transfer to the receiving terminal against supplying power plants.

Regasification terminals are important, but these infrastructures highlight the question concerning the acceptability of the risk. However, these infrastructures are defined as emerging risk inasmuch the hazards associated with these installations were not fully explored to date [3,4]. The issue of security of these systems should be addressed through careful and thoughtful assessment of the risks related and proper communication to the population. The aim of this work is the risk analysis of an offshore regasification terminal. The process of risk analysis involves several basic steps [5,6]:

- Description of the system;
- Hazard identification for selection system;
- Frequency estimation & consequence analysis;
- Risk mapping.

2. Offshore-LNG Terminal: FSRU

The LNG terminal is one of the important parts for supplying and distributing natural gas. The importance of this kind of infrastructure is increasing in time. The FSRU is located in offshore areas at the Indonesia bay, with 23 meters depth and capable of providing the network with national gas about 500 billion MMBSCD of gas natural per day. The case study of the fire risk assessment will be carried out in loading arms and gas metering systems in FSRU.

![FSRU process block diagram](image)

Figure 1. FSRU process block diagram

Figure 1 defines the process which occurs in the FSRU for this project. It starts from LNG transfer from LNG Carrier to the FSRU tanks. Afterward, the LNG form from FSRU tanks is being transferred to the regasification plant and changing into a natural gas form [7,8]. Thus, natural gas is being continued for gas transfer to the receiving terminal using a subsea pipeline to supply power plants. During the process, pressure and temperature on the system must be maintaining correspond to the standard operational procedure. LNG handling facilities of LNG-FSRU comprise the following main systems.

- Loading arms & crossover
- Cargo handling equipment: high and low duty compressors and high and low duty heaters and LNG vaporizers,
- FSRU tanks
- LNG pumps in storage tanks
- Regasification plants
- Spread mooring
- Knock-out drum and flare tower or cold vent stack
- Gas export metering
- Unloading arms

The FSRU in this case is moored for 20 years of operation. Moreover, marine crew data are needed for risk assessment. Likewise, the weather condition in the FSRU operational location is described as follows:
• Minimum sea water temperature : 25°C
• Maximum seawater temperature : 32°C
• Maximum significant wave height: 1.8 m
• Maximum current speed : 1.1 m/s
• Maximum wind speed : 26 m/s

3. Methodology
The current study using a methodology for assessing the risk level of hazardous activity. The technique provides numerical estimation to allow understanding of the risk exposure to people or other areas of interest. Also the standard methodology for the study is presented in Figure 2.

![Figure 2. The methodology of fire risk assessment on FSRU](image)

The methodology in Figure 2 will apply to determine the process of fire risk assessment in the case study. The method begins with hazard identification using Hazard & Operability (HAZOP) method following by frequency estimation using the Fault Tree Analysis (FTA) method to find and estimate fluid leakage bore scenarios in the system. Henceforth, the Event Tree Analysis (ETA) method is to determine fire event which will be occurring in the FSRU system. Moreover, consequence analysis in this case study will be measure using fire modeling software so fire distribution in the system could be loamy. As a result, the amount of marine crew that might be exposing owing to fire events could be determined. Finally, risk mapping in the FSRU will be carrying out to perceive hazard event position under f-N Curve UK Offshore standard, if risk mapping is in the unacceptable condition, therefore, mitigation will be performed using the Layers of Protection Analysis (LOPA) method.

4. Hazard Identification
Risk analysis in this case begins with hazard identification using Hazard and Operability (HAZOP) BS IEC 61882. Hazard and Operability (HAZOP) is an initial method in risk assessment to identify problems [6]. HAZOP problem identification is widely used in a process system, the main function is to determine, classify, and identify the problem. In using HAZOP, the first step is dividing the system into nodes. Hereafter, each node in the system could be analyzed to forecast their potential failures and consequences one using guidance from the HAZOP. That guidewords are guidewords, deviations, possible causes, consequences, safeguards, comments, and action required. In this study, fire risk assessment is in loading arms and gas metering systems in the FSRU, thus it should be dividing into five nodes.
Table 1. Node location in FSRU

| Node | Location                        |
|------|---------------------------------|
| 1    | LNG Carrier to FSRU Tank        |
| 2    | LNG Carrier to FSRU Tank        |
| 3    | LNG Carrier to FSRU Tank        |
| 4    | Regasification Plant to Gas Metering |
| 5    | Gas Metering to Gas Export Manifold |

Table 1 defines each node in the system from the existing locations. Using all nodes from Table 1, the HAZOP can be defined using the HAZOP worksheet. Figure 3 is the example of the HAZOP worksheet in node 5.

5. Frequency Analysis

Frequency estimation will be carried out using the formula from references which are Det Norske Veritas (DNV) Failure Frequencies Guidelines Process Equipment Leak Frequency Data for use in Quantity Risk Assessment (QRA) and Onshore & Offshore Reliability Data (OREDA). Those references will define the frequency value on each node. In this study, possible accident scenarios in the FSRU shall derive by:

- System leakage of the pipe, valves, & safeguards
- System failure of the pipe, valves & safeguards

The initial step of frequency analysis is performed using the FTA method, it will be done to carry out a failure identification of a system. FTA is widely used in studies relating to risk analysis and reliability in a system [5]. FTA has a function-oriented or well-known approach with the term “top-down” approach. Analysis of the FTA starts from the system level at the top and will continue down to the basic event. Henceforth, the analysis of the FTA in this case study has the main result of the top event in the form of gas releases on each node. In carrying out FTA analysis, logic gates will be used to assist the FTA process. Therefore, from this method, it could be concluded while that fire event originally is caused by a gas leak. To be noted that the FTA in this study is caused by system leakage or system failure. Furthermore, each system consisting of pipes, valves, and safeguards which could determine leakage frequency value [9,10].

As a result, frequency analysis using FTA comes up with three scenario dimensions of release, define as follows:

Figure 3. HAZOP worksheet on node 5
- Small-bore (10-50 mm)
- Medium bore (50-150 mm)
- Full bore (>150 mm)

The result of the frequencies value related to each bore scenario for gas release in each node can be depicted in Table 2.

**Table 2. Frequency value for gas release in all dimension on each node**

| Node | Bore Scenario | 10-50 mm | 50-150 mm | >150 mm |
|------|---------------|----------|-----------|---------|
| 1    | 9.48E-04      | 2.24E-04 | 3.37E-05  |
| 2    | 9.39E-04      | 2.22E-04 | 3.33E-05  |
| 3    | 8.59E-04      | 2.02E-04 | 3.03E-05  |
| 4    | 6.83E-04      | 1.58E-04 | 2.29E-05  |
| 5    | 5.32E-04      | 1.26E-04 | 1.89E-05  |

Afterward, the result of the frequencies value of gas release from Table 2 is will be used to identifying the fire event which might be emerging in each node. Thus, the Even Tree Analysis (ETA) method will comply with the analysis. Using the Chemical Process Quantitative Risk Analysis (CCPS) 2nd Edition as a reference, the amount of the probability and fire event [4] which might be occurring in the FSRU could be defined as in Figure 4.

![Figure 4](image)

**Figure 4.** Generic event tree of flammable gas and flammable liquid

As the results, the frequency value and fire event which occurs in FSRU for each node from FTA gas leakage bore scenarios can be defined in Table 3 on the next page.

**Table 3. Frequency estimation for fire event in FSRU**

| NODE | 10-50mm | 50-150mm | >150mm | 10-50mm | 50-150mm | >150mm | 10-50mm | 50-150mm | >150mm |
|------|---------|----------|--------|---------|----------|--------|---------|----------|--------|
| 1    | 9.48E-05| 2.24E-05 | 3.37E-06| 6.40E-04| 1.51E-04 | 2.28E-05| 2.13E-04| 5.04E-05| 7.59E-06|
| 2    | 9.39E-05| 2.22E-05 | 3.33E-06| 6.34E-04| 1.50E-04 | 2.25E-05| 2.11E-04| 4.99E-05| 7.50E-06|
| 3    | 8.59E-05| 2.02E-05 | 3.03E-06| 5.80E-04| 1.36E-04 | 2.05E-05| 1.93E-04| 4.55E-05| 6.83E-06|
| 4    | 6.83E-05| 1.58E-05 | 2.29E-06| 4.61E-04| 1.07E-04 | 1.54E-05| 1.54E-04| 3.55E-05| 5.15E-06|
| 5    | 5.32E-05| 1.26E-05 | 1.89E-06| 3.59E-04| 8.53E-05 | 1.28E-05| 1.20E-04| 2.84E-05| 4.25E-06|
6. Consequence Analysis
In the consequence analysis, the fluid under consideration is a natural gas depend on the node’s location. Consequence analysis will be performed using FRED software. The simulation is will be complying in 24 hour time using the real weather condition in an operational location on day and night condition. Since death consequences on the marine crew of the FSRU could be caused by fire events, therefore, heat flux value in fire events should be determined [5]. Table 4 defined the heat flux value of fire events.

| 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 |

It can be concluded from Table 4 that perish consequences could occur when the heat flux value is greater than 10 kW/m². However, gas dispersion events of LNG are not applicable or do not have the impact of death on humans since LNG is a non-toxic gas, but at a certain level, it could adverse on human respiratory function. As a result, Table 5 exhibit the number of defunct consequences in marine crew brought about fire event.

| Node | Leak Scenario | Jet Fire | Flash Fire | Gas Disp. |
|------|---------------|----------|------------|-----------|
|      | 10-50mm       | 6        | 6          | 3         |
| 1    | 50-150mm      | 6        | 6          | 6         |
|      | >150mm        | 6        | 6          | 6         |
| 2    | 10-50mm       | 6        | 6          | 3         |
|      | 50-150mm      | 6        | 6          | 6         |
|      | >150mm        | 6        | 6          | 6         |
| 3    | 10-50mm       | 6        | 1          | 3         |
|      | 50-150mm      | 6        | 3          | 6         |
|      | 10-50mm       | 6        | 6          | 6         |
| 4    | 10-50mm       | 2        | 2          | 2         |
|      | 50-150mm      | 6        | 6          | 6         |
|      | >150mm        | 6        | 6          | 6         |
| 5    | 10-50mm       | 2        | 2          | 2         |
|      | 50-150mm      | 4        | 6          | 4         |
|      | >150mm        | 4        | 6          | 4         |

Considering the risk acceptability criteria contained in the standard f-N Curve UK Offshore, the local risk can be considered acceptable since the limited number of people present on the terminal [6].
7. Conclusions
Hazard identification is carried out on loading arms and gas export metering systems of an FSRU using the Hazard and Operability (HAZOP) method. The systems are divided into 5 nodes. Yet, a cause of the deviation is damage to systems such as pipes, valves, and safeguards. This deviation causes the potential for fire hazards. Afterward, frequency analysis is carried out using the Fault Tree Analysis (FTA) method. The FTA defines three leak scenarios, which are, 10-50 mm, 50-150 mm, and >150mm. Hereafter, the ETA method is applied to obtain three hazard events, namely jet fire, flash fire, and gas dispersion. Subsequently, consequence analysis using fire modeling software is performed to determine the magnitude of each hazard event that has an impact of deadly consequences on humans. In this respect, the risk mapping result indicates acceptable and ALARP conditions, therefore mitigation is not needed in this fire risk assessment.

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