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Quantitative risk assessment of medium-sized floating regasification units using system hierarchical modelling

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ABSTRACT

Currently there are no sufficiently detailed and specific regulations and guidelines applicable to Floating Regasification Units. In view of the fact that these units are likely to become more popular in the near future, their safety needs to be examined urgently.

During the design of the world's first medium-sized floating regasification unit a qualitative risk assessment was carried out. Although the results are useful, they cannot be used for developing rules and regulations directly. For such purposes some detailed quantitative studies are essential. This paper addresses this gap and introduces a hierarchical system modelling method to overcome the problem of the lack of direct statistical accident data of novel systems.

The method was implemented in IQRA (integrated quantitative risk assessment), a piece of software developed in-house for quantitative risk assessment. The safety of the floating regasification unit mentioned above was assessed using this software and the results were compared against the results obtained from conventional qualitative and the quantitative risk assessment.

It was found that the qualitative risk assessment had a tendency to overestimate the frequency of the accidents but to underestimate their consequence, while the quantitative risk assessment based on the result of the qualitative assessment inherently underestimated both the frequency and the consequence of hazards. The hierarchical modelling was found to be an excellent method of dealing with complex systems with short operational history.

1. Introduction

With the continuous increase of the world LNG trade reaching 241.1 MT (million tonnes) in 2014, LNG terminals are struggling with the problem of providing stable natural gas supply for power plants and industrial systems. As a consequence, demand for LNG regasification facilities has grown rapidly: the global regasification capacity at terminals was recorded at 724 MTPA (million tonnes per annum) in 2014, which was about 500 MTPA higher than the level in 2000 (IGU, 2015).

To meet the ever rising demand, floating regasification units (FRUs) started to be deployed at offshore sites in 2005 and, as of 2014, a total of 16 FRUs are operating with a total capacity of 54 MTPA across 11 countries (IGU, 2015; Victoria, 2016). FRUs are particularly useful for smaller markets where more flexible and cost-effective ways to satisfy the demand are necessary.

However, LNG is regarded as a dangerous fluid possibly leading to several types of critical accidents, particularly fire and explosion. As a result, a joint project team consisting of Korean Register of Shipping and other stakeholders has investigated the risk of new compact LNG regasification systems to be fitted on a medium-sized FRU by means of a hazard and operability (HAZOP) study during the design of the FRU (Lee, 2016). The study found that the risk level of fire/explosion initiated by leaks from the process equipment is unacceptably high, and safety recommendations were made for installing appropriate number of gas detectors working together with automatic leakage isolation mechanisms near three major systems: the LNG tank, the boil off gas (BOG) processing units and LNG regasification units (Korean Register, 2015).

Although all the participants of the study agreed on the results obtained, it was recognised that HAZOP studies do have inherent limitations. Firstly, it will be difficult to quantify the risk with high credibility, and, secondly, it relies on experts' opinion too much, possibly leading to personal biases and consequent misjudgement (Rausand and Høyland,

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List of symbols

A_C	Area concerned (m^2)
A_L	Cross-sectional area of leak (m^2)
C_L	Discharge coefficient used for liquid (= 0.61)
C_G	Discharge coefficient (=0.85)
g_c	Gas constant (1 kg m/N·sec^2)
MW	Molecular Weight (kg/kmol)
NF_{EX}	Number of fatalities by explosion (persons)
NF_{FF}	Number of fatalities by flash fire (persons)
NF_{PF}	Number of fatalities by pool fire (persons)
NF_{JF}	Number of fatalities by jet fire (persons)
P_A	Atmospheric pressure (Pa)
P_{BW}	Overpressure of blast wave (Pa)
P_s	Absolute pressure inside pipe (Pa)
PB_{PF}	Probit corresponding to probability of fatalities
PO_D	Population distribution (persons)
PR_F	Probability of fatalities
PR_{F_PF}	Probability of fatalities by pool fire
PR_{F_EX}	Probability of fatalities by explosion
Q_{LR}	Leak rate for liquid (kg/s)
Q_V	Leak rate for vapour (kg/s)
q_{TR}	Thermal radiation (W/m^2)
R	Gas constant, 8314 (J/mol·K)
r_C	Radius of concerned area (m)
t	Exposed time (= 60 s)
T_s	Storage temperature (K)
ρ_{LNG}	LNG density (kg/m^3)
λ	Failure rate per year

2004). As a result, this HAZOP study concluded with a recommendation that a careful examination be carried out to determine the appropriate number of gas detection systems required for each system.

This paper addresses the shortcomings of HAZOP studies and conventional selective quantitative risk assessment by investigating the safety of the FRU using an enhanced framework for quantitative risk assessment using an in-house software based on hierarchical system modelling.

2. Approaches adopted

2.1. Background

In general, risk assessment can be carried out qualitatively and/or quantitatively (Rausand and Høyland, 2004). HAZOP is a typical qualitative approach and the framework used for a HAZOP study on the regasification unit (Korean Register, 2015) is illustrated in Fig. 1. The main aim of the study was to identify potential hazards associated with the LNG regasification unit fitted on an FRU, and to provide recommendations for enhancing the safety of the FRU in question if and where deemed necessary. It used a combination of HAZOP parameters (flow temperature, pressure and level) and guide words ('no', 'less', 'more' and 'reverse') to identify assorted hazards. The degree of frequency and consequence for the identified hazards was then assessed based on the experience and judgement of the expert panel.

There are many more examples of qualitative studies on LNG systems. For example, Tugnoli et al. (2010) performed the safety assessment of LNG regasification systems onshore, concluding that advanced tools are required for investigating the safety levels of LNG plants more systematically. Paltrinieri et al. (2015) identified potential hazards associated with LNG regasification plants in a qualitative way. They highlighted the lack of experience as the key limitation of the qualitative method. Giardina and Morale (2015) have carried out a qualitative risk assessment by combining an FMECA and HAZOP methods to investigate the safety of LNG regasification plant. Like other qualitative studies, the risk of the proposed plant had been determined based on the knowledge of experts.

Similar to HAZOP, hazard identification study (HAZID), failure mode and effects analysis (FMEA) and What-if analysis are widely acknowledged as cheap and simple qualitative risk assessment methods where a qualitative risk matrix is often used to measure the levels of likelihood and severity. In all these methods the risk is determined by combining the severity of its impact with the likelihood of its occurrence (Rausand and Høyland, 2004). They rely heavily on expert judgment and experience, and this may prove problematic when assessing the risk of systems for which there is lack of knowledge and experiences (Vinnem, 2007; Nicola et al., 2015). Nevertheless, there is no denying that there are some advantages in using qualitative risk assessment methods.

For more stringent safety investigations, however, a quantitative method through which frequency and consequence of unwanted events can be quantified based on reliable statistics and analytical/computer-aided calculations will be necessary (Rausand and Høyland, 2004). On the other hand, for complex systems having a number of equipment working at different operating conditions, the industry often uses 'selective' quantitative risk assessment which examines only the risks associated with particular scenarios, operating conditions or sub-systems which are pre-identified as critical or hazardous through qualitative studies. Spouge (1999) and Vinnem (2007) have outlined general guidance of quantitative risk assessment applicable to offshore oil and gas units. Likewise, there are some example studies (Dan et al., 2014; ISO, 2015) using this framework as illustrated in Fig. 2. In this framework, qualitative risk assessment is preceded in order to identify critical parts of systems before 'selective' quantitative risk assessment where the focus is placed on investigating the risk of the critically-identified parts.

D'alessandro et al. (2016) has developed a decision-making tool to select an LNG regasification plant site. In this study, the feasibility of the plant site was determined through a selective quantitative risk assessment where potential hazards were identified in a qualitative way. Martins et al. (2016) also carried out a quantitative risk analysis of LNG regasification unit based on the selected hazardous scenarios.

The selective quantitative risk assessment have been also extensively applied to complex LNG technologies in the variety of marine/offshore industries. For example, Jeong et al. (2017a) investigated the explosion risk of a high pressure fuel gas supply system fitted to LNG fuelled-ships while Chae (2016) compared the risk impacts for different types of on-board LNG liquefaction systems. In addition, Park et al. (2017) have evaluated the safety of structure of LNG liquefaction process systems for FLNG against the potential explosion and Kim et al. (2016) carried out fire simulations to determine the optimal position of water deluge systems for an offshore unit through the selective quantitative risk assessment.

The selective methods, however, inherently rule out the hazards which are either unidentified or deemed minor, possibly underestimating the overall risk level.

2.2. Proposed method

Due to the short operational history of FRUs the statistical accident data is in very short supply. A method to derive the probability of failure of novel systems from the known historical data is, therefore, needed. Such a method was developed and applied to the current study. In essence, it breaks down the plant to be studied into components for which the historical data exist. The data for the overall system can then be built up by combining the component data. Not only does this method allow the use of existing data on individual components of the system,